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Mediating Heat and Light:

A Visualization-based Tool for the Analysis and Development of Dynamic Shading Control Protocols

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SIGraDi 2022
Critical Appropriations

Proceedings of the XXVI Conference of the Iberoamerican Society of Digital Graphics (SIGraDi) 2022

7-11 November, 2022
School of Architecture

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Welcome to SIGraDi 2022

Miguel Cruchaga Belaúnde, Dean
Universidad Peruana de Ciencias Aplicadas, Perú

17 years ago, we had the privilege of hosting a SIGraDi Conference. Both institutions were going through our founding years, and we had the privilege of sharing experiences with those who consolidated, for Architecture and Urbanism, the enormous contribution of new technologies that would take the development of graphic representation to great levels of improvement.

During those days, our campus was full of dynamism and students of all careers were equally interested in the themes and the promises of revitalization and opening of new horizons to the university world.

We promised to help them enter the Andean territory, and to spread their great value in the Subcontinent, as they had been doing and promoting with great success. Our relationship has grown stronger and our interest in the subject has kept us in touch.

We await the start of SIGraDi 2022 with expectation and enthusiasm. We want to know your progress, what your new goals are and what insights the fields of research and teaching offer us.

Welcome SIGraDi!

Bem-vindo a SIGraDi 2022

Miguel Cruchaga Belaúnde, Dean
Universidad Peruana de Ciencias Aplicadas, Perú

Durante 17 anos tivemos o privilégio de sediar um Congresso SIGraDi. Ambas as instituições atravessavam os nossos anos de fundação e tivemos o privilégio de partilhar experiências com quem consolidou, para a Arquitetura e o Urbanismo, o enorme contributo das novas tecnologias que levariam o desenvolvimento da representação gráfica a grandes níveis de melhoria.

Durante esses dias, nosso campus estava cheio de dinamismo e estudantes de todas as carreiras estavam igualmente interessados nos temas e nas promessas de revitalização e abertura de novos horizontes para o mundo universitário.

Prometemos ajudá-los a entrar no território andino e difundir seu grande valor no Subcontinente, como vinham fazendo e promovendo com grande sucesso. Nosso relacionamento se fortaleceu e nosso interesse pelo assunto nos manteve em contato.

Aguardamos o início do SIGraDi 2022 com expectativa e entusiasmo. Queremos conhecer seu progresso, quais são seus novos objetivos e quais insights os campos de pesquisa e ensino oferecem a você.
Bem-vindo SIGraDi!

Bienvenidos a SIGraDi 2022

Miguel Cruchaga Belaúnde, Dean
Universidad Peruana de Ciencias Aplicadas, Perú

Hace 17 años tuvimos el privilegio de ser anfitriones de un Congreso de SIGraDi. Ambas instituciones recorríamos nuestros años fundacionales y tuvimos el honor de compartir experiencias con quienes consolidaban, para la arquitectura y el urbanismo, el enorme aporte de las nuevas tecnologías que llevarían el desarrollo de la representación gráfica a grandes niveles de superación.

Durante esos días, nuestro campus estuvo lleno de dinamismo, y los estudiantes de todas las carreras se interesaron por igual en los temas y las promesas de revitalización y apertura de nuevos horizontes al mundo universitario.

Nos comprometimos a ayudarlos a introducirse en el territorio andino y a extender su gran valor en el subcontinente, tal como lo venían haciendo e impulsando con mucho éxito. Nuestra vinculación ha crecido cada vez más y nuestro interés por el tema nos ha mantenido en contacto.

Aguardamos el inicio de SIGraDi 2022 con expectativa e ilusión. Queremos conocer sus avances, saber cuáles son sus nuevas metas y qué intuiciones les suscitan los terrenos de la investigación y la enseñanza.

¡Bienvenido SIGraDi!

Preface

Pablo C. Herrera, Chair SIGraDi 2022
UPC, Perú

The School of Architecture of the UPC was created in 1994. In 1999 it participated in the initiative of the Virtual Workshop of the Americas directed by architects Guillermo Vásquez de Velasco and Antonieta Angulo from Texas A&M University. Thanks to Guillermo's interest in promoting SIGraDi, we began to participate in the congresses in 2003 in Rosario, Argentina. Since then and consecutively, 20 years have passed, and UPC has hosted the Congress of the Ibero-American Society of Digital Graphics in its IX version, in 2005, and this 2022 its XXVI edition.

Participating in the gestation process of different initiatives that SIGraDi has promoted allowed us to ensure technology implementation paths in our School of Architecture. From mandatory courses on BIM and digital fabrication starting at the fourth semester, to elective courses on photorealistic visualization, audio visual storytelling, infographics, and computational design. Precisely, living the differences of adopting computerized technologies and the evolution of the first computer workshops that we promoted in the region since 2006, together with the Homo Faber exhibitions on digital fabrication since 2015 and the edition of the book for the twenty-five years of SIGraDi, continues to motivate us to grow. This within a community and participatory culture that assimilates disruption and prepares us to coexist and appropriate technologies, understood as allies of our processes, which emerge from the context of exploration and curiosity to solve real problems.

Critical Appropriations, the theme that we promote at SIGraDi 2022, becomes a call to reflection on the origin and process of the actions of a transformative design and its possibilities, from the role of technology and its effect on the social, cultural, material, and educational spheres.

SIGraDi 2022. Critical Appropriations was organized into 7 topics and 30 subtopics: Programming Cultures (Agent-Based Systems, Data Analytics, Generative Design, Machine Learning, Parametric Analysis, Predictive Modeling and Shape Grammars); Manufacturing & Industry 4.0 (Robotics, Digital Fabrication, Internet of Things, Blockchain and Decision Making); Interactions & Collaborations (User Experience, Mixed Realities, Virtual Reality, Codesign, BIM Adoption and Interdisciplinary Design); Special Topics (Digital Heritage, Inclusive Design, Media Art and COVID-19); Life Long Learning and Digital Education (Hybrid Education and Online Learning);

Design, Nature and Ecosystems (Smart Cities & Environments, Sustainable Design, Building Performance, Bio-Inspired Design and Living Things).

These topics prompted the generosity of 20 instructors and their twelve connected workshops from 10 countries in a call for 170 participants, which take place between November 7 and 8.

Between November 9 and 11, Philip F. Yuan (China), Shelby Elizabeth Doyle, Daniel Cardoso, Sandra Manninger, Matias del Campo (USA), Felipe Ferrer and Benito Juárez (Peru) present their appropriations in Metaverse, Robotic Fabrication, Computational Feminism, Other Computations, Regenerative Manufacturing, Digital Biology, Neural Networks, Artificial Intelligence, Low-High Tech, and Glocalism.

In these three days, SIGraDi 2022 presents the research of 267 authors from Argentina (4), Brazil (40), Chile (8), China (2), Colombia (5), Costa Rica (1), Denmark (2), Germany (2), Hong Kong (1), Italy (1), Mexico (4), Peru (1), Portugal (4), Singapore (1), Taiwan (1), Turkey (5), United Kingdom (7), USA (13) and Uruguay (2). 19 countries with works in English (46), Portuguese (35) and Spanish (23) that make up this volume of 104 articles in 24 sessions organized by language.

SIGraDi 2022 shares different appropriations as triggers for dialogue with others, from which new reinterpretations will continue to create a digital culture that promotes its own agendas towards other geographies.

This XXVI SIGraDi 2022 Conference is inspired by the intensity of everyday life and society, with the enjoyment and appropriation of technologies in their different forms.

From Lima, Peru, we are immensely grateful to each of the local and international teams that allow us to be here, connected, sharing, and enjoying our appropriations with the hope of meeting in person very soon.

Welcome to SIGraDi 2022.

Prefacio

Pablo C. Herrera, Chair SIGraDi 2022
UPC, Perú

A Faculdade de Arquitetura da Universidade Peruana de Ciências Aplicadas (UPC) foi criada em 1994. Em 1999 participou da iniciativa do Workshop Virtual das Américas dirigido pelos arquitetos Guillermo Vásquez de Velasco e Antonieta Angulo da Texas A&M University. Graças ao interesse de Guillermo em divulgar a SIGraDi, começamos a participar dos congressos em 2003 em Rosário, Argentina. Desde então, e consecutivamente, 20 anos se passaram, e a UPC sediou o SIGraDi em 2005 e agora em 2022, o XXVI Congresso da Sociedade Ibero-Americana de Gráfica Digital.

Participar no processo de gestação das diferentes iniciativas que a SIGraDi tem promovido, permitiu-nos garantir caminhos de implementação da tecnologia na nossa Faculdade de Arquitetura. Desde cursos obrigatórios sobre BIM e fabricação digital do quarto ciclo, até cursos eletivos sobre visualização fotorrealista, narrativa audiovisual, infografia e projeto computacional. Precisamente, vivendo as diferenças da adoção de tecnologias computadorizadas e a evolução dos primeiros workshops de informática que promovemos desde 2006 na região, juntamente com as exposições Homo Faber sobre fabricação digital desde 2015 e a publicação do livro do vigésimo quinto ano da SIGraDi, continua nos motivando a crescer dentro de uma cultura comunitária e de participação. Isso assimila a disrupção e nos prepara para conviver e apropriar-nos das tecnologias, como aliadas de nossos processos, que emergem do contexto de exploração e curiosidade para resolver problemas reais.

Apropriações Críticas, tema que promovemos no SIGraDi 2022, torna-se um chamado à reflexão sobre a origem e o processo das ações de um design transformador e suas possibilidades, a partir do papel da tecnologia e seu efeito no social, cultural, material e educacional.

SIGraDi 2022. Apropriações Críticas foi organizado em 7 tópicos e 30 subtópicos: Programming Cultures (Agent-Based Systems, Data Analytics, Generative Design, Machine Learning, Parametric Analysis, Predictive Modeling e Shape Grammars); Manufacturing & Industry 4.0 (Robotics, Digital Fabrication, Internet of Things, Blockchain e Decision Making); Interactions & Collaborations (User Experience, Mixed Realities, Virtual Reality, Codesign, BIM Adoption e Interdisciplinary Design); Special Topics (Digital Heritage, Inclusive Design, Media Art e COVID-19); Life Long Learning and Digital

Education (Hybrid Education e Online Learning); Design, Nature and Ecosystems (Smart Cities & Environments, Sustainable Design, Building Performance, Bio-Inspired Design e Living Things).

Esses temas motivaram a generosidade de 20 instrutores e seus 12 workshops conectados de 10 países em um chamado para 170 participantes, que acontecerá entre 7 e 8 de novembro.

Entre 9 e 11 de novembro, Philip F. Yuan (China), Shelby Elizabeth Doyle, Daniel Cardoso, Sandra Manninger, Matías del Campo (EUA), Felipe Ferrer e Benito Juárez (Peru) apresentam suas apropriações em Metaverse, Robotic Fabrication, Computational Feminism, Other Computations, Regenerative Manufacturing, Digital Biology, Neural Networks, Artificial Intelligence, Low-High Tech, e Glocalismo.

Nestes três dias, o SIGraDi 2022 apresenta a pesquisa de 267 autores da Argentina (4), Brasil (40), Chile (8), China (2), Colômbia (5), Costa Rica (1), Dinamarca (2), Alemanha (2), Hong Kong (1), Itália (1), México (4), Peru (1), Portugal (4), Cingapura (1), Taiwan (1), Turquia (5), Reino Unido (7), EUA (13) e Uruguai 2). 19 países com trabalhos em inglês (46), português (35) e espanhol (23) que compõem este volume de 104 artigos em 24 sessões organizadas por idioma.

O SIGraDi 2022 compartilha diferentes apropriações como gatilhos para o diálogo com os outros, a partir das quais novas reinterpretações continuarão a criar uma cultura digital que promova suas próprias agendas para outras geografias.

Este XXVI Congresso SIGraDi 2022 é inspirado na intensidade do cotidiano e da sociedade, com a fruição e apropriação das tecnologias em suas diferentes formas.

De Lima, Peru, somos imensamente gratos a cada uma das equipes locais e internacionais que nos permitem estar aqui, conectados, compartilhando e desfrutando de nossas apropriações com a esperança de nos encontrarmos pessoalmente muito em breve.

Bem-vindo ao SIGraDi 2022.

Prefacio

Pablo C. Herrera, Chair SIGraDi 2022
UPC, Perú

La Facultad de Arquitectura de la UPC se creó en 1994. En 1999, participó en la iniciativa del Taller Virtual de las Américas, dirigido por los arquitectos Guillermo Vásquez de Velasco y Antonieta Angulo desde la Universidad de Texas A&M. Gracias al interés de Guillermo por promover SIGraDi, empezamos a participar en los congresos desde 2003 en Rosario, Argentina. A partir de entonces, y de forma consecutiva, han transcurrido 20 años, y la UPC ha sido sede de SIGraDi en 2005 y, en 2022, del XXVI Congreso de la Sociedad Iberoamericana de Gráfica Digital.

Participar en el proceso de gestación de las distintas iniciativas que SIGraDi ha promovido nos permitió asegurar caminos de implementación de tecnologías en nuestra Facultad de Arquitectura, desde cursos obligatorios sobre BIM y fabricación digital a partir del cuarto ciclo hasta cursos electivos en visualización fotorrealista, narración audiovisual, infografía y diseño computacional. Precisamente, vivir las diferencias de adoptar tecnologías computarizadas y la evolución de los primeros talleres computacionales que promovimos desde el 2006 en la región, junto a las exhibiciones Homo Faber sobre fabricación digital desde el 2015 y la edición del libro por el vigésimo quinto año de SIGraDi, nos sigue motivando a crecer dentro de una cultura comunitaria y de participación. Esta asimila la disrupción y nos prepara para convivir y apropiarnos de las tecnologías, como aliados de nuestros procesos, que emergen desde el contexto de la exploración y la curiosidad para resolver problemas reales.

Apropiaciones Críticas, el tema que impulsamos en SIGraDi 2022, se convierte en un llamado a la reflexión sobre el origen y proceso de las acciones de un diseño transformador y sus posibilidades, desde el rol de la tecnología y su efecto en el contexto social, cultural, material y educativo.

SIGraDi 2022. Critical Appropriations se organizó en 7 tópicos y 30 sub tópicos: Programming Cultures (Agent-Based Systems, Data Analytics, Generative Design, Machine Learning, Parametric Analysis, Predictive Modeling y Shape Grammars); Manufacturing & Industry 4.0 (Robotics, Digital Fabrication, Internet of Things, Blockchain y Decision Making); Interactions & Collaborations (User Experience, Mixed Realities, Virtual Reality, Codesign, BIM Adoption y Interdisciplinary Design); Special Topics (Digital Heritage, Inclusive Design, Media Art y COVID-19); Life Long Learning and Digital Education (Hybrid Education y Online Learning); Design, Nature and

Ecosystems (Smart Cities & Environments, Sustainable Design, Building Performance, Bio-Inspired Design y Living Things).

Estos tópicos impulsaron la generosidad de 20 instructores y sus doce talleres conectados desde 10 países en una convocatoria para 170 participantes, que tienen lugar entre el 7 y 8 de noviembre.

Entre el 9 y 11 de noviembre, Philip F. Yuan (China), Shelby Elizabeth Doyle, Daniel Cardoso, Sandra Manninger, Matías del Campo (EE.UU.), Felipe Ferrer y Benito Juárez (Perú) presentan sus apropiaciones en Metaverse, Robotic Fabrication, Computational Feminism, Other Computations, Regenerative Manufacturing, Digital Biology, Neural Networks, Artificial Intelligence, Low-High Tech, y Glocalismo.

En estos tres días, SIGraDi 2022 presenta las investigaciones de 267 autores de Argentina (4), Brasil (40), Chile (8), China (2), Colombia (5), Costa Rica (1), Dinamarca (2), Alemania (2), Hong Kong (1), Italia (1), México (4), Perú (1), Portugal (4), Singapore (1), Taiwan (1), Turquía (5), Reino Unido (7), EE.UU. (13) y Uruguay 2). 19 países con trabajos en idioma inglés (46), portugués (35) y español (23) que conforman este volumen de 104 artículos en 24 sesiones organizadas por idiomas.

SIGraDi 2022 comparte distintas apropiaciones como detonantes del diálogo con otros, a partir de los cuales nuevas reinterpretaciones seguirán creando una cultura digital que impulsa sus propias agendas hacia otras geografías.

Este XXVI Congreso SIGraDi 2022 se inspira en la intensidad de la vida cotidiana y la sociedad, con el disfrute y apropiación de las tecnologías en sus diferentes formas.

Desde Lima, Perú, agradecemos inmensamente a cada uno de los equipos locales e internacionales que permiten que estemos aquí, conectados, compartiendo y disfrutando de nuestras apropiaciones con la esperanza de reunirnos muy pronto de manera presencial.

Bienvenidos a SIGraDi 2022

SIGraDi President's greetings

Marcelo Bernal, President
Sociedad Iberoamericana de Gráfica Digital, SIGraDi

This Book of Proceedings gathers the body of work presented at the XXVI Congress of the Ibero-American Society of Digital Graphics, SIGraDi, organized by the UPC, Lima, Perú.

This year the call for "Critical Appropriations" questions the tension between the regional and the global research agendas. How do we cultivate our identity and originality while being influenced by global research trends? Or how do we influence back those trends from our regional experiences? This bidirectional question is particularly important considering the languages and territorial distribution of our international community. While actively connecting new researchers, educators, practitioners, and institutions within the boundaries of our territory, increasingly we attack members from all over the world that every year chose SIGraDi to share their work. Our challenge is not only the Iberoamerican integration but becoming a platform for global discussions.

This publication is possible thanks to the generous contribution of our members through different committees and roles, starting with our global community, who, for one more year, chose to submit their original work to SIGraDi.

The Local Organizing Committee, besides leading the overall organization of SIGraDi's major event, the international congress, organized two parallel events: "Homo Faber," an exhibition of the Latin American Fablabs, and the workshops on the first two days of the congress.

The Scientific Committee, including one hundred forty-seven members from twenty-five different countries, reviewed and validated the quality of the research endeavors presented here through a rigorous double-blinded peer review process.

The Executive International Committee during the last year has been focused on updating the internal procedures and platforms, developing the new venue handbook to guide new institutions in the process of organizing the annual congress, inviting new members to the scientific committee, working on the indexation of our proceedings, and editing two journals, the International Journal of Architectural Computing (IJAC) and Gestão & Tecnologia de Projetos (GTP) that publish extended versions of selected work of the SIGraDi members every year.

Finally, special thanks to the Leaders of the twelve workshops from Greece, Brazil, Japan, the United States, the UK, Chile, Peru, Argentina, Mexico, and Iran, who generously share their knowledge and expertise to move our community forward.

Saludos del presidente de SIGraDi

Marcelo Bernal, presidente
Sociedade Iberoamericana de Gráfica Digital, SIGraDi

Este Livro de Atas reúne o conjunto de trabalhos apresentados no XXVI Congresso da Sociedade Ibero-Americana de Gráfica Digital, SIGraDi, organizado pela Universidade Peruana de Ciências Aplicadas, UPC, Lima, Peru.

A chamada deste ano para "Apropriações Críticas" questiona a tensão entre as agendas de pesquisa regional e global. Como cultivamos nossa identidade e originalidade enquanto somos influenciados pelas tendências globais de pesquisa? Ou como influenciamos essas tendências a partir de nossas experiências regionais? Essa questão de mão dupla é particularmente importante considerando os idiomas e a distribuição territorial de nossa comunidade internacional. Enquanto conectamos ativamente novos pesquisadores, educadores, profissionais e instituições dentro dos limites de nosso território, cada vez mais visamos membros de todo o mundo que a cada ano escolhem o SIGraDi para compartilhar seu trabalho. Nosso desafio não é apenas a integração ibero-americana, mas tornar-se uma plataforma de debate global.

Esta publicação é possível graças à generosa contribuição de nossos membros através de diferentes comitês e funções, a começar pela nossa comunidade global, que, mais uma vez, optou por submeter seus trabalhos originais ao SIGraDi.

O Comitê Organizador Local, além de liderar a organização geral do comgresso mais importante do SIGraDi, o congresso internacional, organizou dois eventos paralelos: "Homo Faber", exposição dos Fab Labs latino-americanos, e as oficinas dos dois primeiros dias do O congresso.

O Comitê Científico, que inclui cento e quarenta e sete membros de vinte e cinco países diferentes, revisou e validou a qualidade dos esforços de pesquisa aqui apresentados por meio de um rigoroso processo de revisão por pares duplo-cego.

O Comitê Executivo Internacional durante o último ano se concentrou na atualização de procedimentos e plataformas internas, desenvolvendo o novo manual da sede para orientar novas instituições no processo de organização do congresso anual, convidando novos membros para o comitê científico, trabalhando na indexação de nossos anais e editar duas revistas, International Journal of Architectural Computing (IJAC) e Gestão &

Tecnologia de Projetos (GTP) que publicam anualmente versões estendidas de obras selecionadas de membros do SIGraDi.

Finalmente, um agradecimento especial aos líderes dos doze workshops da Grécia, Brasil, Japão, Estados Unidos, Reino Unido, Chile, Peru, Argentina, México e Irã, que generosamente compartilham seus conhecimentos e experiências para levar nossa comunidade adiante.

Saludos del presidente de SIGraDi

Marcelo Bernal, presidente
Sociedad Iberoamericana de Gráfica Digital (SIGraDi)

Este libro de actas reúne el cuerpo de trabajo presentado en el XXVI Congreso de la SIGraDi, organizado por la UPC, Lima, Perú.

Este año la convocatoria de "Apropiaciones críticas" cuestiona la tensión entre las agendas de investigación regional y global. ¿Cómo cultivamos nuestra identidad y originalidad mientras nos vemos influenciados por las tendencias de investigación globales? ¿O cómo influenciamos esas tendencias desde nuestras experiencias regionales? Esta pregunta bidireccional es particularmente importante considerando los idiomas y la distribución territorial de nuestra comunidad internacional. Mientras conectamos activamente a nuevos investigadores, educadores, profesionales e instituciones dentro de los límites de nuestro territorio, atacamos cada vez más a miembros de todo el mundo que cada año eligen SIGraDi para compartir su trabajo. Nuestro desafío no es solo la integración iberoamericana, sino convertirnos en una plataforma de debate global.

Esta publicación es posible gracias a la generosa contribución de nuestros miembros a través de diferentes comités y roles, comenzando por nuestra comunidad global, quienes, un año más, optaron por enviar su trabajo original a SIGraDi.

El Comité Organizador Local, además de liderar la organización general del evento más importante de SIGraDi, el congreso internacional, organizó dos eventos paralelos: "Homo Faber", una exposición de los Fab Labs latinoamericanos, y los talleres de los dos primeros días del congreso.

El Comité Científico, que incluye 147 miembros de 25 países diferentes, revisó y validó la calidad de los esfuerzos de investigación presentados aquí a través de un riguroso doble proceso ciego de revisión de pares.

El Comité Ejecutivo Internacional durante el último año se ha enfocado en actualizar los procedimientos y plataformas internas, desarrollar el nuevo manual de sede para guiar nuevas instituciones en el proceso de organización del congreso anual, invitar a nuevos miembros al comité científico, trabajar en la indexación de nuestras actas y editar dos revistas, International Journal of Architectural Computing (IJAC) y Gestão & Tecnologia de Projetos (GTP), que publican versiones extendidas de trabajos selectos de los miembros de SIGraDi cada año.

Finalmente, un agradecimiento especial a los líderes de los 12 talleres de Grecia, Brasil, Japón, Estados Unidos, Reino Unido, Chile, Perú, Argentina, México e Irán, quienes generosamente comparten su conocimiento y experiencia para hacer avanzar a nuestra comunidad.

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Alcanzando el metaverso: cómo la fabricación une lo virtual y lo real
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Keynote Presentation

Touching Metaverse
How Fabrication Bridges the Virtual and the Real

Alcanzando el metaverso
Cómo la fabricación une lo virtual y lo real

Philip F. Yuan
Tongji University, China

Abstract. We live in the era when the subject-object relationship of architectural design needs to be re-pondered and reassembled, the era we usually call posthumanism. Facing global warming, geopolitical upheaval and the pandemic, while confronting the challenge of the mutual development of architecture and society, we need to redefine and rethink the relationship between globalization and locality to reflect the contradictions and the opportunities brought by the current trend of human-machine collaboration and Object-Oriented Ontology. We, as architects, need to take a serious look at the parallel development of virtual and real worlds, and phygital futures presents the challenge of an architectural ontological approach to thinking and design tools. The talk will explore this issue through my research and practice.

Speaker biography

Philip F. Yuan is a professor at the College of Architecture and Urban Planning (CAUP) at Tongji University, Thomas Jefferson professor at University of Virginia (UVA, 2019), the visiting professor at Massachusetts Institute of Technology (MIT, 2019) and Royal Melbourne Institute of Technology (RMIT, 2021). He is also the co-founder of DigitalFUTURES and Editor in Chief of Architectural Intelligence journal, the founder of Archi-Union Architects and Fab-Union Technology, council member of UIA Professional Practice Commission (PPC). Yuan is a pioneer in architectural intelligence and robotic fabrication, making achievements in both academic research and architectural practice. He emphasizes the integration of technological innovation and architectural culture, building environment and ethics, constantly seeking human-machine collaboration in the era of post-humanism.

Keynote Presentation

Learning by doing

Aprender haciendo

Felipe Ferrer
PUCP, Perú

Resumen. Desde nuestro taller y durante varios ciclos, capturamos de diversos lugares del Perú su cultura local y energía, y aprendimos de sus métodos constructivos. Experimentamos con tecnologías digitales y, a través de procesos empíricos, tratamos de amalgamar lo local con lo global. Creemos que el cruce entre tecnologías —*hi tech*— y —*low tech*— es la clave para entender el potencial de donde estamos trabajando. En la ciudad de Lima, uno puede encontrar ciertas paradojas socioeconómicas y políticas con mecanismos muy sofisticados y, a la vez, primitivos. Nos interesa usar tecnologías globales de punta, pero trabajamos con las técnicas locales de construcción y procesos artesanales. Apuntamos a responder de una manera muy local a problemas globales. Investigamos la intersección entre la arquitectura y lo artesanal, lo digital y lo físico, y el proceso de fabricación y su construcción. Aprender cómo hacer, cómo construir es entender los materiales y cómo transformarlos, comprender cómo se vinculan los diferentes elementos entre sí; es explorar sistemas constructivos y ver cómo operan a diferentes escalas; es afrontar cómo hacer realidad lo que diseñamos.

Speaker biography

Felipe Ferrer Cárdenas (Lima, 1978). He is a registered architect and founder of V.Oid. He is a professor at the PUCP where he has taught courses on Digital Fabrication, Final Degree Projects, and Experimental Workshop V on experimental design. He has a master's degree in Advanced Architectural Design from Columbia University where he was also a professor of the advanced design master's degree (2005-2006). He worked with Diller Scofidio + Renfro (2005-2010). In Italy they awarded him the Gold A' Award and he was nominated for the Mies Crown Hall Americas Prize Award in Chicago with the AGP eGlass Factory project in Lima. Felipe was selected as Curator for the Peruvian Pavilion at the Venice Biennale 2020-21 where he resignifies bars in public spaces to turn them into artifacts to interact with.

Keynote Presentation

Architecture and Artificial Intelligence
Rise of a Paradigm

Arquitectura e inteligencia artificial
El surgimiento de un paradigma

Matías del Campo
University of Michigan, United States

Abstract. We are currently experiencing the emergence of a new design methodology based on the application of artificial intelligence. The rise of a new paradigm in architecture design. In this lecture, Dr. Matias del Campo and Dr. Sandra Manninger offer an insight into a wide spectrum of possible applications within this new design ecology. The lecture, based on the book “Neural Architecture”, approaches the problem from two specific directions: the theoretical underpinnings of design methods that are capable of interrogating the deep layers of the history of our discipline, and the implementation of AI as a practical tool. Painting a picture of an architecture design ecology that includes nonhuman players, estranged architectural objects, and a posthuman ethos regarding agency and authorship, the lecture provides an opportunity to interrogate an environment that is already a reality, surrounding us on a daily basis. How will the discipline adapt to this rapidly changing landscape? How can we, as architects, contribute to the ongoing dataset building and avoid the pitfalls of cultural and racial bias? Will it change the way we as architects work in the future? This and more will be discussed in the keynote lecture 'Architecture and Artificial Intelligence - Rise of a Paradigm'.

Speaker biography

Dr. Matias del Campo is a registered architect, designer, and educator. He is an Associate Professor at Taubman College of Architecture and Urban Planning, University of Michigan (UoM), director of the AR2IL – The Architecture and Artificial Intelligence Laboratory at UoM, and affiliate faculty member of Michigan Robotics and MIDAS the Michigan Institute of Data Science. Most recently he published the AD Machine Hallucinations – Architecture and Artificial Intelligence with Wiley, and his book Neural Architecture – Design and Artificial Intelligence with ORO editions.

Speaker biography

Dr. Sandra Manninger is an architect, researcher, and educator. Born and educated in Austria, she co-founded SPAN Architecture together with Matias del Campo in 2003. SPAN Architecture's research highlights how to go beyond beautiful data to discover something that could be defined voluptuous data. This coagulation of numbers, algorithms, procedures, and programs uses the forces of thriving nature and, passing through the calculation of multi-core processors, knits them with human desire. Her award-winning projects have been published and exhibited internationally, e.g., at La Biennale di Venezia 14/16/18/21, MAK, Autodesk Pier 1 and have been included in the permanent collections of the FRAC, Design Museum in Munich, or the Albertina in Vienna. Sandra Manninger has taught internationally at, e.g., the TU Vienna, University for Applied Arts, DIA Bauhaus in Dessau, UPenn, Tongji and Tsinghua Universities, at the University of Michigan, and the Royal Melbourne Institute of Architecture.

Keynote Presentation

A Carrier Bag of Tools for Computational Feminism

Un maletín de herramientas para el feminismo computacional

Shelby Elizabeth Doyle
Iowa State University, United States

Abstract. This lecture will share work from the first six years of the ISU Computation & Construction Lab (CCL). The CCL is a physical space that houses digital fabrication machines and robotics – as well as a home to pedagogical experiments, fabricated objects, and theoretical ambitions collected under the hypothesis that computation is informed by and productive of architectural cultures. Or said differently: the CCL is a 'carrier bag' to hold the tools for constructing a feminist future for technology (See Le Guin). The CCL gathers these strategies for architecture and computation under the term computational feminism, operating relentlessly upon the cultures of architecture and computation using disciplinary tools: writing, teaching, coding, drawing, making, and building. Projects from each of these categories will be presented as methods for reflecting on how architect and designer's make-with, attribute, and historicize computational knowledge and labor.

Speaker biography

Shelby Elizabeth Doyle, AIA is an Associate Professor of Architecture and Stan G. Thurston Professor of Design Build at the Iowa State University College of Design, co-founder of the ISU Computation & Construction Lab (CCL), and director of the ISU Architectural Robotics Lab (ARL). The central hypothesis of CCL and Doyle's work is that computation in architecture is a material, pedagogical, and social project; computation is both informed by and productive of architectural cultures. This hypothesis is explored, through the fabrication of built projects and materialized in computational practices. The CCL is invested in questioning the role of education and pedagogy in replicating existing technological inequities, and in pursuing the potential for technology in architecture as a space of and for gender equity. Doyle received a Fulbright Fellowship to Cambodia, a Master of Architecture from the Harvard Graduate School of Design, and a Bachelor of Science in architecture from the University of Virginia.

Keynote Presentation

Other Computations

Otras computaciones

Daniel Cardoso Llach
Carnegie Mellon University, United States

Abstract. A growing body of architectural and design scholarship seeks to understand, for example, computational design methods' manifold effects on the design professions, their historical origins, pedagogical implications, as well as their potentials for both creative design and managerial efficiency. However, the bulk of these efforts has focused on practices and institutions of the global North. As a result, our understanding of the role of digital technologies in architecture and design is framed by historical and theoretical armatures that closely reflect concerns, and interests, native to these locations —chiefly the United States, UK, and Europe— and thus carry with them assumptions that, when unchecked, can occlude important questions and domains of analysis. How might we articulate other accounts of digital design and construction that do not place regions outside of the global North on the receiving end of technology and innovation? How might we dismantle the conceptual past that condemns entire regions and peoples to perpetually catch up with a seemingly pre-determined future? This talk will explore these questions through a series of recent investigations in the field of "other computations.".

Speaker biography

Daniel Cardoso Llach is Associate Professor of Architecture at Carnegie Mellon University, where he chairs the Master of Science in Computational Design and co-directs CodeLab. He is the author of publications, exhibitions, and artifacts exploring the nexus of design and computation through sociotechnical and historical lenses, including the book Builders of the Vision: Software and the Imagination of Design, and the forthcoming Designing the Computational Image, Imagining Computational Design, with Theodora Vardouli. Cardoso Llach's work has been supported by the Graham Foundation for Advanced Studies in the Fine Arts, Canada's Social Science and Humanities Research Council, Google's Artists + Machine Intelligence program, among others. He is also a 2021-22 Pennsylvania Manufacturing Fellow and founding co-editor of the Design, Technology, and Society Routledge book series. Daniel holds a Ph.D. and a MS (with honors) from MIT, and a B. Arch. from Universidad de los Andes at his native Bogotá.

Keynote Presentation

Regenerative Manufacturing | Beyond the 4th Industrial Revolution

Fabricación regenerativa | Más allá de la 4.ª Revolución Industrial

Benito Juárez
Fab Lat, Perú

Abstract. Unlike the exponential increase in digital information, every year we lose globally the bio-information contained in the DNA of the multiple species that become extinct due to human actions, specially by activities such as construction, agriculture, transport, and manufacturing, that directly affect the increase of global warming. The digital information vs. bio-information appear to travel on opposite growth curves. The loss of biodiversity in our planet is the consequence of a predatory economic model, which extracts raw materials and gives back contamination. How to strengthen the development of a regenerative and collaborative economy, based on the co-creation of value from bio-information, which stimulates and encourages the increase of local and global biodiversity? Regenerative Manufacturing | Beyond the 4th Industrial Revolution is a space to reflect on the opportunities offered by bio and digital technologies to develop a new generation of design and manufacturing models that increase the biodiversity of the planet.

Speaker biography

Benito Juarez is pioneer in digital manufacturing technologies in Peru and Latin America. Co-founder of the Latin American Fab Labs Network. Creator of the Floating Fab Amazon project, selected by the United Nations for the global launch of the 17 SDG (NYC, 2015) as “the World’s most disruptive project on Sustainable Manufacturing and Climate Change” (Summit Solutions, UN 2015). Creator of the SimbioCreación methodology, which promotes the culture of Exponential Collaborative Creativity. Co-founder of NUTRIGENE (Singularity University 2016), a company dedicated to eradicating malnutrition in the world through a nutrient printer. Director of Supernodo Latinoamérica (Fab Lat) from where he works for technological democratization through the creation of inclusive projects and avant-garde products based on digital fabrication, revaluing the riches in biodiversity and multiculturalism of Latin America.

Workshops Presentation
Apresentação dos Workshops
Presentación de talleres

The workshops will take place on November 7th and 8th. SIGraDi 2022 workshops will occur online via Blackboard Collaborate or similar video conferencing platform. The workshops at SIGraDi are an opportunity for students, teachers, and professionals from Latin America to explore the possibilities of digital technologies as allies of the design process, sharing their experience with their peers from different parts of the planet. As in every year, we are sure that it will be an enriching and knowledge space that promotes appropriations.

Os workshops acontecerão nos dias 7 e 8 de novembro. Os workshops do SIGraDi 2022 ocorrerão on-line via Blackboard Collaborate ou plataforma de videoconferência similar. Os workshops da SIGraDi são uma oportunidade para estudantes, professores e profissionais da América Latina explorarem as possibilidades das tecnologias digitais como aliadas do processo de projeto, compartilhando sua experiência com seus pares de diferentes partes do planeta. Como em todos os anos, temos a certeza que será um espaço enriquecedor e de conhecimento que promove apropriações.

Los talleres se llevarán a cabo los días 7 y 8 de noviembre. Los talleres de SIGraDi 2022 se realizarán en línea a través de Blackboard Collaborate o una plataforma de videoconferencia similar. Los talleres de SIGraDi son una oportunidad para que estudiantes, docentes y profesionales de América Latina exploren las posibilidades de las tecnologías digitales como aliadas del proceso de diseño, compartiendo su experiencia con sus pares de diferentes partes del planeta. Como cada año, estamos seguros de que será un espacio enriquecedor y de conocimiento que promueva apropiaciones.

Workshops Presentation*

WS1.
Biomimetic Design and prototyping: A digital toolkit for designers
Alexandros Efstathiadis & Ioanna Symeonidou
University of Thessaly, Greece

WS2.
Torres paramétricas a tectônica da concepção algorítmica à fabricação digital
Ana Carolina Santos Vicente & Wallace Dornelas
Universidade Federal de Viçosa, Brazil

WS4.
Optimizing into the Probable Future. Predictive Models of Sustainable Building Performance
Marcelo Bernal, & Victor Okhoya
Perkins&Will Design Process Lab, United States
Tyrone Marshall & Cheney Chen
Perkins&Will Energy Lab, United States
Mohamed Imam
Perkins&Will Vancouver, Canada

W5.
AR + Design: Augmented Reality Immersive Design Method
Yang Song
University of Liverpool, United Kingdom

W6.
Get Your Ph.D. Done
Paula Gómez Z.
Georgia Tech Research Institute, Atlanta, United States

* For reasons beyond our reach, the instructors of Workshops W3 and W8 had to cancel their calls at SIGraDI 2022.

W7.
Architectural Intelligence: Multimodal ML applications in Design
George Guida & Indrajeet Halder
Harvard University, Graduate School of Design, Cambridge, United States

W9.
Diseño 3D a partir de modelos basados en inteligencia artificial
Michael Hurtado
UPC, Perú

W10.
Diseño de exoesqueletos en productos
Patricio Rabus
Universidad de Buenos Aires, Buenos Aires, Argentina

W11.
Ibrida: Metodologías de dibujo desde la fabricación digital e inteligencia artificial aplicada al bocetaje para la producción de arte contemporáneo
Fernanda Olivares & Eduardo Ramírez
Ciudad de México, México

W12.
ML Plugin: Develop a Machine Learning plugin for Grasshopper
Mohammad Pourfooladi
Art University of Isfahan, Iran

Workshop Presentation W1

Biomimetic Design and Prototyping: A digital toolkit for designers

Workshop in English

Alexandros Efstathiadis & Ioanna Symeonidou
University of Thessaly, Greece

Biomimicry is the interdisciplinary science that studies nature's models and draws inspiration from them to solve contemporary design challenges. However, processing, evaluating, and imitating biological systems can be a daunting task for designers and architects. For this reason, specialized methodological tools have been developed to assist the biomimetic design process and bridge the existing knowledge gap. Furthermore, advancements in parametric, generative CAD software enable the extraction and emulation of complex biological structures. Algorithmic design allows for the generation of unlimited design permutations through a series of interactive parameters that can be altered by the user on-demand and in real-time, according to design requirements. Intricate biomimetic structures surpass the technical capabilities of traditional fabrication technologies. However, progress in additive manufacturing (AM) technologies like fused filament fabrication (FFF), enables the production of complex topologies. In nature, the information that guides the building process is stored in the DNA of organisms. Similarly, the data that dictates the 3D printing of a model is stored in the form of a G-code created by specialized slicing software. Biomimetic design combined with 3D printing is driving a paradigm shift in sustainable design. The workshop will provide an analytical strategy that will enable designers to extract, emulate and prototype biomimetic structures. Initially, the concept of biomimicry will be introduced. A variety of biological structures will also be presented along with specific biomimetic tools and databases. Afterwards, a series of algorithmic and parametric modeling tools and plug-ins will be explored in Rhinoceros 3D and Grasshopper 3D. In the end, the models will be transferred to the slicing program Cura where the.G-code for the AM process will be generated. The intricacies of 3D printing complex biomimetic geometries will be analyzed.

Keywords. Design, Nature and Ecosystems, Bio-Inspired Design, 3D printing

Topics. Day 1. Introduction to biomimicry; Presentation of biological structures, biomimicry tools and databases; Exploration of modeling tools in Grasshopper; Participant work in groups. Day 2. Introduction to 3D printing; 3D printing and biomimicry; Participant work in groups; Feedback and guidance; Final presentations

Workshop Presentation W2

Torres paramétricas a tectônica da concepção algorítmica à fabricação digital

Workshop em Português

Ana Carolina Santos Vicente & Wallace Dornelas
Universidade Federal de Viçosa, Brazil

Esse Workshop pretende aplicar os entendimentos acerca da tectônica digital, assim como a manipulação de seus elementos fundantes, desde a fase de concepção paramétrica, através do Grasshopper, até a de fabricação digital. Para isso, inicialmente será dada uma introdução teórica à tectônica digital, com foco nos principais autores que trataram do tema, e dos seus elementos (Estrutura, Manipulação, Material, Construção e Interação), propostos por estudos recentes. Em seguida, a fim de possibilitar o desenvolvimento de torres paramétricas, será ministrado um tutorial utilizando Rhinoceros + Grasshopper (e o plug-in Lunchbox), cujo foco será explorar componentes como a estrutura, pavimentos, envoltória, manipulação formal e materialidade das torres, considerando os fundamentos da tectônica e as possibilidades de fabricação digital (impressão 3D ou corte à laser). Para isso. Espera-se que os participantes possam compreender como considerar os elementos da tectônica nos processos de projeto computacionais, aliando de maneira declarada as dimensões funcionais e artísticas da arquitetura.

Keywords. Manufacturing and Industry 4.0, Digital Fabrication, Digital Tectonics, Computational Design Processes.

Topics. Day 1. Introdução teórica ao tema da tectônica digital. Tutorial Rhino + Grasshopper (torre paramétrica). Apresentação e início da atividade (divisão em grupos e desenvolvimento das torres). Day 2. Continuação do desenvolvimento das torres (acompanhado pelos ministrantes). Preparação dos arquivos para fabricação (orientado pelos ministrantes). Apresentação e discussão dos resultados

Workshop Presentation W4

Optimizing into the Probable Future. Predictive Models of Sustainable Building Performance

Workshop in English

Marcelo Bernal, & Victor Okhoya
Perkins&Will Design Process Lab, United States
Tyrone Marshall & Cheney Chen
Perkins&Will Energy Lab, United States
Mohamed Imam
Perkins&Will Vancouver, Canada

We aim to lead a hands-on discussion that asks how we might consider and anticipate the impact of climate change on buildings and the environment to speculate, imagine, and innovate new models of design intervention that can modulate better performance outcomes in an uncertain future. Although parametric analysis is an emergent data-driven approach to building performance analysis, few practitioners understand effective methods of evaluating parametric analysis data. Furthermore, even fewer understand predictive models and how to estimate uncertainties. In these two days' workshops, the participants will learn how to simulate performance models based on weather files that represent different scenarios for climate changes (current, 2050, and 2080) and then generate design alternatives, analyze the performance of large design spaces, sample large design spaces, interpolate simulated data using machine learning predictive methods, visualize data for qualitative data exploration, and perform sensitivity analysis for quantitative assessment and estimation of the contribution of individual parameters in the overall performance.

Keywords. Climate Change; Design Space; Machine Learning; Data Visualization; Sensitivity Analysis.

Topics. Day 1. Climate Model Scenarios; Generative Design; Parametric Analysis: Data Visualization. Day 2. Sampling the Design Space; Sensitivity Analysis; Predictions-based Machine Learning; Decision Making.

Workshop Presentation W5

AR + Design: Augmented Reality Immersive Design Method

Workshop in English

Yang Song
University of Liverpool, United Kingdom

W5 aims to introduce the knowledge of exploring immersive parametric design through the Augmented Reality (AR) environment. As the quintessential 3D-4D design field, architectural design has been limited throughout its history by 2D or cumbersome 3D representation. Even though computer-aided architectural design and modelling software is widely used to produce digital 3D models, the conventional screen-based visualization methods for design and analysis are restrictive to how well the user understands the space on a computer screen, as the design is done outside the building site, hence there might be disparities between the design and final. This limitation may be eliminated by AR technology, which has become readily available, together with tools facilitating the easy creation of 3D-4D models as holograms onsite. Furthermore, with its interactive input features, AR can increase the potential for interaction between humans and data. As we immerse ourselves into rapidly developing AR, this technology can also radically change how one interacts with and experience the built environment, enhancing or altering or adding a new layer of information to the surrounding environment. This workshop explores how AR technology can change the ways of architectural design. Ideas like immersive design, as well as real-time modification experience and interaction with the built environment and the metaverse, will therefore actuate as the central core for the research streams.

Keywords. Interactions and Collaborations, Mixed Realities (AR), Immersive Design.

Topics. Day 1. AR introduction; Basic AR interactive functions for design inputs; Design algorithm development. Day 2. AR immersive design workflow demonstration; Structural stability simulation; Participant design algorithm development and final outcome.

Workshop Presentation W6

Get Your Ph. D. Done!

Workshop in English

Paula Gómez Z.
Georgia Tech Research Institute, Atlanta, United States

Finish your Ph.D. in a defined period of time. This is a participatory, non-specific topic workshop. It will cover techniques to get your Ph.D. done by understanding the drivers of your progress. It requires active participation, teamwork and sharing your academic experiences with the instructors and other participants. The outcomes are two. First, a deep understanding of a set of techniques to be able to finish the dissertation, and second, an implementation plan for the milestones: Qualifying paper and exam, topic proposal, dissertation writing, Ph.D. defence, and graduation!

Keywords. Lifelong Learning, Ph.D., Education, Decision Making.

Topics. Day 1. Why haven't you finished? Time management, Decide in advance. Day 2. Owning (your topic), Writing (your dissertation), Becoming (a Ph.D.).

Workshop Presentation W7

Architectural Intelligence: Multimodal ML applications in Design

Workshop in English

George Guida & Indrajeet Halder
Harvard University, Graduate School of Design, Cambridge, United States

We have now reached a historical moment of convergence between text and image processing, bringing forward new multimodal creative processes. Dalle2, StableDiffusion, and Midjourney are challenging current cultural practices of architectural production where a single text input can generate thousands of novel images. This workshop will reposition the role of language and semantics within architecture and introduce students to the opportunities of text-image models and 3D form generation for early design stages. Generated through a combination of the latest machine learning (ML) models, students will be taught how to generate images from text inputs and use these to inform a computational process of 2D to 3D reconstructions. The parameters behind each model and semantics specificity of each text input establish a new creative exchange between human and machine, where human agency finds new meanings. Following an introduction to ML applications architectural design, students will develop three sequential exercises related to 1) envelope making; 2) plan making; 3) a quasi-architectural or metaverse proposals to challenge the first two assignments. The course thus engages ways to reposition language within the design process through new methods and design metrics and considered these practices as challenging current cultural practices of architectural production.

Keywords. Programming Cultures, Machine Learning, Generative Design, Neural Networks, Metaverse

Topics. Day 1. Students will develop three sequential exercises related to 1) envelope making; 2) plan making; 3) a quasi-architectural or metaverse proposals to challenge the first two assignments. Day 2. The third step focuses on creating constructible and discretized forms that hybridize the 2D image outputs. The two primary workflows that we shall delve into are a NURBs based creation of forms in Rhino and several Grasshopper plugins (Monolith, Pufferfish, MeshEdit, Human, Python etc) and vozelized space-based methods using Houdini.

Workshop Presentation W9

Diseño 3D a partir de modelos basados en inteligencia artificial

Workshop en español

Michael Hurtado
UPC, Perú

Since the appearance of image generation models, there has been a growing interest in their use in areas such as art, design, and architecture. More recent are the text-to-image generation models that have shown the importance of choosing the right terms in the prompt to produce an image, this is known as prompt engineering. In this workshop, two 3D computational design methods will be presented, based on the use of image generation using AI. The first is based on the GAN generation model, specifically we will use the StyleGAN algorithm, which allows us to train the network from images chosen in a database, and the second method is based on the use of modifiers from a model. text-to-image generation model known as diffusion model, for this work we will use Stable Diffusion. Finally, through the Grasshopper plugin we will convert the resulting 2D image into a 3D model that can be used within the architectural computational design process.

Keywords. Manufacturing and Industry 4.0, Artificial Intelligence, 3d models, AI design.

Topics. Day 1. Artificial Intelligence fundamentals, diffusion models of text-to-image generation and GAN models, Grasshopper and how to convert a 2D image to 3D.

Workshop Presentation W10

Diseño de exoesqueletos en productos

Workshop en español

Patricio Rabus
Universidad de Buenos Aires, Buenos Aires, Argentina

Gracias a las posibilidades que ofrecen los actuales métodos de fabricación digital en simbiosis con los *softwares* 3D generativos, la estética resultante se convierte en un conductor en el diseño que llevó a la aplicación de las técnicas de diseño arquitectónico a escala de productos. El modelado 3D y las técnicas de impresión 3D han cuestionado las prácticas de diseño y fabricación, las cuales han liberado a los diseñadores de la estética anterior, y, sobre todo, han permitido recrear, visualizar y producir estructuras sustraídas de la naturaleza ya no como un recurso estético, sino funcional. Cuando una trama 2D, en una superficie, se utiliza como eje para una forma tubular se obtiene una estructura espacial. Si el punto de partida es una trama de crecimiento orgánico, el resultado será extremadamente poderoso en términos estructurales. El exoesqueleto es la forma en que está compuesto el hueso humano y animal. No se refiere tanto a una trama específica, sino a un tratamiento o forma de concreción. Se pueden obtener exoesqueletos de múltiples maneras: desde trama triangular a geometrías Voronoi, desde bordes de volúmenes poliédricos a dibujo de segmentos manualmente.

Keywords. Manufacturing and industry 4.0, digital fabrication, generative design, design, nature and ecosystems, bio-inspired design.

Topics. Day 1. Generative design, digital fabrication, bio-inspired design. Day 2. Generative design, digital fabrication, bio-inspired design.

Workshop Presentation W11

Ibrida: metodologías de dibujo desde la fabricación digital e inteligencia artificial aplicada al bocetaje para la producción de arte contemporáneo

Workshop en español

Fernanda Olivares & Eduardo Ramírez
Ciudad de México, México

Este taller está dirigido a artistas contemporáneos, *makers*, diseñadores y a la comunidad creativa para experimentar la traducción de métodos de dibujo a las herramientas de fabricación digital como escaneo e impresión 3D, modelos anatómicos e inteligencia artificial. Ibrida tiene como objetivo construir puentes hacia la hibridación de lo análogo y lo digital. Mediante el rescate de principios de dibujo anatómico y nuevas posibilidades de producción artística desde un enfoque multidisciplinario, el participante enriquecerá diversas exploraciones y alcances para crear un proyecto phygital a través de herramientas tecnológicas.

Keywords. Digital craft, life long learning and digital education, phygital artificial intelligence.

Topics. Day 1. Digital Anatomy, AI and phygitality, traditional drawing methods translated to the digital, AI and new image conceptions, figure model and pose with 3D scan, contemporary art, and hybridization.

Workshop Presentation W12

ML Plugin: Develop a Machine Learning plugin for Grasshopper

Workshop in English

Mohammad Pourfooladi
Art University of Isfahan, Iran

In 1950, Alan Turing asked, “Does a machine think?” A simple question that was the beginning of research on machine learning. Today, “Artificial Intelligence” (AI) is used in most fields of everyday life and learning it can greatly help in the development of new technologies. “Machine Learning” (ML) is one of the parts of artificial intelligence that must be learned to work in this field. The learning process in machine learning begins with data as input until the machine uses them to find the patterns in that data set and make better decisions based on the discovery of their patterns and the insights gained. Machine learning and how to use it for scientific research can be a powerful tool for architects. This workshop aims to provide a basic learning platform for entering the field of machine learning and how to write code for architecture, as well as building the tools desired by the architect for research and design with the help of artificial intelligence tools. In this workshop, students learn how to use the machine learning libraries in the Rhino software to create a plugin that is customized according to their needs.

Keywords. Programming Cultures, Generative Design, Machine Learning, Artificial Intelligence, Develop a Digital Tool.

Topics. Day 1. Basics of programming with C#, Basics of machine learning, Examples of using ML for architectural goals, Generative design using ML, Design evaluation with ML. Day 2. How to develop a plugin, Using ML Libraries, Building the customized plugin.

PhD Workshop
Workshop para doutorandos
Taller para doctorandos

PhD Workshop Committee

Frederico Braida (Chair)
Universidade Federal de Juiz de Fora, Brazil
Fernando Lima
Belmont University, United States
Maria Elena Tosello
Universidad Nacional del Litoral, Argentina
Paula Gómez
Georgia Tech Research Institute, United States
Rodrigo Martín-Iglesias
Universidad de Buenos Aires, Argentina
Silvia Patricia Hernández
Universidad Nacional de Córdoba, Argentina

The SIGraDi PhD Workshop is a unique opportunity for PhD students to present and discuss their research proposals in the CAAD field and related topics. The workshop aims to promote interaction between doctoral students and more experienced researchers and collaboration between doctoral students working on similar topics. Student enrolments at any stage of the work are welcome. The workshop will take place on November 7th and 8th from 9am to 11:30am (GMT -3:00). It is planned to discuss up to 10 proposals. In the case that more than 10 proposals are approved in the review process, the ones that represent the diversity of topics in the area will be selected for presentation. The remaining candidates are welcome to attend the workshop as listeners. The Committee will select the best presentation, whose author will receive a certificate and a SIGraDi Conference attendee registration (or reimbursement), which includes one year's membership of the society. In addition, the best presentations could be selected for the Global PhD Workshop.

Exhibition
Exposição
Exhibición

Homo Faber 3.0
Appropriation of Digital Fabrication from Latin America
Apropriação da Fabricação Digital pela América Latina
Apropiación de la fabricación digital desde Latinoamérica

Curators

Pablo C. Herrera
UPC, Perú
Rodrigo Scheeren
Universidade Federal da Bahia, Brazil
David Moreno Sperling
Universidade de São Paulo, Brazil

Homo Faber 3.0: Appropriation of Digital Fabrication from Latin America is inspired by local challenges, vulnerable communities, and semi-peripheral geographies, from the creative strategies that drive pioneers, developers, and end-users in our region with digital fabrication, as an ally of their processes of design, in any of its forms. For this version, the following categories are promoted: Artistic/Hacking; Bottom up / Community / Craft; Construction Components; Low-High Technologies; Robotic Strategies; Pedagogical Elements and Mobile Fab Labs. Homo Faber 3.0 explores the domestication, interpretation, and application of digital fabrication in the region, which stimulates the logic of technological appropriation of Homo Faber, beyond simple curiosity, automation, and personalization, to distance itself from the modest technological manipulation of Homo Fabricatus. Appropriation as a critical practice makes visible processes that create the foundations of a digital culture that establishes local agendas for other geographies, implementing technical solutions in synergy with situated ecosystems. This invitation to Homo Faber 3.0 hopes to reveal inspirations and synthesize thoughts from making objects, spaces, and environments.

Exhibition

Homo Faber 3.0. Categories and Laboratories
Homo Faber 3.0. Categorias e Laboratórios
Homo Faber 3.0. Categorías y laboratorios

Low-High Technologies

Superlimão, *São Paulo, Brazil*
Dum Dum LAB, *Valparaíso, Chile*
RILAB | UNL, *Santa Fé, Argentina*
Taller 1:1 | PUCP, *Lima, Perú*
FabLab U. de Chile, *Santiago, Chile*
LEFAD | PUC Minas, *Belo Horizonte, Brazil*
DATLab, UNaM, *Misiones, Argentina*
Laboratorio Bio, *Medellín, Colombia*
UNICAP ICAM-TECH, *Recife, Brazil*
MicroUtopias Lab, *Medellín, Colombia*

Pedagogical elements

IEH | UBA, *Buenos Aires, Argentina*
FabLab Belas Artes, *São Paulo, Brazil*
LAMO | UFRJ, *Rio de Janeiro, Brazil*
Fab Lab Tech Mx, *México DF, México*
Robot_Lab, *Bogotá, Colombia*

Artistic/Hacking

Morfolab | UPB, *Medellín, Colombia*
1maginari0 | UFMG, *Belo Horizonte, Brazil*
Estudio Trujillo-Pisanty, *México DF, México*
Vestibles, *Santiago, Chile*
Plasma | UNICAMP, *Campinas, Brazil*
WE-Labs, *Lima, Perú*

Mobile Fab Labs

FabLab Unal, *Medellín, Colombia*
FabLab Austral, *Puerto Williams, Chile*

Tracks
Sessões
Sesiones temáticas

Programming Cultures
Agent-Based Systems
Data Analytics
Generative Design
Machine Learning
Parametric Analysis
Predictive Modeling
Shape Grammars

Interactions and Collaborations
User Experience
Mixed Realities
Virtual Reality
Codesign
BIM adoption
Interdisciplinary Design

Special Topics
Digital Heritage
Inclusive Design
Media Art
COVID-19

Manufacturing and Industry 4.0
Robotics
Digital Fabrication
Internet of Things
Blockchain
Decision Making

Life Long Learning and Digital Education
Hybrid Education
Online Learning

Design, Nature, and Ecosystems
Smart Cities and Environments
Sustainable Design
Building Performance
Bio-Inspired Design
Living Things

Other Computations
Digital Craft

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Programming Cultures: Agent-Based Systems

Autonomous Collective Housing Platform: Digitization, Fluidization and Materialization of Ownership

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Abstract. New social phenomena like digital nomads urge an upgrade in housing ownership. This research proposes an autonomous housing platform that shapes residential communities into adaptive and reconfigurable systems, framing a cycle of digitalization, fluidization, and materialization of housing ownership. Specifically, the interactive interface carries the flexible ownership model that uses virtual space voxels as digital currency; the artificial intelligence algorithm drives the multilateral ownership negotiation and circulation, and modular robots complete the mapping from ownership status to real spaces. Taking project TESSERACT as a case study, we verified the feasibility of this method and presented expected co-living scenarios: the spaces and ownership are constantly adjusted according to demands and are always in the closest interaction with users. By exploring the ownership evolution, this research guides an integrated and inclusive housing system paradigm, triggering critical evaluation of traditional models and providing new ideas for solving housing problems in the post-digital era.

Keywords: Agent-Based Systems, Digital Platform, Housing Ownership, Space Planning Algorithm, Discrete Material System

1 Introduction

In the post-digital era, the fluctuating environment and complex demands are forcing a critical reshaping of traditional housing models. The deterioration of the natural and social environment, such as climate chaos, economic collapse, and pandemic threat, leads to rapid iterations in living behaviors and spaces. At the same time, the advancement of digital technology makes the living needs of individuals and groups present a trend of diversification and personalization. As a result, digital nomadism with frequent mobility has emerged: supporting a

globalized nomadic life through online mobile work, corresponding to the temporary nature of the accommodation and the *intermittence of citizenship*. (Bravo, 2010) With the outbreak and spread of COVID-19, the number of digital nomads who make up today's workforce has increased significantly and continues to grow. The internal reasons include the employers' acceptance of remote work and the employees' desire for low living costs. The operation and transaction methods of traditional rigid housing ownership are facing unprecedented impact.

With the mobile requirement of population and ownership, the disruptive digital housing platform emerges as an online flexible and interactive information medium. The rapid expansion of rental-focused platforms such as Airbnb, which allows users to freely trade residential spaces of any size, form, and duration, is *increasingly blurring the boundary between short-term temporary uses and long-term residential uses*. (Ferreri & Sanyal, 2021) The rise of online platforms and the digitization of space property have intensified the mobility of social housing and profoundly affected the volatility of capitalist ownership, leasing practices, and space transactions.

The housing needs of digital nomads provide a particular research context to further explore the possibilities of ownership digitization and test new ideas for integration with the flexible housing platform. Therefore, from the perspectives of society, economy and architecture, this research proposes an autonomous housing model with digital ownership as a breakthrough to solve the current rigid ownership problem. As a unique platform medium, it shapes residential communities into adaptive and reconfigurable systems, framing a cycle of digitalization, fluidization and materialization of housing ownership. Taking the project TESSERACT as a case study, we build interactive interfaces to carry the flexible ownership model that uses virtual space voxels as digital currency, write artificial intelligence algorithms to drive the multilateral negotiation and circulation of ownership, and assemble modular robots to complete the mapping from ownership status to real spaces.

Finally, we verified the feasibility of this method within a certain scope and presented expected co-living scenarios: the spaces and ownership are constantly adjusted and circulated according to the demands and are always in the closest interaction with users. By exploring ownership evolution, this research establishes an integrated and inclusive global housing system paradigm, triggering critical evaluation of traditional models and providing new ideas for solving housing problems in the post-digital era.

2 Literature Review

Ownership refers to the owner's right or state to possess, use, benefit and dispose of property, and its evolution has activated different models of private property rights that shaped the principal economic models of society. (Athiana,

2019) As real estate, the ownership of housing establishes a deep connection and bond between people and land (living spaces), making residence an accumulation of property and a manifestation of power, and nurturing the formation of personal belongingness and the preservation of social stability. Historically, different forms of housing ownership have significantly shaped the evolution of the residential environment (cities and architecture), and vice versa, the development of both can also lead to new modes of ownership. Today, the direct, stable, and limited relationship between people and the land will be disrupted and transformed into an indirect, online, and broader interconnection.

As a supporter of this interconnection, interactive platforms originate from the new raw material of capitalism in the digital era: data as a way to maintain economic growth. *Platform capitalism* (Srnicek, 2017) enables interaction between different roles, allowing users to create their own products, services and marketplaces, enhancing the concentration and circulation of ownership. In this context, such digital technologies for housing are referred to as *"platform real estate", which better encapsulates the connective capacities and paths of action related to ownership, use, and exchange of land and buildings*. (Shaw, 2020) The prosperity of digital platforms changes the relationship between capitalism and housing problems, facilitating the informal expansion of the real estate industry, exacerbating the dynamics and indeterminacy of social housing, and advancing the digital transformation of the present ownership model and space transaction mechanism.

In the practice or research of digital housing platforms, new ownership and transaction models are constantly emerging. In practice, representative platforms such as Airbnb and WeLive, mainly based on rental services, can trade limited ownership like use rights. Among them, *Airbnb allows common homeowners to rent out vacant rooms of any size, form, and duration as accommodation for tourists*. (Guttentag, 2015) The system reservation mode is similar to that of a hotel: the owner uploads free space information, and the tenant searches the space according to specific needs, so that both parties can rent or book different types of spaces freely and conveniently, realizing the segmentation and refinement of the ownership and subverting the traditional leasing method. *WeLive, on the other hand, is committed to creating a mutual community.* (Hansen-bundy, 2018) The operator centralizes static ownership and distributes mobile use rights to tenants, encouraging them to share and exchange spaces, organize group activities, form social networks, and regain the healing properties of communities.

Research on housing platforms based on advanced algorithms and artificial intelligence technologies provides new ideas of ownership evolution. The project *Nomas* (Hosmer et al., 2020) has set up an ownership exchange system: users have a stable spatial state within the platform and can switch between various locations in the world to adapt to a globalized nomadic life. Unlike the platform in Welive, which tends to be a social network, Nomas has artificial intelligence algorithms as the backbone, which is not only the brain responsible for plan generation and evaluation, but also the bridge linking

different roles. However, since the opposing position between investors and users still exists, the fairness and neutrality of the algorithm need to be discussed and supervised. *Public Parts proposes an autonomous communal life platform managed by artificial intelligence* (Rodrigues et al., 2021), which adopts a collective ownership model where occupants jointly possess the housing community and participate in space assembly and system maintenance. This project completely removes capital from the platform, relies on artificial intelligence algorithms for space allocation and organization, and creates a user-driven resocialized community with a communist nature.

In Airbnb, WeLive, and Nomas, the use rights are finely distributed to each user, while in Public Parts, the ownership belongs to the entire collective. These two types of attempts represent different approaches to realizing ownership innovation, facilitating transactions of rights and exchanges of spaces. However, due to the simplification of the traditional capital operation relationship, the latter is more inclined to an idealistic harmonious vision based on the user's moral level and technical literacy, which may hide practical problems that are difficult to solve. This research still hopes to retain the variable relationships between investors and users in digital platforms to promote the further digitization and quantification of ownership rather than just blurring the concept in a utopian commune.

3 Methodology

The project TESSERACT is a futuristic housing platform for digital nomads and other mobile lifestyles. Through the overall quantification of the ownership model, a user-centered global housing system with a continuous lifecycle is constructed to realize the free interaction and rapid circulation of ownership. Its research process revolves around the three steps of digitalization, fluidization, and materialization of ownership:

1) Digitization: the integrated digital platform undertakes comprehensive management, defining a flexible ownership model with voxelized space nodes as vectors of digital ownership.
2) Fluidization: the multi-agent algorithm based on reinforcement learning drives the multilateral negotiation and circulation of ownership to provide solutions and balance interests.
3) Materialization: the discrete robotic material system completes the construction and reconfiguration of physical spaces, enabling the material mapping of ownership.

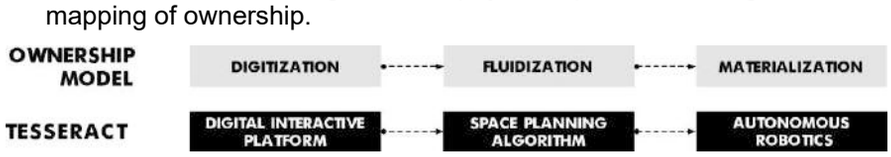

Figure 1. The Correspondence between digital ownership research process and TESSERACT system composition. Source: Authors**.**

3.1 Ownership Digitization Rooted in Interactive Platform

The platform-based digitalization of ownership in TESSERACT separates ownership from geographical locations or territorial belongings and quantifies it as an abstract digital code in the platform database. Digital ownership can retain value across relocations and expand, contract, transfer and circulate anytime and anywhere.

Specifically, the ownership model relies on a 3D grid consisting of discrete space voxels with side lengths of 0.3m. Each voxel in the grid contains basic information such as ID, position, typology, color, and multi-level feature information related to living, including lighting conditions, landscape views, etc. According to their information status, the nodes have different ownership codes and values. For example, the value of nodes with sufficient sunshine in the site is generally higher than those without sunshine. In the operation process, the characteristic information will be imported in the form of a formula or a bitmap and converted into a three-dimensional matrix with a value between 0 and 1. The superimposed ownership value is the sum of the products of these different data information D and the value coefficient K.

$$O_N=K_1*D_1+K_1*D_1+....+K_1*D_1 \quad (1)$$

At this time, the traditional possession of the whole building is quantified as the occupation of the space voxels. Therefore, the partial ownership set of all nodes occupied by the spaces forms the overall ownership in the platform.

$$O(User)=O_{N1}+O_{N2}+....+O_{NI}=O_{space} \quad (2)$$

In addition, the concept of Space Currency (SC) is introduced as transaction chips in the digital platform, which measure the specific value amount of ownership in different space voxels.

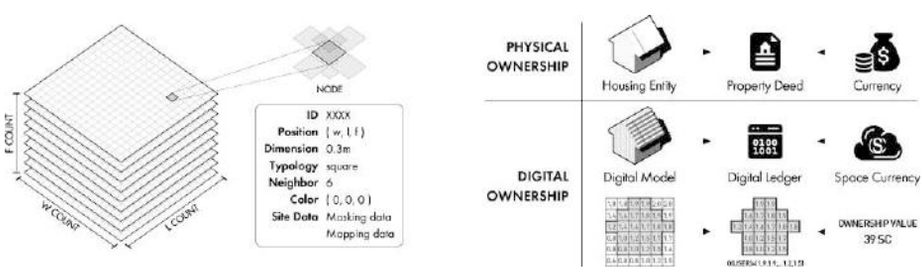

Figure 2. Left: the 3D grid and a node. Right: the comparison between traditional physical ownership and digital ownership. Source: Authors**.**

Based on the above principles, when users enter the platform, they can buy and hold a certain amount of space currency according to the local exchange rate and purchase the ownership of the space voxels required for the

corresponding residence in the base station. If users would like to change the living range, they only need to resell the unnecessary space voxels to other users or the system and buy new parts. In order to incentivize customer to customer (C2C) space tradings, the ownership transaction fee among users is lower than that between users and the system.

3.2 Ownership Fluidization Driven by Space Planning Algorithm

The flow of digital ownership in TESSERACT coincides with the exchange of users' living space, forming the essential part of the housing platform. Therefore, a user-oriented distributed spatial planning algorithm, which takes a multi-agent system as a framework and integrates bottom-up local agents and top-down global constraints, is developed to coordinate user needs, site conditions, investment programs, and other multilateral elements and relationships. Additionally, the implantation of reinforcement learning realizes the behavior control of the agent to adapt to the changes in users' living and social needs, completing the real-time generation and reconfiguration of the spaces and continuously promoting ownership circulation.

The space planning algorithm operates on the above-mentioned three-dimensional grid, which contains a set of programmable colored agents representing spaces owned by users. Based on specific behavior patterns, these agents occupy space voxels to expand the territorial ranges and form internally closed geometries. Through the release of pheromones, they conduct constant communications with neighbors and the environment, shaping spatial boundaries in the negotiation among multiple agents.

3.2.1 Ownership Configuration

For each user, the configuration of ownership corresponds to the generation of spaces, related to the individual living demand. Therefore, this algorithm introduces Space Code to correlate the user's specific needs for the room as the local target of the planning behavior. It consists of three parameters describing volume, proportion, and form, representing the space size, the aspect ratio, and the basic shape of the required space. A Space Code links a separate living space, and a user can set multiple codes. In this case, the digital ownership of the user is:

$$O(User)=O_{Space1}(V_1,P_1,F_1)+O_{Space2}(V_2,P_2,F_2)+...+O_{SpaceN}(V_N,P_N,F_N) \quad (3)$$

Reinforcement learning is applied as a decision-making mechanism to control the operation strategy of the agent in real-time, mapping the parameters in Space Code to the planning behavior to form a voxelized model. The training dataset is 600 groups of parameters generated by random combinations of {V, P, F} within a defined range. The agent's behavior is controlled by policy (x, y, z), in which the three variables represent the growth intensity in each direction.

The training purpose is to help the agent respond to Space Code, continuously adjusting the parameter combinations in the policy to make the occupied region match the design goal. The training rewards include immediate rewards (the captured node is within the target range), staged rewards (the proportion of qualified nodes reaches 30%, 60%), and final reward (the proportion of qualified nodes exceeds 95%). After $6*10^6$ episodes, the training curve is basically stable. At this time, the agent can adapt to the changes in Space Code in real-time and accomplish the corresponding space planning tasks.

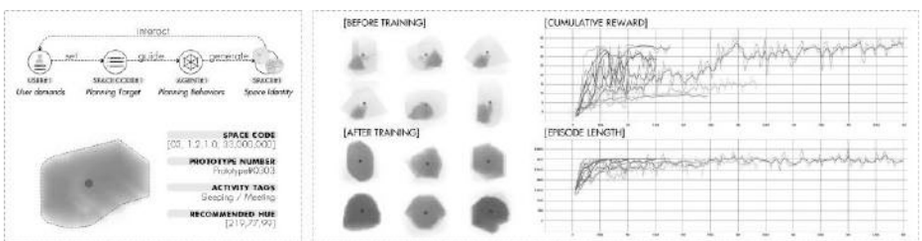

Figure 3. Left: the principle and example of Space Code. Right: The behaviors of the agents after training, and the graphs (pink one success) with the cumulative reward and the episode. Source: Authors**.**

3.2.2 Ownership Circulation

For multiple users, the circulation of ownership corresponds to the reconfiguration of spaces, related to the collective organizational inclination. The algorithm uses Negotiation Code to meet the adjacency requirements of users or the system, guiding the attraction and repulsion behaviors between multiple agents and realizing the negotiation and transaction of node occupancy through deformation or displacement. Similarly, the Negotiation Code is also composed of three parameters. The ownership contains the part based on Space Code and the other part affected by Negotiation Code:

$$O(User)=O_{Space1}(V_1,P_1,F_1)+O_{Space2}(V_2,P_2,F_2)+...+O_{SpaceN}(V_N,P_N,F_N)$$
$$+O_{Negotiation1}(I_1,C_1,E_1)+O_{Negotiation2}(I_2,C_2,E_2)+...+O_{NegotiationN}(I_N,C_N,E_N) \quad (4)$$

Specifically, in Negotiation Code, Interaction Tendency represents the adjacency willingness between the agent and its neighbors. For each surrounding agent, there is a weight factor $K_{I\text{-}A}$ between [-2,2], which guides the generation of attractors and determines the repulsive or attractive strength. Cluster Tendency is expressed as K_C between [-1, 1], describing the agent's relationship to space clusters of similar or opposite colors. Environment Tendency demonstrates the agent's thirst for environmental resources. The factor K_E aggregates their reaction to preset site information, leading to specific behaviors such as phototaxis or light avoidance.

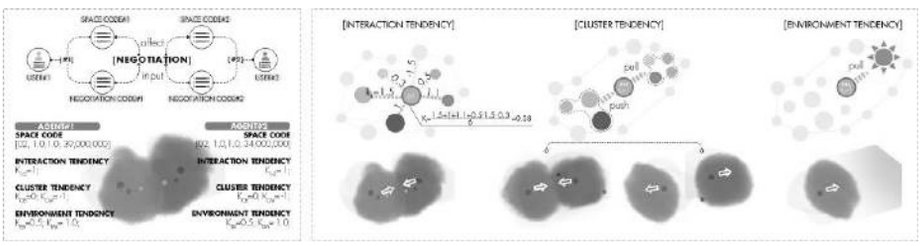

Figure 4. Left: the principle and example of Negotiation Code. Right: Three parameters of Negotiation Code. Source: Authors**.**

3.2.3 Ownership Restriction

For the entire space system, the global constraints are embedded in the discrete planning environment in the form of data matrices, not only including information such as lighting conditions that determine the value of space ownership, but also includes the global regulation behind the platform: imposing necessary restrictions on changes in digital ownership through influencing the planning behaviors of the agents. Among them, masking data is used to mark areas that cannot be occupied by living spaces, such as core tubes, historical relics, public squares, etc., while mapping data can record the natural and social background and zoning information in the planning environment.

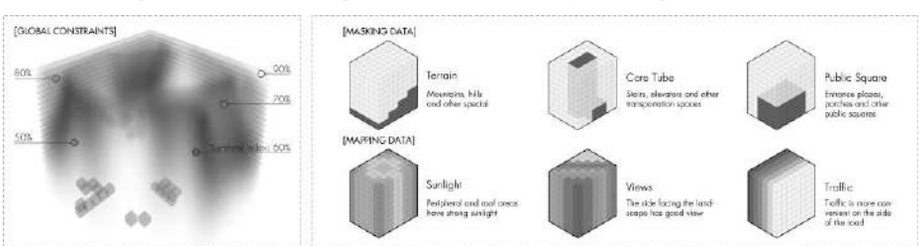

Figure 5. Left: the example of a global constraint in the planning environment. Right: the examples of mapping data and masking data. Source: Authors**.**

3.3 Ownership Materialization Supported by Robotic Material System

Materializing digital ownership is the last step in the TESSERACT platform operational process. The autonomous material system composed of voxelized static components and modular robots maps the changes of virtual projects to the reconfiguration of physical reality in real-time. In the prototype design, the static component and the robot are cubes with a side length of 0.3m, corresponding to voxels in the ownership model. The static components are bricks that make up the building, shaping spaces by stacking and combining, while the robots are equipped with power units, reconfiguring spaces by actively changing the positions of the static components.

In terms of fabrication, the static components can be divided into actuation, structural, and panel parts. The actuating parts facilitate relative sliding and locking, equipped with cross slots in the positive directions of each axis and flat knobs in the opposite. The structural parts form a frame with tracks for gears in the knobs. The panel parts determine the decorative coating, which can be replaced according to the user's preference or selected from the traditional materials to blend into the local built environment. Modular robots are the same size as static components with similar fabrication details, but structural parts are filleted to prevent collisions during movement. Two servomotors are installed behind each knob for driving and steering. The body of one robot consists of three linked cubic parts forming an L-shaped combination with an action mode for sliding its cubic parts along tracks in its body or in static parts. Robots can slide, change direction, push and pull, and lock and unlock through the mutual collaboration for reconfiguration tasks.

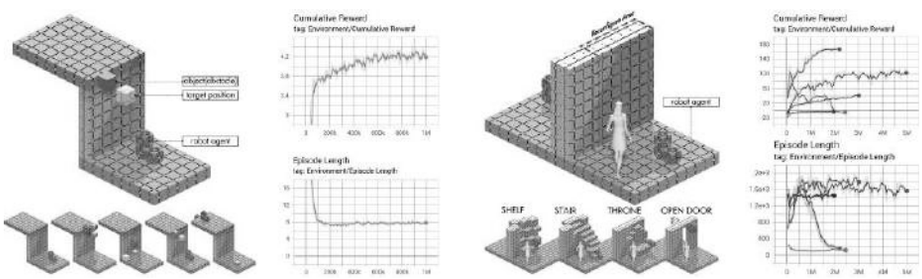

Figure 6. The training models and the training results of robots. Source: Authors**.**

Reinforcement learning is used to formulate adaptive strategies for the robots to coordinate the biased and constrained behaviors in dynamically changing structured environments. The simulator was set up with L-shaped robots composed of three independent agents taking observations of the current and target state of each agent and component to carry on a curriculum learning with increasing difficulty. The reward is set to be inversely proportional to the distance from the target. If situations like falling off the bounds or touching the obstacles occur, the agent will be punished by -1 point, and rewarded with 10 points when reaching the target position. Additional rewards are also related to metrics such as robot energy consumption. In the final training results, the robotic agents can autonomously select moving targets, arrange action steps, complete the construction and reconfiguration tasks of various spatial states such as opening doors and windows, laying stairs, and shaping furniture with strong execution and cooperation capabilities.

4 Results

This digital ownership model is of great significance for maximizing space utilization. It makes space transactions as convenient as mobile payment and substantially stimulates users' willingness to update the current space. By assigning extra spaces or deploying activity venues, the system meets and adapts users' various requirements for living, realizing the rational allocation of space resources. Besides, this model allows users to camp in different base stations around the world, establishing a global housing pattern. When the user has travel, business trip, immigration and other needs, the digital ownership can be automatically transferred to the target site to generate a remote residence that conforms to the accustomed lifestyle, maintaining a warm sense of belonging.

In the circulation of digital ownership, the space planning algorithm establishes a multilateral convention to maintain the AI-assisted algorithm's position as an intermediary between users and investors, balancing the reasonable interests of each party. In a range of 12m*12m*6m, we conducted experiments on the space group generation with five agents to simulate the ownership activities of two users in the system. In the experiment, the Cluster Tendency is set to 1 to ensure that agents of the same user form a group. By adjusting the Interaction Tendency, we simulated the gradual process of the organizational relationship between two users from no tendency to mutual resistance and mutual acceptance. The real-time planning results are shown in Figure7. The space occupancy relationship is negotiated, and different spatial forms emerge, verifying the algorithm's ability to drive ownership flow and promote mobility.

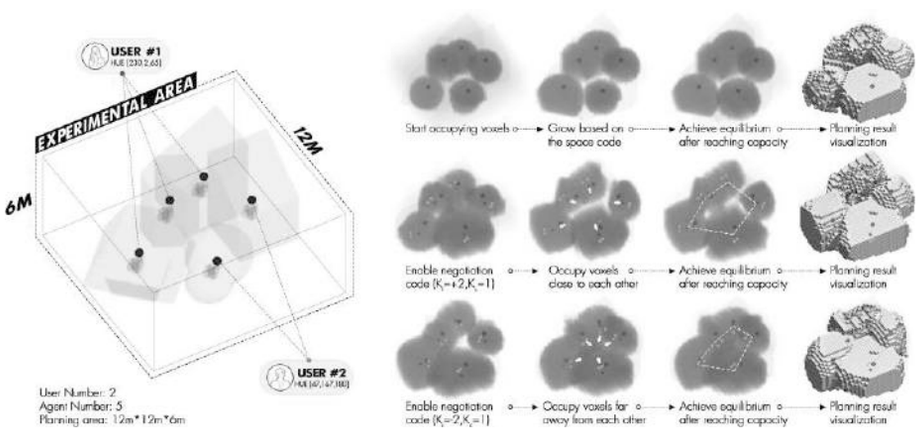

Figure 7. The planning process of three stages in the experiment. Source: Authors**.**

Finally, the material system is the basis for the materialization of ownership, giving the housing system unique flexibility. The physical prototypes are

manufactured by 3D printing at a scale of 1:1. The two servomotors installed on the robotic knobs are Dynamixel AX-12A, driven by Raspberry Pi to link their speed, rotation angle, and other information with the digital model in Unity3D. In the experiment, the robots can achieve basic tasks such as handling, pushing and pulling, which preliminarily proves the feasibility and stability of the system.

The above results effectively demonstrate the viability and integrity of TESSERACT as a housing model with digital ownership, which can support nomadic life in the context of requirement complexity and extreme mobility.

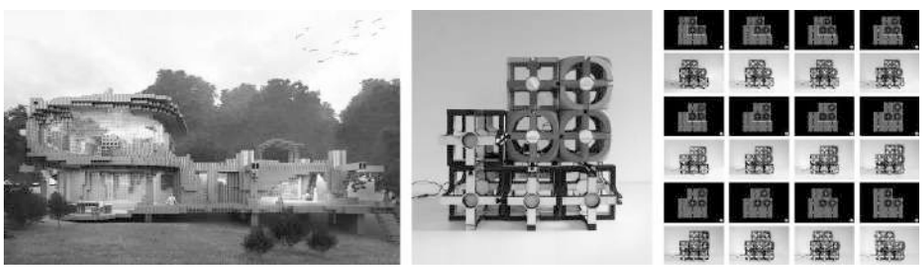

Figure 8. Left: project TESSERACT rendering. Right: the experiment of pushing and pulling a static component. Source: Authors**.**

5 Conclusion

In the post-digital era, the dwelling needs of digital nomads provide a special research context, and digital housing platforms' model updates traditional socioeconomic issues. By reflecting on the concept of solidified physical ownership, this study comprehensively explores a new model of housing ownership and the co-living vision in autonomous housing systems through the cycle of ownership digitization, fluidization, and materialization.

TESSERACT enables different groups to obtain equal and direct access to decision-making and interaction to fully coordinate various housing requirements. At the same time, the flexible and mobile digital ownership model transforms the concept of property from a territorial attribution to a digital symbol, while encouraging residents to sell idle space resources at any time to realize the system's transformation and maximize spatial utilization. TESSERACT is a promising model to test new capital ideas and digital intelligent design, leading to the circulation and reallocation of ownership. It forces a revolution in the housing industry, activating new ways of working and inhabiting and driving the grow of an autonomous architecture system.

In future work, more simulations based on real big data and participated by actual users are crucial, including the construction and optimization of interaction interfaces, the introduction of technologies such as blockchain to ensure fairness and transparency of AI, and the experiments on stronger mechatronics to shape large-scale spaces, etc. In addition, more evaluation

mechanisms and visualization methods need to be introduced to better control the rationality of the generated spaces. TESSERACT proposes a well-thought-out vision for a housing system, showing the unwavering courage and unprejudiced attitude to face the conflict of post-digital housing issues.

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References

Athiana, A. (2018-2019) *Housing Ownership as a Digital Platform in Garcés 'Conditio Posthuma a Study on the Correlation Between the Fear of Apocalypses & Global Nomadism in the Age of Hyperobjects.* London: Univeristy College London, Bartlett School of Architecture.

Bravo, L. (2010). Genius loci and genius saeculi: a sustainable way to understand contemporary urban dynamics. In *14th International Planning History Society (IPHS) conference proceedings, Urban Transformation: controversies, contrasts and challenges, Istanbul: ITU-Urban and Environmental Planning and Research Center* (Vol. 2, pp. 543-554).

Ferreri, M., & Sanyal, R. (2021). Digital informalisation: rental housing, platforms, and the management of risk. *Housing Studies*, 1-19.

Guttentag, D. (2015). Airbnb: disruptive innovation and the rise of an informal tourism accommodation sector. *Current issues in Tourism*, 18(12), 1192-1217.

Hansen-bundy, B. (2018). Can The Welive Experiment Actually Change The Way We Live? *GQ*, 88(2), 98-104.

Hosmer, T., Tigas, P., Reeves, D., & He, Z. (2020). Spatial Assembly with Self-Play Reinforcement Learning. In B. Slocum, V. Ago, S. Doyle, A. Marcus, M. Yablonina and M. del Campo (Eds.), *Distributed Proximities. Proceedings of the 40th Annual Conference of the Association for Computer Aided Design in Architecture, ACADIA* (pp. 382-393). Online + Global.

Rodrigues Silva Dória, D., Ramaswami, K., Claypool, M., & Retsin, G. (2021). Public parts, resocialized autonomous communal life. *International Journal of Architectural Computing, 19*(4), 568-593.

Shaw, J. (2020). Platform real estate: Theory and practice of new urban real estate markets. *Urban Geography, 41(8)*, 1037-1064.

Srnicek, N. (2017). *Platform capitalism*. John Wiley & Sons.

Woldoff, R. A., & Litchfield, R. C. (2021). *Digital nomads: In search of freedom, community, and meaningful work in the new economy.* Oxford University Press, USA.

A Pre-Evaluation Tool for Interior Designs of High-Rise Office Buildings by User Movement Simulation after Covid'19

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Abstract. User movement optimization has become a more crucial design parameter in high-rise office interior design after the Covid'19 pandemic. This study aims to develop a pre-evaluation tool using vertical and horizontal user movement simulation in a high-rise building; to guide the pre-design phase of an office interior. Agent-based simulation software (AnyLogic v8.7.10) analyzes the relationship between circulation, design elements, and space. First, initial design which is created by the interior design team is evaluated by this simuation; later different interior design alternatives are simulated and tested to compare the results. Therefore, early design decisions taken by the design team are subject to change, reducing user intensity in specific locations throughout the day. This study concluded that the simulations' results can be integrated into the design decisions by the design team to develop effective interior designs led by new office design parameters after Covid'19.

Keywords: Agent-based systems, Office design, High-rise building, Covid'19, Interior design

1 Introduction

To optimize the movement-based design principles after Covid'19, the new office design parameters need to be set forth. Since there are many studies on office design optimization (Boje, Li, 2018), building occupancy simulation (Rai, Hu, 2018), agent based systems (Muravev, 2021; Norouziasl, 2020; Luo et al., 2017), pedestrian traffic (Rodriguez et al., 2013), ant colony optimization (Guarnizo, Pineda, 2019), elevator traffic (So, Al-Sharif, 2015) and wayfinding (Kuliga et al. 2019; Vilar et al., 2012; Hölscher et al. 2009); there are few research (Lee et al. 2021; Kelsey, 2021; Gomez et al. 2021) on the means of new working habits and user movement after Covid'19 pandemic.

This pandemic condition added new dimensions to an already complex design problem. With the Covid-19 pandemic, user movements have changed office life, creating new working habits and rules. Designers must consider the spread risk of viruses in the air and surface. To reduce virus spread, examining a multi-story structure and simulating it according to user movement is necessary. Most studies on agent-based simulation performance have focused on isolated floor levels in the horizontal plane (Hölscher et al., 2006). In a multi-story building, it is necessary to examine its relationship with other floors, vertically and horizontally to analyze the user's movement. This manuscript aims to offer new interior design simulations in a multi-level building while considering the interior design decisions.

The case study was carried out in an office building which is still under construction in Istanbul Financial Center with 2,500 employees and 17 directorates (35.000 sqm), total of 17 floors. The interior design layout of this office building is assigned to an architectural design office. Within this manuscript, authors used an agent-based simulation model to test the initial design layout, simulating the high-rise office building's vertical and horizontal user movement. To limit the study, this case study has been conducted between 12th and 13th floors, designed to host the Technical Vice Presidency Department (Table 1), a total of 385 employees. Later, the results of the simulations and the design suggestions are presented to the design office; new alternatives are simulated and compared according to the criteria; total distance, time, speed, and user density.

2 Movement-Based Design Studies and New Office Design

User movement is one of the most significant parameters affecting building traffic. Although recent work on crowd simulation focuses on public zones (Lu et al., 2016), it is challenging to simulate and examine large crowds in real-time because the agents are not programmed to make independent decisions. The model should consider both, dealing with individual human movement and interactions between them (Boje, Li, 2018). Other academic work has also been produced to develop models to simulate user movements with agent and graph-based applications (Rai, Hu, 2018). Within this perspective, agent-based modeling is also found useful and practical as a method for this study.

Interior design decisions that affect user movement should be reconsidered to optimize building traffic. The primary step in modeling and simulating occupancy behavior is collecting and monitoring user data (Park et al., 2019). To collect and analyze these data, user movement parameters must be measured.

These parameters have been divided into three major categories: (i) users' presence and absence or the number of people in space; (ii) users' location within a space; and (iii) users' preferences, energy-related behaviors, and interactions with the building (Naylor et al., 2018). Moreover, the Covid'19 pandemic, which has affected millions' lives, caused new social distance rules, personal interactions and eventually changed our working habits (Lee et al. 2021). This pandemic has altered personal interactions and hybrid working became the new normal. Physical distance between individuals is considered a key strategy for limiting Covid'19 transmissions among various mitigation measures (Matrajt and Tiffanny 2020, Nediari et al. 2021). Physical-distancing intervention is the most effective strategy for dealing with recurring infectious diseases. (Caley et al. 2008; Kleczkowski et al. 2015; Dascalu et al. 2020; Harweg et al. 2020). Therefore, it is crucial to rethink on office interiors within the social distance parameters.

After studying the office interiors both in literature and on-site projects, it is revealed that the most important design criteria to be considered in post-pandemic office designs are:

- Designing open spaces next to working areas for fresh air,
- Expanding sports fields to encourage employees to take action,
- Effective handling of ventilation per the number of employees
- Designing all spaces with automatic doors and hygienic surfaces,
- Reducing the density in the building by creating a hybrid working order with flexible working hours.
- Widening circulation areas,
- Expanding social spaces,
- Encouraging people to use stairs,
- Isolation and diversification of group work areas,
- Ensuring social distance rules.

The last five criteria are primarily used to evaluate the alternative plan layouts.

3 Methodology

Based on the key findings described in the previous section, this research aims to test a methodology for simulating the users' movement to optimize high density zones. In office buildings, where human density and movement are high, a solution proposal has been presented in order to reduce the high density during the Covid-19 pandemic process. This pandemic impacted on new office design layout, and how they can be adapted to the new normal. According to World Health Organization Exposure to COVID-19 at work zones depends on the likelihood of people coming within 1 meter of each other, constant physical contact with people who may be infected with COVID-19, and contact with contaminated objects.

In this study, a high-rise office building which is still under construction, located in Istanbul Financial Center is taken as a case study. Two floors, 12th and 13th, is simulated to limit the study. Relevant user data is taken from the insurance company, which will occupy this building for the next 20-30 years (Table 1).

As an agent-based design tool, AnyLogic v8.7.10, a program that allows the movements of agents to be observed in a system where floor plans can be input as input, is decided to be used. The flow chart of the method is explained below in (Fig.1). The user and obstacle types are defined. Obstacles are defined as the building core, walls, obstacles in the furnishing, etc., where user types are defined as workspace, entry-exit nodes, queue and waiting zones, floor, and speed. After this point, vertical and horizontal movements are coded.

As in the method, the initial plan designed by the design office is simulated. Then, some changes in the plans are made, different alternatives are created depending on the social distance parameters, which were mentioned before. As a result, all the alternatives are evaluated depending on the total distance, time, and speed parameters.

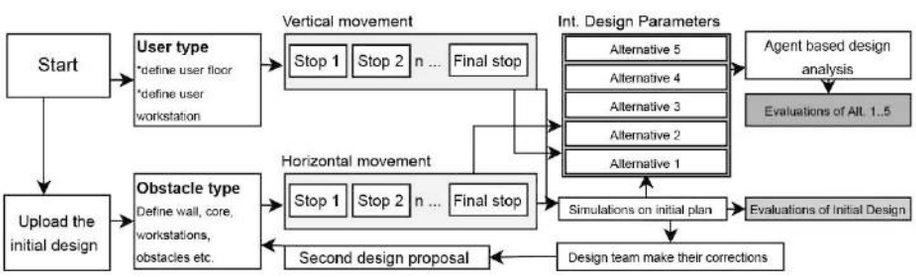

Figure 1. Flowchart of the method

3.1 Case Study: High Rise Office Interior Design at IFC

The 17-floor office building's floor plans in the Istanbul Financial Center (IFC) have been tested to evaluate its interior design decisions with user interaction. A semi-governmental insurance company will work in this building with 2000 people on 35.000 sqm. The interior design project is expected to finish by August 2022.

To develop a movement analysis in Anylogic, this work is limited to the vertical and horizontal movement between two floors. The movements of the 12th (148 people) and 13th floors (237 people) as simulated, assuming that it is a multi-story building and that the interaction between floors is also important. All employees arrive on campus at approximately the same time. The reason for choosing these two floors is that the employees are related, and the circulation is expected to be high. All employees' work zones are defined in the examined floor plans, and color codes define different departments (Fig. 2).

Agents are defined with the following attributes: Movement diameter, speed, role, start points, activity points, and exit points. There are three types of agents,

one moves horizontally on the 12th, the other horizontally on the 13th, and the last type moves vertically between two floors.

Table 1. The Divisions of Technical Vice Presidency Depart. on 12th and 13th floors

		Director	Dept. head	Personel
12th floor	Directorate of Non-Vehicle Insurance	1		
	(T-12-A) Head of Operations 1 Term Insurance		1	18
	(T-12-B) Head of Operations 2 Term Insurance		1	28
	(T-12-C) Head of Indv. Non-Vehicle Ins. and Product Dev.		1	11
	(T-12-D) Head of Construction and Energy Insurance		1	12
	(T-12-E) Head of Transportation Insurance		1	19
	Directorate of Auto, Agriculture and Actuary	1		
	(T-12-F) Head of Financial Insurance		1	19
	(T-12-G) Head of Agriculture Insurance		1	8
	(T-12-H) Head of Auto Insurance and Product Dev.		1	17
	(T-12-I) Head of Actuary, Data Analysis and Reports		1	11
	(T-12-J) Head of Auto Tariff Man., Reports and Traffic Ins.			
	Reserv Seat			13
	Total			**148**
13th floor	Directorate of Operations and Risk Engineering	1		
	(T-13-A) Head of Bank Operations		1	129
	(T-13-B) Head of Agent Operations		1	35
	(T-13-C) Head of Risk Engineering		1	15
	Directorate of Reasurance and Corporate Technics	1		
	(T-13-D) Head of Corporate Technics and Sales		1	23
	(T-13-E) Head of Directly Related Institutions		1	3
	(T-13-F) Head of Reasurance and Special Risks		1	9
	(T-13-G) Head of Corporate Sales (Life and Retirement)		1	7
	Reserv Seat			7
	Total			**237**

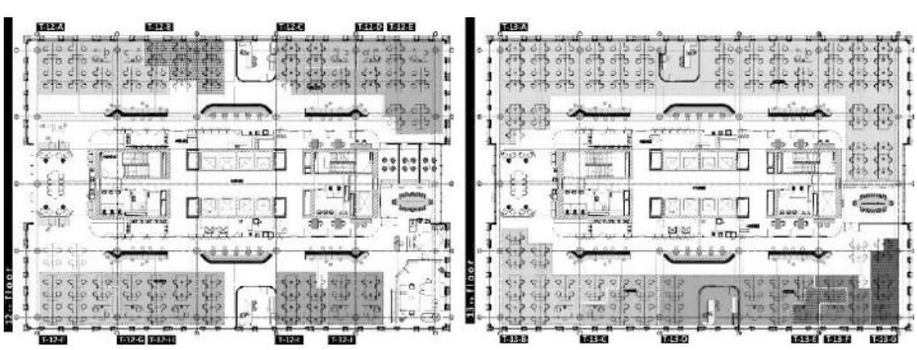

Figure 2. The plan layout of 12th (left) and 13th (right) floors (north is upwards).

3.2 Simulation Setup

The people on the 12th and 13th floor to be simulated are placed in your floor plan according to the given work schedule. The probable action scenario is simulated with the obstacles defined to the agents that comply with this program. The agents reach the destination by passing the obstacles according to the scenario. The result of this simulation gives us the output of the distances traveled and the human density that may occur.

3.3 User Simulation Interface

To simplify simulation of the proposed framework, it is assumed that all employees first enter the building, some stop by the cloakroom, and then move to their workstations. While the scenario is being simulated, the density map is created and the movement of the agents is observed. With the inputs entered into the AnyLogic program, the speeds of the agents, their destinations (workstations), and obstacles in the overall plan are defined.

When creating a new model, the New toolbar button is clicked, and the New Model wizard appears. One should specify the name and the location where the model files need to be stored. After that, *minutes* is selected as the model time units and you finish to complete the process. After the new model is created, it already has one agent type called *Main* and an experiment called *Simulation*. Agents are the main building blocks of the AnyLogic model. In this case the *Main* agent is where all the logic of the model is defined, plan drawing of the office is uploaded and the flow chart describing the user flow process is defined (Fig. 3).

When you want to add a drawing to the interface; *entry, target, elevator lines* and *obstacles* (walls, core of building, desks, columns) are defined so that the route can be simulated and agents can move.

The process flowchart of AnyLogic defines user movement. The first step in the flowchart is *PedSource*, which creates the start point of the simulation. *PedSource* generates agents at the intended location (elevator zones). *PedSelectOutput* directs agents to their zones in specified conditions. *PedGoTo* defines the exit point of agents, which is the elevator zone. *PedChangeLevel* directs pedestrians to a different level. *PedWait* brings pedestrians to wait for a specified time in a specified location. *PedSink* finishes the simulation. When the simulation is started, the agents spawn in the defined area and begin to move to their target points. Agents notice each other and obstacles, then move at a desired speed without touching them. When they arrive at their workstation, they wait there for the time defined in the flow chart (Fig. 4).

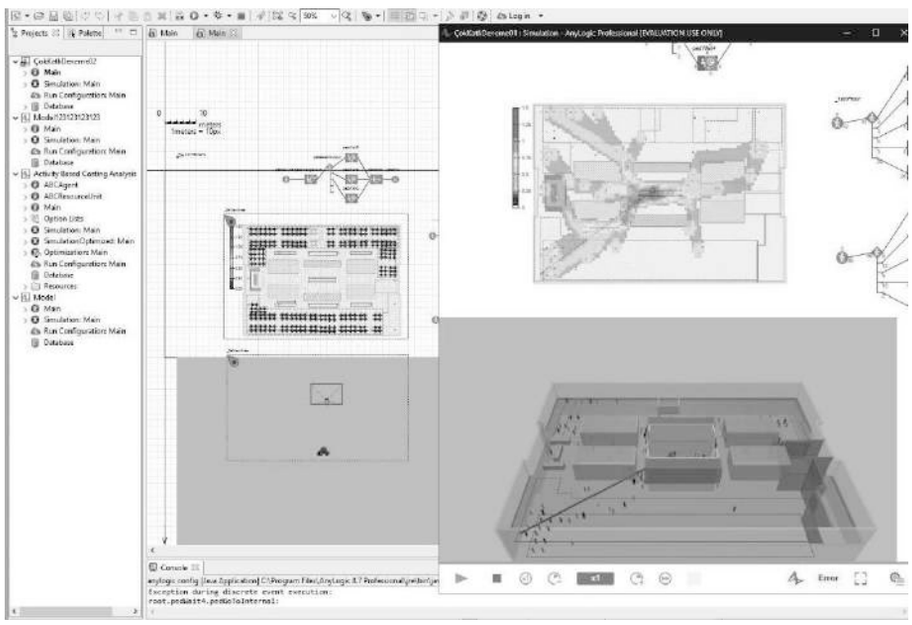

Figure 3. Anylogic v8. simulation interface

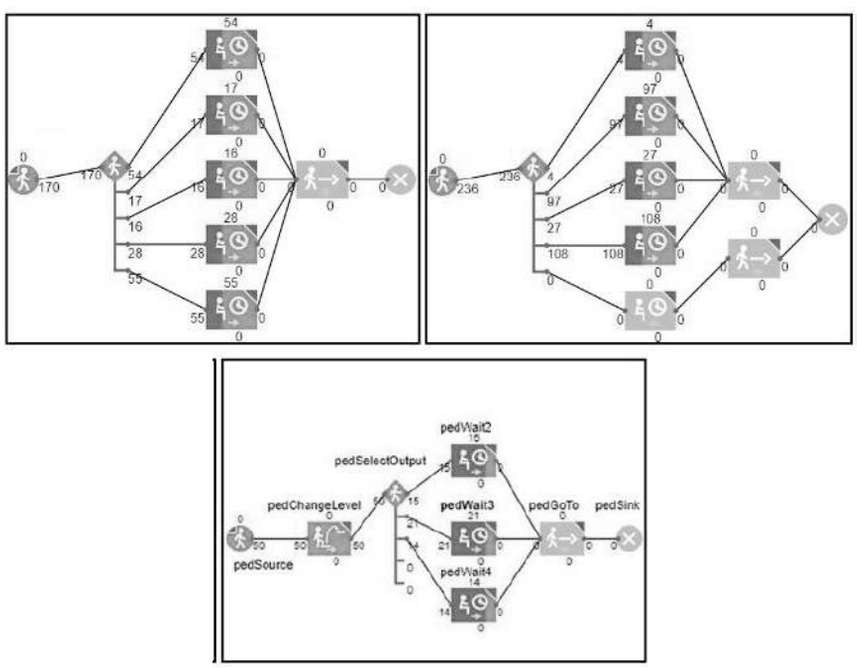

Figure 4. Anylogic coding for simulations, (left) 12th floor, (middle) 13th floor, (right) inbetween floors

4 Results

After the simulation setup is ready, the initial design is first tested, and the results can be seen in Figure 5. The color code shows that person/m2, red shows 1.5 person per m^2. After the Covid'19 pandemic, it is found that the overall density should be one person (10 m^2). The people are assumed to reach their floor via eight elevators or stairs in the core and then reach their workstations. In this simulation, we see that there are high densities in the social corner (in the west wing), therefore, more social corners should be designed.

In Alternative 1, the cloakroom's location is changed, and put in the middle of the plan for both sides. It is assumed that after arriving the building, people will reach their floor, visit cloakroom for their coats, and then reach their workstations. Unexpectedly, changing the cloakroom's location didn't improve the design at all. In Alternative 2, a door is assigned to the core, to provide an east-west circulation between the workstations and the core. As seen in Table 2, the min. distance and total time (route) is the lowest in this alternative, which is best through these alternatives. Alternative 3 is an option where cloakroom is removed, so there is less traffic on the circulation areas. Alternatively, people may use their closets for personal belongings.

In Alternative 4, social desks, which are located on north and south wing, are removed. There is a critic that those desks are blocking the workstations, but the results came out unexpectedly. There are more red zones in Alternative 4 rather than the previous ones. As a final, Alternative 5 is created, social desks are removed and distance between the workstations are widened. With this alternative, the number of people on the floor is also lesser than before.

User density map was observed to reduce virus spread. In the study on alternative plans; the average of the red color value (RGB:R) of the resulting maps was calculated. After this color channel calculation, improvements have been made to alternative floor plans with high-density red color zones (Table 3).

As a result of simulated alternative plans; we can observe that the least density occurs in the 5th plan alternative.

Table 2. Results of alternative plans on distance, time and speed on 12th and 13th floors (385 agents)

	Total distance (m.)	Total Time (sec.)	Average speed (m./sec.)
Initial Design	33	45.70	0,76
Alternative 1	36.85	47.94	0,77
Alternative 2	31.52	41.03	0,78
Alternative 3	32.68	44.55	0,76
Alternative 4	32.36	44.65	0,76
Alternative 5	32.89	44.76	0,76

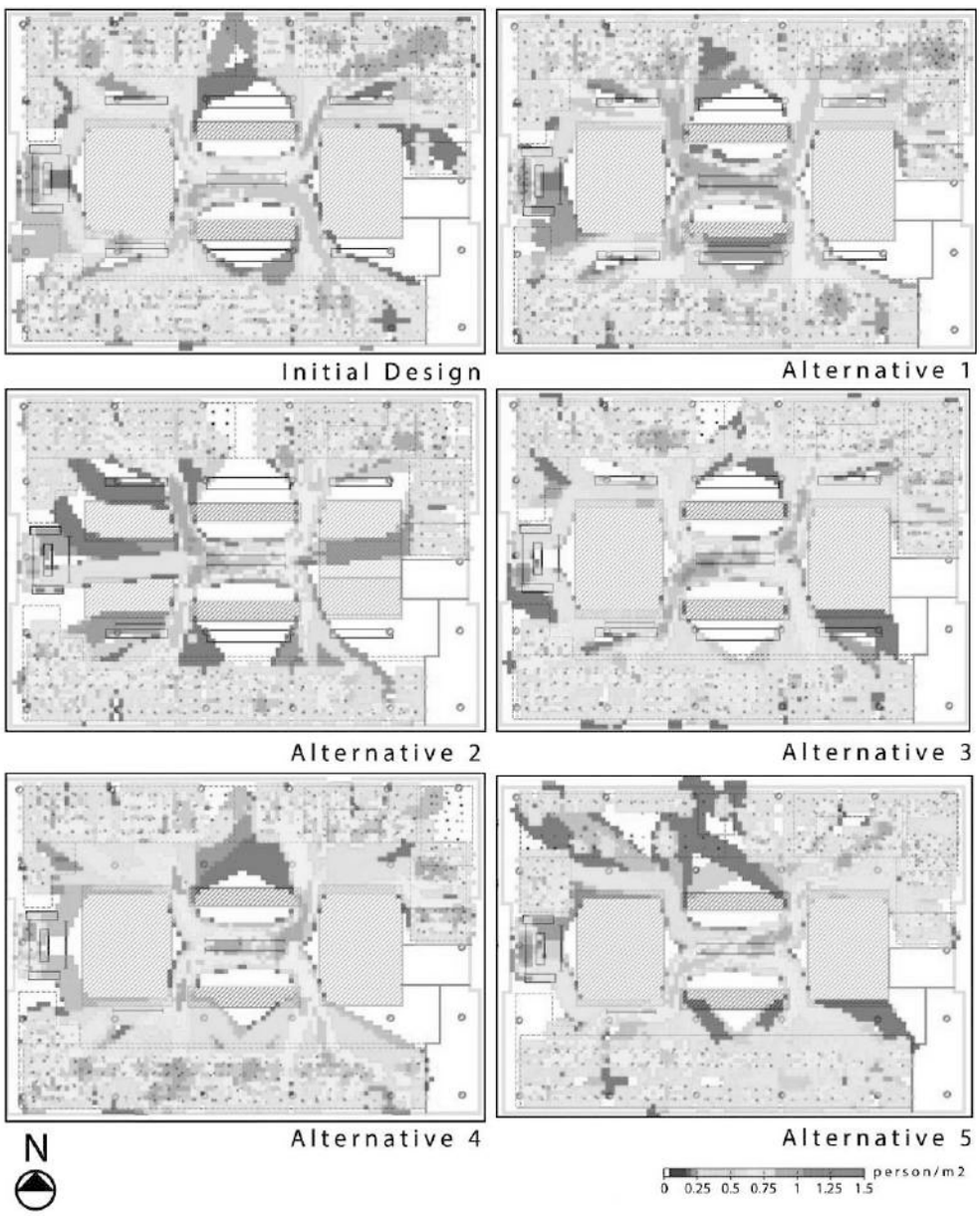

Figure 5. Simulation results of the alternative interior designs (13th floor)

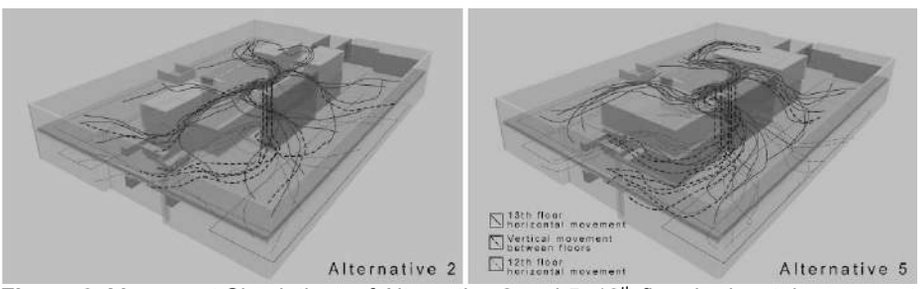

Figure 6. Movement Simulations of Alternative 2 and 5: 13th floor horizontal movement (red continuous line), Vertical movement between floors (dark blue dashed line), 12th floor horizontal movement (light blue dotted line)

Table 3. Color space and channel statistics of the simulations (RGB:R) for the user density analysis

	avg	med	min	max
Initial Design	191	212	82	254
Alternative 1	190	211	74	254
Alternative 2	183	191	82	254
Alternative 3	186	198	81	254
Alternative 4	187	206	82	254
Alternative 5	177	177	83	254

5 Discussion

This simulation enables experimentation on a valid digital representation of a system. It is essential to think about new means of public spaces and working habits after Covid'19. After feeding the model data and receiving the simulation results, the proposed design can be improved wherever the high density becomes a problem. The results showed that simulating user movement in a high-rise office building and changing design decisions will optimize building traffic and improve for a healthier indoor space. This study suggests that office buildings' user movement patterns can differ depending on their business relations. The study focuses on the analysis and verification of modeling of user behavior patterns in office buildings due to user movement data.

This study developed a framework to model and simulate user behavior in office buildings to improve interior design decisions with designers using predefined parameters like employee scheduling, working area location, and user speed. Preventing the spread of the Covid'19 virus and examining architectural spaces with a density map in advance allows solutions to be produced.

Several decision-making processes, such as path change behaviors when simulation continues, require improvements in the study.

In a future study, the whole building will be simulated with all the users. Also, it will be possible to analyze post-occupancy evaluations after the users move

into the office building (2023 April) and start working there. It is also suggested that group events at the ground level, such as meetings and organizations, can be analyzed similarly once sufficient data has been collected and analyzed.

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References

AnyLogic. (2020). Pedestrian Library. https://www.anylogic.com/features/libraries/pedestrian-library/

Boje, C., & Li, H. (2018). Crowd simulation-based knowledge mining supporting building evacuation design. Advanced Engineering Informatics, 37 (103–118). https://doi.org/10.1016/j.aei.2018.05.002

Caley, P., Philp, D. J., & McCracken, K. (2007). Quantifying social distancing arising from pandemic influenza. Journal of The Royal Society Interface, 5(23), 631–639. https://doi.org/10.1098/rsif.2007.1197

Gomez, P., Hadi, K., Swarts, M., Kemenova, O., Bernal, M., Spatiotemporal Modeling: Spread of COVID-19 in Educational Settings: The Role of Architecture in A Pandemic, 9th ASCAAD Proceedings, pg. 421-434, 2021.

Guarnizo, O., & Pineda, I. (2019). Three Dimensional Adaptive Path Planning Simulation Based On Ant Colony Optimization Algorithm. 2019 IEEE Latin American Conference on Computational Intelligence (LA-CCI). https://doi.org/10.1109/la-cci47412.2019.9037049

Hölscher, C., Büchner, S. J., Meilinger, T., & Strube, G. (2009). Adaptivity of way- finding strategies in a multi-building ensemble: The effects of spatial structure, task requirements, and metric information. Journal of Environmental Psychology, 29 (208-219). https://doi:10.1016/j.jenvp.2008.05.010

Kuliga, S. F., Nelligan, B., Dalton, R. C., Marchette, S., Shelton, A. L., Carlson, L., & Hölscher, C. (2019). Exploring Individual Differences and Building Complexity in Wayfinding: The Case of the Seattle Central Library. Environment and Behavior, 51(5), 622–665. https://doi.org/10.1177/0013916519836149

Lee, B., Lee, M., Mogk, J., Goldstein, R., Bibliowicz, J., & Tessier, A. (2021). Designing a Multi-Agent Occupant Simulation System to Support Facility Planning and Analysis for COVID-19, DIS '21: Designing Interactive Systems Conference 2021, 15–30. https://doi.org/10.1145/3461778.3462030

Kelsey, D. (2021) Office Typology for the Post-Covid Workforce, Master's Thesis, University of Washington.

Kleczkowski, A., Maharaj, S., Rasmussen, S., Williams, L., & Cairns, N. (2015). Spontaneous social distancing in response to a simulated epidemic:a virtual experiment. BMC Public Health,15(1). https://doi.org/10.1186/s12889-015-2336-7

Lee, B., & Ahn, C. R. (2021). Agent-based simulation to predict occupants' physical-distancing behaviors in educational buildings. 2021 Winter Simulation Conference (WSC). https://doi.org/10.1109/wsc52266.2021.9715451 Luo, X., Lam, K. P., Chen, Y., & Hong, T. (2017). Performance evaluation of an agent-based occupancy simulation model. Building and Environment, 115, 42–53. https://doi.org/10.1016/j.buildenv.2017.01.015

Matrajt, L., & Leung, T. (2020). Evaluating the Effectiveness of Social Distancing Interventions to Delay or Flatten the Epidemic Curve of Coronavirus Disease. Emerging Infectious Diseases, 26(8), 1740–1748. https://doi.org/10.3201/eid2608.201093

Muravev, D., Hu, H., Rakhmangulov, A., & Mishkurov, P. (2021). Multi-agent optimization of the intermodal terminal main parameters by using AnyLogic simulation platform: Case study on the Ningbo-Zhoushan Port. International Journal of Information Management, 57 (102-133). https://doi.org/10.1016/j.ijinfomgt.2020.102133

Nediari, A., Roesli, C., & Simanjuntak, P. M. (2021). Preparing post Covid-19 pandemic office design as the new concept of sustainability design. IOP Conference Series: Earth and Environmental Science, 729(1), 012095. https://doi.org/10.1088/1755-1315/729/1/012095

Norouziasl, S., Jafari, A., & Wang, C. (2020). An agent-based simulation of occupancy schedule in office buildings. Building and Environment, 186, 107352. https://doi.org/10.1016/j.buildenv.2020.107352

Park, J. Y., Ouf, M. M., Gunay, B., Peng, Y., O'Brien, W., Kjærgaard, M. B., & Nagy, Z. (2019). A critical review of field implementations of occupant-centric building controls. Building and Environment, 165, 106351. https://doi.org/10.1016/j.buildenv.2019.106351

Rai, S., & Hu, X. (2018). Building occupancy simulation and data assimilation using a graph-based agent-oriented model. Physica A: Statistical Mechanics and Its Applications, 502 (270–287). https://doi.org/10.1016/j.physa.2018.02.051

Rodriguez, S., Zhang, Y., Gans, N. & Amato, N. M. (2013). Optimizing aspects of pedestrian traffic in building designs. IEEE/RSJ International Conference on Intelligent Robots and Systems, 1327-1334, https://doi:10.1109/IROS.2013.6696521

Naylor, S., Gillott, M., & Lau, T. (2018). A review of occupant-centric building control strategies to reduce building energy use. Renewable and Sustainable Energy Reviews, 96, 1–10. https://doi.org/10.1016/j.rser.2018.07.019

So, A., & Al-Sharif, L. (2015). Elevator Traffic Analysis: Analytical Versus Simulated. Elevator World, 63(1), 98–101.

Vilar, E., Rebelo, F., & Noriega, P. (2012). Indoor Human Wayfinding Performance Using Vertical and Horizontal Signage in Virtual Reality. Human Factors and Ergonomics in Manufacturing & Service Industries, 24(6), 601–615. https://doi.org/10.1002/hfm.20503

Vizzari, G., Crociani, L., & Bandini, S. (2020). An agent-based model for plausible wayfinding in pedestrian simulation. Engineering Applications of Artificial Intelligence, 87, 103241. https://doi.org/10.1016/j.engappai.2019.103241

Human Behavior Simulations to Determine Best Strategies for Reducing COVID-19 Risk in Schools

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Abstract. The dynamics of COVID-19 spread have been studied from an epidemiological perspective, at city, country, and global scales (Rabajante, 2020, Ma, 2020, and Giuliani et al., 2020), although after two years of the pandemic we know that viruses spread mostly through built environments. This study is part of the Spatiotemporal Modeling of COVID-19 spread in buildings research (Gomez, Hadi, and Kemenova et al., 2020 and 2021), which proposes a multidimensional model that integrates spatial configurations, temporal use of spaces, and virus characteristics into one multidimensional model. This paper presents a specific branch of this model that analyzes the behavioral parameters, such as vaccination, masking, and mRNA booster rates, and compares them to reducing room occupancy. We focused on human behavior, specifically human interactions within six feet. We utilized the multipurpose simulation software, AnyLogic, to quantify individual exposure to the virus, in the high school building by Perkins and Will. The results show how the most effective solution, reducing the occupancy rates or redesigning layouts, being the most impractical one, is as effective as 80% of the population getting a third boost.

Keywords: Spatiotemporal Modeling, Behavior Analytics, COVID-19 Spread, Agent-Based Simulation, COVID-19 Prevention

1 Introduction

Beyond social distancing, and especially for countries or states where policies are loose or non-existent, the question is: What parameters of the space configuration and the organizational schedule can be modified to reach similar levels of protection or reduction of risk for our students? Even countries with previous virus prevention policies are adapting to life with the virus, and as

of April 19th, 2022, U.S airlines have officially ended the mask travel mandate (Chokshi, Murphy 2022). This change in national policy highlights this shift in society's perception of COVID-19. It is important to continue research of virus spread in enclosed spaces in order to modify prevention techniques relative to the risk exposure.

Furthermore, Lippi and Mattiuzzi's (2022) assessment of mRNA booster dose efficacy highlights that there is an ongoing debate as to whether or not a booster dose restores, increases, or does not affect COVID-19 immunity six months after receiving two doses of a vaccine. Astoundingly, six months after vaccination, individuals are only 59% protected against COVID-19 infection. However, receiving a booster dose increases this protection to 65% or more.

To restore immunity, it is essential that people who have received the vaccine greater than six months ago obtain a booster shot, especially since 100% of the current March 2022 shares of SARS-CoV-2 sequences are the Omicron variant, which is one of the most infectious (Yale Medicine). Additionally, a greater number of boosted individuals helps impede the spread of the pandemic, as booster-vaccinated individuals have a lower viral load when infected with COVID-19 (Lippi, Mattiuzzi 2022).

Past research has evaluated the role of masking in conjunction with vaccines on the spread of COVID-19 in a school environment, to make the return to in-person school as safe as possible. The data shows that if 95% of the community is vaccinated and nobody wears a mask, then there will be only 2 excess COVID-19 cases per 100 students (Head, et al. 2022). However, since the CDC states that only 65% of Americans are fully vaccinated, this is not representative of the community and alternative vaccine and mask wearing combinations must be considered. Additionally, the U.S Census Bureau states that 6% of Americans are under 5 years old, which is the minimum age to get vaccinated. Thus, it was currently impossible to reach a 95% vaccination rate.

Another important aspect of the research is the question - who is wearing a mask, what type of mask are they wearing, and how often? Knowing the percentage of people wearing masks is crucial for running agent based simulations with masking parameters. In a 2020 study, it was noted that overall, young people were 20% less likely to wear a mask than their older counterparts (Haischer, Michael H., et al., 2020). Since 18 – 24 year olds are the least likely to wear a mask out of all the age groups, it is important to study masking and vaccination effects in this age group in order to determine the worst-case scenario of spread.

The overall research goal is to study how individual human interaction within six-feet, without maintaining social distance, can impact the overall COVID-19 exposure of a population, while taking into account the booster dose efficacy, mask-wearing behavior, and mask use behavior. The following research questions are investigated: What COVID-19 prevention policy is most effective

and practical to implement in a built environment? Is increased societal masking as effective as if 80% of the population were to get boosted? What is the relationship between increasing virus prevention measures or decreasing the number of people present? For example, if the objective is to decrease individual exposure by 50%, can this also be achieved by decreasing the room occupancy by 50%?

2 Methodology

2.0 Experiment Design

The research design is based on the layout of the second floor of school, modeled as 30.6 meters wide and 93.2 meters long. AnyLogic Software was utilized for agent-based modeling, which simulated 100 students as agents arriving from the staircase on the left corner, entering one of the classrooms, and exiting, in a 50 second interval simulating one 50-minute class period. The school layout has five classrooms, and 20% of students entered each classroom to evenly distribute the agents. This spatial distribution does not significantly influence infection, and avoids agent congregation, to focus solely on how masking and vaccination rates affect the spread of COVID-19. While 20% of the student agents will leave through another staircase, the rest of them will enter the open-space library area (top of Figure 1) and spend some time there before leaving.

Further spatial analysis was conducted using Rhinoceros 3D, which outputs the total exposure count per classroom. The output from the AnyLogic model was inputted into Rhino, to study the model from a spatial perspective considering the total area of the room, number of agents in the room, and total time spent in the room. Figure 2 displays the space configuration for the school. The agents begin walking past classroom 4, with their path ending in classroom 0.

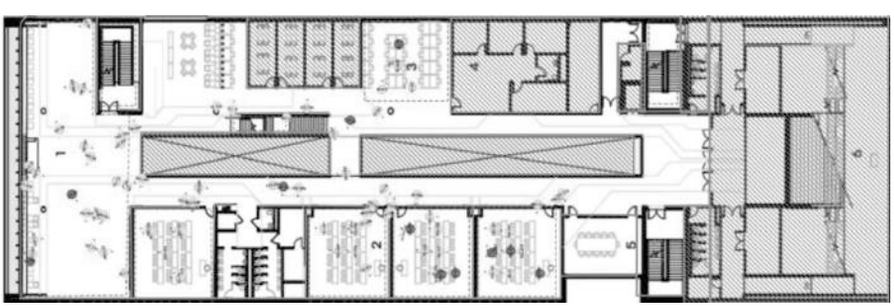

Figure 1. Agent-based modeling on the high school 2nd floor

Figure 2. Spatial modeling of high school 2nd floor

2.1 Parameters Identified for Simulation in AnyLogic

2.1.1 Building Parameters:

The project, provided by Perkins & Will Design Process Lab, is a high school in Alabama, and it was the specific layout we used for the case study is of the second floor of school library, consisting of five classrooms, a hallway, and a stairwell.

2.1.2 Agent parameters:

The agent parameters include the following:

Occupancy: 100 agents
Number of Known Cases in Building: **10%**

Vaccination Status:

- Not fully vaccinated: Someone who is either not vaccinated at all against COVID-19 or has been vaccinated only once.
- Fully vaccinated without booster: A person who will have been fully vaccinated but not have received a booster shot.
- Fully vaccinated with booster: One who has been fully vaccinated in addition to receiving at least one booster shot.

PPE (Personal Protective Equipment) level:

- No mask: The person never wears a mask, neither indoors nor outdoors
- Fabric mask: Three-to-five layers of tightly woven fabric
- Surgical mask: A mask with three layers of filtration and fluid resistance
- N-95 respirator: Fit-tested, with five layers of filtration (and fluid resistance)

Health Status:

- Healthy, not sick with COVID-19 (Omicron variant)
- Symptomatic and actively contagious with COVID-19 (Omicron variant)

2.1.3 Scenarios:

Below is an outline of four different scenarios, which combine parameters in unique ways. Table 1 shows the parameters for each scenario, and the percentage of agents assigned to each parameter.

Scenario A: The current United States situation. It serves as a control group relative to Scenarios B and C. It is modeled off of the case rates, vaccination rates, and policies in United States in the spring of 2022. For example, as of March 28, 2022, 11% of people were not fully vaccinated, while 62.3% of people were vaccinated but not boosted (CDC: Our World in Data 2022). Additionally, the mask wearing data assumed that individuals follow CDC guidelines, which as of February 25th, 2022, state that 70% of Americans can stop wearing masks (Mandavilli 2022). However, for the remaining 30% of Americans that may continue to wear a mask, it was arbitrarily chosen that an equal majority of agents would wear either a fabric or surgical mask due to relative ease of purchase, with the remaining 1% of Americans wearing an N-95.

Scenario B: Increase number of boosted and vaccinated agents. It aims to improve the vaccination and booster situation of Scenario A by increasing the number of agents who are boosted and/or vaccinated. The mask wearing data remains the same as in Scenario A. To evaluate the effectiveness of the booster shot in decreasing the exposure risk, the number of agents with a booster shot was increased to 80%. To focus the insights on the effect of increasing the number of boosted individuals alone, this scenario assumed that every individual was vaccinated. The mask wearing assumptions remained the same as in Scenario A. Table 1 shows the vaccination parameters for Scenario B, with the percentage of agents assigned to each parameter.

The purpose of this scenario was to (1) evaluate how an increase in the number of boosted agents affects the total exposure count and (2) compare Scenario B with Scenario C, to determine whether changing vaccination status or mask-wearing is more effective in decreasing exposure count. If mask-wearing largely declines or ceases in the real-world, as seen through the recent U.S. airline policy change (Chokshi, Murphy 2022), the efficacy of the vaccine and/or booster alone must be evaluated.

Scenario C: Increase number of agents wearing a mask. It improves the mask wearing behavior of individuals, by increasing the number of agents wearing a mask, especially surgical and N-95 masks, while keeping the vaccination status the same as in Scenario A. To evaluate the effectiveness of masks in decreasing exposure count, the number of agents wearing a mask, especially a surgical or N-95 mask, was increased. To focus solely on improving masking-behavior and mask type, the vaccination status parameters remained the same as in Scenario A. Table 1 shows the masking parameters for Scenario C, with the percentage of agents assigned to each parameter.

The percentage of agents wearing masks was chosen based on research that was done during the peak of the pandemic in the US according to which 83% of Americans reported wearing a mask to mitigate risk (Hearne, Nino 2021). We adjusted this rate in our model to 90% to account for the increase in booster shots and vaccination from Scenario B. Thus, since we are assuming that everyone is vaccinated in Scenario B, we are assuming that a higher percentage of agents are wearing masks than during the peak of the pandemic.

Scenario D: Decrease the number of agents by 50%. This scenario keeps the same parameters as Scenario A, while decreasing the number of agents by 50%. This serves as a comparison to the measures implemented in Scenario B and Scenario C. Scenario D implements the same parameters as Scenario A, only decreasing the number of agents from 100 to 50. The purpose of decreasing the agents by 50% is to display the effectiveness of booster shots and masks. For example, if decreasing the overall exposure by 50% is obtained by either extensive masking and boosting or decreasing the agents by 50%, then the results may generate societal motivation to mask and get boosted to prevent having to implement lower occupancy restriction policies with social distancing measures. Thus, Scenario D aims to show the relative effectiveness of COVID-19 prevention measures versus decreasing human interaction.

Table 1. Percentage of agents assigned to each parameter for Scenario A, B, C, D

Parameter	Scenario A (100 agents)	Scenario B (100 agents)	Scenario C (100 agents)	Scenario D (50 agents)
Not fully vaccinated	11%	0%	11%	11%
Fully vaccinated without booster shot	62.3%	20%	62.3%	62.3%
Fully vaccinated with booster shot	26.7%	80%	26.7%	26.7%
Not wearing a mask	70%	70%	10%	70%
Wearing a fabric mask	14.5%	14.5%	30%	14.5%
Wearing a surgical mask	14.5%	14.5%	55%	14.%
Wearing an N-95 mask	1%	1%	5%	1%

2.2 Software and Metrics

The four scenarios were modeled in AnyLogic (version 8.7.10) for agent-based simulation. The software utilizes Java, and boolean logic was applied to assign agents to the specified parameters per scenario. The reference path of agents and results from AnyLogic were input into Rhinoceros 3D (version 7).

To evaluate the outputs, we introduce two variables: epidemiological status, which is quantified through infection amount, and exposure count. Each agent has an epidemiological status of either sick or healthy. Healthy means that the agent is not currently sick, but they have a low amount of virus particles from the vaccine, resulting in an initial infection amount of 0.1. If an agent is currently sick, they have an initial infection amount of 0.9. Each scenario randomly assigned 10% of the agents to be sick.

Exposure count is used to evaluate how exposure to COVID-19 increases as the agents interact in each scenario. Each time two agents are within six feet of each other, the exposure count of an individual agent increases based on the parameters in each scenario. For example, if an agent with a booster shot interacts with a sick agent, they receive less exposure than a non-boosted agent that interacts with a sick agent. Table 2 below shows how exposure count is affected by the various parameters. The decrease in exposure count with those vaccinated with a booster shot based on research showing that a person vaccinated with two doses is 80% protected from COVID-19 death, and a booster shot restores an individual to its original immunity (Lippi, Mattiuzzi 2022). The decrease in exposure count for those without a booster is based on data showing that after 25 weeks, vaccine effectiveness against the Omicron variant decreases to less than 20% (Sidik, S. M, 2022). The decrease in exposure count for fabric masks, surgical masks, and N-95 masks models real-world mask efficacy (Gurbaxani, Brian M).

Table 2. How each parameter decreases exposure count for an agent.

Parameter	% decrease in exposure count
Not fully vaccinated	0
Fully vaccinated with no booster	20
Fully vaccinated with booster	80
No mask	0
Fabric mask	33
Surgical mask	56
N-95 mask	96

3 Results

For each scenario, five trials were conducted to account for the randomized agent movement in each scenario. Preliminary data analysis involved averaging the exposure count for each trial, which was calculated as the sum of the exposure count per agent divided by the number of agents. This was again averaged over five trials to obtain an overall average. Further data analysis included calculating the standard deviation of each scenario. Figure 3 is a box plot that displays the mean, standard deviation, and range of each scenario.

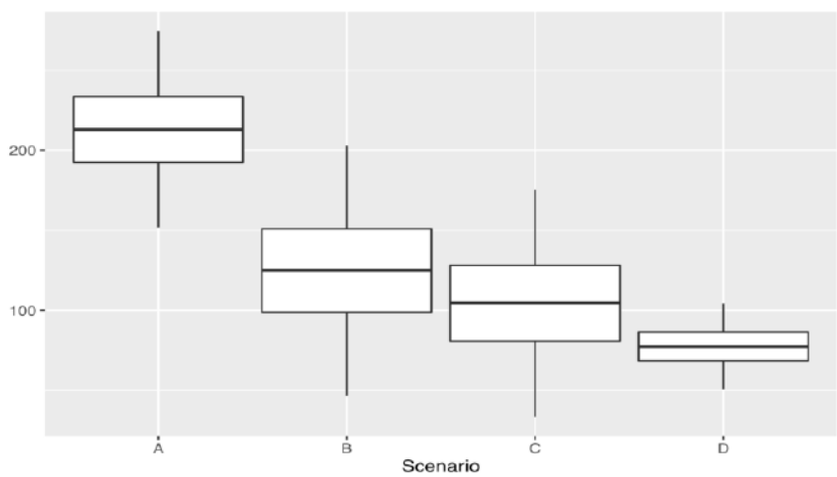

Figure 3. Box plot of exposure output's mean by scenario. Description below.

Scenario A, B, and C all have a population of 100 agents, while scenario D has a population of 50 agents. By using a 95% confidence interval, confidence interval ranges for each scenario are calculated: Scenario A has range [209.0747, 217.0933] for its mean with 20.456 standard deviation; Scenario B has range [119.804, 130.014] with standard deviation 26.044; Scenario C has [99.868, 109.1536] with standard deviation 23.69; Scenario D has [74.912, 79.876] with standard deviation 9.954.

Scenario B had the highest standard deviation, indicating that there is more uncertainty in the data due to outliers. Clearly, the outputs of Scenario D has the least uncertainty as it has the lowest standard deviation. Additionally, relative to Scenario A (control), which had an average overall exposure count of 213, Scenario D decreased the overall exposure count most significantly, by 63.6%. Scenario B decreased the overall exposure count by approximately 41.3%, while Scenario C decreased the overall exposure by approximately 50.9%.

3.1 Results Compared

The most novel aspect of this study was introducing booster variables into an agent-based simulation and studying the efficacy of booster doses in conjunction with mask-wearing behavior. Introducing spatial variables beyond social distancing reveals that schools should consider implementing mask mandates or require booster doses to reduce overall agent exposure count by at least 50%. One limitation of our study is that we are unable to directly compare vaccination and masking. Because of this, we only compare the output of Scenario B, C, and D directly to Scenario A. While Scenario D reduces occupancy by 50% and is the most effective in terms of decreasing overall agent exposure, it would be the least practical solution for schools to implement as it would require every building to either reduce room capacity or be physically modified. Scenario B and C both reduce the agent exposure by similar amounts (around 50%) with Scenario C, increased masking, being the more effective of the two. This shows that increased masking can be just as if not more effective than 80% of the population getting boosted.

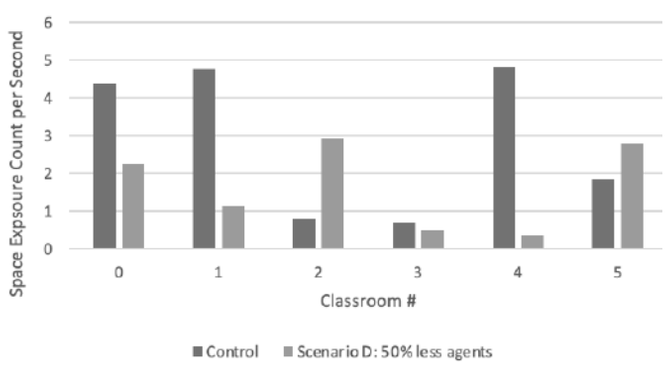

Figure 4. Space Exposure Count per second in each Classroom: Control, Scenario D

Thus, Scenario C, increasing the number of agents wearing a mask to 90% without changing the current March 2022 percent of vaccinated and boosted individuals, shows to be effective, and likely the most practical method to implement in a school environment. Therefore, the policy that would be most beneficial to implement in schools would be to increase masking and require masks with a higher filtration level such as replacing cloth masks and bandanas with surgical masks and N-95 masks.

Further spatial analysis shows that classrooms closer to the entrance result in a larger space exposure count per unit of time, which is measured as the exposure count per second, occurring when agents are less than 6 ft from one another. Room 4 (Figure 2) is of particular interest, as it is the closest room to where agents enter. When the total number of agents decreased by 50%, the exposure count per time decreased by a magnitude of 12 in room 4.

Furthermore, room 0 contained all the agents by the end of the simulation. Agents spent over 8000 seconds in room 0, while only spending an average of 1000 seconds in each classroom. The lower exposure count in room 0 versus room 4 shows that allowing agents to aggregate in a larger space was effective in decreasing the exposure count over time, as room 0 was over three times larger than the classrooms.

4 Discussion

Spatiotemporal modeling continues to be an effective way to model COVID-19 spread through individuals as it allows in-depth analysis of behavioral parameters, such as vaccination, masking, and mRNA booster rates in a controlled, simulated environment. The insights provided through this study furthers current research on the impact of human interactions on COVID-19 spread. The insights from this study will only be effective if schools implement the advised policies; this model emphasizes the fact that COVID-19 spread occurs even in ideal scenarios where every individual is vaccinated, and thus policies to prevent the spread of the disease are still necessary.

In the short-term, future research will involve expanding the current parameters and adding additional variables. For example, the epidemiological status of an individual was simplified down to just two possible cases - sick or healthy - but this could be expanded to include sick individuals who are symptomatic versus asymptomatic, as well as sick individuals who are vaccinated versus unvaccinated. Studying how a vaccinated/boosted COVID-19 carrier spreads the virus would be fascinating, especially as research shows that boosted individuals carry a lower viral load when catching the virus (Lippi, Mattiuzzi 2022).

Additionally, the time since vaccination should be considered, as people who are farther from their initial two-dose sequence are less protected from contracting COVID-19 than people who have been recently vaccinated or boosted. Lastly, partial vaccination (1 dose) was not considered in this model. This should be accounted for in future work, as well as the type of vaccine received, since mRNA vaccines are shown to be more protective than alternative vaccines (Bhandari 2021). Another short-term application is to explore the effectiveness of the new CDC quarantine guidelines, to determine if people are still at high-risk of exposure when interacting with people who have only quarantined for 5-days.

From an architectural perspective, the modification of layouts is another alternative to be explored. Preliminary spatial analysis reveals that classroom 4, the room closest to the entrance, had the largest exposure count over time. The exposure count in classroom 4 decreased by a magnitude of 12 when the number of agents was decreased by 50%. However, as decreasing occupancy

rates is likely ineffective as a long-term solution, schools should consider staggering entry time or ensuring there are multiple hallway entry points to decrease exposure count over time.

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References

Bhandari, T. (2021, December 28). *What makes an mrna vaccine so effective against severe COVID-19?* Washington University School of Medicine in St. Louis. Retrieved March 2022, from https://medicine.wustl.edu/news/what-makes-an-mrna-vaccine-so-effective-against-severe-covid-19/#:~:text=In%20clinical%20trials%2C%20both%20were,considered%20for%20 emergency%20use%20 authorization.

Centers for Disease Control and Prevention. (n.d.). *CDC Covid Data tracker*. Centers for Disease Control and Prevention. Retrieved March 2022, from https://covid.cdc.gov/covid-data-tracker/#vaccinations_vacc-total-admin-rate-total.

Centers for Disease Control and Prevention. (2022, February 10). *Effectiveness of face mask or respirator use in indoor public settings for prevention of SARS-COV-2 infection - California, February–December 2021*. Centers for Disease Control and Prevention. Retrieved March 2022, from https://www.cdc.gov/mmwr/volumes/71/wr/mm7106e1.htm

Covid-19 vaccine boosters administered per 100 people. Our World in Data. (n.d.). Retrieved March 2022, from https://ourworldindata.org/grapher/covid-vaccine-booster-doses-per-capita?country=BGD~BRA~CHL~IND~ITA~PAK~RUS~SGP~USA~OWID_WRL.

Giuliani, D., Dickson, M. M., Espa, G., & Santi, F. (2020). *Modelling and predicting the spatio-temporal spread of Coronavirus disease 2019 (COVID-19) in Italy*. http://arxiv.org/abs/2003.06664

Gomez Z., P., Hadi, K., Kemenova, O., & Swarts, M. (2020). Spatiotemporal Modeling of COVID-19 Spread in Built Environments.

Gomez Z., P., Hadi, K., Swarts, M., & Olga Kemenova, M. B. (2021). Spatiotemporal Modeling: Spread of COVID-19 in Educational Settings: The Role of Architecture in A Pandemic.

Gurbaxani,, B. M., Hill , A. N., Prabasaj, P., Prasad, P. V., & Slayton , R. B. (2021). *Evaluation of Different Types of Face Masks to Limit the Spread of SARS-*

CoV-2 – A Modeling Study. MedRxiv. Retrieved July 12, 2022, from https://www.medrxiv.org/content/10.1101/2021.04.21.21255889v1.full-text.

Haischer, M. H., Beilfuss, R., Hart, M. R., Opielinski, L., Wrucke, D., Zirgaitis, G., Uhrich, T. D., & Hunter, S. K. (n.d.). *Who is wearing a mask? gender-, age-, and location-related differences during the COVID-19 pandemic*. PLOS ONE. Retrieved March 2022, from https://journals.plos.org/plosone/article?id=10.1371%2Fjournal.pone.0240785

Head, J. R., Andrejko, K. L., & Remais, J. V. (2022, January). *Model-based assessment of SARS-COV-2 delta variant transmission dynamics within partially vaccinated K-12 school populations*. Lancet Regional Health. Americas. Retrieved March 2022, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8614621/.

Hearne, B. N., & Niño, M. D. (2021, January 19). *Understanding how race, ethnicity, and gender shape mask-wearing adherence during the COVID-19 pandemic: Evidence from the COVID impact survey - journal of racial and ethnic health disparities*. SpringerLink. Retrieved March 2022, from https://link.springer.com/article/10.1007/s40615-020-00941-1

Ma, Z. (2020). *Spatiotemporal fluctuation scaling law and metapopulation modeling of the novel coronavirus (COVID-19) and SARS outbreaks*. http://arxiv.org/abs/2003.03714

Mandavilli, A. (2022, February 25). *New C.D.C. guidelines suggest 70 percent of Americans can stop wearing masks*. The New York Times. Retrieved March 2022, from https://www.nytimes.com/2022/02/25/health/cdc-mask-guidance.html

Mattiuzzi, C., & Lippi, G. (2022, January 3). *Primary COVID-19 vaccine cycle and booster doses efficacy: Analysis of Italian nationwide vaccination campaign*. OUP Academic. Retrieved March 2022, from https://academic.oup.com/eurpub/advance-article/doi/10.1093/eurpub/ckab220/6493335?login=true.

Rabajante, J. F. (2020). *Insights from early mathematical models of 2019-nCoV acute respiratory disease (COVID-19) dynamics*. http://arxiv.org/abs/2002.05296

Sidik, S. M. (2022, March 18). *Vaccines protect against infection from Omicron subvariant - but not for long*. Nature News. https://www.nature.com/articles/d41586-022-00775-3

Programming Cultures: Data Analytics

Social Housing Mass Customization: Description of a system for real-time cost and spatial generation

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Abstract: This study explores mass customization as an alternative strategy for social housing provision. The paper aims to demonstrate the implementation of an integrated system based on the connection between Building Information Modeling and algorithmic-parametric modeling technologies, seeking to design variability with real-time cost and time data control of single-family housing units. We developed the study according to five phases: (1) context analysis and design language definition; (2) rule-based design system definition; (3) cost and execution time estimation; (4) computer system based on the specified technologies definition; (5) quantitative evaluation and qualitative evaluation of the system. The experiment demonstrates that with the aid of algorithmic-parametric modeling, building information manipulation and visualization can be responsive enough to meet mass demands.

Keywords: Data analytics, Mass customization, Social Housing, BIM, Cost control

1 Introduction

This paper explores the theme of mass customization (MC) for social housing provision as an alternative strategy to standardized mass production. MC promotes value to a product by matching the end-users demands with the maintenance of production costs close to standardized mass production. For this, according to Piller (2019), operational (design, manufacturing, and assembly) and logistic (supply and transportation) processes must be flexible yet stable. According to Kolarevic and Duarte (2019), the technological means for this are already available in the design field. Previous studies have been successful in implementing different levels of automation of the design process, such as the integrated system of Benros and Duarte (2009), the system of

customization of apartment plants of Veloso, Celani, and Scheeren (2018), among other examples.

As a next step, it is important to define systems that, in addition to design variability, assist in the visualization and manipulation of building data responsible for controlling execution costs of the generated solutions. This control becomes even more critical in projects targeting socioeconomically vulnerable populations, where resources are generally scarce.

Thus, this work's goal is to demonstrate the implementation of a computational system for MC of single-family housing, target to designers as users, based on the communication between Building Information Modeling (BIM) and algorithmic-parametric modeling (APM), capable of generating topological and dimensional variations with control and estimation of execution cost and time. For this study, we chose as a specific context of application the case of involuntary resettlements in the city of Teresina, Piauí.

1.1 The case of Residential Park Brazil

To avoid generic solutions, we chose a real scenario, the case of the Residential Park Brazil housing complex in Teresina, Piauí – Brazil, where we extracted context information to define a specific design language. The execution of this complex was a City Hall action to relocate families whose residences were affected by the North Lake Urban Program, carried out to promote interventions in the environmentally and socially vulnerable northern region of the city. Hence, this complex has 1022 residential units, which justifies the application of an MC strategy.

In the initial research, we carried out a survey on the houses in the affected region before their demolition, using images captured by Google Maps and technical reports from the City Hall. We noticed that most houses were based on self-constructed ceramic brick masonry and covered with ceramic tiles supported by a wooden structure.

2 Methodology

For the development of the system, we accomplished the following phases: (1) context analysis and definition of the design language; (2) definition of a rule-based design system; (3) definition of cost and execution time estimation; (4) definition of the computer system based on the specified technologies; (5) quantitative evaluation and qualitative evaluation of the system.

The first phase consisted of (1) preliminary research to collect contextual data such as the profile of the affected properties and families, local cultural and geographical aspects, and local building code rules. The work focused on the formal and spatial aspects of the housing units; thus, we adopted the existing land division, with lots of approximately 10x25m. After gathering the

information, we developed the design language based on several manually developed solutions, namely the language corpus.

Based on the language corpus, we started defining the (2) design rules, targeted to be manipulated by qualified architects, who are responsible for interpreting the needs of the end-users and evaluating the quality of the generated results. Therefore, we opted for a design logic that allows greater design freedom instead of automatic solution control. In this design logic, the rules obey a hierarchical system where the designer defines a formal-spatial relationship, from which he/she can freely assign room functions to the generated spaces. However, we opened an exception to pre-define a social bathroom. It aims to encourage the grouping of wet areas, as this is a recommended strategy to facilitate plumbing execution and future expansions in a coordinated manner (Brandão, 2011).

The (3) execution cost calculation method is twofold: we used the Basic Unit Cost per square meter (cub/m²) and the estimation by the references of the National Cost and Index Research System (SINAPI). Cub/m² is a reference index that is popular but low accurate compared to SINAPI. Thus, we use the SINAPI as an official value and cub/m² as the maximum reference value.

The cub/m² uses a standard reference value per meter according to construction classes, calculated and released monthly by the National Construction Industry Unions according to the criteria stipulated by Brazilian Standard NBR 12.721. As it does not consider the values of foundations and building installations, we decided to use the cost factors constants of these stages (Fn) in Table 1. For precision of the roof cost, we deducted from the cub/m² a factor equivalent to the roof cost (fC) and then added the SINAPI value-based method (C3) available in Table 2. We did this change because the roof area can be larger than the house area, so considering them equal could distort the final cost.

$$\text{Cost} = ((\text{cub} \times A) \times (F1 + F2 + F3 - fC)) + C3 \qquad (1)$$

Table 1. Cost factors of the stages of the work

Symbol	Factors	Value
F1	Foundation cost factor	4.1
F2	Electrical installations Cost factor	4.8
F3	Plumbing installations cost factor	12.7
fC	Roof cost factor	15

Source: Mattos, 2006.

The SINAPI references are reports of inputs (materials, workforce, and equipment) and compositions according to each Federation Unit. We present the calculation methods based on the values and compositions of SINAPI in Table 2.

Table 2: Method for estimated cost calculation based on the values collected from the SINAPI references.

Symbol	Execution phase	Formulas
C1	Wall	area * cost per m²
C2	Waterproofing of walls	(area *2) * cost per m²
C3	Roof	(area * slope factor) * cost per m²
C4	Concrete slab cast in situ	slab volume * concreting volume cost slab volume * armor rate) * cost per kg of the frame slab cost = concreting + frame
C5	Prefabricated slab	area * cost per m²
C6	Superstructure	weight of beams * cost per kg weight of the columns * cost per kg superstructure cost = beams + columns
C7	Doors	number of doors * unit cost
C8	Windows	window span area * m² cost
C9	**Total cost**	**C1+C2+C3+C4+C6+C7+C8**
C10	Foundation	total cost * f1
C11	Electrical installations	total cost * f2
C12	Plumbing installations	total cost * f3
C13	**Unit final cost**	**C9+C10+C11+C12**

Source: Authors, 2022.

To estimate the execution time, we extracted the value of the involved professionals' working hours and the associated cost per square meter of the constructive components of the analytical composition cost references of SINAPI. In cases where there is more than one professional involved, we consider the highest time value and, depending on the construction component, instead of the area, we used the volume or mass of the component. Based on

these numbers, the total execution time required (T) is calculated based on the product of area (A) for the required time per m² (t/m²):

$$T = (A \times t/m^2) \quad (2)$$

Next, we calculate the cost of the professional per m² (c) by multiplying the value of the professional's hour (p) by the total time required per m², then the value of all professionals involved in the execution of the component is added:

$$c = (p1 \times t1/m^2) + (pn \times tn/m^2) \quad (3)$$

Last, we can estimate the total execution cost by multiplying the values of (T) and (c).

In the next phase, we based the (4) definition of the computer system on the communication between the APM Grasshopper environment, which runs inside the CAD software Rhinoceros 3D, and the BIM platform Autodesk Revit. We connected the platforms using the Rhino inside Revit plugin, based on a bidirectional information transmission protocol (Iasbik, Martinez, & Gazel, 2020). We selected these tools as some tests have demonstrated that Grasshopper has a processing performance advantage compared with Dynamo (Brito, Silva, & Checcucci, 2020). Also, because of the range of plugins available for the Grasshopper environment, such as the external plugin HUMAN UI, used to develop the user interface. Finally, Revit was connected to the Twinmotion virtual reality environment using the Datasmith export plugin.

Finally, (5) evaluation of the system's results was twofold. First quantitatively, calculating the combinatorial cardinalities (number of elements of a set) of all the design parameters. Second, qualitatively, by developing five different solutions to meet the same housing program requirements within a specific cost range between R$75.000,00 ($13945,96) and R$80.000,00 ($14.875,70) per unit, approximately 20% lower than the average value per unit of the existing residential complex.

3 Results

3.1 Design language

We chose a roof system made of corrugated fiber cement panels suspended and supported by a lightweight steel frame to provide an open shading area with air circulation above the house. Windows and doors are lightweight, easy-to-install aluminum panels that can be easily removed and reinstalled. The complementary steel frame structure provides support for coverage in unbuilt areas and maintains the stability of the roof's rectangular format, regardless of the shape of the housing. The masonry is executed with ceramic bricks, seeking

to respect local constructive traditions, low cost, and ease of access to material and labor. The bricks of the external walls have a structural function. The foundation slabs are reinforced concrete cast in situ, while the ceiling slabs system are prefabricated lattice joists with insulation of ceramic blocks. Figure 1 shows an instance of the established design language.

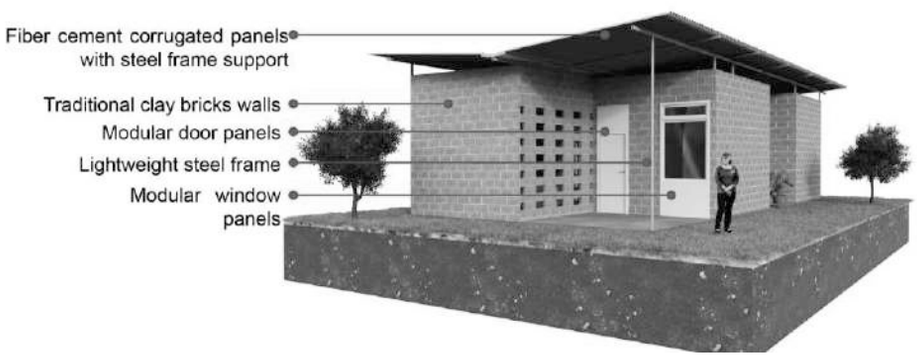

Figure 1: Instance of the universe of possible solutions generated by the developed system and its main constructive characteristics. Source: Authors, 2022.

3.2 Rule-based design system

Next, we describe the rule-based design system focusing on the logic behind the functional groups at each design stage rather than detailing the specific rules. Figure 2 illustrates the branching of design steps.

The first stage defines a mesh made of eight parametric modules, distributed in pairs (AB, CD, EF, GH), represented in Figure 4, which define the formal-spatial boundaries of the building. The longitudinal configuration of the modules seeks to optimize the occupation of the existing lots and establish a clear sense of expansion.

Four functional groups define the modules manipulation rules: (a) changing dimensional parameters; (b) addition or subtraction of modules, which generates opened functional covered areas within the lot; (c) connection between adjacent modules for expansion and reduction, or full integration between them; (d) opening of external spaces between modules for the creation of external circulation in the lot.

We based the wet areas definition phase on four functional groups: (a) subdivision of modules, (b) change of dimensional parameters, (c) exclusion of modules, and (d) positioning of the water tank. The system applies the subdivision rules according to the module that allocates the bathroom, the attached wet areas, and the hydraulic shaft direction defined by the designer. Dimensional constraints certify that the subdivision has the minimum functional and circulation area and does not exceed the module's dimensions. Exclusion rules will ensure that there will always be a ventilation outlet in wet areas.

Finally, the housing water tank's position will always be above the wet area's core.

In the roof definition stage, restrictions guarantee that its rectangular shape will always cover the entire perimeter of the building. This restriction aims to create functional covered external areas, facilitate execution, and lower the final cost. The functional groups define the (a) roof type based on the number and direction of slopes and (b) dimensional parameters that control the inclination, eaves size, and distance between supports.

The last step defines the location and insertion points of doors and windows based on two functional groups: (a) subdivision of the mesh curves to define the vertices that allocate the openings in the center and end-points of the curves, and (b) identification of vertices according to the x and y coordinates.

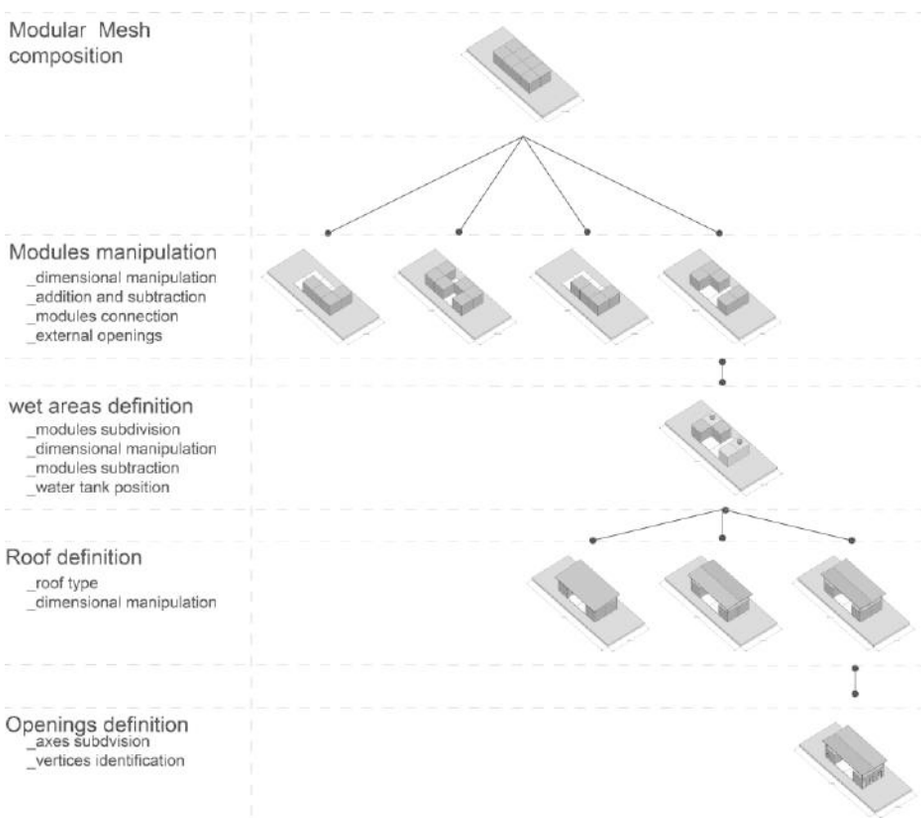

Figure 2: House evolution based on the design language developed. Source: Authors, 2022.

3.3 Computer system

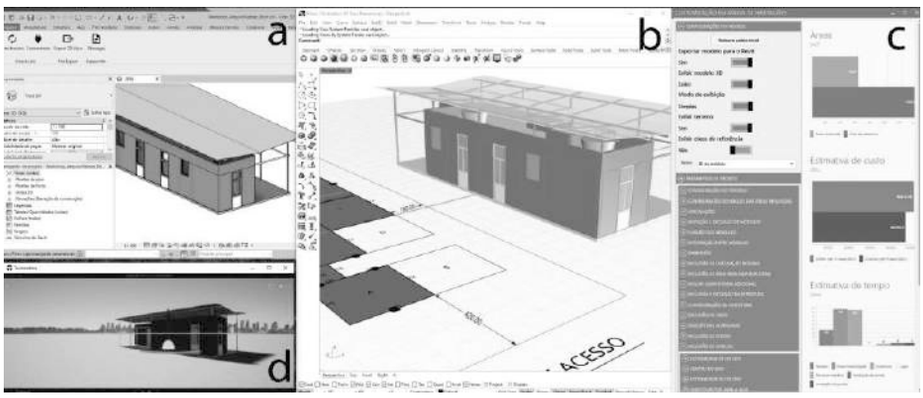

Figure 3: Presentation of the computer system: a) BIM model updated in real-time as the designer manipulates the user interface; b) 2D and 3D representation of the solution inside Rhino 3D; c) interface for parameter settings and building data visualization; virtual reality model loaded inside Twinmotion. Source: Authors, 2022.

The implementation of the computer system is responsible for automating the design process and the construction data manipulation for ease of visualization of solutions and decision-making. Figure 3 shows the system's interface.

The system works based on three groups of parameters: (1) design parameters, (2) building components data parameters, and (3) model display parameters. The design parameters activate the functional groups responsible for triggering the design rules to generate the reference geometry for positioning the building components created within Revit. These BIM components feds the second parameter group, where the designer chooses the component type. These components' information will input data to develop the CAD model within Rhino 3D and the central BIM model within Revit and feed the costing and time calculation routines to generate real-time estimations. The last parameter group allows the system's user to view or hide the 3D models, change the level of detail of the CAD model, and display auxiliary information for a better understanding of the design logic. Figure 5 represents this workflow.

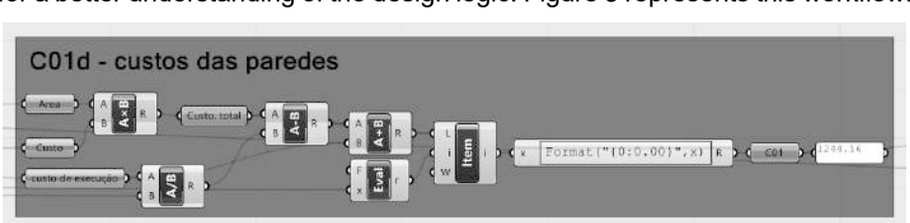

Figure 4: Routine definition example of wall execution cost calculation. Source: Authors, 2022.

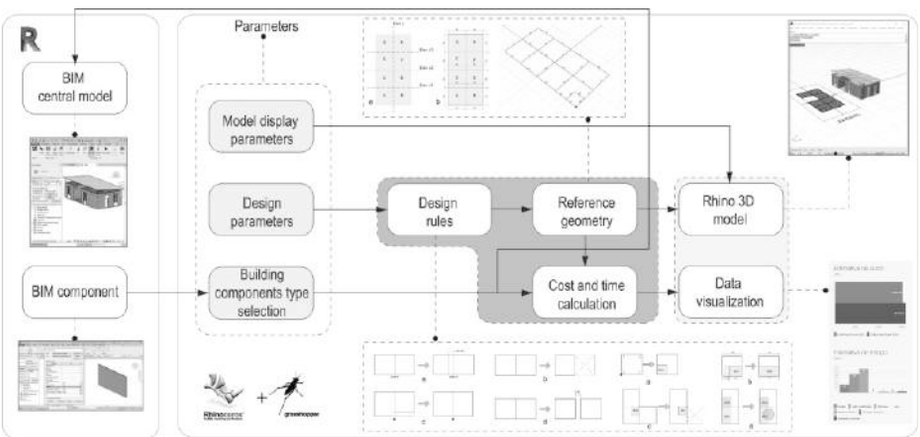

Figure 5: A computer system diagram for housing generation and data visualization. Source: Authors, 2022.

The user interface aims to make parameter manipulation and visualization of building data more fluid and user-friendly by compiling all the necessary information in one dropdown menu to make decision-making easier. Finally, we used the Datasmith plugin to transfer the BIM model to a virtual reality environment with one click.

Figure 6: User interface. a) display parameters; b) design parameters; c) building component parameters; d) building and roof area information; e) execution cost information based on the SINAPI method (orange) and cub/m² method (gray); f) execution time by construction phase. Source: Authors, 2022.

3.4 System's evaluation

Next, we present the combinatorial calculus of spatial arrangements, disregarding dimensional parameters.

Table 3: Method for estimated cost calculation based on the values collected from the SINAPI references.

Combinatorial calculation considering possible spatial arrangements:
Total = (4)14 x (2)22 x (6)2 x 8 x 7 x 3
Total = 6.809.442.636.584.189.952

Source: Authors, 2022

Figure 7: Results generated using the developed platform. A = constructed area of projects in m²; C = construction cost estimate, based on SINAPI references in BRL currency. Source: Authors, 2022.

In the qualitative evaluation, we developed five house options for a family of a young couple with two children, with the need for a room for manual work with independent access to receive clients. The five solutions were developed and documented in approximately 3 hours, respecting the pre-established cost and room areas.

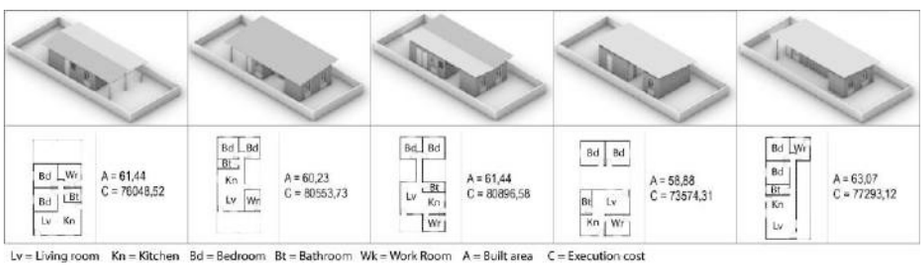

Figure 8: Results from the cost control exercise. A = constructed area of projects in m²; C = construction cost estimated, based on SINAPI references in BRL currency. Source: Authors, 2022.

4 Discussion

This paper aimed to describe the process behind the computational implementation of a rule-based design system with execution cost and time control of mass customized social single-family housing units, based on the communication between APM and BIM technologies.

The experiment demonstrates that the aid of APM provides elasticity and agility for manipulating and visualizing building data to meet mass demands. Therefore, we were able to verify that the transfer of data from the BIM platform to a design script has the potential to assist the implementation of MC as a strategy for social housing provision.

For example, a simple one-click action changed the specification of all walls of a design option from 14x19x29 to 9x19x29 ceramic blocks, making it possible to realize the impact of reducing the total execution cost by $ 601,17 in less than 1 second. In another example, it was possible to quickly identify that the increase in the steel frame weight has a significant impact on the construction costs, allowing us to evaluate with precision and agility the cost-benefit relations of the building solutions of the design language. It is also noteworthy that considering local constructive cultural characteristics in the design language suggests that the use of programming routines for developing houses is not necessarily associated with generalist solutions.

However, there are limitations and improvements to consider. The code does not count some items, such as kitchen finishes, sanitary parts, and other detail items. Also, we highlight that we still did not develop a qualitative evaluation system of the results. We implemented some restrictions, such as

minimum circulation width and control of openings to open spaces in the lot. However, as the algorithm allows a high number of formal variations, the architect remains the mediator in the decision-making process, both during the initial configuration of the unit and future changes, by anticipating possible modifications throughout the time, based on the family's profile. Furthermore, the system still needs to be tested by architects to evaluate its usability. Furthermore, the system still needs to be tested by architects to evaluate its usability.

For future development, we plan to insert new building elements in the cost calculation estimation, define and implement new quality control restriction rules, and create an objective performance evaluation subsystem to assist the system's users, as well as perform tests on its usability.

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References

Benros, D., & Duarte, J. P. (2009). An integrated system for providing mass customized housing. Automation in Construction, 18, 310-320.

Brandão, D. Q. (2011). Disposições técnicas e diretrizes para projeto de habitações sociais evolutivas. Ambiente Construído, 11(2), 73-96.

Brito, B. L., Silva, F. T., & Checcucci, É. d. (2020). Estudo Comparativo entre ferramentas de projeto paramétrico. XVIII Encontro Nacional de Tecnologia do Ambiente Construído ENTAC 2020. Porto Alegre: ANTAC.

Iasbik, M. P., Martinez, A. C., & Gazel, J. L. (2020). Integration of BIM and Algorithmic Design logics through data exchange between Grasshopper plugin and Revit and Archicad software. 24th Conference of The Iberoamerican Society of Digital Graphics (pp. 470-477). Medelín: The Iberoamerican Society of Digital Graphics (SIGraDi).

Kolarevic, B., & DUARTE, J. P. (2019). From massive to mass customization and design democratization. Em B. Kolarevic, & J. P. Duarte, Mass customization and design democratization (pp. 1-12). Abington: Routledge.

Mattos, A. D. (2006). Como preparar orçamentos de obras: Dicas para orçamentistas, estudos de caso, exemplos. São Paulo: Editora Pini.

Piller, F. T. (2019). Creating a sustainable mass customization business model. Em B. Kolarevic, & J. P. Duarte Mass customization and design democratization (pp. 30 - 40). Abington: Routledge.

Veloso, P., Celani, G., & Scheeren, R. (2018). From the generation of layouts to the production of construction documents: An application in the customization of apartment plans. Automation in Construction (96), 224-235.

Visualization of architecture design collection using image subsets: the case of FAU-UFRJ media library

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Abstract. This paper presents part of a research carried out as a graduation project which investigated new approaches for viewing the digital collection of graduation projects of the School of Architecture and Urbanism at the Federal University of Rio de Janeiro - the "Portal Midiateca". In addition to visualization, the objective is also to survey open source tools and document the process, enabling other researchers to have access to instruments for analysis and visualization of cultural collections. The visualizations and analysis used as data the images (hue, saturation, brightness, similarity) and metadata (themes and year of publication) of the graduation projects sent by the students. They were made using VIKUS Viewer to examine the collection in a dynamic website with timeline and similarity visualization tools; and ivpy in a notebook environment to produce static mosaics from different groups of images according to their color measurements.

Keywords: Data analytics, Information visualization, Visual rhetoric, Cultural analytics, ETL

1 Introdução

Este trabalho descreve uma experimentação de visualização de dados do acervo digital de Trabalhos Finais de Graduação (TFG) da FAU-UFRJ - apresentado online com o nome "Portal Midiateca". O artigo tem como objetivo principal documentar a metodologia e ferramentas usadas para analisar as imagens dos projetos de arquitetura cadastrados - e alguns de seus subconjuntos - por meio de diferentes sínteses visuais, de modo a subsidiar futuras análises da produção acadêmica da escola.

Entendemos que um acervo de trabalhos finais do curso de arquitetura e urbanismo, além de institucional, pode ser entendido como um acervo cultural. Esses documentos expressam a interpretação particular de síntese da

graduação a partir do ponto de vista do aluno. As análises sobre este tipo de acervo ajudam a instigar reflexões no campo da teoria e da prática do ensino, além da sua difusão ser potencial fonte de pesquisa para diversos públicos – de alunos de graduação em busca de repertório projetual a pesquisadores de pós-graduação em busca de um panorama sobre as visões de arquitetura e urbanismo de determinada escola. Dentre os exemplos, a partir da própria Midiateca da FAU-UFRJ, temos a análise de trabalhos selecionados para uma exposição virtual (Kamimura et al, 2019) e, em trabalho anterior, uma análise das estruturas de busca textual disponíveis como ferramentas auxiliares ao ensino (Paraizo e Freire, 2015).

Buscando ampliar as possibilidades de análise, para além das buscas pelos metadados – inclusive pela falta de homogeneidade das informações –,este trabalho busca explorar análises baseadas nas imagens dos projetos. Foram utilizados dois sistemas digitais de visualização da informação (VIKUS Viewer e ivpy), cada um permitindo diferentes formas de leitura e interpretação. Este trabalho é fruto de um trabalho final de graduação da FAU-UFRJ de mesmo nome, tendo por orientador um dos coautores deste artigo, Rodrigo Cury Paraizo, e pelo coorientador Gonçalo Castro Henriques.

2 A Midiateca FAU-UFRJ

A reforma curricular de 1996 da FAU-UFRJ, entre outras medidas, criou o Trabalho Final de Graduação, nome dado ao trabalho de conclusão do curso. Os trabalhos foram armazenados nas versões física e digital. Em 2004, foi criado o primeiro site para disponibilização desse conteúdo, o portal “Mediateca do TFG”, pouco tempo depois descontinuado. Em 2013, com financiamento da FAPERJ e maior apoio institucional, o site “Midiateca FAU-UFRJ” foi elaborado, a partir de técnicas de banco de dados mais robustas.

O acervo é constituído, portanto, pelas informações referentes aos TFGs apresentados pelos alunos. Essas informações compõem-se de dados enviados pelos autores (imagens, título, resumo, localização, palavras-chave), das informações provenientes da Comissão Coordenadora do TFG (como banca de avaliação, orientadores, ano de publicação), e de dados de catalogação da própria equipe do acervo (como premiações, categorias e temas).

A quantidade e qualidade dos dados recebidos varia por uma série de fatores: em primeiro lugar, o envio é realizado pelos alunos, com validação mínima dos dados e poucas diretrizes de formato, após a defesa da banca final. Em relação às imagens, por exemplo, cabe a cada autor decidir quantas deverão ser enviadas e quais (podem ser pranchas inteiras ou desenhos isolados). Além disso, os dados, ao longo do tempo, acompanham as variações nas demandas e resoluções relativas ao TFG no curso (e relativas à própria Midiateca). A estrutura de dados também não é estática e precisou passar por adaptações ao longo do tempo (o acréscimo da localização

geográfica é um exemplo). Estabelecer essa história dos dados foi fundamental na etapa posterior de visualização e análise para melhor compreensão dos resultados.

Finalmente, é importante ressaltar o papel dos repositórios online de trabalhos de conclusão na divulgação de uma espécie de identidade pública de cada curso de arquitetura e urbanismo. Exemplos brasileiros, além da Midiateca FAU-UFRJ, incluem o site "MemoriAU", da UFPR, e o "Trabalho Final de Graduação: Publicação Online", da USP. É notável que muitos desses sites existem em paralelo com os repositórios online de TCCs das Universidades (o site atual de TFGs da USP é conectado diretamente ao repositório geral) – e a observação desses dois sistemas evidencia que estamos diante de um tipo específico de trabalho de conclusão, com suas próprias categorias de busca e recuperação dos dados, para além das usuais. Dado que a maior parte dos trabalhos finais tem forte apoio nas imagens, e isso se reflete nos seus registros, é importante estabelecer modos e ferramentas de pesquisa e análise desse tipo de dado.

3 Registrando Objetos Culturais

Em trabalhos anteriores (Cabral e Paraizo, 2015; Paraizo et al, 2014; Paraizo e Cabral, 2012), observamos que o registro de objetos culturais em bancos de dados estruturados traz questões importantes relativas à classificação e completude dos dados. Na verdade, trata-se de um registro menos dos dados diretamente obtidos do objeto (como seria o caso, por exemplo, de uma nuvem de pontos obtida por escaneamento a laser de uma edificação) do que de dados sobre o objeto: são, portanto, seus metadados que são levados em consideração para classificação e análise – e são interpretações essencialmente subjetivas sobre esse objeto, especialmente aquelas informações que o caracterizam culturalmente.

No banco de dados desenvolvido por Silva (Silva e Paraizo, 2008), projetos desenvolvidos para o Programa Favela-Bairro eram decompostos e reinterpretados pelo pesquisador em uma linguagem de padrões, conforme a proposição original de Alexander et al (1977). Na proposta de Kós (2003) para um sistema online de registro e classificação de documentos históricos sobre o Rio de Janeiro, a associação de cada documento a uma parte da cidade é uma tarefa subjetiva atribuída a quem alimenta o sistema. Na implementação atual do ImagineRio (Dahdah e Metcalf, 2016), a localização de documentos e fotos também depende da interpretação subjetiva, assim como muitos dos metadados que acompanham as imagens.

Outra referência de interpretação de um acervo cultural digital é a visualização do banco de dados da Biblioteca Digital Alemã (Deutsche Digitale Bibliothek) realizado através do laboratório Urban Complexity Lab da Potsdam University of Applied Sciences. Trata-se de um repositório com acervo digital

híbrido, que concentra objetos de várias instituições científicas e culturais alemãs.

Ainda que as imagens de um TFG sejam representações – necessariamente incompletas e insuficientes – do projeto, são um meio razoável para ter um contato mais direto com o conteúdo propriamente dito da proposta, bem próximo daquilo que foi apresentado para a própria banca no momento da avaliação. Por outro lado, Blair (2008) propõe que há uma retórica visual nas imagens, uma capacidade discursiva própria, capaz de motivar o convencimento e a ação. Sendo preponderantes no discurso arquitetônico, reside aí a importância de desenvolver ferramentas que auxiliem na análise das imagens. Para além das funções de busca que permitem a recuperação de um trabalho em particular, ou de um conjunto de trabalhos, trata-se de permitir a comparação e análise por meio de técnicas visuais que promovem leituras do acervo no todo ou em parte, facilitando a produção de interpretações por meio da elaboração de novas representações.

Para produzir essas representações, lançamos mão de técnicas e conceitos associados à visualização da informação. De acordo com Manovich (2020, p. 189), a visualização de informações (ou *infovis*, na abreviação em inglês) pode ser definida como um mapeamento entre dados discretos (valor específico ou categórico) e uma representação visual. Significa que cada número absoluto e/ou categoria que pode ser extraído do repositório terá uma representação gráfica proporcional ao montante. As decisões gráficas de representação devem também contribuir para uma interpretação clara e com o mínimo de ambiguidade e indução ao erro. Manovich (2020, p. 7) propõe ainda o conceito de “analítica cultural” (cultural analytics) para designar a visualização de informações de bancos de dados culturais em larga escala, como o caso de repositórios de trabalhos que estão em constante expansão em função da formação de novos alunos.

Para buscar a visualização ideal das informações sobre um acervo cultural, não basta ter o domínio pleno das ferramentas de visualização. Como dispõe Manovich (2020, p. 190), o objetivo da visualização da informação é descobrir a estrutura do conjunto de dados. A construção dessa visualização precisa partir do ponto de vista de um interpretador, alguém capacitado que entenda as particularidades que o objeto cultural possui. Um pesquisador que possui familiaridade com o acervo terá mais capacidade para determinar se os resultados são mais ou menos fiéis à realidade, além de estar apto a identificar padrões que não estão claros em um primeiro momento.

A leitura proposta não se baseia na figuração contida nas imagens – que poderiam ser a base para um trabalho envolvendo inteligência artificial –; a classificação a partir de valores abstratos, no entanto, permite elaborar associações cruzadas imprevistas, de caráter exploratório, com estruturações e atribuições semânticas nem sempre claras em um primeiro momento. Ainda que os resultados específicos dos testes realizados sejam limitados neste estágio, trata-se de um processo potencialmente importante para auxiliar na investigação de um conjunto de imagens cujas atribuições semânticas são

relativamente rarefeitas, pelas características de entrada dos dados, como comentaremos adiante.

4 Metodologia

A partir das técnicas de analítica cultural, procuramos examinar os dados visuais enviados pelos alunos para a Midiateca por meio de técnicas de agregação e comparações automatizadas entre as imagens. O maior desafio consistiu no fato de que se trata de um conjunto de dados bem pouco estruturado, em que falta a uniformidade tanto da estrutura quanto do conteúdo, já que não há quantidade predeterminada de imagens por trabalho nem tipos específicos de representação (como plantas, cortes, fachadas), sendo inteiramente por conta de cada autor a seleção do que vai ser enviado. Foi necessário buscar um elemento em comum presente em qualquer imagem para fins de comparação, como as propriedades da imagem (cor, saturação, brilho).

A manipulação dos dados seguiu uma interpretação da metodologia proposta por Mazza (2009), constituída de três etapas: a transformação dos dados, para garantir os tipos adequados de dados (fluxo ETL - extract, transform and load), o mapeamento visual, que distribui os dados em um espaço gráfico de acordo com seus tipos, e a efetiva visualização do resultado. A manipulação dos dados foi experimentada tanto usando processamento local (usando o Github para versionamento dos arquivos) quanto por processamento em nuvem (executando scripts em linguagem Python em notebooks no “Colaboratory”, da Google).

Após uma etapa de testes iniciais de viabilidade dos sistemas, com um conjunto restrito de trabalhos e imagens, foi feita uma extração do conjunto dos dados brutos diretamente do banco de dados da Midiateca, a partir de login fornecido pela equipe da Midiateca. Foram extraídas 11 tabelas no total e uma pasta com todas as imagens disponíveis até fevereiro de 2022.

A etapa de transformação dos dados consistiu em limpar, organizar e formatar de acordo com as necessidades de visualização e uniformização dos dados. No caso, encontramos entradas duplicadas de alunos e professores, imagens duplicadas e outras sem relação com projetos (mais de 300 imagens descartadas), palavras-chaves sem relação com o conteúdo do TFG (entrada realizada pelo aluno) e entradas de alunos sem projeto correspondente, o que acaba condicionando as tomadas de decisão a respeito das visualizações. Neste momento, a revisão é essencial para que não haja equívocos na hora das análises, ressaltando a importância de estar familiarizado com as informações – bem como com a própria história do acervo. É também nesta etapa que são tomadas algumas decisões em relação à formatação dos dados: por exemplo, como lidar com ausência de dados. Ao final do ETL, o resultado é uma base de dados (ou dataset) limpos e estruturados, normalmente em

tabela de dados. Este trabalho está disponível para visualização através do link: shorturl.at/IPQT3.

Após a transformação, elabora-se o mapeamento visual do que se pretende estudar, ou seja, a organização de informações no espaço gráfico disponível, induzindo e orientando diferentes leituras dos dados. As visualizações possíveis, naturalmente, dependem dos dados disponíveis, de como esses dados estão estruturados, e das decisões de design que direcionarão a visualização. Assim, dados georreferenciados tendem a ser visualizados por mapas, enquanto dados temporais tendem a ser estruturados em linhas do tempo, e assim por diante. A etapa de visualização foi feita em dois sistemas distintos: o primeiro conjunto de visualizações foi produzido através da ferramenta VIKUS Viewer, e a segunda pelo ivpy, um pacote de visualização de iconografias em linguagem Python.

VIKUS Viewer

Desenvolvido por Christopher Pietsch no Urban Complexity Lab da University of Applied Sciences Potsdam na Alemanha, o VIKUS Viewer permite criar um acervo digital iconográfico ordenado por tempo, similaridade, categorias e georreferenciamento, através de uma aplicação web open source voltada para coleções culturais (https://github.com/cpietsch/vikus-viewer).

A ferramenta permite navegar entre as imagens ordenadas por seus metadados, que podem ser exibidos para cada imagem. A organização principal é em formato de linha do tempo horizontal, agrupando as imagens de cada período verticalmente. A visualização por similaridade faz uma análise computacional das imagens em busca de padrões de cor, forma e textura e organiza as imagens aproximando as que são semelhantes entre si.

Para poder utilizar esta visualização, foi clonado o repositório do projeto no Github, para que pudéssemos alterá-lo sem interferir no original. O resultado está disponível em https://github.com/mechlerc/vikus-viewer-midiateca. As instruções disponibilizadas e o modelo de estrutura de dados, deram as diretrizes para a etapa de ETL. Foi necessário clonar outro repositório para gerar os arquivos necessários para a visualização por similaridade, conforme descrito no projeto.

Este processo requer bastante poder computacional quando executado localmente, e o tempo do trabalho varia em função das características do computador. Foram analisadas 10.783 imagens – entre baixa e média resolução - em um computador com processador Intel Core i9, memória RAM 64GB, placa de vídeo NVIDIA Quadros 4000, levando cerca de 14 horas ininterruptas de tempo de processamento. Em análise com um conjunto menor de imagens (aproximadamente 3500 fotografias em alta resolução), o tempo de processamento foi por volta de 5 horas.

Este processamento só precisou ser realizado uma vez, e teve como resultado uma pasta com as imagens redimensionadas para visualização na ferramenta e um arquivo .CSV com valores de similaridade e coordenadas para cada imagem. Estas coordenadas serão usadas para a visualização por gráfico

de dispersão, uma vez que a posição da imagem em relação a outra reflete o quão semelhantes elas são entre si.

ivpy

A biblioteca de software “Iconographic Visualization in Python” - ivpy foi desenvolvida por Damon Crockett com o objetivo de criar visualizações de dados iconográficos a partir de imagens (cor, saturação, brilho, similaridade, etc) e as organizando em agrupamentos (clusters) com coordenadas 2D, voltado para ambientes do tipo notebook, para processamento em nuvem.

O projeto é open source e está disponível para download no Github (https://github.com/damoncrockett/ivpy). Seu grande potencial reside nas várias experimentações que podem ser feitas a partir do mesmo conjunto de imagens, além do processamento em nuvem. A extração das informações utilizando o ivpy no Colab foi de aproximadamente 3 horas e 40 minutos. Este resultado pode ser visualizado através do link: shorturl.at/bitz8.

A saída é no formato de imagens .PNG sintetizando cada categoria de análise do conjunto. Um ponto negativo para esta visualização é a saída em imagem estática, sem a possibilidade de interação ou uso de filtros secundários - como pesquisa por autor e nome de projeto -, com difícil visibilidade das imagens originais do mosaico.

5 Resultados

O período efetivamente analisado, devido à presença de imagens em quantidade suficiente para análise e consolidação, se restringiu aos anos de 2013 a 2020. Foram feitas visualizações agrupando as imagens por similaridade (geral e a partir de uma amostra), cronologicamente e por temas de projeto (conforme classificação na Midiateca).

VIKUS Viewer

Dado a quantidade de imagens de trabalhos por ano, a visualização por linha do tempo resultou um pouco confusa, evidenciando apenas o volume de trabalhos por ano. É preciso, portanto, efetuar filtragens para obter uma leitura mais significativa. Um ponto interessante desta estrutura de visualização é a capacidade de relacionar alguns eventos importantes, como a implantação do modelo remoto em 2020, e a produção dos trabalhos.

Na análise por similaridade, foi possível notar alguns padrões. Na figura 1, é possível apontar um eixo cortando o conjunto ao meio. De um lado, temos uma grande área com imagens em que predomina o branco, do outro temos as imagens coloridas. Na primeira área, a maioria das imagens são representações técnicas, como plantas, cortes e fachadas. Com o ivpy, foi possível contabilizar que o número de imagens em que predomina branco é de

5394 imagens, quase metade do total. Pelo sistema, é possível ainda filtrar os trabalhos por temas e por termos nos demais metadados, criando subconjuntos ordenados por similaridade, ou na linha do tempo, por exemplo.

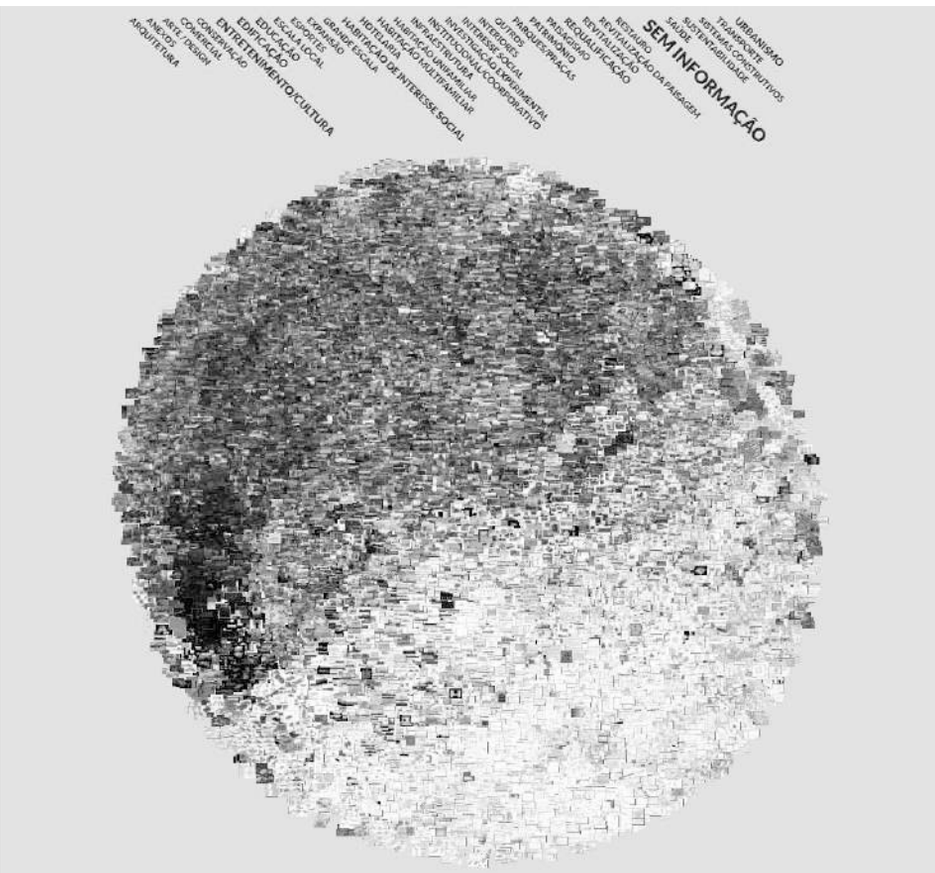

Figura 1. Visualização de agrupamento por similaridade em formato circular, com filtros por temas. Fonte: https://mechlerc.github.io/vikus-viewer-midiateca/

A composição da imagem - elementos geométricos, proporção de ocupação e afins – parece influenciar nos agrupamentos, aproximando imagens do mesmo trabalho por terem a mesma linguagem de representação.

No agrupamento em tons mais amarelados (fig. 2), notam-se imagens de renderizações de ambientes internos, com a escolha de luminosidade quente. Também há presença da materialidade da madeira ou de móveis em tons pastéis.

As áreas em que o azul (fig. 2) e verde predominam muitas vezes se confundem e compõem bastante do lado colorido. Nelas se concentram a representação de ambientes externos. Daí se notam similaridades nos tons de

azuis representando os céus em diferentes trabalhos, e o mesmo acontece com o verde da vegetação. Em pesquisas futuras, pode-se, por exemplo, especular sobre eventuais limitações técnicas e escolhas estéticas.

Figura 2. Zoom In de áreas em tom amarelo e azul do agrupamento por similaridade, respectivamente. Fonte: https://mechlerc.github.io/vikus-viewer-midiateca/

lvpy

Foram extraídas apenas informações das cores das imagens, trabalhando com a escala HSV (hue, saturation and value), usando o conceito de cor dominante de cada imagem. Esta escala permite fazer agrupamentos tanto por cada uma das categorias – matiz, saturação ou brilho – quanto por suas combinações, além de trabalhar com intervalos em cada uma delas.

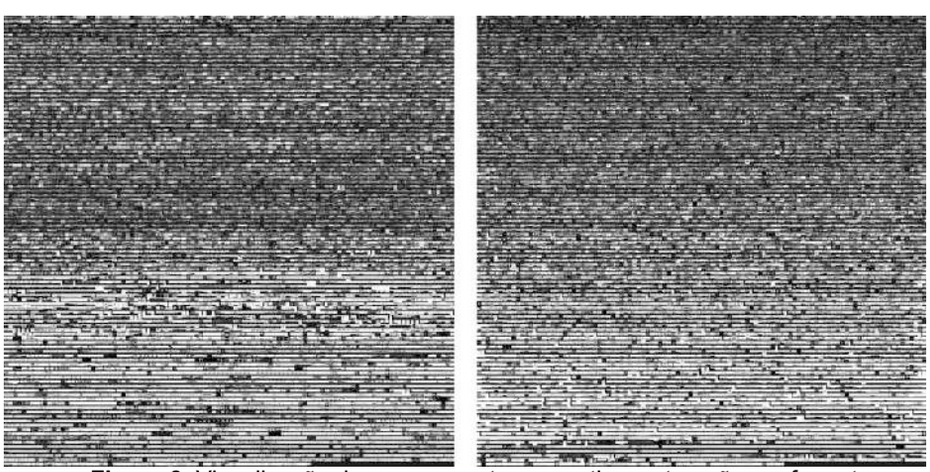

Figura 3. Visualização de agrupamento por matiz e saturação em formato retangular, respectivamente. Fonte: https://mechlerc.github.io/vikus-viewer-midiateca/

Foram feitos 3 tipos de agrupamentos das imagens: total, por ano e total de um ano (parcial). A figura 3 é o resultado do agrupamento total por matiz, e total por saturação, evidenciando a divisão percebida com o VIKUS Viewer. Aqui fica mais claro o intervalo de cores mais comuns, como o azul e o vermelho. A visualização total por saturação revela a proporção de imagens com predominância de cores saturadas, seja por partido gráfico, seja pela maneira como a imagem foi construída (renders noturnos, elementos gráficos com cores vibrantes, fundo de prancha colorido são alguns exemplos que podem influenciar na proporção deste resultado).

A figura 4 representa o agrupamento por matiz em função do ano de defesa. No ano de 2013, ano de publicação da nova plataforma, houve um número significativo de imagens coloridas. A média do número de imagens por projeto é de 5 imagens, com desvio-padrão de 3, o que pode indicar que naquele ano a maior parte das entregas foram compostas por uma prancha síntese e algumas imagens avulsas. No ano seguinte, há uma ruptura completa neste padrão, pois a área de imagens com fundo branco passa a ocupar uma faixa maior na borda, quase metade do raio, além de ter um diâmetro proporcionalmente maior que em 2013. Em números absolutos, foram enviadas 785 imagens em 2013 e 1205 imagens em 2014, porém o número de projetos em cada ano é bem próximo, 138 no primeiro e 134 no segundo, indicando que a quantidade de trabalhos não interferiu no volume de imagens e nem na representação dos materiais enviados.

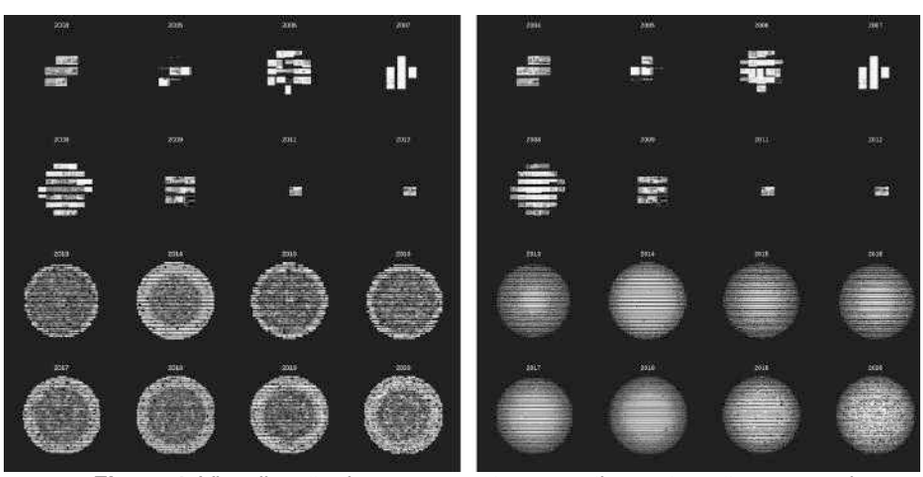

Figura 4. Visualização de agrupamento por matiz e saturação por ano de publicação em formato circular, respectivamente. Fonte: https://mechlerc.github.io/vikus-viewer-midiateca/

Analisamos as imagens de 2013 quanto ao matiz, agrupadas por temas. No entanto, este arranjo se mostrou pouco frutífero para análise, visto que as imagens por temas quase sempre se referem ao mesmo trabalho.

6 Discussão

Os desafios de se trabalhar com os dados do Portal Midiateca estão relacionados a dois fatores: poder computacional e heterogeneidade dos dados. A exigência do poder computacional local aumenta na medida da necessidade de interatividade com os dados. Buscar conjuntos de dados mais homogêneos – ou trabalhar para diminuir esse problema – também abre caminhos para mais possibilidade de leitura.

Várias possibilidades de análise dos dados da Midiateca se abrem para futuras pesquisas. No caso das imagens, é possível pensar em formas de agrupar imagens por projetos, por exemplo; extrair paletas de cores de cada projeto; depurar temas e palavras-chave para estudar melhor os agrupamentos. Além disso, é possível pensar em combinar as análises de imagens com técnicas de text mining a partir dos resumos para reforçar as questões temáticas.

Como o campo da representação é amplo, é possível levantar outras abordagens que não seja por cor para a análise dos TFGs. Uma possibilidade interessante – conquanto mais complexa e dependente de ainda maior poder computacional – seria o desenvolvimento de uma inteligência artificial (IA) treinada para a identificação de tipos de imagem – como render, colagem, planta-baixa, prancha-resumo. Com a identificação dos elementos que caracterizam cada tipo e a organização do conjunto de dados de controle por um pesquisador, seria possível formular questões como: qual é o tipo de representação mais comum da vegetação em plantas técnicas? Quantas imagens possuem representação de figura humana? Quantos trabalhos foram representados com croquis por orientador, ou por ano?

Os experimentos demonstraram a possibilidade de uma leitura menos condicionada pela estrutura de dados, permitindo a identificação de alguns padrões imagéticos emergentes, subsidiados pelo devido cruzamento com as informações contingentes da produção desses dados. O artigo, com isso, avança na discussão sobre as possibilidades de exploração de dados de objetos culturais, que são notoriamente difíceis de estruturar e comparar em grandes conjuntos.

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Referências

Alexander, C., Ishikawa, S., & Silverstein, M. (1977). *A pattern language: Towns, buildings, construction*. Oxford University.

Blair, J. A. (2008). The Rhetoric of Visual Arguments. Em C. A. Hill & M. Helmers (Orgs.), *Defining Visual Rhetorics* (p. 41–62). Taylor & Francis.

Cabral, M. C. N., & Paraizo, R. C. (2015). História, arquitetura e links: Registros digitais e fontes de arquitetura na cidade do Rio de Janeiro. *Acervo*, *28*(1 jan-jun), 216–227.

el-Dahdah, F., & Metcalf, A. C. (2016). *ImagineRio*. ImagineRio. http://imaginerio.org/

Kamimura, R., Freire, W. Vi., & Paraizo, R. C. (2019). Curadoria para a exposição digital-interativa da Midiateca da FAU/UFRJ. *Anais: XXXVII ENSEA / XX CONABEA*, *1*, 504–514.

Kós, J. R. (2003). *Urban spaces shaped by past cultures: Historical representation through electronic 3D models and databases* [PhD, University of Stratchclyde, Glasgow].

Manovich, L. (2020). *Cultural Analytics*. The MIT Press.

Mazza, R. (2009). *Introduction to Information Visualization*. Springer.

Paraizo, R. C., & Cabral, M. C. N. (2012). Arquitetos estrangeiros no Rio de Janeiro: Critérios de análise e catalogação. Em G. A. Elali & M. Veloso (Orgs.), *Caderno de resumos do II ENANPARQ: Teorias e práticas na arquitetura e na cidade contemporâneas* (Vol. 1, p. 166). Edufrn.

Paraizo, R. C., & Freire, W. V. (2015). A construção da experiência: A midiateca online da FAU-UFRJ como ferramenta auxiliar de projeto e interpretação do trabalho final de graduação. *Anais: XXXIV ENSEA / XVIII CONABEA*, *1*, 405–416.

Paraizo, R. C., Cabral, M. C. N., & Silva, E. M. (2014). Arquitetos estrangeiros no Rio de Janeiro no século XX: bancos de dados de objetos culturais. *Sigradi 2014 - Design in Freedom*, *1*, 473–478.

Silva, E. M. (2006). *O hiperdocumento como memória do projeto urbano* [Dissertação (Mestrado em Urbanismo)]. Universidade Federal do Rio de Janeiro.

Silva, E., & Paraizo, R. (2008). Urban Projects Database Based on Alexander's Pattern Language:The Case Of Favela-Bairro. International Journal of Architectural Computing, 6(3), 261–277. https://doi.org/10.1260/1478-0771.6.3.261

Understanding participation through a data-driven approach

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Abstract. Participatory models in urban regeneration are increasingly integrated in local agendas. Yet there is still a need for evaluation methodologies of those models and their impact. This paper presents a data-driven and computational methodology to measure the impact of the BIP/ZIP program in Lisbon. Using qualitative coding, data integration, unsupervised machine learning models for data clustering and interactive visualization dashboards the study aims to explore the large and complex dataset of the projects of BIP/ZIP and identify correlation patterns between their data and especially the areas of implementation, the networks of partners and the identified activities. Departing from the pilot-case of BIP/ZIP, the proposed methodology is a first step towards the development of a generalizable evaluation framework for participatory models in urban regeneration, that considers them as urban practices and hence evaluates them based on appropriate urban tools.

Keywords: Participatory Strategies, Participation Evaluation, Data-Driven Evaluation, Unsupervised Learning, Data Visualization.

1 Introduction

Citizen participation in urban regeneration and governance is increasingly integrated in national and local development strategies, as a tool to foster social and territorial cohesion and inclusivity. This rising turn is significantly attributed to international directives for sustainability to which national and local governments commit, that consider participatory urbanism a key for the achievement of sustainability targets. For instance, the New Urban Agenda envisions *"cities and human settlements that are participatory*" (United Nations (Habitat III), 2017, p. 5) and focus on safe, inclusive and pluralistic societies, prioritising the specific needs of those in disadvantaged situations, while the 2030 Agenda for Sustainable Development devotes its 16.7 target for

sustainable development to actions that "*ensure responsive, inclusive, participatory and representative decision-making at all levels"* (Annex of the 2030 Agenda, 2017).

Nevertheless, despite the unprecedented integration of participatory processes in urban strategies at a local level, there is an imbalance between the implementation of these strategies and the assessment of their impact (Falanga, 2019). Scholars and practitioners that engage with the evaluation of urban regeneration policies that adopt participatory processes are confronted with a challenge caused predominantly by the complexity of the concept of participation and its operationalisation into practice (Falanga, 2020).

Looking at theory on participation retrospectively, the fundamental work of Sherry Arnstein (1969) "Ladder of citizen participation" focused on the conceptual categorisation of participation according to the redistribution of power between the authorities and the participants. Later, participatory theory followed the communicative turn in planning (Bahreldin, 2013), also accompanied by changes on the conceptual understanding on evaluation tools. In this regard, scholars have defined more complex frameworks grounded to the multi-dimensional reality, such as Archon Fung's (2006) *Democracy Cube* that takes into consideration multiple factors, such as who are the participants, what are the tools and how are processes linked to policymaking. Such multi-criteria approaches in the definition of participation allow for more complex correlations among the selected parameters, providing insightful considerations for the nature and operationalisation of participatory processes. In extension when applied to bodies of case studies or projects that define entire strategies, they allow for comparability and clustering and can hence be a valuable tool for the future of these strategies.

Stemming from a multi-dimensional definition and hence evaluation of participatory models, this research explores a data-driven methodology based on urban analysis rather than policy evaluation tools and highlights the importance of an assessment model that considers the data produced by the individual projects of the participatory policies.

1.1 The BIP/ZIP Program

The research is grounded on the BIP/ZIP Local Partnerships Program in Lisbon, the first participatory budget implemented at municipal level in a European capital. Launched in 2011 by the Department of Housing and Local Development of the Municipality of Lisbon, the BIP/ZIP Local Partnerships Program is part of a bigger instrument of collaborative public policy called Bairros e Zonas de Intervenção Prioritária that aims to improve the quality of life and territorial cohesion in disadvantaged neighbourhoods of the city through urban regeneration.

The Local Partnerships Program contains an annual cycle of funding for initiatives and projects ignited through local partnerships. In this sense, the program enables bottom-up initiatives to emerge and be realised in

neighbourhoods of Lisbon that have been characterised as ‘priority’ after an initial diagnostic mapping of socio-economic, environmental and urban factors (CML, 2010). As of its 2021 edition, the program counts 426 realised interventions in 67 urban neighbourhoods, affecting more than 100.000 habitants per year and is characterised as an URBACT good practice (CML & DMHDL, 2017). In light of the program’s reformation and ambition to upscale its grants (An Integrated Toolbox for Deprived Neighbourhoods | URBACT, 2021), it is imperative to learn from the realised projects and inform its further development.

The need for assessment of the BIP/ZIP program has been recognised by Lisbon City Hall which in 2013 employed a team of consultants to design an evaluation model. Supporting this team and researcher that specialises in evaluation of participatory processes, Roberto Falanga (2019), published in 2019 an Index of the evaluation of the BIP/ZIP Program, focusing on the triangulation of three key elements: local partnerships, initiatives and public funding. This research aims to stem from Falanga’s fundamental work and suggest a computational data-driven approach on the analysis and evaluation of the BIP/ZIP projects, to reveal new forms of relationships between the elements of participation and their socio-territorial impact.

1.2 Data Driven evaluation

The standardisation of process through looking at data provide insights for the sustainability of participatory mechanisms and the establishment of their role in public policies (Falanga, 2019). Data-driven analysis has long been integrated and advancing in research in architecture and urban studies. For instance, KPI based evaluation of scenarios includes multiple applications, such as predictions and assessment of environmental performance or architectural design scenarios. Based on the insightful results in other domains, we explore the hypothesis of the application of such a methodology in the field of participation evaluation with the identification of the right set of KPIs. To this, we employ an already developed interactive dashboard by part of the authors (Duering et al., 2022) designed to serve the purpose of performance impact assessment for urban development. The data analysis and visualization components of the dashboard have been developed as an open-ended framework, thus allowing the integration of diverse datasets and KPIs such as the ones of the BIP/ZIP program of this study.

Beyond information that is easy to codify into KPIs for the dashboard, such as number of partners, locations and funding, a major challenge of this research has been the translation of qualitative information, such as the activities conducted within each one of the participatory projects into quantified data. To this, we followed a manual mapping process that required our expertise and review of sustainability impact indicators.

2 Methodology

2.1 Data Collection and cleaning

The first part of the methodology refers to the collection of data and their preparation, cleaning and feature extraction for the composition of a dataset. The initial phase of the evaluation methodology described in this paper is dedicated merely to understanding correlations and patterns that stem from the existing raw data. The selection of appropriate variables to measure the impact of the program in the city of Lisbon has been significantly shaped by the available public data of the projects. The main sources are the applications of the projects published at the BIP/ZIP website (*BIP/ZIP*, n.d.), the Forum Urbano website (*Forum Urbano*, n.d.) that includes a mapping of the realised projects up to the 2020 edition, as well as the annual calls for applications, called Ciclo e Regras (*BIP/ZIP*, n.d.). The dataset used in this study was informed and validated by the Municipality of Lisbon, through a research collaboration of the authors.

In the dataset, each project is treated as a data point with all the relevant attributes associated to it. The first attributes relate to the project's identity and are specifically the name of the project and an ID number, as well as the year of the project's application. These features are significant for the connections among the different datasets created for the analysis process. Furthermore, the attributes of the location of each project have been selected as a significant feature both for this preliminary step of the evaluation and most importantly for the future visualisation of the results in a geolocated maps. At this stage, the location of each project is described through the number of the BIP/ZIP priority area or areas (1-67) where it is implemented.

The first key indicator examines the generation of partnerships for the projects, containing raw data on the types of partners-institutions. The recorded types comprise 18 categories, such as neighbourhood, cultural, religious, sports associations, non-governmental organisations and non-profit cooperatives. Additionally, the theme of each project refers to the scope of the initiative and is defined during the application phase with the form of a selection among five predefined categories. The categories are consistent throughout the ten years, with minor updates on their titles and objectives and refer to projects that target to Improve Neighbourhoods Life; Skills and Entrepreneurship; Community Space; Prevention and Inclusion; and Promoting Community Dynamization and Citizenship. Initiatives can be given funds up to €50,000 each, but it is advisable that applications demonstrate complementary funding by external resources, proving the ability to sustain the operation of the project after the first year of municipal grant. Hence, the indicator of funding is described by two values, one provided by BIP/ZIP and one by external sources. Moreover, an important parameter for understanding the projects impact in the priority neighbourhoods refers to the target group attribute to which the project

addresses, and which can be children; youth; elderly; families; vulnerable groups; and adults (Figure 1).

2.2 Activity Mapping

The final parameter set of selected attributes refers to the activities executed throughout each project, based on the application phase. These attributes are the most difficult to record in an organised way, as the available information is based on free descriptive text. The first attempt to codify the activities has been approached with semantic techniques, such as Natural Language Processing models and word clouds, however the results were not as useful as expected. A second attempt includes the method of cycles of qualitative coding (Saldana, 2021). The initial free text is codified in keywords and further assigned to categories by the authors. The categorisation is based on an index of parameters that relate to social and spatial impact for sustainability (Colantonio et al., 2009; Global utmaning, 2017; Maio et al., 2020; Van Herck et al., 2019) (Figure 2).

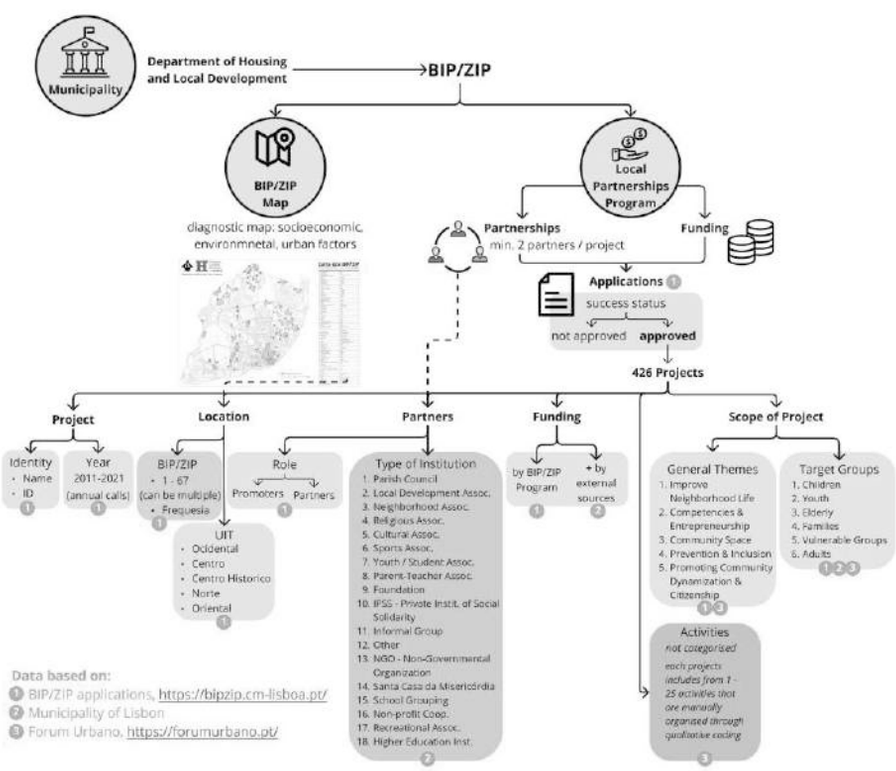

Figure 1. Data collection diagram.

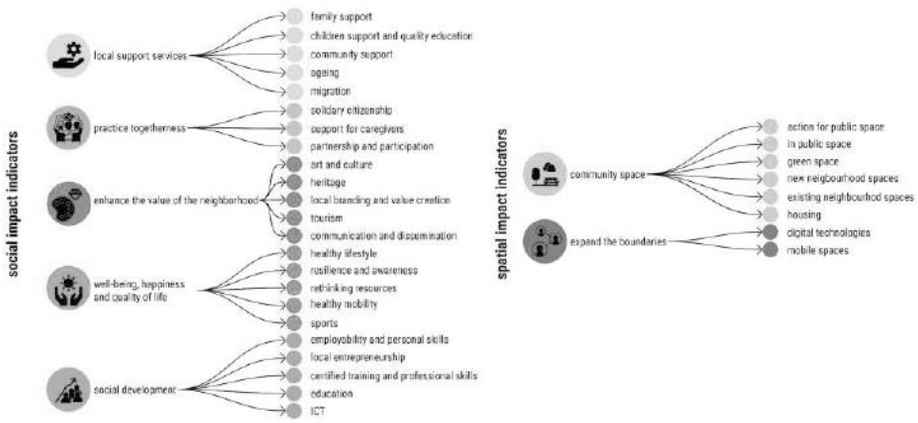

Figure 2. Activity mapping: social and spatial impact indicators.

2.3 Data Analysis

The methodology followed aims to assist the evaluation of the projects in relation to the BIP/ZIP program in its entirety by identifying correlations between the partners, the locations of the projects, the activities mapped and the general attributes of each project, such as the internal and external funding, the themes and target groups and the year of implementation. The total number of selected attributes for each project in conjunction with the number of projects adds up to a very large number of data points and a complex dataset that is not manageable without automated and machine learning driven data analysis methods. Using unsupervised machine learning clustering methods, the large dimensionality of projects' dataset can be reduced and visualized to an understandable parameter space, thus allowing to abstract information and identify correlations between the different project attributes. The clustering methodology focuses on the 3 main aspects of the projects' data: locations; partners; and mapped activities.

The development of custom visualisation dashboards, based on an existing interactive dashboard for KPI-based impact assessment developed by the authors (Duering et al., 2022) allows for further exploration of the correlation of the projects' attributes, thus reducing even more the complexity and allowing for interactive interrogation of the data based on specific evaluation questions. These dashboards are informed not only by the raw project data, but also by the mapped activities per project as well as the output data of the clustering models. The 4 visualization dashboards are used interchangeably to help understand the complex relationships between the 3 main clusters of locations, partners and activities and the general attributes of the projects.

2.4 Data Clustering

The large dimensionality of the projects' data is reduced using a clustering methodology. As each project can be associated with multiple BIP/ZIP areas, partners and activities, associating and visualizing these attributes along with general attributes of the projects in one dashboard would lead to an overly complex analysis. The attributes for each clustering model are therefore reduced to relevant attributes for the 3 specific aspects of the program and then collectively used with general data of projects to identify patterns. Different unsupervised machine learning clustering models have been attempted for each analysis step with varying results, such as k-means clustering, principal component analysis (PCA), self-organizing map (SOM) and T-distributed Stochastic Neighbourhood Embedding (tSNE). Python scripts, open-source models, Google Colab collaborative code notebooks and the open-source data mining and visualization software Orange have been used to explore and visualize the clustering models. The results are produced with a k-means clustering model using an elbow variable clusters method.

For the locations clustering, the projects' BIP/ZIP areas are mapped in a table, producing a 67 dimensions vector per project. The number of areas per project is correlated with the different locations' clusters to identify correlations between project types and the number of locations involved. The locations dashboard contains locations per project, clusters and number of locations as well as activities and partners clusters.

Mapping the individual partners of each project resulted in an index that exceeds the 4700 entries. To reduce this complexity for the partners' clustering model, the partners are instead mapped in 18 institution types, as specified by the Municipality of Lisbon. Therefore, the mapping of the partner types per project is formative of an 18-dimensional vector per project which is consequently used to produce 4 clusters of partner types with common characteristics. Again, the number of partners (which can be more than 1 per type) is also used to inform the partners clustering and dashboard along with the locations and activities clusters.

Finally, the activities clustering model is based on the data produced by the manual activity mapping. The data is structured in a table of number of instances of activity types per each project. The 34 categories of activities resulted in a 34-dimensional vector per project which is used for the activities clustering. As per the other clustering methods, the number of activities as well as the locations and partners clusters are also included in the activities' dashboard. The results from all the clustering models are also directly integrated in the general dashboard, which creates an overview of all clusters along with the general data of the projects. Clustering models, such as k-means, tSNE and SOM are also inclused as interactive components of all dashboards, allowing further clustering of sub-selections of the data of each of the 4 dashboards (Figure 3).

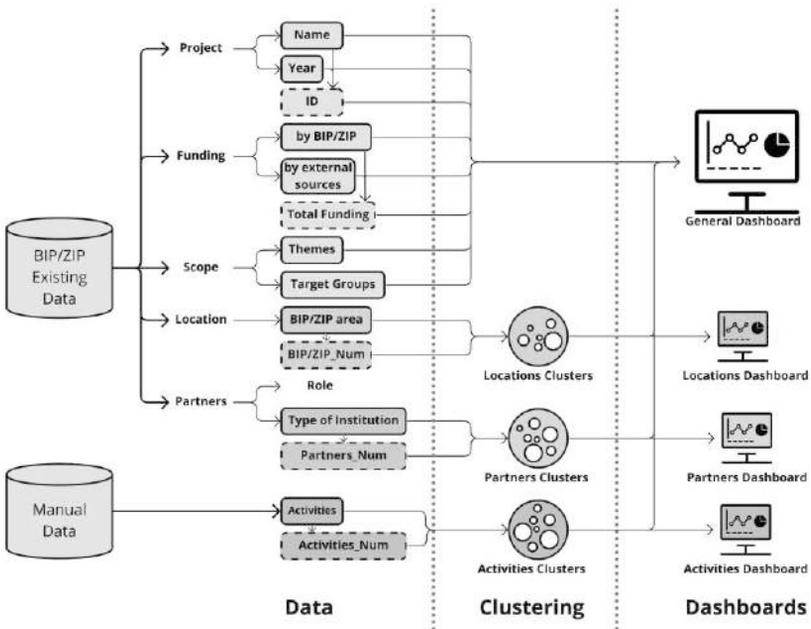

Figure 3. Methodology Diagram.

2.5 Interactive Dashboards

A key component of the data analysis is the interactive dashboard for KPI-based evaluation. Further to the ability of visualizing a large dataset, the dashboard components allow deep data exploration, using interactive graphs with associated sub-selections of data, KPIs comparison, as well as correlation matrices, selectable scatter plots and clustering models, all of which are used to understand and identify patterns in the large dataset of the BIP/ZIP program. In total, 4 different dashboards are produced using raw data, processed data and results of the clustering models. The locations, partners and activities dashboards are used individually as well as in conjunction with the general dashboard, informed by all data and clusters. The dashboards are developed in HTML using Python and Bokeh, an interactive visualization library. For the developed dashboards a local Python server is also developed to run the ML models, produce the KPIs and graphs and serve all data and visualizations to the HTML pages of the dashboards.

Using the interactive and selectable parallel coordinates tab in all dashboards, the users can select different attributes of projects, such as a specific activities cluster, the range of funding or part of the program's timeline and interactively see updated graphs and KPI metrics showing the comparison of the sub-selection with the general distribution of KPIs for all projects. This interactive exploration of the data is instrumental for understanding the

relatively complex dataset. At the same time, the dimensionality reduction tab can be used to cluster the data with different clustering models and visualize the attributes in scatter plots. Sub-selecting data points directly on the scatter plots and then investigating their KPIs distribution is valuable to understand more specific relationships between the projects' elements. Finally, the correlation matrix can be used to quickly visualize the correlations between attributes of the project both for all data points as well as very importantly for any sub-selection on the scatter plot or parallel coordinates plot. This fully connected interactivity among all graphs is invaluable for drawing conclusions from the data (Figures 4,5).

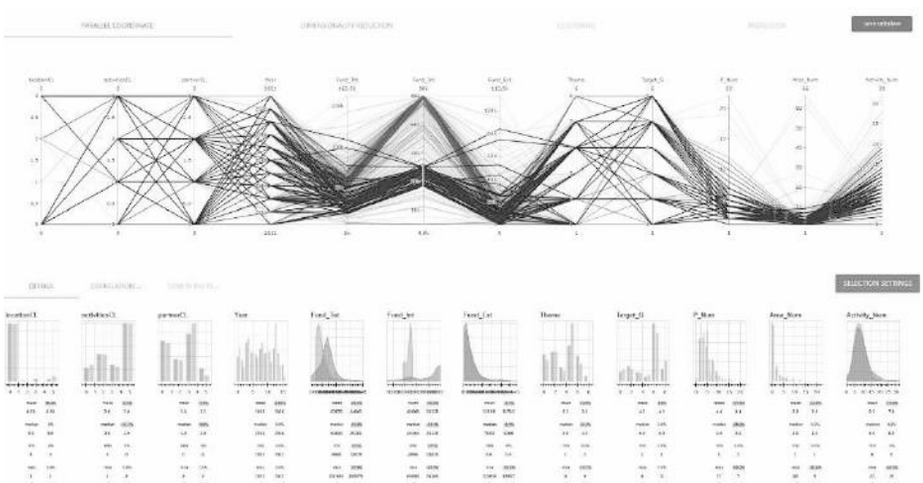

Figure 4. Interactive dashboard: parallel coordinates tab.

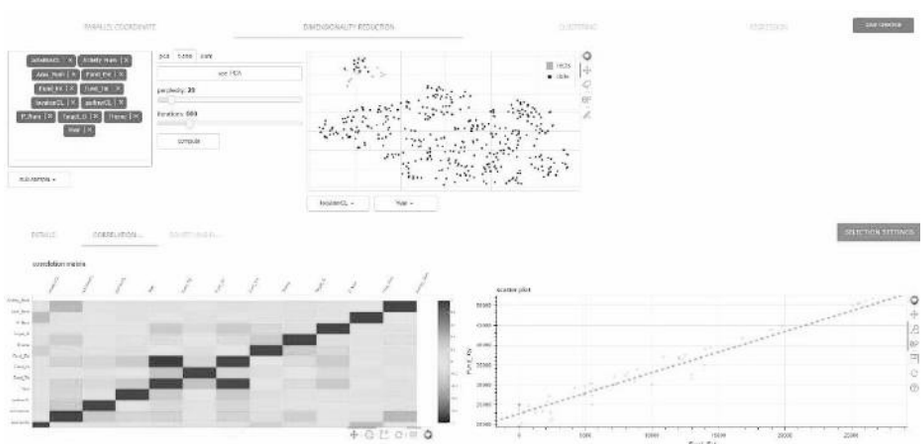

Figure 5. Interactive dashboard: dimensionality reduction tab.

3 Results & Discussion

Through the tested methodology, we have been able to collect, map, analyse and visualize the large dataset of the BIP/ZIP program and explore correlations within complex relationships of projects, partners, areas, activities, and general attributes of more than 400 projects. An exhaustive presentation of these correlations is not in the scope of this paper, as its focus is on the methodology of evaluating participator. It is important to note that for the preparation of the dataset a large amount of data points have been analysed, cleaned and manually processed. Therefore, for a generalization of the proposed methodology a robust data integration methodology would be necessary. Nevertheless, we consider that the developed methods along with their modular character can be a significant first step for data-driven evaluation of participatory models.

3.1 Locations, Partners & Activities Clusters

The ability to identify clusters with discrete characteristics and then correlate them with specific attributes is key in understanding relationships among the elements of the projects, especially because a similar exercise with all data incorporated proved very inefficient and incomprehensible. In the locations clusters results, clear patterns of project types emerged, with 1 major cluster of low number of locations (1-2 areas), and 3 clusters of large numbers of areas (1-10, 4-17, 27-67 areas). This allowed for clear correlation between smaller and larger spatial scale projects. The clustering of partner types yielded even more unpredicted patterns of partner constellations. For example, the inclusion or not of Local Development Associations as partners in projects produced 2 distinct clusters. This result correlates with how local groups such as cultural, sports and youth associations form partnerships of larger number of partners in comparison to projects with no or little local groups. These patterns can also be used to reflect on budgetary, thematic or other requirements of projects and how BIP/ZIP enables them. Furthermore, the activities clustering delved deeper in the specifics of the projects' foci, with resulting clusters of specific activities groups, translated as "arts & culture", "support and awareness", "identity" and "skills and entrepreneurship" clusters.

3.2 Visualization dashboards

The resulting 4 visualization dashboards accumulate the dataset of the study and their interactive components allow for a very instructive exploration of the BIP/ZIP program. Although this visualization is only a first step towards a data-driven evaluation of the program, it clearly shows how powerful the integration of interactive visualization components with unsupervised ML models can be. The interactive dashboards can produce inexhaustible associations and visualizations of data, allowing the users to examine every

aspect of the projects, from constellations of partners to patterns of activities, funding and themes, providing useful feedback for the future of the project. Nevertheless, a detailed and critical evaluation of these results is needed to optimize and further develop the interactive dashboards, KPIs and ML models to better match the program's specific needs.

4 Conclusion

The study contributes to the conceptualisation of participatory models, such as the participatory budget of BIP/ZIP, as multi-dimensional systems that are defined by complex relationships of attributes. The methodology has been significantly shaped by the available data of the BIP/ZIP Program, which means that a potential transferability would require a recontextualization, or a selection of data that are meaningful for the new contexts. Despite being case-specific, this study aims to move beyond certain research outputs, and focus on the methodological contribution.

First, it suggests two ways for the simplification of complex data that would possibly contain correlations difficult to translate. These are the use of codified categorisation rather than individual free entries, such as in the case of the partners attribute that is introduced as types of institutions, and the use of clustering methods that provide unsupervised categorisation. Moverover, it examines the integration of qualitatively mapped attributes in addition to raw existing data. This step offers plenty of potential for the further development of this case and the transferability to other contexts, as it demonstrates that any additional qualitative attributes can be inserted in the dataset, as long as their integration is consistent to the data preparation process of the methodology. For example, a valuable parameter to be considered, would be the participatory assessment of the impact of each project, by the partners or residents. Also, employing the tool of a dashboard and the multiple analysis and visualisation techniques enables the correlation of selected attributes and hence the response to targeted questions. Most importantly, the interactive character of the dashboard allows for quick visualisations and experimentation.

Finally, through this data- and KPI-driven methodology for assessment of participatory programs, the study aims to denote the significance in looking at participatory budgets not merely as policies, but as formative of urban process and hence evaluated as such, using tools of urban analytics. This, as far as the authors are concerned, is a significant research innovation in the field of evaluation of participatory programs.

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References

An integrated toolbox for deprived neighbourhoods | URBACT. (2021). https://urbact.eu/integrated-toolbox-deprived-neighbourhoods

Annex of the 2030 Agenda. (2017). Annex: Global Indicator Framework for the Sustainable Development Goals and Targets of the 2030 Agenda for Sustainable Development. *Work of the Statistical Commission Pertaining to the 2030 Agenda for Sustainable Development*, 1–21.

Arnstein, S. R. (1969). A Ladder of Citizen Participation. *Journal of the American Planning Association*, 35(4), 216–224.

Bahreldin, I. Z. (2013). An Approach to Community Participation Evaluation Framework. *Buildings and Roads Research*, V(January 2013), 15–32.

BIP/ZIP. (n.d.). Retrieved July 19, 2022, from https://bipzip.cm-lisboa.pt/

CML. (2010). CARTA DOS BIP / ZIP Bairros e Zonas de Intervenção.

CML, & DMHDL. (2017). *Good Practice Summary – Lisbon Local Development Strategy for Neighborhoods or Areas of Priority Itervention (BIP/ZIP): an integrated toolbox.*

Colantonio, A., Dison, T., Couch, C., Fraser, C., & Percy, S. (2009). Measuring Socially Sustainable Urban Regeneration in Europe. *Creating Sustainable Environments*.

Duering, S., Fink, T., Chronis, A., & Koenig, R. (2022). *ENVIRONMENTAL PERFORMANCE ASSESSMENT-The Optimisation of High-Rises in Vienna*.

Falanga, R. (2019). Measuring citizen participation in urban regeneration: a reflection on the construction of the participation index for the Bip/Zip programme in Lisbon. *Urban Development Issues*, 62(1), 47–60.

Falanga, R. (2020). Formulating the success of citizen participation in urban regeneration: Insights and perplexities from Lisbon. *Urban Research and Practice*, 13(5), 477–499.

Forum Urbano. (n.d.). Retrieved July 19, 2022, from https://forumurbano.pt/

Fung, A. (2006). Varieties of participation in complex governance. P*ublic Administration Review* (Vol. 66, Issue SUPPL. 1, pp. 66–75). Smith and Wales.

Global utmaning. (2017). Local Implementation of the SDGs & The New Urbanism Agenda Towards A Swedish National Urban Policy. *Global Utmaning Association*.

Maio, S. de, Kuhn, S., Esteve, J. F., & Prokop, G. (2020). *Indicators for European cities to assess and monitor the UN Sustainable Development Goals (SDGs)*.1–222.

Saldana, J. (2021). *The Coding Manual for Qualitative Researchers* (4th ed.). SAGE.

United Nations (Habitat III). (2017). *NEW URBAN AGENDA*. www.habitat3.org

Van Herck, B., Vanoeteren, V., & Janssen, K. (2019). *Local Indicators for the 2030 Agenda (Sustainable Development Goals).*

The Tourist's Image of the City: A comparative analysis of the visual features and textual themes of interest across three global metropolises

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Abstract. Tourist attractions play a major role in shaping 'mental images' of cities. The growing availability of urban big-data in recent years has opened up novel lines of inquiry into the nuances of urban imageability and sentiment. Drawing upon crowdsourced hybrid data in the form of both textual descriptions as well as photographs for 750 tourist attractions across Boston, Singapore and Sydney, this work compares the predominant themes of discussion and visual features of interest that shape tourist sentiment towards these cities. The study collects over 3500 user reviews and uses Latent Dirichlet Allocation (LDA) for the extraction of high-level topics of discussion. Object detection is also run on over 6000 photographs, and unsupervised clustering is carried out on extracted features to identify clusters of visual elements which capture tourist attention. The findings reinforce the popular identity of Boston as a city steeped in history, while strong perceptions of nature and greenery emerge from Singapore. Tourist interest in Sydney is dominated by specific anchors such as the Sydney Harbor Bridge.

Keywords: Urban Tourism, Topic Modeling, Sentiment Analysis, Unsupervised Clustering, Big Data

1 Introduction

Tourist destinations play a major role in defining the popular 'image' of a city. Be it the Statue of Liberty in New York, the London Bridge, or the Colosseum in Rome – these anchors often become synonymous with their respective urban centers themselves, and remain ingrained in everyday public consciousness. The tourists' image of a city often also comprises far more nuanced visual and experiential elements, which go beyond specific sites or structures. These elements become the building blocks of a city's 'identity', and are often

considered to be 'intangible' elements that can only be experienced, but not easily analyzed.

While there have been numerous studies over the past decade inquiring into urban tourist sentiment, the exponential growth of big-data over the past few years have opened up valuable methodological approaches in this regard (Alaei et al. 2019). Social media data from platforms such as Twitter, Filckr and Tripadvisor has emerged as a popular data-source for such recent research directions (Galí et al. 2015, Valdivia et al. 2017, Cardone et al. 2021). Moreover, geolocated Point of Interest (POI) data available through platforms such as Google Places, and Foursquare provide valuable access to user-reviews, user-photographs, and visitation patterns, at a very high spatio-temporal resolution (Marti et al. 2019).

A number of methodological approaches have been employed in the past for inquiries into the experiential dimensions of the urban realm. While sentiment analysis is a popular method in this regard, topic modeling has been gaining popularity as a tool for exploring the different dimensions of subjective experience in cities (Kovacs-Gyori et al. 2018, Ghahramani et al. 2021). There have, however, been very few lines of inquiry that draw upon hybrid textual and photographic data to extract both visual features of interest as well as themes of discussion, as semantic content over and above quantitative sentiment scores. Such an approach can allow for the cataloging of structured high-level data with regards to the dimensions of tourist experience, and also has potential to be integrated into data-query and visualization platforms.

This body of research inquires into the major textual themes of discussion and visual features of interest contributing to popular sentiment amongst citizens/visitors towards urban tourist attractions in three cities – Boston, Singapore and Sydney. It further investigates the similarities and differences in these patterns across these urban centers, thus exploring the unique experiences that remain anchored to their respective perceptual identities.

2 Methodological Framework

2.1 Data collection

In order to extract meaningful content with regards to features of interest and themes of discussion, both visual as well as textual data becomes important. Visual data in the form of crowdsourced tourist photographs can provide valuable cues into the kinds of features within the city that the tourists were interested in. Textual data, on the other hand, comprise tourist generated descriptions or appraisals of urban anchors and environments. Such kind of data (in the form of reviews, comments etc.) provide insights into the themes of discussion emerging from different tourist destinations, along with the predominant sentiment associated with these themes.

While numerous platforms exist today that can serve as valuable repositories of both the above-mentioned data forms, this work set forth three primary criteria for selecting the data source. Firstly, the data needed to be of high spatial resolution. In other words, the data should be geo-located with an accuracy that is high enough for meaningful inferences with respect to its location to emerge. Secondly, the data should also be of high temporal resolution. In other words, the exact time and date of the review/photographs should also be available. Finally, the data should contain adequate and relevant semantic content with regards to the different qualitative aspects of tourist experience, which is often a challenge.

Based on these criteria, Point of Interest (POI) data sources emerged as the most appropriate in this regard. While there are numerous major POI data aggregators globally (such as Google Places, Foursquare and Yelp), this body of research adopted Google Places as the primary data source for analysis.

Data for points of interest listed as 'tourist attraction' was programmatically collected across the three cities using the Google Places API. The first round of data collection involved the collection of basic place details using the 'Nearby Search' API call. Query locations and radii were set at regular intervals across the cities, and places data queried from each location. The data included attributes such as location, place name place id, rating, total user ratings and the like. Next, for each of the places now listed in the dataset, 5 top reviews and 10 photograph ids were programmatically collected using the 'Place Details' API call. For each review, the query returned attributes such as author name, language, rating, review text and a timestamp. For each photo id, the query also returned author name, timestamp and the photo url. The final step in the data collection pipeline was to programmatically download each photograph using the photo url, and to store the files with meaningful filenames corresponding to the photo ids recorded in the dataset. **Table 1** below summarizes the volume of data collected through this pipeline.

Table 1. Summary of Google Places data collected

Boston	Singapore	Sydney
139 locations	430 locations	580 locations
603 reviews	1939 reviews	2721 reviews
1241 photos	4086 photos	5587 photos

2.2 Sentiment Analysis

The first step in the analysis pipeline was the extraction of overall sentiment from each review. This was carried out in Python, using the NLTK Vader pre-trained sentiment analyzer (Hutto and Gilbert 2014). This resulted in a single compound sentiment score (between -1 and +1) being associated with each review. While such a method of sentiment analysis does not yield high level understandings of the content of the reviews themselves, it is nevertheless an effective tool for grading the reviews on a linear scale, and thus separating the negative, positive and neutral reviews. The compound scores were then aggregated by location (tourist attraction), and visualized on a map to check for possible spatial dimensions to sentiment distribution (**Fig 1**).

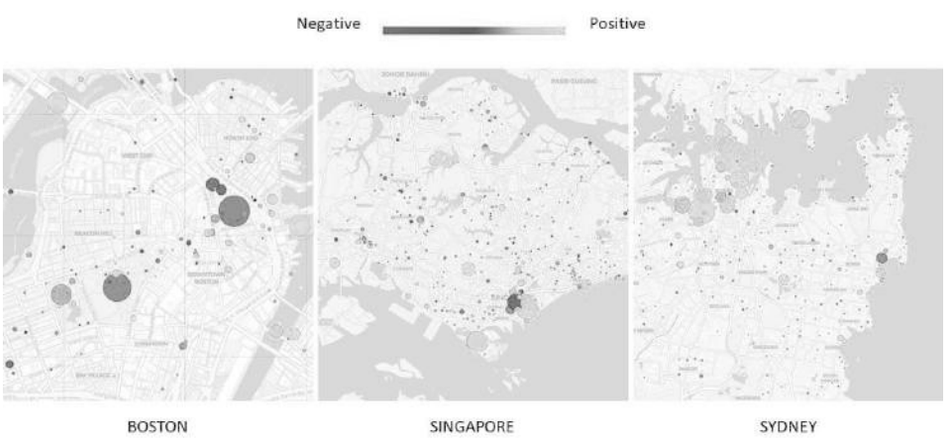

Figure 1. Overall compound sentiment scores for tourist locations across the three cities. Size indicates number of ratings (used here as a proxy for number of visits)

2.3 Topic Modeling

Extraction of overall sentiment, while useful for discriminating between positive and negative reviews, does not provide us with insights into the themes of discussion associated with each review. For this, an unsupervised Latent Dirichlet Allocation (LDA) (Blei et al. 2003) model was implemented on the city-specific datasets, in order to extract the most frequently occurring high level topics that were emerging from the reviews. An LDA approach was preferred to clustering, since a single review could contain more than one topic. Stop words were first removed from each review text, and the remaining words (tokens) were lemmatized (grouping together of inflected forms so that they can be analyzed as a single item). These words were converted into a dictionary of tokens which defined the feature space of the reviews themselves. The reviews were then encoded as bags of words (frequencies of each word in the dictionary). These formed the input vectors for the LDA model.

Based on iterative testing and evaluation, the 10 most common topic-clusters were extracted for each city using LDA **(Fig. 2)**. The clusters were in the form of collections of individual tokens, and corresponding coefficients which described the degree to which they contributed to the topic that defined that cluster. The high-level topics that defined each cluster thus needed to be manually inferred from the individual tokens and their coefficients.

Figure 2. Topic modeling on review texts from Boston, along with their spatial distributions.

The larger aim of this body of research however was to investigate the themes of discussions emerging from tourist locations *in the context of sentiment*. It was necessary to infer not only the overarching topics emerging from these cities, but rather the topics that were consistently associated with negative sentiment, and those associated with positive sentiment. To this end, for each city, the individual reviews that had the highest sentiment ratings as well as those with the lowest were separated. Given the frequency distribution of review sentiment values, this was achieved by filtering all reviews with a sentiment score higher than 0.85, and those with scores lower than -0.25. This generated two separate datasets for each city, containing the reviews with best and worst sentiment scores respectively. The topic modeling workflow was then run independently on both the datasets for each city, in order to extract the high-level topics that were associated with positive and negative tourist sentiment respectively.

2.4 Visual feature extraction and unsupervised clustering

For extraction of visual features of interest, a faster-RCNN object detection model trained on the Open-Images V4 dataset (Kuznetsova et al. 2020) and provided by TensorFlow (Abadi et al. 2016) was run on the tourist photographs from each city. The model inferred the high-level semantic content contained within the images **(Fig. 3)**. This generated a dataset for each photograph containing the top 100 objects detected in them, along with the confidence scores for each detection. For analysis, only the features associated with confidence scores of 0.10 or higher were retained within the dataset.

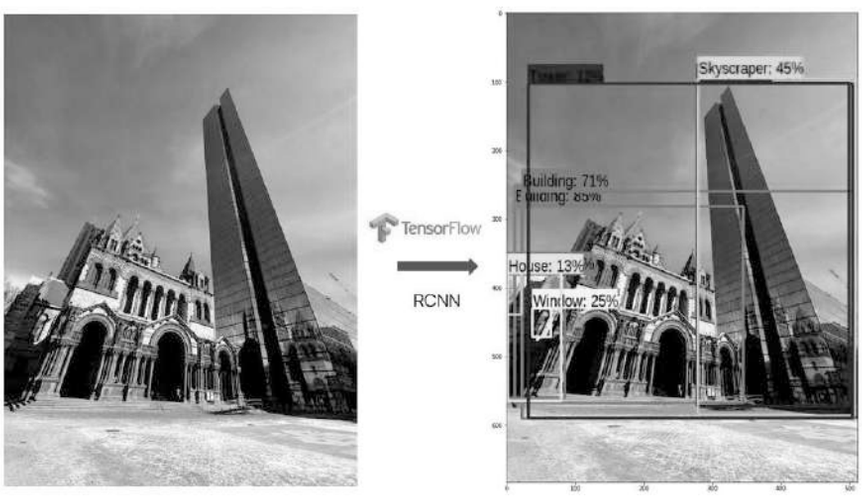

Figure 3. Faster RCNN object detection model for extraction of features of interest.

In order to infer the features that were consistently correlated with tourist interest within the cities, an unsupervised k-means clustering algorithm was used. Each data point associated with each photograph was converted into a bag of features, with the frequency of each feature occurrence recorded within the feature vector. Clustering was implemented in Python, using the scikit-learn library (Pedregosa et al. 2011). Based on iterative implementation, between 10 to 25 clusters were extracted from the photographs of each city.

3 Results – The dimensions of tourist experience

3.1 The Talk of the Town: Themes of tourist discussion

The results of the topic modeling exercise successfully mapped out several interesting dimensions of the unique themes of discussion that remain associated with tourist sentiment in different cities. They also provided valuable

insights into the unique symbolic associations that are forged between the cities and the tourists through these seemingly innocuous everyday discussions.

In Boston, most common high-level topics revolved around historic buildings, churches and sites, conducted tours revolving around museums, aquariums, and statues, enjoyable experiences in parks such as beautiful and peaceful walks, and also enjoyable experiences with children and kids. Most of these topics were associated with strong positive sentiment, and overlapped greatly with the topics emerging from the positive review dataset. Topic modeling on the negative review dataset however revealed interesting themes such as complaints about Boston's weather (often in the context of tours being cancelled due to rain), discussions and debates around the history of slavery and the independence movement, consistent frustration with traffic at specific points in the city (such as its tunnels and bridges), and sporadic complaints about having to climbing stairs in some tourist locations.

The discussions emerging from Singapore were radically different. Unlike Boston, there was far less focus on history, and greater focus on nature, landscapes, and serenity. Common topics in this regard included numerous discussions surrounding birds and bird-watching in gardens, small and quiet playgrounds, beautiful and relaxing temples and churches, enjoyable tours in museums, good times with children and family, and very interestingly, numerous discussions surrounding staff at tourist establishments. The positive review dataset also revealed high-points in the tourist experience such as enjoyable rides in parks and jogging activities by the waterfronts. Interestingly, the negative discussions also surrounded very similar themes. There emerged multiple instances of frustration with long entrance queues in front of tourist establishments, bad staff, unpleasant experiences with children in parks, and general complaints about dirt and lack of cleanliness **(Fig. 4)**.

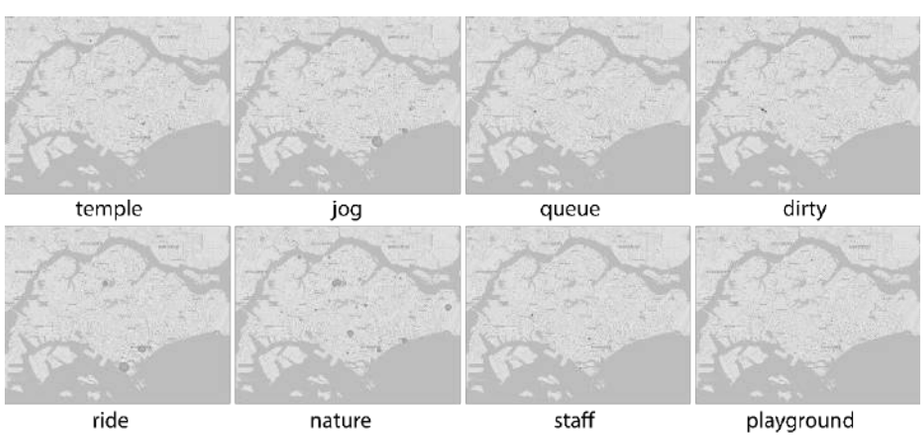

Figure 4. Spatial distribution of themes corresponding to extreme positive and negative tourist sentiment in Singapore.

Sydney, on the other hand, had a very different identity as emergent from tourist discussions. While the Sydney Harbor and specifically the Harbor Bridge recurred in multiple discussions, there was also a lot of talk about picnics by the waterfronts and also by the city's beaches. Discussions surrounding food was also a dominant theme in this context. Interestingly, there were multiple discussions surrounding toilets in the context of beach visits by tourists. Other topics were more in common with the other cities, such as talk surrounding children's playgrounds and churches. Unlike Boston and Singapore, the reviews with extreme good and bad reviews had topics which were different from the topics emerging from all reviews taken together. High-points associated with positive tourist sentiment revolved around specific sites such as the zoo and art galleries. Others were more generic and pertained to conducted tours and beaches. Low-points emerging from the city surrounded themes such as bad staff, poor equipment in parks, lack of proper public toilets and, interestingly, complaints about dogs.

Overall, the discussions and themes emerging from these three cities tie back strongly to the core experiential identities that they present to their tourists – that of Boston as a city steeped in history, Singapore as a city cradled within nature but with exciting activities, and Sydney as a city dominated by its harbor and its beaches. **Table 2** summarizes the key positive and negative topics emerging from these three cities.

Table 2. Summary of topics associated with highest (+ve) and lowest (-ve) tourist sentiment across the three cities.

	Boston		**Singapore**		**Sydney**	
+ve	Great guide/tour/ food	Great churches	Temple tour	Jogging/ safe	Fantastic tours	Zoo/ Food
	Aquarium/ Museum	Park/ skating	Amazing rides	Park/ nature	Art galleries	Nice beaches
-ve	Climbing stairs	Tunnel/ traffic	Entrance queues	Dirt/ cleanliness	Public toilets	Bad staff
	Rain/ruined tours	Slavery/ massacre	Bad staff	Unpleasant playground	Poor equipment	Dogs

3.2 The Image of the City: Visual features of tourist interest

As discussed at the very outset, every city presents very unique visual identities to tourists and visitors. These visual identities are often associated with nuanced configurations of specific visual features, which appear and disappear as tourists move around the city, but at the same time leave lasting impressions upon the subconscious mind of the visitor. The unsupervised clustering carried out as a part of this work was an attempt to empirically

uncover some of these nuances, and the ways in which they forge different visual identities in different cities.

The overarching popular identity of Boston as a city steeped in history and historic sites was validated through this exercise. The most common cluster of visual features of interest surrounded those pertaining to historic brick facades that characterize many neighborhoods in Boston. Interestingly enough, a vast majority of these features appeared in photographs that were captured by tourists along Boston's famous 'Freedom Trail' – a 2.5-mile path through the city that weaves through important anchors of the history of the United States. In this context, another important set of features frequently capturing tourist attention were plaques, signage and information boards, which frequently accompany tourist destinations (**Fig. 5**). Urban parks also formed a major visual attractor, with a significant percentage of tourist photographs capturing such spaces. Selfies, group photographs and photos of other tourists formed another major cluster that captured tourist attention.

Figure 5. Plaques and signages around tourist attractions formed one of the strong features of tourist interest in Boston

The identity of Singapore as a city surrounded by nature emerged through the photographs as well, with a vast majority of features of interest pertaining to parks and semi-urban landscapes. These photographs were spread out finely across the length and breadth of the island city-state. The photos however also revealed how local vegetation characteristics can generate lasting visual identities. Elements such as palm trees were a recurring feature in tourist photographs and, in many cases, formed the primary subject matter of the photographs themselves. Other imageable features included the skyscrapers and skylines that characterize downtown Singapore **(Fig. 6)**. In many cases these elements were framed across waterfronts or the harbor. Finally, a very unique set of features of tourist interest emerging from the city were those surrounding fish – both in the form of living creatures in aquariums as well as in the form of food.

The visual features capturing tourist attention in Sydney tied back strongly to the themes emerging from the topics of discussion as discussed in the earlier section. The Sydney Harbor, and specific anchors such as the Harbor Bridge and the famous Opera House dominated tourist photographs. These appeared

both as primary subjects, as well as backdrops in generic harbor front photographs. What was even more interesting was the prominence of boats (including ferries and yachts) as strong visual attractors. It is worth noting here that while both Boston and Singapore are harbor cities as well, boats did not contribute as much to the visual attention-field of the tourist. Moreover, images of fine dining, with features such as wineglasses and food in formal settings frequently recurred as a visual theme underlying the visitor's experience of Sydney.

Figure 6. Skyscrapers and skylines – a popular subject of tourist interest in Singapore.

The features of visual interest emerging from the three cities opened up unique insights with regards to the specific elements within a tourist's visual field that actually capture tourist attention. It also revealed the unique ways in which low level visual features combine and recombine in different ways to generate high-level visual identities of cities. **Figure 7** summarizes the key feature-clusters emerging from the three cities.

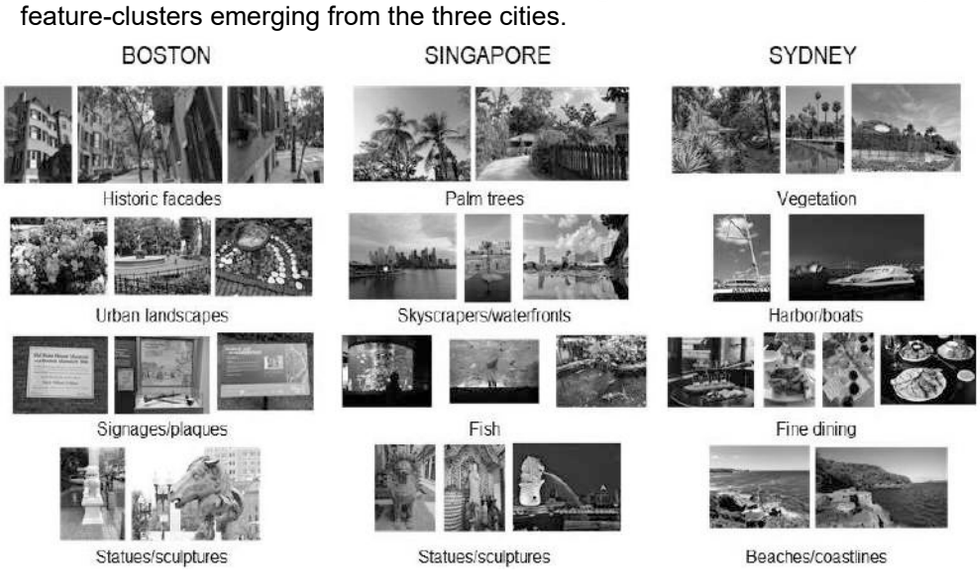

Figure 7. Summary of the top clusters for visual features of tourist interest across the three cities

4 Conclusion – Empirical approaches to urban identity

This work relied upon hybrid (textual and photographic) data to analyze the major themes of discussion and features of interest that contribute to overall sentiment towards urban tourist attractions in three cities. More importantly, it compared these patterns across cities, thus exploring the unique ways in which visual elements and textual themes come together to define urban identity.

However, there are a number of challenges and limitations with regards to such empirical approaches that are worth touching upon. Firstly, the platform from which such urban data is sourced is never neutral, and inevitably introduces a specific lens through which the city is understood and analyzed. Citizens and visitors talk about different aspects of urban life on different platforms, and do so in very different ways. The discussions generated about the same urban location on Twitter, Google Places and Flickr will be very different, and the nuances of these differences need to be kept in mind when working with such data. Secondly, most urban POI data aggregators are careful to mask sensitive personal information of the users that are generating the data, due to privacy considerations. While this is understandably an important necessity, it nevertheless does make it difficult for the analyst to discriminate between individuals visiting tourist locations as actual tourists, and those with a far greater degree of familiarity with the city visiting those same locations. Urban identity is a complex affair, and the tourist's identity can seldom be equated with the identity forged on the minds of long-term citizens. Moreover, the crowdsourced images and reviews analyzed for a given attraction were uploaded by different users, thus making it difficult to tease out meaningful correlations between visual and textual material. Thirdly, the current state of the art in object recognition as implemented in this work relies upon predetermined classes of visual elements that can be detected through the workflow. It thus relies upon a fixed symbolic vocabulary of elements that the model 'looks for', and is not equipped to comprehend different symbolic frameworks through which a tourist may interpret the very same visual content. Finally, and most importantly, the study relied on textual material in the English language. This inevitably introduces a specific research gaze, and excludes analyses of the urban experience of non-English speaking tourists in these cities.

Having said that however, the analytical methodology demonstrated through this work has potential to become a valuable tool for future studies. As discussed earlier, while topic modeling and sentiment analysis have been carried out for multiple urban studies in the past, the analysis of hybrid visual and textual data through unsupervised clustering is a novel approach. Extracted visual features and textual themes complement each other in the context of urban sentiment, and can provide nuanced and comprehensive insights which are often otherwise missed within mainstream sentiment analysis and topic modeling workflows. It is hoped that the methods outlined in this paper are taken forward to address future questions within an undeniably complex domain – that of subjective urban experience.

References

Abadi, M., Barham, P., Chen, J., Chen, Z., Davis, A., Dean, J., Devin, M., Ghemawat, S., Irving, G., Isard, M., & others. (2016). TensorFlow: A system for Large-Scale machine learning. *12th USENIX Symposium on Operating Systems Design and Implementation (OSDI 16)*, 265–283.

Alaei, A. R., Becken, S., & Stantic, B. (2019). Sentiment analysis in tourism: Capitalizing on big data. *Journal of Travel Research*, *58*(2), 175–191.

Blei, D. M., Ng, A. Y., & Jordan, M. I. (2003). Latent dirichlet allocation. *Journal of Machine Learning Research*, *3*(Jan), 993–1022.

Cardone, B., Di Martino, F., & Sessa, S. (2021). GIS-based fuzzy sentiment analysis framework to classify urban elements according to the orientations of citizens and tourists expressed in social networks. *Evolutionary Intelligence*, 1–10.

Galí, N., & Donaire, J. A. (2015). Tourists taking photographs: The long tail in tourists' perceived image of Barcelona. *Current Issues in Tourism*, *18*(9), 893–902.

Ghahramani, M., Galle, N. J., Ratti, C., & Pilla, F. (2021). Tales of a city: Sentiment analysis of urban green space in Dublin. *Cities*, *119*, 103395.

Hutto, C., & Gilbert, E. (2014). Vader: A parsimonious rule-based model for sentiment analysis of social media text. *Proceedings of the International AAAI Conference on Web and Social Media*, *8*(1), 216–225.

Kovacs-Gyori, A., Ristea, A., Havas, C., Resch, B., & Cabrera-Barona, P. (2018). # London2012: Towards citizen-contributed urban planning through sentiment analysis of twitter data. *Urban Planning*, *3*(1), 75–99.

Kuznetsova, A., Rom, H., Alldrin, N., Uijlings, J., Krasin, I., Pont-Tuset, J., Kamali, S., Popov, S., Malloci, M., Kolesnikov, A., & others. (2020). The open images dataset v4. *International Journal of Computer Vision*, *128*(7), 1956–1981.

Martí, P., Serrano-Estrada, L., & Nolasco-Cirugeda, A. (2019). Social media data: Challenges, opportunities and limitations in urban studies. *Computers, Environment and Urban Systems*, *74*, 161–174.

Pedregosa, F., Varoquaux, G., Gramfort, A., Michel, V., Thirion, B., Grisel, O., Blondel, M., Prettenhofer, P., Weiss, R., Dubourg, V., & others. (2011). Scikit-learn: Machine learning in Python. *The Journal of Machine Learning Research*, *12*, 2825–2830.

Valdivia, A., Luzón, M. V., & Herrera, F. (2017). Sentiment analysis in tripadvisor. *IEEE Intelligent Systems*, *32*(4), 72–77.

The analysis of architectural discourse in the context of computational public opinion: Data mining of Google map reviews

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Abstract. New media platforms and mapping tools are created by digital communities, and their representations influence public opinion. Crowdsourcing platforms such as Twitter, Instagram, Google search engines and Maps have no such limitations or boundaries as in the physical space, these platforms are creating new virtual public places. To assess and forecast the accessibility and aesthetic issues of urban spaces in Istanbul, text and image data from Google Maps were employed. In this study, we searched at the reviews of certain public/semi-public places by using text mining and image analytics tools. Recently designed or renovated 11 public buildings and open places were chosen. The main findings of this exploratory study are that; 1) the level of being public can be understood from the crowdsourcing, 2) image analytics of crowdsourced visual data can assist to identify the aesthetic quality, and 3) the accessibility capacity of public spaces can be identified.

Keywords: Data Analytics, Public Spaces, Architectural Criticism, Collaborative Map, Accessibility-Aesthetic issues.

1 Introduction

Mapping of social media platforms have been creating the public opinion that forms the cybernetic world-picture and social formations. Also, the novel architectural and environmental discussions have expanded far beyond their original field of experts, as developed by the public we refer it here as the 'computational public'. Despite the fact that this notion has been used previously (Karami et al., 2018), we further define the term ‘computational public’ as a relatively new concept within the scope of this exploratory study. The purpose of this paper is to methodically demonstrate the possibility of identifying problems in public spaces in terms of aesthetics and accessibility, and to make

comparisons of these spaces based on the level of being public. According to the Attoe (1978), every response to the environment is a form of criticism. Architectural criticism can be considered through boundary of academic and professional lenses, but crowdsourcing platforms such as Twitter, Instagram, and Google search engines or maps have no such limitations or boundaries of the physical space. So, crowdsourcing could be useful from the point of incorporating all parts of society for understanding the discourses about the built environment. In architecture and urban planning in general, figuring out where all kind of boundaries (surfaces, walls, social contexts, level of accessibility etc.) between public and private spaces are, is a very important question. For Kimmel, (2018) this is especially true now that computational design technologies allow us shaping of the complex transformable surfaces to tend to blur the lines between virtual and physical spaces. On the other hand, computational design and digital technologies can also create new kinds of virtual public spaces as well as communities. So, these concepts are explained in the literature review briefly. In this exploratory study, we focus on architectural scale discourse and image sharing activities in Google Maps. The paper will investigate architectural scale in the urban context in terms of aesthetics and accessibility, and contribute to current methods for revealing built environment criticisms using the crowdsourced data. Text from Maps' reviews is used to evaluate and predict the aesthetics and accessibility of urban public places. We've focused on 11 publicly accessible urban landscapes with squares or open-air spaces surrounded by novel/contemporary architectural buildings/features in Istanbul. Those spaces with different scale and access were built between 2012 and 2021. We used architectural website Arkiv (Url-1) to select recently designed or renovated public buildings and open spaces that are separated into two sub-groups: one of the group is "semi-public / pseudo public", the other one is "public spaces".

2 Reviews on different types of public spaces and place semantics

Public space is a broad term in itself. Urban squares, public parks, passages, memorials, streets, markets, playgrounds, open green spaces, greenways, courtyard of mosques, waterfronts, are all included in this term (Mac Síthigh 2012). Public space's form and function have changed over time. It has always shaped urban fabric with its functions as a market place, gathering point, and media for cultural contacts and political discussions; and with its diverse forms as agoras, forums, piazzas, squares, streets, theaters, parks, libraries, coffeehouses (Carr et al. 1992; Madanipour 2003 as mentioned in Paköz, Sözer, and Doğan 2022). Technology and knowledge have transformed societies towards to digital societies, thus the meaning of public space needs rethinking (Crang, 2000). The computational public, in our definition, are

individual citizens forming the digital communities that create virtual spaces as well as create the public opinion using all types of expressions (e.g. likes, dislikes, emojis, texts, multimedia). The computational public expresses their opinion and could create a common voice. Pseudo-public spaces, on the other hand, is defined as any space owned and managed by for-profit enterprises (Langstraat and Van Melik, 2013 as cited in Paköz et al., 2022). Common examples for pseudo public spaces could be plazas and shopping centers. Also, virtual public spaces e.i. social media platforms, online forums or entertainment platforms are refered to the computational public where people could either discuss in groups or be the audience of public discussions (Li, 2010). The character of public space has shifted with the advent of the digital age, the role it once served has been transformed as they privatized, socializing has dwindled, and so on. A blurring of the boundaries between public and private areas has occurred (Paköz et al., 2022). Han et.al (2019) discuss the recognition of publicness as understood by everyday users of public space. They propose that Yang's (2013) notion of "spatial publicness" to overcome the deficiencies in the existing framework. For them, the concept of spatial publicness is crucial to understanding how public spaces are used and understood by end-users. For Sınmaz (2018), with the urban transformation (regeneration) agenda, semi-public spaces, which have been missing from the growth of Turkish cities, especially in the last 30 years, can be made again. In this sense, privately owned public places are not common in Istanbul's building regulation, thus we used the concepts of semi-public, semi-private or pseudo public spaces. Istanbul is high density (3049 person/km2) and a very-crowded city (15.5 million in 2020 based on the data in tuik.gov.tr), and this makes the city a good "candidate for open-source investigations of the place semantics using the geolocation tools. Place semantics research focuses on comprehending the meaning of places through human descriptions and human-place interactions (Hu, 2018). Large-scale surveys can reveal how people interact with built-environment open spaces. Such analysis reveals a city's architectural discourses and tastes. Unstructured natural language text like social media posts, blogs, and Wikipedia entries is also growing quickly. Textual data reveal people's understanding and views of their social and natural settings (Hu, 2018). Unstructured text data can be used to extract place semantics and understand people-place interactions. Thematic, geographical, and temporal frameworks can be used to study place semantics (Hu, 2018). Thus, geotagged social media data could be used for text mining to understand place semantics. Google Maps generates a self-centered/user-centered world map. Each person's particular map or "lens on the world" reduces "our shared world." (Ström, 2020). According to Ström (2017), relatively few works critically investigate the impact of a tool like Google Maps on the production of space and subjectivity. In recent years, proliferation of street view imagery (SVI) data (development of services like Google Street View), breakthroughs in machine learning and computer vision that enable automatic information extraction is well suited for assessing characteristics of the built environments (Biljecki & Ito,

2021). In the same vein, there are some studies that analyses users' Google Maps reviews to quantify the reviews about certain architectural or urban places (Borrego & Navarra, 2020; Munawir et. al, 2019).

3 Methodology

The research objective is to understand whether the level of public quality of the selected public places matches the online map data (photos and reviews). In addition, the objective of the research is the investigation of public (critical) discourses on the existing architectural built environment through the text mining technique of crowdsourcing. Exploratory data analyses are methods for summarizing or revealing features of interest within a dataset that would not be visible through traditional close reading (Saldaña, 2018). In this paper, sentiment analysis, word cloud and topic modeling analysis combined with image analytics are adapted to retrieved texts from the Google Maps reviews. First, data that is reviews and review images is collected on selected publicly accessible buildings. Natural Language Processing (NLP) techniques, such as sentiment analysis, help researchers explore textual data as mention earlier. Orange Data Mining that is a user-friendly tool, extracts topics from text and analyzes the meaning of the expressions. Text sentiment analysis, opinion mining, and topic detection and tracking are new social media-oriented text processing methods (Zong et al., 2021). The objective of sentiment analysis is to quantify the emotional intensity of a text's words and phares. Python based visual programming interface of Orange makes easily possible it to import text format to analyze them with the help of Text Mining add-ons. Image classification and clustering have also been done to compare the Google Maps image groups in general. Image classification is a procedure in computer vision that can categorize an image based on the visual content of the image (Sanghvi, 2020). The workflow in below adapted to figure out general variations about the topics (accessibility, aesthetic) among the levels of being public (semi-public or public) of the selected places (Figure 1).

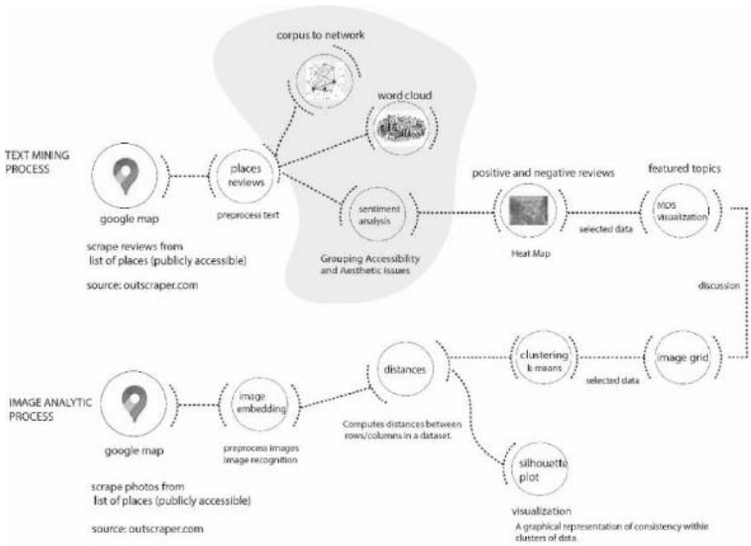

Figure 1. Workflow of text mining and image analytics, prepared by authors.

By this, one of the aims is to investigate the relations of the computational public with an architectural scale in different urban places on online platforms. The chosen places in Istanbul are shown in the map below (Figure 2).

Figure 2. The location of selected places on the Istanbul Google Maps view (the color oranges are semi-public/pseudo public, the color yellows are public spaces).

Due to the significant differences in the total number of reviews made for places, we retrieved the reviews made between the years 2021-2022 into analysis. For this, we selected a subset of most new 250 reviews of 11 places from two different urban categories in Istanbul (Table 1).

Table 1. The selected places for text mining and image analytics, retrieved from Google Maps.

no	Name of place	type	Review rate	Total images	Total reviews	Built date
1	Yapıkredi Bomonti ada	Semi-public	4,5	51	4403	2015
2	Beykoz Kundura Factory	Semi-public	4,4	13	798	2018
3	Galataport	Semi-public/pseudo public	4,6	20	6711	2022
4	Meydan Mall	Pseudo public	4,4	26	12566	2010
5	Atatürk Cultural Center	Pseudo public	4,6	25	951	2021
6	Şişhane park	Public	4,2	18	226	2013
7	Pendik National garden	Public	3,9	22	86	2021
8	Museum Gazhane	Public	4,7	23	3633	2021
9	Küçükçekmece Square	Public	4,0	19	3230	2012
10	Theodosius Cistern	Public	4,6	19	5255	2018
11	Mecidiyeköy Square	Public	4,4	16	257	2021

As seen in the table, there are two different predetermined group; public places consist of Pendik National Park, Küçükçekmece Square, Şişhane park, Museum of Gazhane, Mecidiyeköy Sqaure; semi-public/pseudo public places consist of Galataport, Beykoz Kundura, Meydan Mall, Theodosius Cistern, Ataturk Cultural Center, Bomontiada. When Google map reviews were examined closely, the new design regulations and newly acquired public spaces in the City were praised. The VADER scale was used for quantitative analysis in Sentiment Analysis. With this scale (Hutto &Gilbert, 2014), it was easy to identify the most negatively reviewed subjects. This scale considers neutral all statements except clear ones. Thus, implied or ironic negative statements require a closer look. Using Orange, general keywords were first revealed by Word Cloud analysis then semantic analysis was used to examine the topics. Image analysis used image embedding and silhouette analysis to group similar images. Photos of public spaces are also analyzed to determine where they were taken most often. We can categorize them as follows: indoor (café, restaurant), courtyard/garden/landscape, facades of buildings, view, activity, and action (drink/dinner). The first stage of the exploratory study can reveal some general differences between public and semi-public places, but

general inferences cannot be made. As public space activities and actions diversify, photo sharing increases. In this regard, the fact that Bomontiada is an attraction hub and a building island with relatively more opulent locations also influences the motivation to share photos from that region. As the quality of the spaces improves, so does the citizens' motivation to share. In below, Image grid of two distinct groups together are shown (Figure 3). Public group consist of 5 places, while semi-public group consist of 6 places. Even though they are not equally divided, this is not a mandatory metric for our explanatory research.

3.1 Image Analytics and Text mining

The photographs with similar elements are placed together as shown in Figure 3. When we look at the image grid of semi-public places more closely, we see that it divides the images into four categories: the exterior, the interior, the street view of historical sites, and the place images obtained during the night activity. In the public place image grid, wide-angle and completely open-air images, such as green-sea view and sunset-city silhouette, are grouped together. In general, photographs were shared from aesthetically meaningful points that make the spaces unique. This shows that there is an opportunity to use citizen data as a parameter in the analysis of urban aesthetics for further research.

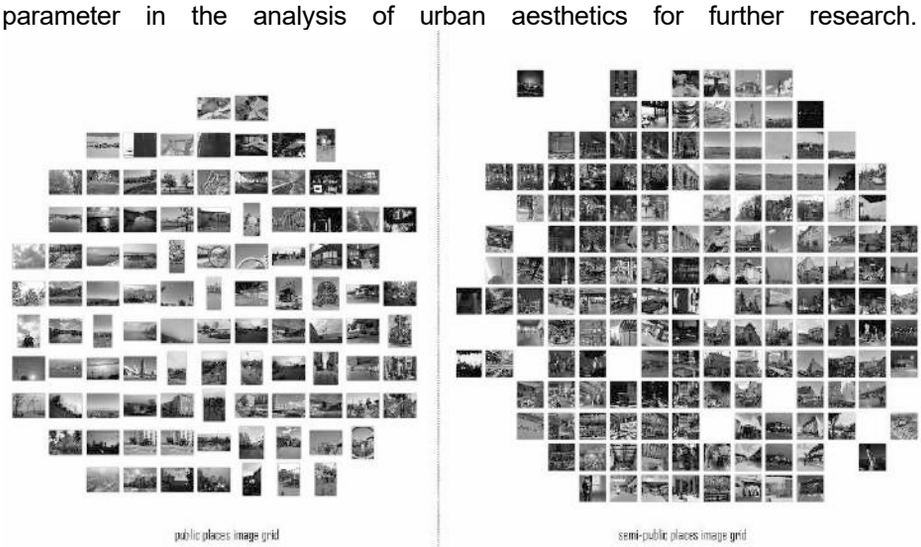

Figure 3. Showing that similar features of images (such as sunset or sea views, indoor and activity) by grouping with image embedding, applied by authors.

Image embedding could be used to identify similar images which is hard to interpret by humans. After embedding images, we can arrange them on the grid in the Image Grid widget so that resembling images are close to one another (Godec, 2022). In a visual representation of this data, you can see how many clusters there are by plotting points' proximity to other points in neighboring

clusters. Then, we adapt as a first one NLP tool: word cloud, and Corpus network analysis and then sentiment analysis. Corpus network (Sulis et al., 2020) and word frequency is to quantify the most frequent words of texts and to understand general review topics about places. Word Cloud shows tokens from the corpus, with the size of the token indicating how often the word appears in the corpus or an average bag of words count when the bag of words features are at the widget's input. In the widget, words are listed by how often they are used (weight). The widget makes documents with tokens from the word cloud that has been chosen (Url-2). For every place reviews, the process was repeated. Sample results of process is shown in Figure 4.

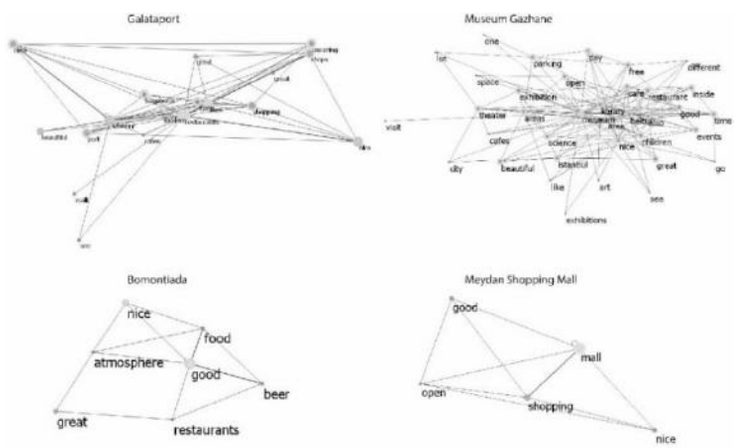

Figure 4. Sample results of corpus to network, applied by authors.

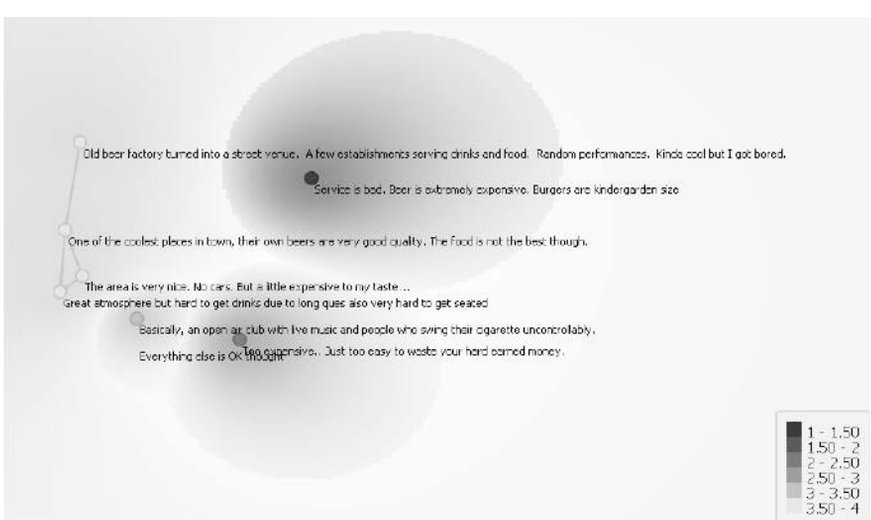

Figure 5. Sample results of negative sentiment analysis Vader module with review rates for Bomontiada, applied by authors.

Sentiment Analysis forecasts the sentiment of every document inside a corpus. It uses NLTK's (Natural Language Processing Toolkit) Liu & Hu and Vader sentiment modules, Data Science Lab's multilingual sentiment lexicons, Arthur Jacobs' SentiArt, and Walter Daelemans' LiLaH sentiment (2020) (Url 3). VADER sentiment modules were used. Some sentiment analysis tools consider punctuation and emoticons. Sentiment analysis tools process text (a sentence, a paragraph, a book, etc.) and produce quantitative scores or classifications indicating whether the algorithm believes the content conveys positive or negative feeling. Some tools measure a text's positivity or negativity (Saldana, 2018). Sample semantic analysis with Vader modules demonstrates problematic concerns and positive qualities of places (Figure 5). Figure 5 shows negative-positive Multidimensional scaling reviews.

4 Results

The research method allows us to address differences-similarities and issues-problems in aesthetics and accessibility in culturally and publicly diverse urban areas. Text mining and image analytics helped us see prominent issues in reviews. We focused on 2021-2022 reviews for this exploratory research. Expanding the sample size will improve future study results. The first corpus-to-network workflow was customized for 11 public and semi-public locations. In table 2, we group the most common review text topics into aesthetic concerns, accessibility issues, and place quality/description. Public and semi-public area review ratings determined the order. Table 2 shows that semi-public places frequently discuss aesthetic terms and topics. Accessibility issues discussed in public places more. The analysis revealed accessibility problems. For instance, reviews of Pendik National Park note the closed entrance and ramps. Ataturk Cultural Center's parking problem is very visible. “View” is also considered an accessibility issue because public spaces need to be visible from all sides. As seen in the table, view issues have been positively discussed in public. The issue of view also seems also important for Galataport, but it has been discussing as negatively because of the cruise at the port blocking the Bosphorus view. Therefore, it was necessary to control with semantic analysis data for each topic and keyword.

Table 2. Data visualization of word cloud and corpus network analysis, prepared by authors.

5 Conclusion

The contribution of the paper will be providing insights of investigating the discourse about architectural scale in the urban context in terms of aesthetics and accessibility and will contribute to current methods for revealing criticisms about the built environment using crowd source data. This study shows that the aesthetic and functional issues change by the level of publicness of urban spaces in the result of crowdsource reviews data mining, this phenomenon is detected on Google Maps Reviews data. In this sense, urban place crowdsource (or crowdsourcing urban data) research might improve by integrating urban areas with varying levels of public space that would be chosen after literature review. With the increase in the number of urban places to be included in the study, the aesthetic and functional issues change related to the level of publicness would be seen. This study demonstrates that online map reviews and location-based photographs could be used to determine the level of public of urban spaces, particularly pseudo public spaces from the perspective of end-user experience of public spaces. As volumes of data are available, online reviews provide valuable information for assessing public places. Also, different social network platforms could include to the analysis process. People (citizen) who experience the selected places and share their experiences in various seasons and various time intervals can provide information on accessibility and quality problems, as well as the aesthetic dimension of their spatial experience and the reasons why certain places have higher aesthetic values than others in terms of place semantics.

References

Attoe, Wayne, Architecture and Critical Imagination, Wiley and Sons, Chichester, 1978.

Borrego, Á. and Comalat Navarra, M. (2021), "What users say about public libraries: an analysis of Google Maps reviews", Online Information Review, Vol. 45 No. 1, pp. 84-98.

Biljecki, F., & Ito, K. (2021). Street view imagery in urban analytics and GIS: A review. Landscape and Urban Planning, 215(November 2020), 104217. https://doi.org/10.1016/j.landurbplan.2021.104217.

Carr, S., M. Francis, L. Rivlin, and A. Stone. 1992. Public Space. Cambridge: Cambridge University Press.

Daelemans, Walter; et al., 2020, The LiLaH Emotion Lexicon of Croatian, Dutch and Slovene, Slovenian language resource repository CLARIN.SI, ISSN 2820-4042, http://hdl.handle.net/11356/1318.

Han S, Kim JW and Kwon Y. (2019), Contemporary Spatial Publicness: Its New Characteristics and Democratic Possibilities. *Sustainability*., 11(17):4729. https://doi.org/10.3390/su11174729

Hu, Y. (2018). Geospatial Semantics. Comprehensive Geographic Information Systems, 2017, 80–94. https://doi.org/10.1016/b978-0-12-409548-9.09597-x.

Hutto, C.J. & Gilbert, E.E. (2014). VADER: A Parsimonious Rule-based Model for Sentiment Analysis of Social Media Text. Eighth International Conference on Weblogs and Social Media (ICWSM-14). Ann Arbor, MI, June 2014.

Godec, P. (2022, 4 May), Image Analytics for Everyone: Image Embeddings with Orange, retrieved from https://towardsdatascience.com/image-analytics-for-everyone-image-embeddings-with-orange-7f0b91fa2ca2.

Karami, A., Bennett, L. S., & He, X. (2018). Mining Public Opinion about Economic Issues. International Journal of Strategic Decision Sciences, 9(1), 18–28. https://doi.org/10.4018/ijsds.2018010102

Kimmel, L. (2018). Possibility of critical practice in computational design: applications on boundaries between public and private space. Cahiers de La Recherche Architecturale, Urbaine et Paysagère, 1. https://doi.org/10.4000/craup.361.

Langstraat, F., and R. Van Melik. 2013. Challenging the 'End of Pub-lic Space': A Comparative Analysis of Publicness in British and Dutch Urban Spaces. Journal of Urban Design 18 (3): 429–448.

Li, S. 2010. The Online Public Space and Popular Ethos in China. Media, Culture & Society 32 (1): 63–83.

Mac Síthigh, D. (2012). Virtual walls? The law of pseudo-public spaces. International Journal of Law in Context, 8(3), 394–412. https://doi.org/10.1017/S1744552312000262.

Madanipour, A. 2003. Public and Private Spaces of the City. London: Routledge.

Meneghetti, F. R. P. M. V. and F. K. (2020). Is it Crowdsourcing or Crowdsensing? An Analysis of Human (Vol. 26, Issue 2).

Munawir, Koerniawan MD and Dewancker BJ. (2019), Visitor Perceptions and Effectiveness of Place Branding Strategies in Thematic Parks in Bandung City Using Text Mining Based on Google Maps User Reviews. *Sustainability*.; 11(7):2123. https://doi.org/10.3390/su11072123

Paköz, M. Z., Sözer, C., & Doğan, A. (2022). Changing perceptions and usage of public and pseudo-public spaces in the post-pandemic city: the case of Istanbul. Urban Design International, 27(1), 64–79. https://doi.org/10.1057/s41289-020-00147-1.

Saldaña, Zoë Wilkinson (2018), "Sentiment Analysis for Exploratory Data Analysis," Programming Historian 7, https://doi.org/10.46430/phen0079.

Sanghvi, Kavish (2020, 8 May), Image Classification Techniques [Medium post], retrieved from https://medium.com/analytics-vidhya/image-classification-techniques-83fd87011cac.Sınmaz, S, (2018), Türkiye'de Kentsel Planlama ve Dönüşüm Sürecinde Eksik bir halka: Yarı Kamusal Mekanlar, Temmuz-ağustos, M. M. O. (n.d.). The Branch Mimarlık ve Tasarım Müzesi.

Ström, T.E. (2017), Mapping Google Maps: Critiquing an Ideological Vision of the World, Doctore of Philosophy, Western Sdyney University.

Ström, T.E. (2020), Journey to the center of the world: Google Maps and the abstraction of cybernetic capitalism, Cultural Geographies 1-19.

Sulis, E., Humphreys, L., Vernero, F., Amantea, I. A., Di Caro, L., Audrito, D., & Montaldo, S. (2020). Exploring network analysis in a corpus-based approach to legal texts: A case study. CEUR Workshop Proceedings, 2690, 27–38.

Yang, S. (2013), Investigation into Shanghai Spatial Publicness. Ph.D. Thesis, Technische Universität München, München, Germany.

Zong, C., Xia, R., & Zhang, J. (2021). Text Classification. In Text Data Mining. https://doi.org/10.1007/978-981-16-0100-2_5.

Url-1 < https://www.arkiv.com.tr/ >, accessed at May, 2022.

Url-2<https://orange3-text.readthedocs.io/en/latest/widgets/wordcloud.html>, accessed at June 2022.

Url-3<https://orange3-text.readthedocs.io/en/latest/widgets/sentimentanalysis.html>, accessed at June 2022.

Programming Cultures: Generative Design

3D Generative Design for Non-Experts: Multiview Perceptual Similarity with Agent-Based Reinforcement Learning

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Abstract. Advances in additive manufacturing allow architectural elements to be fabricated with increasingly complex geometrical designs, however, corresponding 3D design software requires substantial knowledge and skill to operate, limiting adoption by non-experts or people with disabilities. Established non-expert approaches typically constrain geometry, topology, or character to a pre-established configuration, rather than aligning to figural and aesthetic characteristics defined by a user. A methodology is proposed that enables a user to develop multi-manifold designs from sketches or images in several 3d camera projections. An agent-based design approach responds to computer vision analysis (CVA) and Deep Reinforcement Learning (RL) to design outcomes with perceptual similarity to user input images evaluated by Structural Similarity Indexing (SSIM). Several CVA and RL ratios were explored in training models and tested on untrained images to evaluate their effectiveness. Results demonstrate a combination of CVA and RL motion behavior can produce meshes with perceptual similarity to image content.

Keywords: Generative Design, Machine Learning, Agent-Based Systems, Non-Expert Design, Deep Reinforcement Learning

1 Introduction

Recent advances in additive manufacturing (AM) allow architectural elements to be fabricated with increasingly complex geometrical designs and enhanced material and structural efficiencies. 3D modelling software has kept pace, providing approaches to the design of complex, multi-manifold surfaces. While AM supports user-customized design through one-off manufacturing on-demand, design software requires substantial knowledge in 3D modelling or software programming that is challenging for non-experts or people with disabilities to operate.

Researchers at MIT's Architecture Machine Group historically explored ways for non-expert participation in design by incorporating Machine Learning

(ML) in 3D software (Negroponte, 1972). More recently, Google Creative Lab™'s Autodraw™ cognifies an inexperienced artist's scribbles to suggest related content, allowing high-quality drawings to be developed in partnership with software (Motzenbecker & Phillips, 2017). Architectural research has incorporated ML in approaches to design (Bolojan & Vermisso, 2020), addressing performative aspects of user-created designs (Akizuki et al., 2020; Yousif & Bolojan, 2021), and assisting with assembly configurations of predefined design elements (Hosmer et al., 2020). 3D ML approaches have also been developed that leverage 3D Generative Adversarial Networks (3D-GAN) (Wu et al., 2016), StyleTransfer and GANs that map 2D image pixel content to a fixed 3D mesh topology's color and displacement maps, or interpolate several output images into a 3D voxel array (del Campo et al., 2021; Rehm, 2019).

Established design methods, however, do not allow a non-expert user to intuitively specify a 3D intention from multiple sourced, sketched or diagrammed 2D image-based viewpoints to generate a multi-manifold topology 3D model. Existing methods primarily operate on 2D raster images, 3D voxel fields or employ predefined 2D or 3D component parts. Such approaches to architectural design do not attempt to embody an aesthetic character from a user's sketched input by evaluating the perceptual equivalence of 3D design outcomes relative to user-specified 2D image content to inform ML model training.

While extensive research into computer vision (Ham et al., 2019) and ML-based approaches to 3D reconstruction (Soltani et al., 2017) from several sourced images exist within the field of computer science, these focus on image or voxel-based outcomes that are not integrated with other design methods or building performance considerations that would support the production of a polyvalent architectural design outcome. A flexible, non-indexical algorithmic design methodology for multi-manifold topologies is required that can incorporate other design-engineering workflows to safeguard the manufacturing and end-use viability of a non-expert user's design. Agent-based design methods are systemically open to the incorporation of several performance criteria, and have been developed to address AM-specific structural and geometric performance criteria (Stuart-Smith et al., 2020), alongside a narrow set of aesthetic criteria obtained by computer-vision-based visual character analysis methods (Stuart-Smith & Danahy, 2022).

The ability of agent-based systems to weight several often-conflicting design criteria within a computed solution makes the approach well-suited to applications involving machine learning (ML). Agent-based models also enable designs with geometric continuity in three dimensions through vector-based image translation without indexical constraints, yet to date, only agent motion constrained to voxel-space orthogonal coordinates and evaluation methods has been demonstrated for architectural design ML applications (Akizuki et al., 2020). Such methods overly constrain a design's visual character and do not incorporate methods that support agent adaptation to

image data which would facilitate such ML methods obtaining outcomes related to a user's specific inputs.

A novel 3D algorithmic design methodology for multi-manifold geometries is presented that employs reinforcement learning (RL) to train agent motion behavior to translate user-specified image inputs from multiple viewpoints into a 3D design solution generated by agent-based motion (Figure 1). The approach attempts to partially embody visual design character from the user's input images by adapting to image data obtained by computer vision analysis methods, and partly through an ML training approach that seeks to improve the perceptual similarity of design outcomes relative to user input images by Structural Similarity Indexing (SSIM) (OpenCV, 2021). The research does not address AM or specific architectural design or performance parameters as the approach is able to be integrated with prior research addressing these concerns (Stuart-Smith et al., 2020; Stuart-Smith & Danahy, 2022).

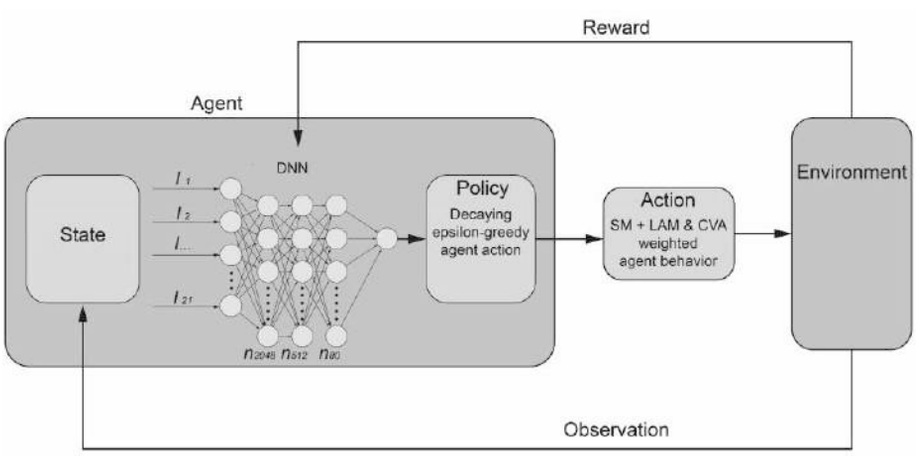

Figure 1. Generative design methodology incorporating two agent-based motion methods, reinforcement learning and computer vision analysis. Source: Stuart-Smith & Danahy, 2022.

2 Methodology

A custom design methodology was developed that involved the creation of a user-orientated 3D setup environment that incorporates user-specified images, and two agent-based motion methods, one capable of adapting to image data using computer vision analysis, and the second, combined with a reinforcement learning (RL) method to train agent behavior to produce results that correspond to the input images. The weighting of computer vision-based adaptation relative to RL-trained behaviour was explored through a comparative analysis of several training runs, with the most successful

model's results evaluated. The methodology involves the following components:

2.1 3D Environment Setup

A 3D environment was defined in Rhino3D (Figure 2a) with a specified 3D closed-volume brep geometry defining its extent. For the purposes of this initial study, a rectangular prism of 5 units length, 5 units width and 10 units height, is used as the environment although the environment could also be of an irregularly shaped geometry. Three perspective views are defined, each in separate viewports (the setup can be extended to any number of perspectival or parallel views). An image plane is defined in Grasshopper at the near and far frustum planes of each view with a proportion and location that corresponds to the environment bounding box. For the purposes of this study of column-like geometries, images are 3330 x 1574 pixels in resolution and can be positioned to be greater or smaller in coverage relative to the environment's bounding dimensions. In Grasshopper, a user is able to select these three input images from their computer. The input images could be photographs of hand-sketches, tablet sketched or drawn in Illustrator or CAD, or sourced reference images.

2.2 Agent-Based Design Method

A custom-developed agent-based simulation builds on prior research into performance-based multi-manifold architectural design (Stuart-Smith et al. 2020), tasking an autonomous particle to make event-based decisions to descend through the 3D environment to define a motion trajectory over a simulated sequence of time-frames which is translated into a 3D Nurbs curve and isosurfaced to create a volumetric mesh. Agent motion is calculated in a series of time-steps where an agent's velocity is added to its current position to define its next position. Two methods were developed to determine an agent's velocity vector over simulated time.

Method 1, Sequential Motion (SM) method: moves an agent incrementally by selecting one of 9 possible vector moves each time frame in simulated time. These moves are derived from a set of four vectors equally distributed around the velocity axis along a conical surface, with two different conical surface angles allowing for sharp and shallow turning at 15 and 40 degrees away from the velocity vector, in addition to a ninth vector pointing straight ahead. These vectors are calculated relative to the agent's current velocity vector each timeframe (Figure 2b, 2c). Agents determine which of the nine moves to implement as part of an RL action (see 2.4).

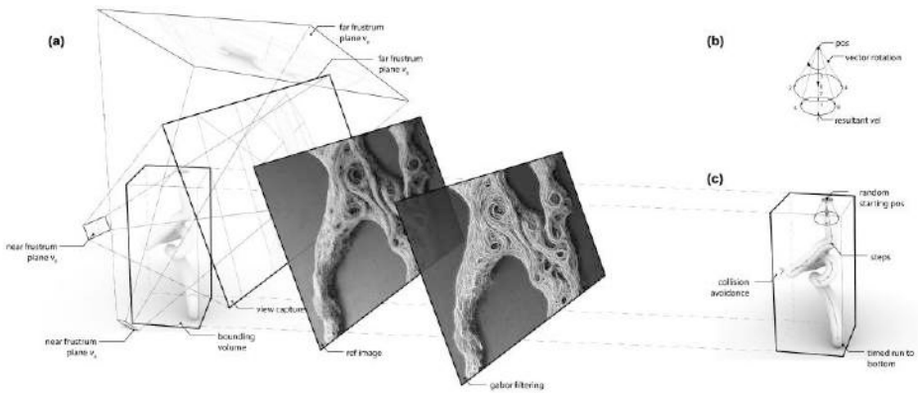

Figure 2. User-sketched 3D geometry generation using Deep Reinforcement Learning (RL), (a) 3D environment, user-input sketches/images and correlated camera view projections, (b) Agent SM: 9 x vector motion options for each timeframe relative to current velocity, (c) Agent SM sequence during RL training. Source: Stuart-Smith & Danahy, 2022.

Method 2, Locally Adaptive Motion (LAM) method: sums several vectors of influence including seeking, avoiding and aligning to several locally perceived environmental data sources. This method is used to adapt agent motion to user-specified image content (see 2.3). Inspired by Craig Reynolds steering behaviors, each vector influence is calculated as a steering vector relative to the current velocity vector, as a turning force (Reynolds, 1999). Each steering behavior is calculated as the average of all influences within a specified radius and field of view from the agent. Behaviors are weighted relative to one another to provide a combined overall agent motion behavior (Figure 3b).

2.3 Computer Vision Adaptation (CVA)

Computer vision methods are used to analyze input images and extract features such as the image silhouette and directional grain, and to remap these within a 3D field, which agents can locally perceive and respond to. Each of the three input images is processed using the computer vision methods ‘Canny Contouring’ and ‘Probabilistic Hough Line Transform’ (OpenCV, 2021). The Canny Contouring edge detection method is utilized to first identify continuous edges in the geometry due to its ability to produce an image that depicts continuous edges in white on a black background through a multistep process that leverages spatial-frequency filtering and hysteresis thresholding (Davies, 2017, p. 136). Using the Canny Edge image output as an input, OpenCV's Probabilistic Hough Lines Transform method is utilized to create a series of line segments that approximate continuous edges within each reference image (OpenCV, 2021).

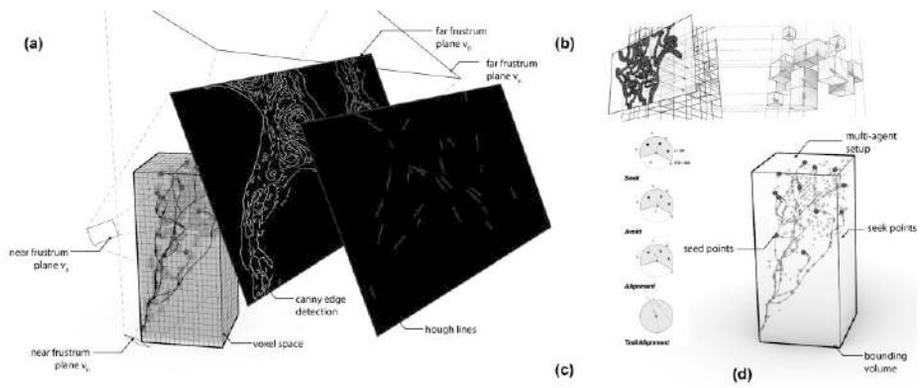

Figure 3. Agent-based Computer Vision Adaptation (CVA) motion. (a) edges from Canny Contour image data and lines from Hough Line Transform are projected into a voxel environment, (b) Canny data is summed as an integer value per voxel, with Hough Lines translated to a single summed vector at the center of each voxel, (c) LAM agent steering behaviors, (d) agent LAM response to CVA data. Source: Stuart-Smith & Danahy, 2022.

Each analysis yields a 2D output image (Figure 3). Hough lines create a series of short lines along features in the image that can be calculated as vectors. Canny contouring illustrates key features in white pixels whose pixel grid indexes can be identified. White pixels are assigned a value of ‘1’ with all other colors assigned ‘0’. The Canny contouring analysis is remapped to a 3D voxel space within the 3D environment comprised of voxels at a resolution equivalent to 100 x 100 pixels. The custom voxel class in Python operates similar to a Bin Lattice, and contains variables to store data from each of the methods. The voxel field used in this initial research comprised of 80x80x180 voxels. Each voxel sums values obtained from corresponding image pixels projected through the 3D voxel space. 2D Data from each image is remapped as projections through the voxel field using the near and far frustum planes to create a virtual trapezoidal volume. Voxels inside this volume are assigned a value of ‘1’. Where there is corresponding data from multiple image projections, this information is summed. For example, one voxel relates to 4 pixels from one image and 4 from a second image. The variable for Canny Contours, therefore, has a value ranging from 0 to 8. If a third view also overlapped in this area the value range would be 0 to 12. The Hough Line Transform outcomes are projected by the same method, but stored as vectors in the center of each voxel. Lines from multiple viewports are summed as one vector result per voxel (Figure 3).

This data-rich 3D environment locally influences LAM behavior of agents as they descend through the environment ensuring they adapt to data content from the user-provided images, seeking high values from Canny Contouring and Gabor Filter analysis, and aligning to vectors obtained from Hough Line analysis. The complexity of LAM behaviour however is immense, and the

agent-based rule set creates a level of abstraction that might at times prevent the agents from fully matching outcomes to image content. As such, an RL method was developed to fine-tune agent behavior in relation to image content.

2.4 Reinforcement Learning (RL)

To provide better design adaptation to user-specified images, a method was developed to support SM agent behavior derived from deep reinforcement learning (RL). An RL method was developed within Rhino3D by connecting to the Windows Powershell via a socket connection. SM agent behavior is adjusted using Keras™'s RL API for TensorFlow 2 (Chollet & others, 2015). A Functional Model comprised of several ReLU dense layers trains non-image-based agent vector steering over 2000 iterations. The RL training model utilises a reward function that is evaluated at every motion step within an SM agent simulation. An agent that attempts to leave the 3D environment is penalized with a negative value of -10, while agents descending all the way to the bottom are rewarded with a value of 20. To encourage multi-manifold topological design solutions the genus of each agent-generated mesh is determined and also provided as a positive integer reward value.

To evaluate the similarity of the results to the image inputs, screen capture is performed from the same viewport as each corresponding image input plane and compared to the input image using OpenCV's Structural Similarity Indexing (SSIM) method which samples different parts of each image, comparing their luminance, contrast and structure to provide an averaged metric of their perceptual similarity (Wang et al., 2004). This evaluation is performed every second time frame. A high SSIM equates to a high reward.

To reward proximity to key features in reference images, Gabor Filtering is performed to highlight local features and edges by evaluating the frequency and orientation of image content (Anuj shah, 2018). Agent proximity to the reference images' Gabor Filter features is rewarded by performing a Gabor Filtering of each reference image and averaging their results. In greyscale Gabor images, features are highlighted by white pixels. The reward function samples the closest pixel projection to the agent and its eight adjacent neighboring pixels, assigning each pixel a value between zero and one (0 = black, 1 = white), summing these values. This is repeated using each input reference image and averaged to provide an overall reward value for image feature content. Following training over 2000 iterations, the trained model can be provided with different input images of similar content. The combined, weighted RL reward function can be described as:

$$f(x) = \frac{(w_1 * \mathrm{g}) + (W_2 * \mathrm{s})}{2} + n + t - B + A$$

Where, $g = \left\lceil \frac{v-e+f-2}{-2} \right\rceil$

with the following variables:
f = number of mesh faces
e = number of mesh edges
v = number of mesh vertices
g = topological genus
n = neighborhood pixel average from Canny contour analysis remapped to 0-1 summed across mesh vertexes in range (V0+V1+Vn.../n)
t = time alive count (reward for surviving for a long time)
s = average SSIM between each view and its user-input reference image
A = reward for arriving at the bottom of the bounding box environment
B = punishment for hitting boundary, ends episode

W_1, W_2, B and A are all constants that can be waited by a user undertaking RL training.

2.5 Behavioral Weighting Evaluation

CVA (see 2.3) ensured LAM agent behavior directly responded to locally perceived input image data yet had no ability to evaluate overall image perception similarity. Conversely, SM agent behavior used in the RL method (see 2.4) trained an agent model to achieve high SSIM values yet had no direct relation to easily obtained local image content. Although combining these approaches was likely to produce more successful (3D designs with more similarity to the input images), the exact ratio these methods should be weighted relative to one another had to be evaluated. To determine this, a series of separate RL training runs were performed which weighted the ratio of CVA relative to the RL method at 25% increments. 2000 iterations of training were performed on separate models with ratios of; 0%/100%, 25%/75%, 50%/50%, 75%/25%, 100%/0%. In each model, incremental motion is performed by weighting and summing a vector calculated by LAM based CVA and a vector calculated using the SM RL method. These are summed and averaged to provide a single motion vector to govern incremental agent motion with a reward evaluated and fed back into the RL training session. Each model was trained on the same input images. The model with the most successful loss and reward metrics was selected for evaluation.

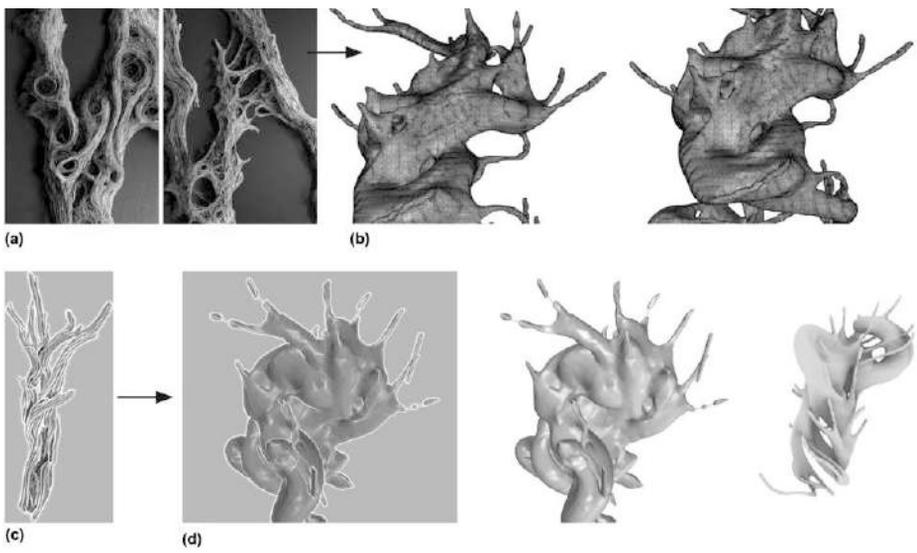

Figure 4. Outcomes from the selected trained model with ratio of LAM CVA agent behavior to SM agent motion of 1:3. Two different sets of image inputs are shown (a & c), and corresponding mesh results (b & d). Source: Stuart-Smith & Danahy, 2022.

3 Results

The training model with a LAM CVA to SM agent behavior ratio of 1:3 exhibited the best loss and reward metrics. 3D results from this model exhibit an abstract approximation of input images, demonstrating multi-manifold design outcomes that embodied some degree of visual characteristics of user-specified input images (Figure 4). Although outcomes only partially related to their respective input images, data from the training model (Figure 5) suggests that the correlation is sufficient to demonstrate the merits of the method. Loss trends downwards indicating model training is optimizing correctly. Reward values also trend upwards, although more training iterations would yield a clearer logarithmic curve for the loss function and a continuous trend upwards in the reward function. This data demonstrates that design outcomes were able to improve SSIM perceptual similarity metrics throughout training.

4 Discussion & Conclusion

The presented method aims to allow a designer or non-expert user to sketch a 3D design from multiple camera view 2D projection planes to generate a 3D multi-manifold mesh design that takes into consideration the perceptual similarity of the design outcome relative to the input images, while

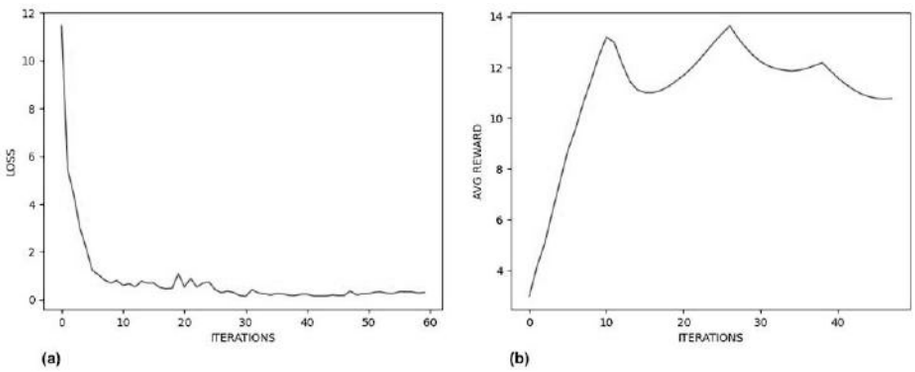

Figure 5. Data from most successful RL model: (a) loss function, (b) reward values.

also aligning to features in the input images. The agent-based approach leveraged CVA to adapt to input image content and RL to train agent motion to improve perceptual similarity and thus benefited from both local behavioral adaptation in addition to goal-orientated deep RL. While the agent RL training was sequential, future work will explore training being distributed and operating within a multi-agent system. The methodology was developed to be compatible with the authors' prior research, allowing future research to incorporate building performance criteria such as structural, geometric, and visual character optimization methods (blind), ensuring the approach can be developed for architectural design applications in future research.

The research demonstrates an intuitive approach to complex geometric design that offers great potential for applications such as user-customized design or rapid response designs for manufacturing on-demand. Questions remain around user engagement with model training. Ideally, a user is able to train a model that aligns with their specific input image types. This would require more explorations into a user-friendly GUI and hardware. Although this proof of concept was undertaken in Rhino3D, the approach could be ported to operate on physical devices such as smartphones, tablets and augmented reality (AR)/virtual reality (VR) headsets to enable greater accessibility and interface enhancements.

It is hoped the research spurs more activity in non-expert design customization, providing end-users greater accessibility to design both alone and in dialogue with professional designers, illustrating a means by which they can co-design the built environment via more user-friendly, adaptive AI-based design software. Recent and emerging metaverse and AR software and hardware applications suggests the research offers a glimpse into greater user-engagement within the design world of tomorrow.

References

Akizuki, Y., Bernhard, M., Kakooee, R., Kladeftira, M., & Dillenburger, B. (2020). Generative modelling with design constraints: Reinforcement learning for object generation. RE: Anthropocene, Design in the Age of Humans - Proceedings of the 25th International Conference on Computer-Aided Architectural Design Research in Asia, CAADRIA 2020, 1.

Anuj shah. (2018, June 17). Through The Eyes of Gabor Filter. Medium. https://medium.com/@anuj_shah/through-the-eyes-of-gabor-filter-17d1fdb3ac97

Bolojan, D., & Vermisso, E. (2020). Deep Learning as heuristic approach for architectural concept generation Creativity and Artificial Intelligence. Proc. ICCC 2019.

Chollet, F., & others. (2015). Keras. https://keras.io

Davies, E. R. (2017). Computer Vision: Principles, Algorithms, Applications, Learning. Elsevier Science.

del Campo, M., Carlson, A., & Manninger, S. (2021). Towards Hallucinating Machines - Designing with Computational Vision. International Journal of Architectural Computing, 19(1). https://doi.org/10.1177/1478077120963366

Ham, H., Wesley, J., & Hendra. (2019). Computer vision based 3D reconstruction : A review. International Journal of Electrical and Computer Engineering, 9(4). https://doi.org/10.11591/ijece.v9i4.pp2394-2402

Motzenbecker, D., & Phillips, K. (2017, May 6). AutoDraw by Google Creative Lab - Experiments with Google. Google Creative Lab. https://experiments.withgoogle.com/autodraw

Negroponte, N. (1972). The Architecture Machine: Toward a More Human Environment. M.I.T. Press.

OpenCV. (2021). About - OpenCV. Open CV Team. https://opencv.org/about/

Rehm, M. C. (2019). Complicit: The creation of and collaboration with intelligent machines. Architectural Design, 89(2). https://doi.org/10.1002/ad.2417

Reynolds, C. W. (1999). Steering behaviors for autonomous characters. Game Developers Conference, 763–782.https://doi.org/10.1016/S0140-6736(07)61755-3

Soltani, A. A., Huang, H., Wu, J., Kulkarni, T. D., & Tenenbaum, J. B. (2017). Synthesizing 3D shapes via modeling multi-view depth maps and silhouettes with deep generative networks. Proceedings - 30th IEEE Conference on Computer Vision and Pattern Recognition, CVPR 2017, 2017-January. https://doi.org/10.1109/CVPR.2017.269

Stuart-Smith, R., & Danahy, P. (2022). Visual Character Analysis Within Algorithmic Design, Quantifying Aesthetics Relative To Structural And Geometric Design Criteria. In J. van Ameijde, N. Gardner, K. H. Hyun, D. Luo, & U. Sheth (Eds.), CAADRIA 2022, POST-CARBON - Proceedings of the 27th CAADRIA Conference - vol. 1, Sydney, 9-15 April 2022 (pp. 131–140).

Stuart-Smith, R., Danahy, P., & Rotta, N. R. la. (2020). Topological and material formation. Proceedings of the 40th Annual Conference of the Association for Computer Aided Design in Architecture: Distributed Proximities, ACADIA 2020, 1.

Wang, Z., Bovik, A. C., Sheikh, H. R., & Simoncelli, E. P. (2004). Image quality assessment: From error visibility to structural similarity. IEEE Transactions on Image Processing, 13(4). https://doi.org/10.1109/TIP.2003.819861

Wu, J., Zhang, C., Xue, T., Freeman, W. T., & Tenenbaum, J. B. (2016). Learning a probabilistic latent space of object shapes via 3D generative-adversarial modeling. Advances in Neural Information Processing Systems.

Yousif, S., & Bolojan, D. (2021). Deep-performance: Incorporating deep learning for automating building performance simulation in generative systems. Projections - Proceedings of the 26th International Conference of the Association for Computer-Aided Architectural Design Research in Asia, CAADRIA 2021, 1.

Carioca modern facades: expanding passive shading systems through computational methods

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Abstract. In the 1940s, modern Rio de Janeiro architects developed passive systems to improve buildings performance, without resorting to air conditioning systems. This research studies the performance of a set of eight buildings, from the Carioca School, investigating in a prospective sense how to improve their performance through computational methods. The authors modelled the eight buildings and analysed as a case study the Nova Cintra building performance, regarding insolation and illuminance, using the environmental software Ladybug and Honeybee. Based on the simulation data, they used combinatorial modeling to change the position of each of the three shading type's modules of the north facade of Nova Cintra, to improve their overall performance. Results confirm that is possible to continue to improve the buildings performance, as already accomplished by the modern buildings, using computational methods to improve, reducing also energy consumption through natural systems and diminishing the need for artificial air conditioning systems.

Keywords: Generative design, Shading performance, Insolation and illuminance analysis, Combinatorial modeling, Carioca modern facades

1 Introdução

1.1 A fachada moderna, o contributo carioca e brasileiro

Embora os primeiros ímpetos modernos tenham chegado por importação, bem logo o Brasil achou um caminho próprio. A sua grande contribuição para a arquitetura nova está nas inovações destinadas a evitar o calor e os

reflexos luminosos em superfícies de vidro, por meio de quebra-luzes externos, especiais. Para a América do Norte isto é coisa de leve conhecida. Tendo que receber de chapa o rude sol das tardes de verão, os grandes edifícios, em geral, ficam como um forno, dada a proteção insuficiente de suas janelas de folhas semi-cerradas. As oficinas modestas então têm que escolher uma dentre duas alternativas: ou assar-se ou proteger-se escassamente por meio de toldos ou venezianas, proteção fraca porque nada podem contra os reflexos do sol nas vidraças. E é curioso verificar-se como os brasileiros fizeram face ao importantíssimo problema, cujo estudo foi o que animou a nossa viagem. (Goodwin & Smith, 1943)

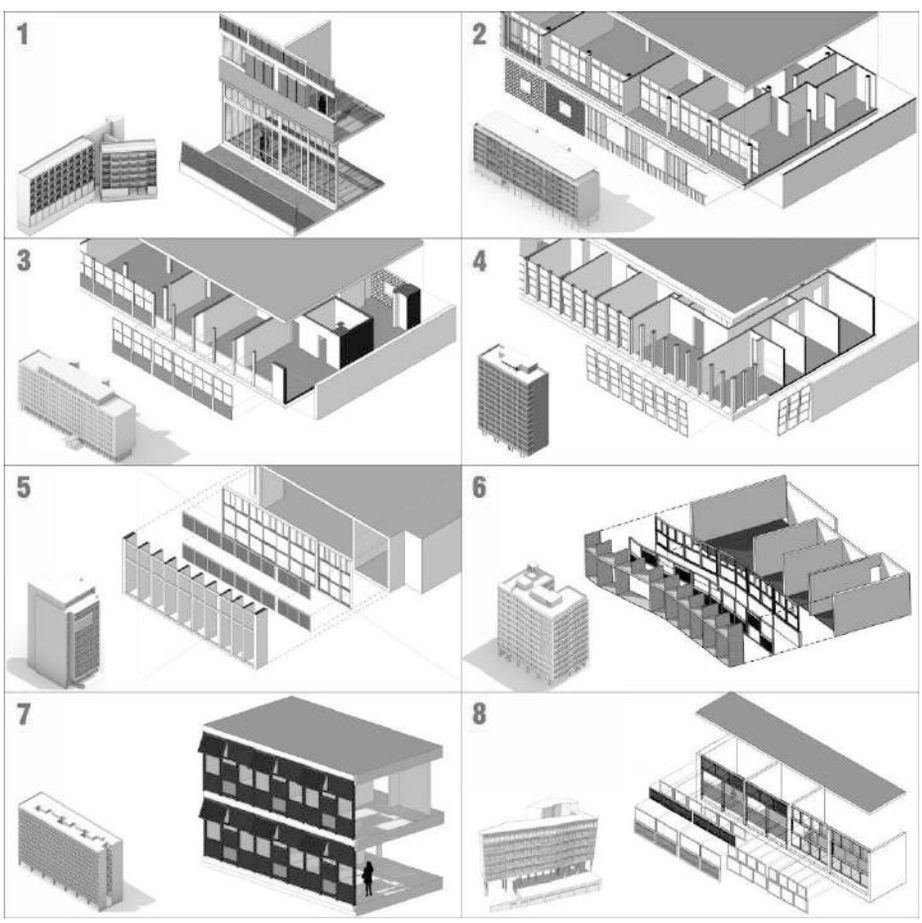

Figura 1. Volumetria e sistema de fachada dos edifícios em estudo. 1- Ed. Barreto, Irmãos Roberto, 1947; 2- Ed. Bristol, Lúcio Costa, 1950; 3- Ed. Nova Cintra, Lúcio Costa, 1948; 4- Ed. Gravatá, Sérgio Bernardes, 1952; 5- Ed. MMM Roberto, Irmãos Roberto, 1945; 6- Ed. D. Fátima, Irmãos Roberto, 1951; 7- Ed. Angel Ramirez, Irmãos Roberto, 1954; 8- Ed. Sambaíba, Irmãos Roberto, 1953. Fonte: Autores, 2022.

No texto acima citado de apresentação do catálogo da exposição *Brazil Builds. Architecture new and old 1652-1942*, Philip Goodwin (1943) justifica a sua visita ao Brasil, nos anos 40. Goodwin pretendia investigar a utilização de sistemas de sombreamento na arquitetura brasileira e carioca, creditando a inovação e a singularidade dos edifícios modernos brasileiros e as soluções desenvolvidas por jovens arquitetos para o problema climático das fachadas dos edifícios. As soluções dessas fachadas adotam diversos tipos de quebra-sol, elementos de proteção solar, ou filtros, singularizados na arquitetura brasileira. Muitas dessas soluções tiveram sua origem no Rio de Janeiro, embora se tenham disseminado por grande parte do país. A adoção, no Brasil, de soluções variadas para a adequação climática das fachadas provocou um efeito de dilatação dos planos de fechamento dos edifícios.

As tramas de cheio e vazio geradas pelas combinações de panos de vidro, varandas espessas e filtros configuram um sistema de camadas, com diferentes graus de permeabilidade, para além da função estrita de vedação das fachadas. A partir desta ideia, selecionamos para investigação um universo de oito edifícios residenciais modernos cariocas (Figura 1). Os edifícios em questão foram agrupados em quatro temas de projeto, de acordo com o projeto das suas fachadas:

- A fachada intermediada por varandas: Ed. Júlio Barros Barreto (Irmãos Roberto, 1947) e Ed. Bristol (Lúcio Costa, 1950) (1,2 Fig.1);
- A fachada intermediada por planos de vidro: Ed. Nova Cintra (Lúcio Costa, 1948), e Ed. Barão Gravatá (Sérgio Bernardes, 1952) (3,4 Fig.1);
- A fachada intermediada por brise-soleil de concreto acoplado: Ed. MMM Roberto e Ed. Dona Fátima e Finúsia (Irmãos Roberto, 1945 e 1951) (5,6 Fig.1);
- A fachada intermediada por filtros, cobogós, venezianas e treliças: Ed. Ramirez e Ed. Sambaíba (Irmãos Roberto, 1954 e 1953) (7,8 Fig.1).

Neste universo de edifícios, selecionamos como objeto de investigação deste artigo o edifício Nova Cintra, que possui mecanismos singulares de adaptação climática passiva, os quais iremos mais à frente descrever.

1.2 Estratégias de projeto

Os quatro temas, ou estratégias de projeto, que selecionamos estão relacionados com as possibilidades abertas pelo Sistema Dominó de Le Corbusier (1914-1917), que viabilizou um novo horizonte de possibilidades de articulação entre a ossatura independente e as soluções de fachada, com grande influência na arquitetura brasileira deste período. O primeiro fator de relação entre os quatro temas de projeto e o sistema dominó diz respeito à autonomia da fachada e à distinção entre elementos estruturais e não estruturais do edifício, ou entre estrutura e fechamento. Este princípio do sistema dominó é explícito nas fachadas longitudinais do Ed. Nova Cintra. O segundo fator de relação diz respeito ao modo como cada edifício incorpora o recuo dos pilares para o interior, solução que Fanelli e Gargiani (2014) e

Eskinazi e Penter (2019) elegem como princípio construtivo fundamental da teoria dos cinco pontos de Le Corbusier – de onde derivam os demais pontos, principalmente as fachadas em fita e as janelas em fita. Este recurso é explorado para obter grandes vãos e esquadrias com melhores condições de iluminação e ventilação no interior, bem como para potenciar a relação do interior com a paisagem. É um importante recurso para ampliar e dilatar, "espessando" as fachadas. O terceiro e último fator de relação diz respeito aos espaços de intermediação entre o domínio público e privado criados por este espessamento. O desenvolvimento de diferentes padrões de espessamento dos planos de fechamento supera a frontalidade da fachada plana, criando um espaço "in-between" que tanto pertence ao interior quanto ao exterior (Leatherbarrow & Mostafavi, 2002), gerando espaços de transição.

Portanto, o sistema dominó, ao concretizar os 5 pontos de Le Corbusier e ao viabilizar a implementação das quatro estratégias de projeto acima citadas, exerce um papel determinante na potencialização da fachada como elemento de intermediação de relações espaciais entre interior e exterior.

1.3 Adaptação passiva - Edifício Nova Cintra

Estudos recentes abordam a adaptação bioclimática passiva de edifícios modernos no Brasil (Lucas & Bastos, 2021) e no Rio de Janeiro em particular, no Edifício Nova Cintra (Cunha, 2021). A capacidade de adaptação do Nova Cintra é relativa a: **1 - Contexto climático,** o Rio de Janeiro durante grande parte do ano possui clima tropical quente e húmido, com alta temperatura e humidade relativa, com mais chuvas no verão e períodos de seca no inverno. Este clima produz desconforto térmico, e um recurso fundamental para o minorar é a renovação de ar interior, combinada com sombreamento, para reduzir o ganho térmico interior, evitando a luz solar direta em excesso, mas aproveitando a luz natural; **2 - Implantação edifício,** este está posicionado longitudinalmente em relação à rua (66 x 44 m), com desvio de 20º a norte. A posição e o tratamento do envelope a norte, este (fachada cega) e oeste (ventilação banheiros), minimizam a carga térmica; **3 - Permeabilidade ao vento**, esta está relacionada com a orientação do edifício, beneficiando do vento dominante sul/sudeste na região, mas também da posição no terreno em degraus, sobre pilotis, com piso superior recuado, e varanda na fachada norte com sombreamento; **4 - Composição fachada e sombreamento**, é de realçar a estrutura recuada em relação à fachada, com métrica 4m nos dois alçados norte e sul, com paredes internas perpendiculares às fachadas maiores e alinhadas entre si. Na fachada norte há sombreamento com brises e cobogós, seguidos de uma varanda que é dividida dos quartos por uma caixilharia de correr. O sombreamento das varandas e alinhamento das paredes internas favorecem a ventilação natural, em grande parte do ano, e controlam a entrada excessiva de luz solar, favorecendo o conforto passivo do edifício, sem ser necessário o recurso a sistemas de ar condicionado.

2 Metodologia: caso piloto edifício Nova Cintra

2.1 Possibilidades expansão sistema

Os processos computacionais, nesta pesquisa, pretendem ter um papel subversivo como tiveram os edifícios modernos no seu tempo, questionando e refletindo sobre o modo de fazer arquitetura, permitindo descobrir e desenvolver processos combinatórios para sistemas passivos, expandindo a sua utilização. Como recombinar os módulos existentes, para melhorar o sistema passivo de sombreamento? Utilizamos simulação computacional para medir o desempenho atual, pensando como este pode ser melhorado. Pensamos em processos diferentes, de acordo com as especificidades de cada edifício, para melhorar o desempenho de cada fachada:

1 - Recombinar módulos existentes [A, B, C], trocando posições, com nova recombinação, por exemplo [B, C, A];

2 - Utilizar módulos existentes, abrindo e fechando painéis de sombreamento, janelas ou muxarabis [A+, A-, A] > [A-, A+, A-];

3 - Alterar parâmetros dos módulos, por exemplo alterar parâmetros do espaçamento ou ângulo de sombreamento dos brises (otimização matemática).

No presente artigo desenvolvemos apenas o processo 1. Pretendemos desenvolver os processos 2 e 3 em futuras etapas da pesquisa.

2.2 Caso piloto, estudo e aplicação

Pretendemos aplicar este estudo aos edifícios referidos, mas escolhemos o edifício Nova Cintra (Figura 2) para um caso piloto devido à sua capacidade de adaptação passiva atrás referida. Escolhemos para análise mais aprofundada a fachada norte, por estar sujeita a condições solares mais extremas e possuir os mecanismos de adaptação atrás referidos, pensando numa recombinação da posição dos atuais módulos de tipos de sombreamento existentes na fachada, de modo a melhorar o desempenho geral da fachada relativamente a critérios que são indicados mais à frente.

2.3 Preparação de modelos digitais

Modelamos parametricamente os oito edifícios em estudo através de dois tipos de algoritmos, um em programação visual e outro em programação textual em Python, ambos no Grasshopper. Traduzimos os dados bidimensionais obtidos através de cortes, fachadas e plantas, para a terceira dimensão. Para ordenar cada edifício por pavimento, ambas as soluções desenvolvidas (visual e textual) têm como entrada do código os elementos de projeto agrupados por materiais e têm como saída estes elementos orientados geograficamente, dispostos de acordo com o piso pretendido.

Assim, a sequência de operações é estruturada em três etapas: transformação das linhas base em objetos 3D, posicionamento de cada objeto no entorno modelado e deslocamento vertical destes de acordo com o andar pretendido. Esta organização dos dados por nível, aplicada a todos os edifícios, permite obter como produto final a volumetria completa dos edifícios, com o entorno do terreno e dos volumes do edificado envolvente, modelados diretamente no software Rhinoceros, numa área de 350 x 350 m. O edifício piloto Nova Cintra foi modelado de acordo com estes princípios.

Preparamos os modelos não para representar os edifícios, mas para permitir analisar o seu desempenho relativamente a dois aspetos: 1 - a insolação (ou irradiação solar), para saber a quantidade de radiação solar, em Wh/m^2 ou kWh/m^2, que incide ao longo do ano sobre o envelope (cobertura e fachadas, incluindo sombreamentos). Calculamos também neste aspeto a irradiação solar total (IRST), em kWh, que corresponde ao valor total da radiação solar incidente sobre uma superfície, que é obtido multiplicando o valor da insolação pela área da superfície em análise; 2 - a iluminância, que permite analisar a quantidade de radiação que após filtrada pelos sombreamentos, entra no interior do edifício. Torna-se assim possível entender quais espaços interiores têm iluminação natural adequada, entre os 100 e os 3.000 lux. Abaixo de 100 lux há falta de luz e acima de 3.000 lux há excesso. Níveis de iluminância elevados podem provocar aumento de temperatura e o uso de sistemas de ar condicionado para arrefecimento.

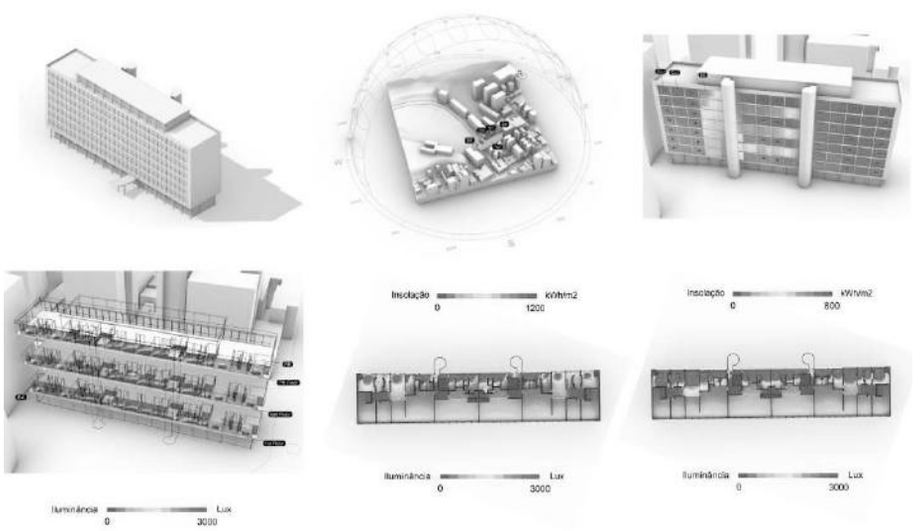

Figura 2. Modelo do edifício Nova Cintra (de cima para baixo, da esquerda para a direita): modelo 3D do edifício; análise da insolação no envelope do edifício; análise da insolação na fachada norte; análise da iluminância no solstício inverno (21 Junho às 12h) do primeiro, quarto e sétimo (último) piso; análise da iluminância do quarto piso, com sombreamento e sem sombreamento. Fonte: Autores, 2022.

2.4 Análise numérica e gráfica do edifício

Após a modelagem paramétrica, utilizamos o Ladybug e Honeybee para analisar o envelope do edifício. Determinamos que superfícies obtêm maior e menor insolação ao longo do ano (Figura 2). A superfície da cobertura é a que tem maior insolação, 1.241 kWh/m^2, seguida da fachada norte que tem 587 kWh/m^2. A cobertura recebe também o maior valor de irradiação solar total (IRST), 1.698.142 kWh (42,8% de todo o envelope), seguindo-se a fachada norte, com 972.971 kWh (24,5 %). Na fachada norte o sistema de sombreamento Cobogó com Janela regista o maior valor de insolação, 696 kWh/m^2, seguido do Cobogó sem Janela, com 651 kWh/m^2, e Brise-Soleil, com 495 kWh/m^2. No entanto, relativamente à IRST, é o Brise-Soleil que recebe mais insolação, 339.656 kWh (75,2% de todos os sombreamentos), devido a ter maior área total, 682 m^2, segue-se o Cobogó com Janela, com 68.924 kWh (15,3%) e 101 m^{2,}, e o Cobogó sem Janela, com 43.057 kWh (9,5%) e 66 m^2.

Analisamos depois o desempenho dos compartimentos interiores do primeiro, quarto e sétimo e último piso, junto da fachada norte do edifício, relativamente à iluminância. Para os restantes pisos interpolamos valores para diminuir o tempo de cálculo das análises. Analisamos no solstício de inverno (21 Junho às 12h), altura em que o sol atinge a posição mais baixa, solstício de verão (21 Dezembro às 12h), posição mais alta do sol, e equinócio de outono (20 de Março às 12h), com o sol numa posição intermédia, relativamente à trajetória anual. Para o solstício de inverno, a média da iluminância dos pisos analisados é de 4.152 lux. O valor desce para 1.528 lux no equinócio de outono, atingindo 640 lux no solstício de verão. Como tal, no solstício de verão e no equinócio de outono a iluminância está dentro de intervalo adequado, entre 100 e 3.000 lux. Para o solstício de inverno, o valor médio excede 3.000 lux, o que pode provocar sobreaquecimento e uso de ar condicionado. Assim, embora os sombreamentos não sejam eficientes durante todo o ano, podemos visualizar a sua capacidade de bloqueio dos raios solares na Figura 2, que mostra a iluminância para o piso intermédio, comparando na fachada norte a solução com aplicação de sombreamentos e a solução sem esta aplicação, para o período do solstício de inverno (21 Junho ás 12h). A solução com sombreamentos diminui consideravelmente a iluminância. Nos compartimentos junto à fachada norte, localizados na parte superior das plantas, podemos notar a extensão da cor vermelha, onde a iluminância é mais elevada e aumenta na planta sem sombreamento.

2.5 Critérios utilizados

Após analisada a fachada norte do edifício, desenvolvemos soluções alternativas para melhorar o seu desempenho energético. Serviram como referência as investigações de Henriques (2012), Kirimtat (2016), Vazquez

(2020), Venâncio (2020) e Mateus (2021), que abordam sistemas de projeto generativo tais como modelação paramétrica e gramáticas da forma, para gerar soluções formais para envelopes e sombreamentos de edifícios, com bom desempenho energético relativamente à iluminância e à insolação.

Esta investigação está situada na mesma temática dos autores acima referidos, desenvolvendo um método de modelação combinatória, a partir dos módulos de tipos de sombreamento existentes no edifício Nova Cintra: o Cobogó com Janela (**Letra A)**, o Cobogó sem Janela (**Letra B)** e o Brise-Soleil (**Letra C**). Realizamos análises mais detalhadas de insolação e iluminância para estes três tipos de sombreamento, ocupando cada tipo de sombreamento as 98 posições possíveis, na fachada norte do edifício. Realizamos as seguintes análises: 1) insolação na face superior do sombreamento, em Wh/m^2; 2) insolação no plano posterior do sombreamento, contabilizando o sombreamento, em Wh/m^2; 3) insolação no plano posterior ao sombreamento, sem contabilizar o sombreamento, em Wh/m^2; 4) iluminância média nos compartimentos junto à fachada norte, em lux; 5) número de pontos, nos compartimentos junto à fachada norte, com iluminância entre 300 e 750 lux.

As análises foram realizadas para os solstícios de inverno (21 Junho) e verão (21 Dezembro) às 10, 12 e 16 horas, com céu CIE, de modo a percebermos o desempenho dos sombreamentos nas situações extremas ao longo do ano. Com os resultados obtidos, elaboramos um processo para encontrar diferentes combinações de tipos de sombreamento na fachada norte do edifício, de modo a melhorarmos o seu desempenho nos seguintes critérios: 1) **minimizar insolação** após o sombreamento, em Wh/m^2; 2) **maximizar número de pontos** no interior dos compartimentos, com iluminância entre 300 e 750 lux, faixa de valores prescrita pela ABNT (2013) que compreende limite inferior e superior de iluminância de entorno imediato; 3) **maximizar iluminância média** (lux) no interior dos compartimentos.

Definimos estes três critérios para as cinco análises acima descritas, procurando conciliar os objetivos de sombreamento, minimizando a passagem de radiação solar para o interior do edifício (critério 1), maximizando o número de pontos no interior dos compartimentos com iluminância adequada (critério 2) e maximizando a iluminância média (critério 3), para assegurar uma iluminação natural adequada no interior dos compartimentos. Automatizamos a coleta de dados das análises com programação visual e textual em Python, criando um código alfanumérico para cada simulação do tipo "*CintraWkwmCIE21jun10:00_LetraA*". Foram realizadas 1x2x1x2x3x3=36 simulações. As análises consideraram o envelope do edifício no contexto urbano, dados climáticos e materiais, além dos 3 critérios acima destacados. Para melhor entendimento dos resultados construímos representações gráficas para interpretar os padrões emergentes, através de meshes com graduação cromática, o que também permitiu identificar eventuais anomalias nos modelos.

2.6 Modelação combinatória e otimização multicritério

Após normalizarmos as diferentes escalas de valores dos resultados das análises, para valores na escala 0-1, testamos diferentes processos para encontrar, para cada um dos cenários (Jun e Dez, às 10,12 e 16h), um melhor valor de desempenho para cada um dos 98 módulos do edifício, organizados numa matriz de 14 x 7 módulos. Inicialmente realizamos testes procurando combinações aleatórias de tipos de letras (A, B, C) e algoritmos genéticos, procurando maximizar a soma de valores de desempenho. Após alguns testes iniciais, chegamos à conclusão que sendo analisado o desempenho de cada módulo, em cada um dos cenários, relativamente aos 3 critérios, que escrevendo um código de ordenamento, com condicionais, permite determinar os melhores valores para cada célula de maneira mais expedita: cada solução corresponde a uma frase numa lista de Letras A, B e C com 98 elementos. A ideia desde o início foi implementar uma análise multicritério por haver critérios divergentes, como a insolação solar e a quantidade de iluminância. Começamos por utilizar primeiro o software *Octopus*, para variar de maneira mais dinâmica o peso de cada um dos 3 critérios. No entanto, entendemos ser mais expedito utilizar um algoritmo para comparar diretamente os resultados de cada critério, considerando pesos fixos aos critérios, para termos uma primeira ideia do universo de soluções, do seu desempenho, e de como se inter-relacionam. Descrevemos de maneira sintética os resultados da seleção multicritério na próxima seção.

3 Resultados

Relativamente aos resultados, os sem ponderação (três primeiras colunas da Tabela 1: A, B, C), que consideram igualmente as pontuações de insolação, pontos de iluminância e iluminância média (ins 1, iluPt 1, iluM 1), tanto em Junho (Jun) como Dezembro (Dez) prevalece a Letra B, às 10:00 e 12:00, enquanto às 16:00 (Jun e Dez) a Letra C é a melhor solução. Considerando mais o critério dos pontos com a iluminância ideal (ins 0.2, iluPt 0.6, iluM 0.2) e pontuando menos os restantes critérios, verificamos que a solução B continua a prevalecer nas mesmas situações do que os critérios sem ponderação, à exceção das 12:00 de Dez em que prevalece a solução C. A letra C prevalece também em Jun 16:00, enquanto que em Dez 16:00 prevalece a letra A. Finalmente, se favorecemos o critério de iluminância média (ins 0.2, iluPt 0.2, iluM 0.6), temos uma igualdade de escolhas tendo três soluções com a Letra C (Jun 12:00 e 16:00, Dez 16:00), sendo a Letra B melhor em outras três situações (Jun 10:00, Dez 10:00 e 12:00). Em resumo, a Letra B, Cobogó sem janela, é a melhor solução em termos globais. Especialmente no critério de minimizar a insolação, mas permitindo também bons desempenhos relativamente à faixa de pontos de iluminância nos valores ideais e à iluminância média.

Tabela 1. Análise multicritério dos tipos de sombreamento (A, B, C) com ponderação da insolação, número de pontos com iluminância 300-750 lux e iluminância média.

LETRAS	A	B	C	A	B	C	A	B	C
MULTI	1 ins	1 iluPt	1 iluM	0.2 ins	0.6 iluPt	0.2 iluM	0.2 ins	0.2 iluPt	0.6 iluM
Jun 10:00	0	88	10	6	72	20	4	53	41
Jun 12:00	0	97	1	0	97	1	0	12	86
Jun 16:00	1	30	67	12	30	56	1	30	67
Dez 10:00	0	95	3	0	95	3	0	95	3
Dez 12:00	29	47	22	36	25	37	29	47	22
Dez 16:00	36	20	42	58	2	38	36	20	42
SOMA	66	377	145	112	321	155	68	257	257
MED	1	68	16	9	51	29	3	39	42

Fonte: Autores, 2022.

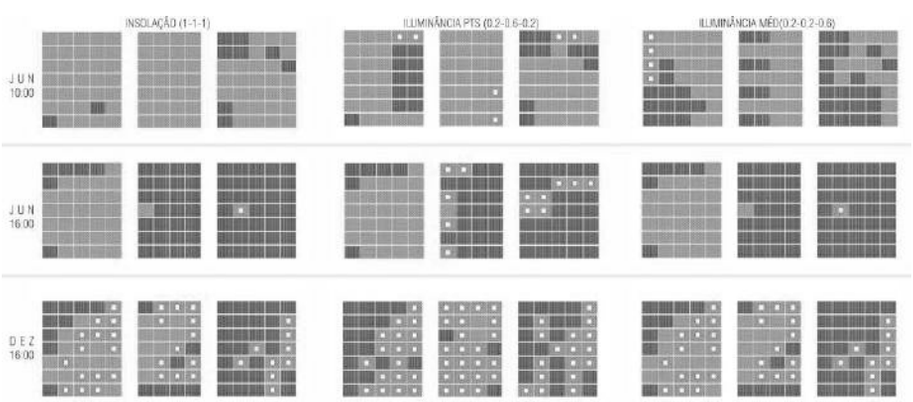

Figura 3. Resultados gráficos da otimização combinatória dos tipos de sombreamento Letra A (vermelho), B (lilás) e C (azul), resultando em uma frase (ACCBAB…) otimizada de acordo com os critérios e a ponderação indicados nas colunas. Fonte: Autores, 2022.

A Letra C é a segunda melhor solução, havendo menos situações em que a Letra A domina. Embora estas conclusões possam ser lidas na Tabela 1, as correlações são mais complexas de analisar. Para melhorar a leitura recorremos à representação gráfica traduzindo as letras em módulos, como sintetizado na Figura 3. Observamos que em Dez, considerando as diferentes ponderações, aparece com frequência a Letra A, o que leva a pensar que falta iluminância, eventualmente devido à posição alta do sol. No fim de tarde é frequente dominar a Letra C, o Brise-soleil, com maior ênfase em Jun 16:00.

4 Discussão de resultados

O modelo computacional desenvolvido simulou o comportamento dos três tipos de sombreamento (A, B, C) e determinou o seu desempenho isoladamente. Através de análise combinatória selecionamos as melhores combinações, relativamente ao desempenho de três fatores, propondo novos padrões combinatórios de fachada, resumidos na Tabela 1 e na Figura 3.

A avaliação multicritério procura que os resultados sejam bons relativamente aos diferentes critérios, sendo que a ponderação dos seus pesos permite compreender como melhorar a solução final. A ponderação com melhor resultado valorizou mais o critério dos pontos com a iluminância ideal (ins 0.2, iluPt 0.6, iluM 0.2), permitindo uma melhoria total no desempenho em Jun às 10:00, 12:00, 16:00 de 50%, 48% e 39%, e em Dez às 10:00, 12:00, 16:00, de 43%, 16% e 11%, o que representa em média uma melhoria de 41,4%. Considerando os três critérios com igual ponderação (ins 1, iluPt 1, iluM 1) ou valorizando mais a iluminância média (ins 0.2, iluPt 0.2, iluM 0.6) a melhoria conseguida é inferior, sendo em média de 31,7% e 28,9%. Foi desenvolvido um algoritmo textual em Python para recolher os resultados de simulação relativamente a cada fator, e a cada letra, depois foi utilizada a modelagem combinatória para procurar a melhor combinação de letras ou tipos de fachada em cada célula, utilizamos finalmente a análise multicritério para testar a sensibilidade do sistema, e escolher a melhor combinação considerando a ponderação dos diferentes critérios. Numa etapa futura, pretendemos aprofundar também a otimização multicritério no software *Octopus*, e comparar com os resultados obtidos utilizando programação textual em Python.

5 Conclusões

Esta pesquisa parte de sistemas modernos de sombreamento, devido à sua originalidade e capacidade para mitigar o clima tropical. Utilizamos métodos computacionais para expandir a utilização deste tipo de sistemas passivos para minorar o uso de sistemas artificiais de climatização (ar condicionado). Selecionamos oito edifícios da escola carioca para modelar através de programação visual e textual. Definimos um primeiro caso de estudo piloto, o edifício Nova Cintra, para analisar a sua insolação e iluminância, no envelope e em detalhe na fachada norte. Utilizamos o modelo computacional para simular e comparar o desempenho de diferentes tipos de sombreamento existentes na fachada norte, aplicando modelação combinatória para estabelecer combinações dos diferentes tipos de sombreamento na fachada relativamente a três critérios de desempenho: insolação, número de pontos com iluminância ideal e iluminância média. Os resultados obtidos confirmam que é possível aplicar métodos computacionais

para melhorar o desempenho de sistemas de sombreamento tradicionais, inovando a partir dos mesmos. Esta metodologia pode ser utilizada também em outros tipos de análise, para procurar melhores combinações computacionais, em outros sistemas de sombreamento, mas também em outros tipos de sistemas tais como de ventilação, acústica, entre outros.

Referências

Associação Brasileira de Normas Técnicas. (2013). NBR ISO/CIE 8995-1: Iluminação de ambientes de trabalho - Parte 1: Interior.

Cunha, V. S. (2021). Avaliação Bioclimática de Edifício Moderno: o caso do Edifício Nova Cintra, Parque Guinle, Rio de Janeiro. Brazilian Journal of Development, 7(5), 47793-47809. https://doi.org/10.34117/bjdv7n5-265

Eskinazi, M. O., & Penter, P. E. (2019). A fachada como interface, de Lucio Costa a irmãos Roberto: Repertório de projeto. 13º Seminário DOCOMOMO Brasil, Salvador. https://docomomobrasil.com/wp-content/uploads/2020/04/110533.pdf

Fanelli, G., & Gargiani, R. (2014). *Histoire de l'architecture moderne. Structure et revêtement*. Presses Polytechniques Romandes.

Goodwin, P. L., & Smith, K. (1943). Brazil Builds. Architecture new and old 1652-1942. The Museum of Modern Art, New York. https://www.moma.org/calendar/exhibitions/2304

Henriques, G. C., Duarte, J. P., & Leal, V. (2012). Strategies to control daylight in a responsive skylight system. Automation in Construction, Elsevier, 28, 91–105. https://doi.org/10.1016/j.autcon.2012.06.002

Kirimtat, A., Koyunbaba, B. K., Chatzikonstantinou, I., Sariyildiz, S., & Suganthan, P. N. (2016). Multi-objective optimization for shading devices in buildings by using evolutionary algorithms. In 2016 IEEE Congress on Evolutionary Computation, CEC 2016 (pp. 3917-3924). IEEE. https://doi.org/10.1109/CEC.2016.7744286

Leatherbarrow, D., & Mostafavi, M. (2002). *Surface Architecture*. MIT Press.

Lucas, C., & Bastos, P. (2021, Abril). O valor bioclimático na arquitetura moderna tropical. Arquitextos, 251.05. *Vitruvius*. https://vitruvius.com.br/revistas/read/arquitextos/21.251/8048

Mateus, D., Duarte, J.P., & Romão, L. (2021). Energy-Based Design: A Digital Design System for the Design of Energy-Harvesting Building Envelopes. In P. Gomez & F. Braida (Eds.), SIGraDi 2021, XXV International Conference of the Iberoamerican Society of Digital Graphics (pp. 831-842). Blucher Design Proceedings.

Vazquez, E., Duarte, J., & Poerschke, U. (2020). Masonry screen walls: a digital framework for design generation and environmental performance optimization. Architectural Science Review, 64(3), 262-274. https://doi.org/10.1080/00038628.2020.1749552

Venâncio, R. (2020). Sombreamento com iluminação: desenvolvimento e teste de modelo paramétrico para facilitar o projeto de proteções solares. Ambiente Construído, 20(4), 59-77. https://doi.org/10.1590/s1678-86212020000400460

Wikihouse: a parametric approach for generating different spatial arrangements

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Abstract. Wikihouse is an open-source, modular, digitally fabricated building system. Despite being the object of many studies in different countries, most of these experiences present a sequence of frames that generate only linear forms without formal variations. In this sense, this study aims to develop a geometry that allows more variations through the repetition of the same module. For this purpose, the research uses visual algorithmic modeling in Grasshopper to generate the geometry. As a result, we inserted the frames into a trapezium and mirrored the main profile, which kept the number of pieces. In future research, we intend to optimize the number of parts, reduce the cost and production time, and build a 1:1 module for validating its constructive stability.

Keywords: Wikihouse; algorithmic modeling; shape variation; temporary architecture.

1 Introdução

A Wikihouse é um sistema construtivo modular, de encaixes em madeira compensada, open-source, e fabricado digitalmente, desenvolvido em 2011 por Alastair Parvin e Nick Ierodiaconou. Segundo os seus desenvolvedores, é um sistema leve, fácil de montar e desmontar, durável e carbono zero. Caracteriza-se também pela facilidade de produção local, manufaturado em pequenos laboratórios a partir de fresadoras controladas numericamente por computador, mas com capacidade de atingir mercados em escala global, dada a facilidade de desmontagem e transportabilidade.

Por ser um projeto open-source, o sistema de encaixes e documentação estão disponíveis online para uso compartilhado, podendo ser alterado e modificado para abrigar diferentes projetos. Variações formais já foram amplamente testadas não apenas no exterior, mas também no Brasil. O primeiro exemplar projetado e construído no Brasil, a Casa Revista, foi

desenvolvido no LAMO 3D/UFRJ (Laboratório de Modelos 3D e Fabricação Digital da universidade), por Clarice Rohde e Andrés Passaro (Passaro & Rohde, 2015). Realizado em duas oficinas abertas de fabricação digital, as 200 peças de compensado de madeira foram usinadas em fresadora CNC durante dois meses e, posteriormente montadas em 2 semanas por estudantes de arquitetura no campus Fundão da UFRJ. Além de ser a primeira Wikihouse da América Latina, segundo Passaro e Rohde (2015), o objetivo do trabalho era adaptar o sistema construtivo Wikihouse para o clima local, adicionando elementos tradicionais da arquitetura brasileira, como o telhado em duas águas, o beiral e a varanda, que atuam como elementos de regulação térmica.

Experiências posteriores também testaram possibilidades do sistema construtivo da Wikihouse: proposição de módulo com geometrias curva e adaptações do sistema de encaixes (Mendonça et al. 2018) também desenvolvido no LAMO3D UFRJ; adaptação ao contexto ambiental brasileiro (Branco et al., 2017); adaptação ao sistema de habitação social no Brasil (Nardelli, Backheuser, 2016; Rocha, et al., 2021), estudos sobre autoconstrução (Nardelli & Pereira, 2017), adaptação de encaixes do sistema construtivo (Almeida et al. 2021); e testes de resistência para otimização de número de peças do sistema (Campolongo & Vicente, 2018). Em 2018, o grupo de pesquisa Nó na Universidade Federal de Viçosa, desenvolveu um protótipo de Wikihouse cujo principal objetivo era otimizar o número de peças, com o intuito de reduzir o custo e o tempo de fabricação e montagem do módulo, já apontados por vários autores como limitações para a escalabilidade do sistema.

No entanto, apesar da ampla experimentação do sistema no Brasil e no exterior, as experiências mantêm o conceito de módulo único, a partir da justaposição em sequência de pórticos que, ao serem dispostos linearmente, geram unidades pavilhonares com variabilidade formal limitada. Nesse sentido, esse artigo tem por objetivo apresentar o desenvolvimento de um pavilhão temporário itinerante e desmontável que permite agrupamentos distintos, não necessariamente lineares, ampliando as possibilidades formais, apesar da repetição do mesmo pórtico. O objetivo principal foi produzir uma geometria modular que permita arranjos espaciais diferentes, ampliando a variabilidade formal do atual sistema da Wikihouse e suas aplicações. O projeto foi elaborado como um pavilhão temporário, de modo que a estrutura seja desmontável, visando a sua incorporação em diferentes localidades e contextos urbanos.

Por sua vez, a associação da modelagem algorítmico-paramétrica ampliou as possibilidades não apenas no processo de geração da forma (com o uso de parâmetros numéricos para desenvolver o posicionamento dos pórticos), quanto à configuração para a fabricação do modelo final. De fato, segundo Caetano, Santos e Leitão (2020), essas estratégias tornam possível explorar e avaliar soluções complexas, fabricar usando técnicas avançadas e controlar vários estágios do processo de projeto.

1.1 Arquitetura temporária

Segundo Kronenburg (2003), a arquitetura temporária pode ser definida por três classificações: (a) Edifícios portáteis: aqueles que podem ser transportados inteiros e intactos, a partir da incorporação de um método de locomoção; (b) Edifícios relocáveis: aqueles que são transportados em partes e, quase instantaneamente, podem ser montados no local; (c) Edifícios desmontáveis: aqueles que são transportados em várias peças para a montagem no local. Para esse trabalho, portanto, adotamos o edifício desmontável, uma vez que ele possui maior flexibilidade para ajustes das dimensões e layout, além da vantagem de compactação no transporte.

No que se refere à desmontagem, em geral os métodos convencionais de construção geralmente apresentam restrições, o que dificulta a recuperação dos materiais de forma economicamente viável. Muitos motivos estão atrelados, como o custo massivo de conexões (como grampos e adesivos) difíceis de serem desfeitas e o uso constante de minerais inorgânicos e orgânicos (como o petróleo) em detrimento de materiais renováveis e baseados em fibra (Guy et al, 2003). De acordo com a NBR 15575-1 (2013), as estruturas dos edifícios são projetadas para durar no mínimo 50 anos. Entretanto, quando analisa-se a duração funcional no uso de um edifício, observa-se que ela é mais curta que a vida técnica dos materiais utilizados em seus componentes construtivos (Barreto, 2017, apud Durmisevic, 2006). Isso gera limitações de ordem econômica, uma vez que há uma parcela do valor despendido que não reflete em seu uso, e outro de ordem ambiental, já que há a exploração de um recurso natural que será desperdiçado no futuro.

Nesse sentido, o sistema Wikihouse possui como qualidades a possibilidade de reuso (por ser desmontável) e a transportabilidade das diversas peças, mas há poucos estudos sobre a flexibilidade para ajustes dimensionais e formais, diretamente relacionados à possibilidade de adaptação do sistema às condicionantes do contexto de inserção, no caso de pavilhões temporários e itinerantes. Como princípios norteadores de projeto, foram considerados, então:

Flexibilidade: possibilidade de diferentes arranjos espaciais, a partir do mesmo módulo, número e tipos de peças. O objetivo é facilitar a alteração de posição e rotação dos pórticos, sem afetar a lógica de montagem de cada módulo, ou seja, elaborar um sistema flexível e simples, que mantém a mesma lógica de montagem.

Simplificação: padronizar o modelo e projetar componentes construtivos simples e leves que permita que os próprios usuários participem e opinem na sua montagem, integrando a população local.

Parametrização: otimizar a produção arquitetônica por meio da modificação de parâmetros pré-estabelecidos e visualizar suas consequências em tempo real;

Permeabilidade: o projeto não deve se isolar no espaço urbano, permitindo a visibilidade e caminhabilidade no espaço inserido;

Efemeridade: permitir a instalação no local por um período de tempo limitado, de modo que o espaço abrigue usos de menor duração que reflitam práticas locais e insira novos olhares para diferentes realidades.

2 Metodologia

Como procedimento metodológico, o trabalho foi desenvolvido a partir (1) da análise de precedentes de modelos de Wikihouse, (2) a modelagem algorítmico-paramétrica em Grasshopper, em associação ao software Rhinoceros, (3) prototipagem para validação do sistema construtivo e da estabilidade do módulo proposto, (4) validação do algoritmo visual a partir da geração de diversas soluções de arranjos espaciais; (5) elaboração do manual de montagem, vislumbrando um processo de construção participativo.

2.1 Análise de precedentes

Para analisar e estudar o sistema construtivo do projeto original da Wikihouse e outros disponíveis na rede, o grupo de pesquisa Nó realizou o levantamento de precedentes e selecionou 5 exemplares como estudo de caso, segundo critérios formais, número de peças, sistema de travamento e tipos de encaixe. Desenvolvida como etapa preliminar, a pesquisa de Mestrado no PPG.au/UFV de Naiara Silva, “O Potencial Da Prototipagem E Fabricação Digital Na Produção De Abrigos Emergenciais”, defendido no PPG.au/UFV, produziu protótipos na escala 1:5 dos projetos selecionados para teste dos sistemas: a Microhouse, Vermont Microhouse, SCS Wikihouse, Wikished e PPES Reading Hut.

A Microhouse foi o primeiro modelo de Wikihouse projetada no Reino Unido. Possui 10,95m de comprimento por 4,18m de altura, comportando uma área interna total de 37,43m², com 9 módulos de 4,33m². Também seguindo o princípio da Wikihouse, a Vermont Microhouse possui 7 módulos de aproximadamente 3,7m² cada, totalizando 25m² que pode variar de acordo com a necessidade de cada projeto. A SCS Wikihouse, por sua vez, foi desenvolvida no intuito de atender à população em vulnerabilidade após os terremotos em 2011 na Nova Zelândia, medindo 4,0m x 2,4m, com dois módulos de 4,8m². Desenvolvido em um workshop do evento Taipei Digital Arts Festival em 2015, o PPES Reading Hut se tornou uma cabana de leitura a uma escola primária em Hsin-Bu Township, no Taiwan, possui 3,75m de largura e 4,32m de comprimento, com uma área total de 12,28m² (PAULA, Nayara Elisa Silva de)

Dentre esses, escolheu-se como ponto de partida, a Wikished, desenvolvida por, Erick Schimelpfenig caracterizada por um galpão simples, que utilizou a biblioteca aberta de componentes do Wikihouse para se aprofundar sobre o modelo construtivo como etapa preliminar ao

desenvolvimento de um projeto de residência unifamiliar, seu objetivo final. Neste exemplar, o sistema se estabiliza por meio de três tipos de encaixes utilizados: o conector dos pórticos S-Joint, os encaixes das chapas de fechamento e os encaixes dos conectores horizontais secundários. Destaca-se principalmente o sistema S-Joint que, por sua simplicidade formal, é constituído por um número menor de peças, o que facilita a parametrização da geometria. Esse sistema foi utilizado também na elaboração de geometrias curvas (Mendonça et al., 2018), o que demonstra as maiores vantagens desse encaixe.

3 Desenvolvimento do método e Resultados

Semelhante à estratégia da Wikished (Wikihouse), a proposta visa gerar pórticos que se conectam por meio de peças de travamento horizontais. No entanto, ao contrário dos módulos de base retangular recorrentes nos modelos de Wikihouse, esse trabalho propõe pórticos inseridos em um módulo trapezoidal submetidos a diferentes combinações, uma vez que geometria do pórtico pode ser rotacionada/espelhada, criando soluções espaciais com diversas variações formais e de implantação. Essa variabilidade é importante não apenas como resultado plástico, mas principalmente para adaptar o objeto ao contexto de inserção, ou seja, as variáveis do lugar tais como restrições de dimensões, variações programáticas, fluxos de pessoas, preexistências, valorização da paisagem, dentre outros. Nesse sentido, os módulos podem se conectar gerando soluções únicas, potencializando as características do ambiente em que está inserido.

Adicionalmente, visando a padronização de peças (para facilitar a montagem e/ou reposição), os encaixes da cobertura foram desenvolvidos de modo independente no conjunto. Para ampliar a variação formal é necessário rotacionar apenas as peças superiores do pórtico, mantendo o mesmo número e geometria das peças (Figura 1).

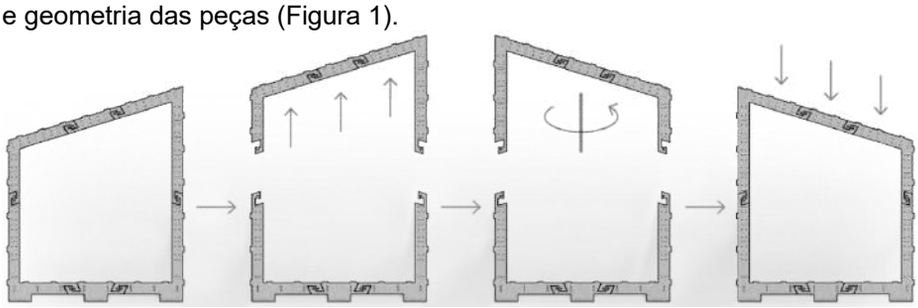

Figura 1. Demonstração do processo de rotação da cobertura.

Como a construção do módulo é realizada por meio de encaixes, o modelo foi desenvolvido para produção em chapas de madeira compensada naval com espessura de 18mm e dimensões de 2200mm x 1600mm. Além de ser um material renovável, o uso dessas chapas viabiliza a fabricação digital por meio

de fresadoras CNC, disponíveis em laboratórios de fabricação digital localizados em diversas cidades brasileiras.

3.1 A Geração da forma a partir da modelagem paramétrica

A definição dos pórticos foi desenvolvida no software Rhinoceros + Grasshopper, partindo dos parâmetros básicos de medida, como comprimento - espaço interno caminhável - menor altura do pé direito e maior altura do pé direito. Por meio do deslocamento (offset) dessa geometria interior, é criada a moldura do pórtico, respeitando a largura definida pelos parâmetros.

Na sequência, são adicionados aos limites externos uma base e seus encaixes de vedação (paredes, piso e cobertura), perfurados para passagem das peças de travamento. Com o objetivo de criar peças padronizadas, foram também inseridas as posições dos planos de recorte no pórtico, tanto na base (que se prolonga até a cobertura), quanto nas paredes.

A partir do pórtico inicial, é determinado um plano inclinado para o rebatimento/espelhamento dos demais pórticos, que resultam em um módulo de base trapezoidal. Essa base é o diferencial desse sistema, permitindo que sejam feitas diferentes combinações de arranjos espaciais. A figura 2 faz uma demonstração gráfica do processo descrito anteriormente, desenvolvido no software Grasshopper (figura 3).

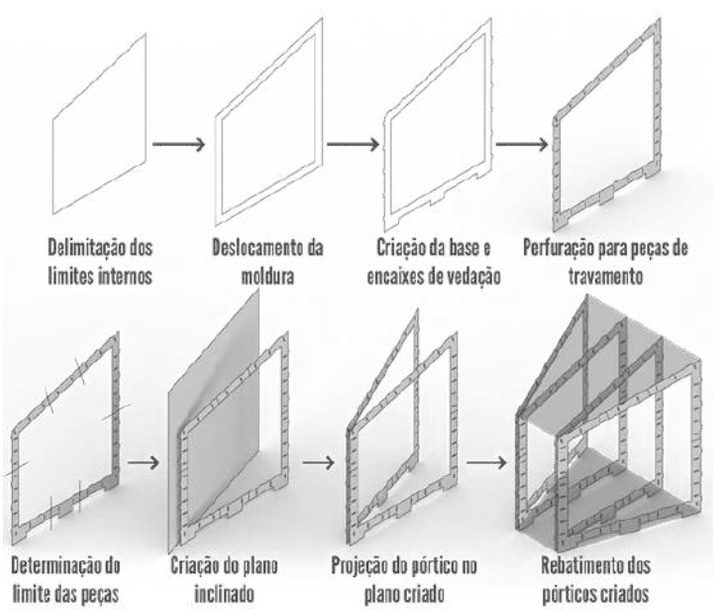

Figura 2. Diagrama apresentando processo de geração da forma.

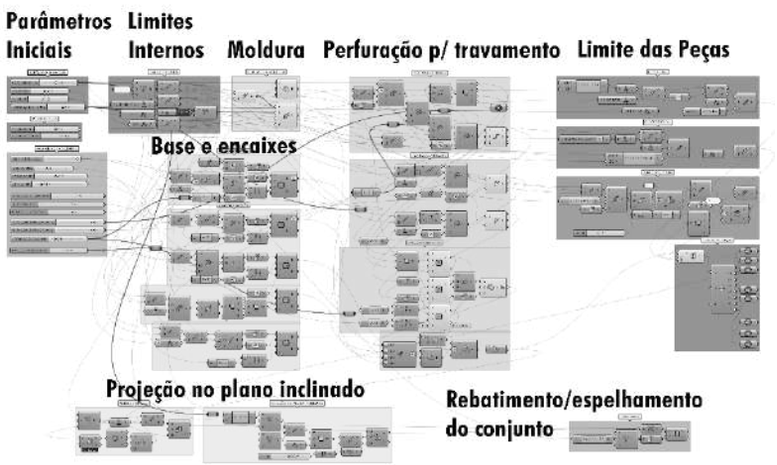

Figura 3. Definição desenvolvida no grasshopper para geração dos pórticos.

3.2 Classificação das peças

Para organizar e auxiliar no processo de montagem de um módulo básico, as peças foram divididas em cinco categorias: pórticos, travamento horizontal, vedações, cobertura/piso e conectores. As peças nomeadas com prefixo A são referentes aos pórticos, sendo as peças A1 referentes aos pórticos centrais e A2 os da extremidade. São as únicas peças que devem ser duplicadas (inseridas lado a lado para dobrar a espessura), visando sustentar toda carga estrutural. Para sua fixação é necessário utilizar os conectores de Junta-S.

Análogo aos pórticos, as peças B1 acoplam-se no centro do sistema e usam cunhas para sua fixação, enquanto as peças B2 (das extremidades) localizadas no piso e cobertura são fixadas por meio de cunhas duplas. As peças da face menor de vedação são classificadas como C1, enquanto as da face maior são identificadas como C2. As últimas peças a serem montadas nos módulos são as de cobertura (D1) e piso (D2), realizando o travamento de todo o sistema. Tanto as vedações quando as coberturas e pisos são fixadas por meio de cunhas simples (Figura 5). São três tipos de conectores utilizados no sistema: a cunha simples, disposta em diversas partes do sistema, a cunha dupla, que ocorre apenas nos travamentos e a Junta-S, recorrente apenas nos pórticos (Figura 4).

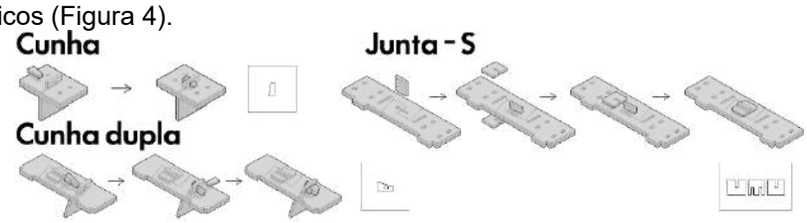

Figura 4. Conectores desenvolvidos para montagem do sistema.

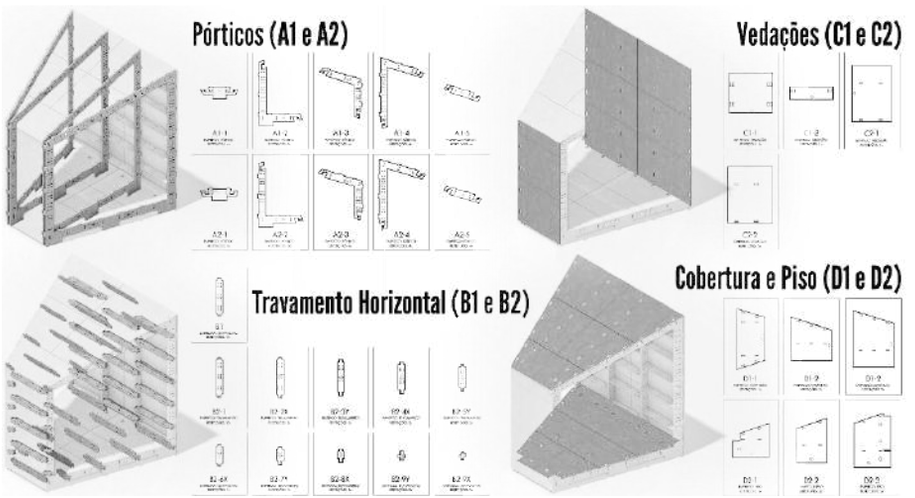

Figura 5. Demonstração das peças existentes nos módulos com suas respectivas planificações.

3.3 Prototipagem

Com o objetivo de verificar a rigidez dos encaixes e estabilidade do sistema e identificar a melhor forma de montagem, durante o processo de projeto, foi desenvolvida uma maquete (figura 6) na escala 1:6 em MDF com espessura 3mm. A partir do modelo físico e com auxílio de profissionais do Departamento de Engenharia Civil da Universidade Federal de Viçosa, verificou-se a necessidade de redução do número de peças, a partir do aumento de suas dimensões, de modo a melhorar a estabilidade dos encaixes das vedações. Esses ajustes aperfeiçoaram o projeto final e foram incorporados à definição no Grasshopper.

3.4 Variabilidade formal para pavilhões temporários

Como os pórticos inserem-se em um trapézio, é possível que haja o acoplamento de diferentes maneiras, tornando o espaço singular em cada contexto de implantação. De acordo com as variáveis do lugar (necessidades, restrições de tamanho, fluxo de pessoas, valorização da paisagem, etc) os módulos podem se conectar de modo que potencialize as características do ambiente em que está inserido. Como modo de tornar o espaço mais participativo, essa própria configuração pode ser feita em contato com a população, tornando os próprios usuários responsáveis pelo produto final.

Além disso, de acordo com as demandas apresentadas em decorrência do uso, novos módulos podem ser incorporados ou removidos, tornando sua implantação sempre dinâmica. Sendo assim, o espaço não se limita a um único

arranjo, podendo se modificar a cada destino em que seja feita sua montagem (Figura 7, 8 e 9).

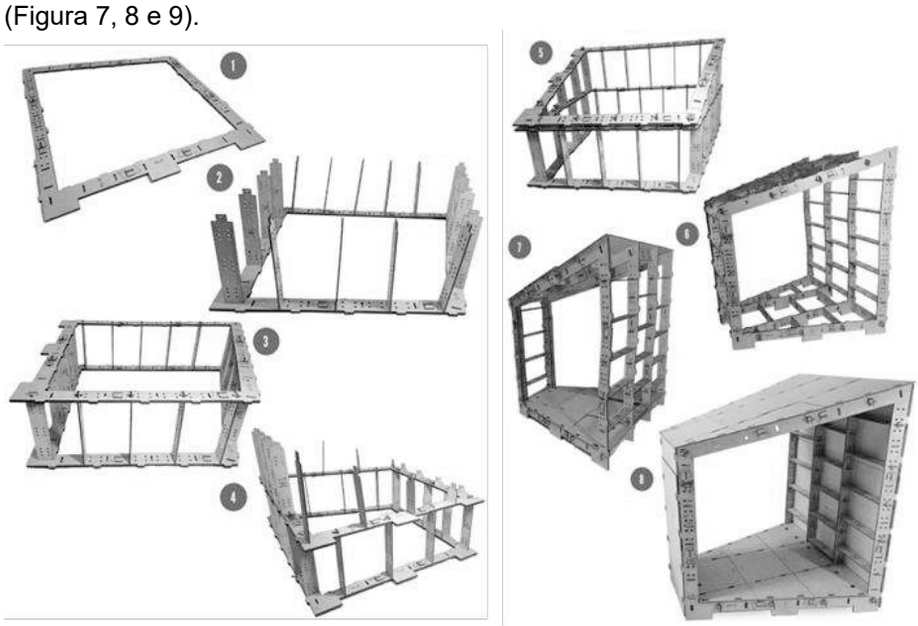

Figura 6. Processo de montagem do protótipo em escala reduzida.

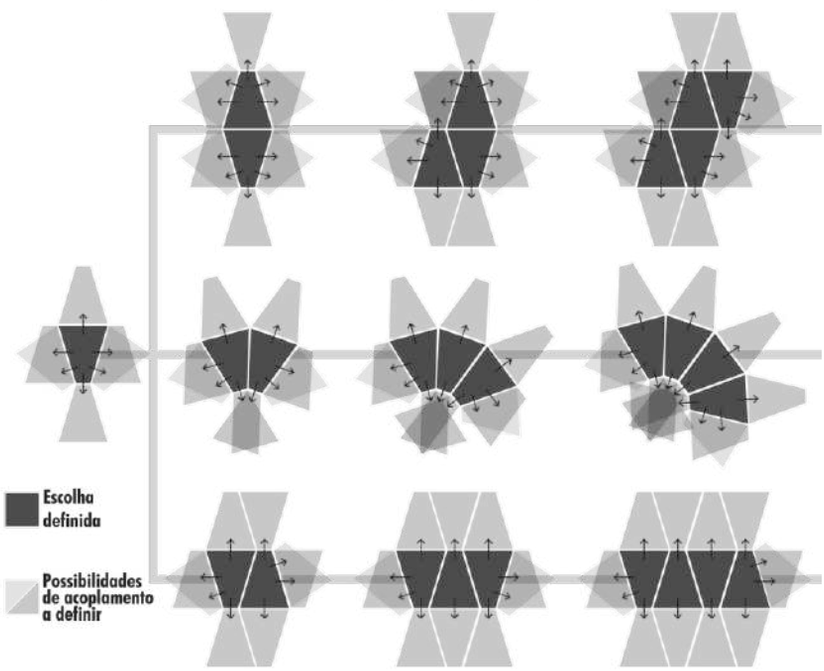

Figura 7. Demonstração das possibilidades de acoplamento permitidas pela geometria.

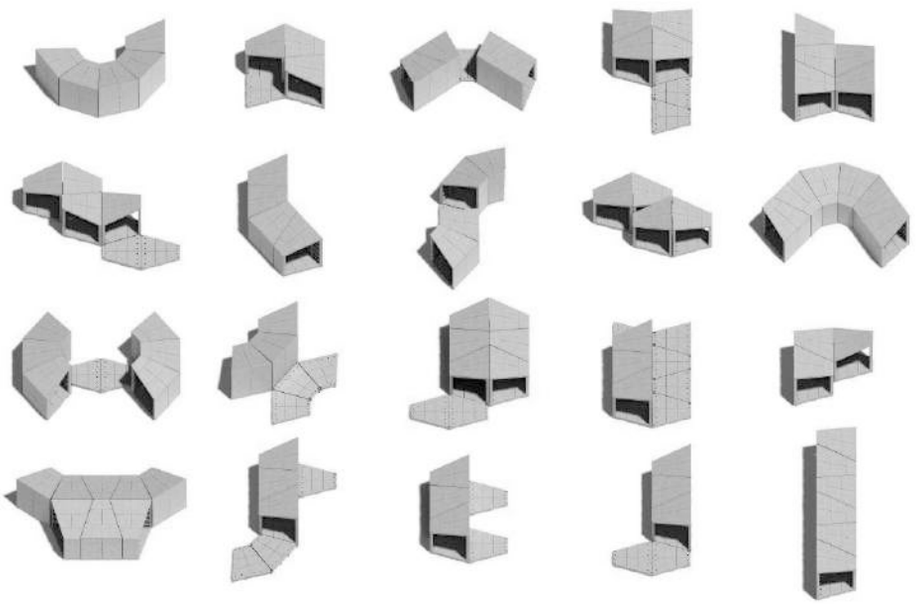

Figura 8. Estudos de acoplamentos diversos a partir do módulo desenvolvido na pesquisa.

Figura 9. Estudos de acoplamentos diversos para pavilhões temporários.

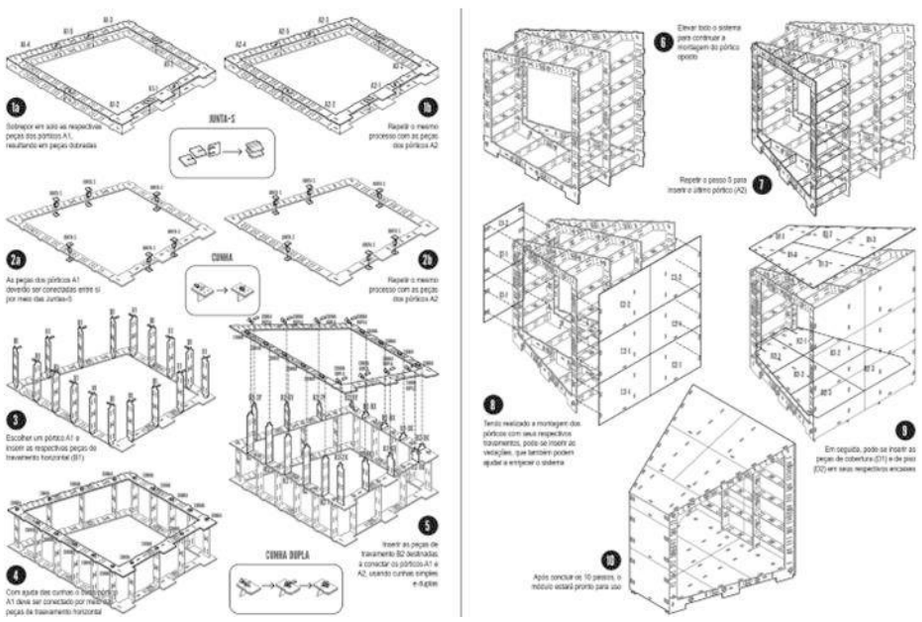

Figura 10. Manual de montagem desenvolvido para o sistema.

4 Discussão

Como resultado, essa pesquisa contribui para ampliar a variabilidade formal do sistema construtivo da Wikihouse, apesar da repetição do mesmo módulo e geometria de pórtico ao propor: (1) um módulo trapezoidal que permite variação dos arranjos modulares; (2) a rotação dos perfis da cobertura, para facilitar o espelhamento dos módulos no momento da construção. A pesquisa também considerou as estimativas de tempo de produção e custo das unidades.

Como etapas subsequentes, pretende-se otimizar o número de peças, para a redução do custo e do tempo de produção, bem como a construção de um módulo na escala 1:1 para a validação da estabilidade construtiva do sistema

5 Agradecimentos

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6 Referências

Almeida, J., Bevilaqua, D., Piaia, L., & Secchi, C. (2021). "Tec-House: Itinerant Modular Space Based On Digital Fabrication", P. 1499-1510 . In: Xxv International Conference Of The Iberoamerican Society Of Digital Graphics. São Paulo: Blucher.

Barreto, B., & Schmid, A. (2017). Um Olhar Sobre O Design Science Research: Construções E Desafios Possíveis De Uma Arquitetura Temporária. Revista Mundi Engenharia, Tecnologia E Gestão, V. 2, N.

Branco, B., Canuto, R., & Cantalice, A. (2017). "Fabricação Digital Aplicada À Habitação De Caráter Emergencial: Um Estudo Sobre A Adaptação De Wikihouses Ao Contexto Ambiental Brasileiro", P. 325-332. In: São Paulo: Blucher, Issn 2318-6968, Doi 10.5151/Sigradi2017- 051

Caetano, I., & Leitão, A. (2020). Architecture Meets Computation: An Overview Of The Evolution Of Computational Design Approaches In Architecture. Architectural Science Review, V. 63, N. 2, P. 165- 174.

Caetano, I., Santos, L., & Leitão, A. (2020). Computational Design In Architecture: Defining Parametric, Generative, And Algorithmic Design. Frontiers Of Architectural Research

Campolongo, E., & Vicente, C. (2018). "Optimization Of A Constructive System Of Subtractive Digital Fabrication: Prototypes And Tests Os Fitting System", P. 423-433 . In: . São Paulo: Blucher.

Guy, B. et al. (2003) Design For Disassembly In The Built Environment. City Of Seattle: Wa, Resource Venture, Inc. Pennsylvania State University

Kronenburg, R. (2003). Portable Architecture. Routledge.

Mendonça, D., Passaro, A., & Castro Henriques, G. (2018). Wikihouse: A Generative And Parametric Tool To Customize Curved Geometries. (D. Sperling, S. Vizioli, Eds.) Proceedings Xxii Sigradi , Iau-Usp. Anais. S.Carlos: Sigradi, Blucher.

Nardelli, E., & Backheuser, L. (2016). "Sistema Wikihouse Aplicado Ao Programa Minha Casa Minha Vida", In: Sigradi 2016 [Proceedings Of The 20th Conference Of The Iberoamerican Society Of Digital Graphics - ISBN: 978-956-7051-86-1].

Nardelli, E., & Pereira, V. (2017) "Autoconstrução, Fabricação Digital E A Construção Autônoma", P. 340-344.

Paula, N. (2019) “O potencial da prototipagem e fabricação digital na produção de abrigos emergenciais”. Dissertação (Mestrado em Arquitetura e Urbanismo) - Universidade Federal de Viçosa, Viçosa. 2019.

Passaro, A. & Rohde, C. (2015). Casa Revista: Arquitetura De Fonte Aberta Proceedings Xix Congresso Da Sociedade Ibero-Americana De Gráfica Digital, 2015, Pp. 70-76.

Rocha, B., Alvarenga, A., & Bolssoni, G. (2021). "Open-Source Social Housing Architecture: Wikihouse “Sr. Manoel”", P. 91-102 . In: Xxv International Conference Of The Iberoamerican Society Of Digital Graphics. São Paulo: Blucher.

Towards a Parametric Variation of Floor Plans: a Preliminary Approach for Vertical Residential Buildings

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Abstract. In the context of the housing demands that respond to several family profiles, allied with the potential of the algorithmic approaches to Architecture, this paper aims to describe an exploratory process of possible solutions toward a generative system of housing distribution in vertical multifamily buildings. As a method, this work presents a parametric design process of a multifamily building, simulating a variety of shape solutions for apartment buildings, in a Grasshopper definition. The work also discusses the data transmission between the parametric modeling using Grasshopper in the Rhinoceros interface and the connection of the final design to Graphisoft's Archicad BIM-based software. As a result, the parametric model allows several design solutions for several building shapes and contexts. For this study, to fully explore the design possibilities, we applied the method in the context of a Brazilian metropolitan city.

Keywords: Generative design, Parametric model, Parametric architecture, Housing, Vertical buildings

1 Introduction

The traditional practice in Architecture is, by nature, customized according to the user demand. However, it is still focused only on a single final product. On the other hand, despite the advances in computational technologies such as algorithmic and parametric design, the Civil Construction sector remains more inert to manufacturing changes at a large scale related to digital fabrication, especially in South America. In this context, there is still a lack of practical experiences that apply the real possibilities that computational design brings to the practice of architecture in our days.

Before the First Industrial Revolution, the manufacturing process was predominantly artisanal. The production processes ended up being customized since it was not possible to establish quality control to produce identical objects

from the hands of the same craftsman. According to Celani & Frajndlich (2016), with the emergence of specialized machines, mass production came on the scene, which means a large-scale production of identical objects. However, with the advent of computers, other computational design and manufacturing processes emerged. As Celani & Frajndlich (2016) state, this allowed the use of non-specialized machines to produce also non-identical objects, such as industrial robots and other computer-controlled machines (or CNCs). The versatility of the machinery makes it possible to explore new and even unique results, directed to specific problems and specific needs (Celani & Frajndlich, 2016; Celani & Pupo, 2008; Kolarevic & Duarte, 2019).

Meanwhile, since the 1960s, we have been discussing the terms digital design, computational design, and algorithmic design, among others (Caetano et al., 2020). These terminologies are nothing more than attempts to address the same theme, precisely the use of computers as a tool for design processes. According to Caetano, Santos, and Leitão (2020), in the last two decades, computational design techniques have been applied in Architecture more focused on new approaches based on computing, such as simulations, optimizations, and new manufacturing methods. Also, according to them, the explorations of computing in architecture have gone deeper through design procedures automation, distributing project tasks and managing large amounts of information, dealing with changes in projects quickly and flexibly, and assisting in form-finding processes through automated feedback.

Another aspect of our questions wanders about the Open Building concept. Defined and deeply studied by John Habraken (1961) and Stephen Kendall (1999), Open Building is a design approach that tries to make possible for long-term usage of the building, for different family profiles as the years pass by, and for the same family as they change their needs due to the passing of time. To accomplish that, they think of a building as composed of several layers, which are grouped into two main levels: the Support (or Skeleton) and the Infill (Avalone & Fettermann, 2020; Habraken, 1961; Kendall, 2004). The Support is supposed to be the most “solid” parts of the building, such as structure, accesses, and common circulation areas, as the Infill can be the interiors of each housing unit, internal walls, and even plumbing systems, that can be designed more flexibly, as to allow for future interventions (Kendall, 2004). In Open Building, these different layers take into account their lifecycle separately, and not the building’s as a whole, and that can be used to design each of the layers as separate parts of a complex design solution.

In this context, this paper shows a possible application of an algorithmic and parametric design toward a generative system for housing in a vertical residential building. In addition to the demand for a variety of housing units for different family profiles, the vertical building has some constraints such as water and sewage installations, and vertical structural elements, among others, that

we need to overcome to achieve different solutions. That is where the Open Building comes in, as we can structure our building according to an open building process, where we define what are Supports and Infills, and allow each of them to be treated and solved separately. As a premise, we seek to combine the algorithmic and parametric design to achieve several possible outcomes, structured algorithmically, to meet diverse demands on a large scale, more than only flexible solutions for standard floor plans.

However, this paper presents only a conceptual model, in the early stages of the design, to be used after all the studies concerning feasibility have already been made and before the definition of spaces and layout distribution. Our proposed model combines a generative design system through a graphical programming language (in Grasshopper) and a BIM-based model (in Archicad) of a possible solution to a vertical residential building.

This study also does not involve the end-users or any platform for public interaction or design choice. However, the code allows solutions suitable for different inputs according to several family profiles. As a case study, we have applied and tested the algorithmic definition in the context of a metropolitan city in Brazil. The aim was to explore a variety of apartments according to different resident demands.

The contribution of this work relies on a take on a code to help in the design of apartment plans on vertical buildings, which is an approach with a few examples from literature. One of those is the customization approach from Veloso et al. (2018), but that is a study regarding shape grammars and an interface for users. We, at our actual stage, think of a code to help designers think of architecture on an Open Building approach, where the Support and Infill portions can be previewed and conceived without affecting the future flexibility necessary to Open Buildings.

2 Methods

The research methods follow four stages: 1) Analysis of some case studies of algorithmic-parametric processes to housing generative systems; 2) Development of a parametric model, using Grasshopper and Rhinoceros software; 3) the integration with BIM software Graphisoft's Archicad, to data extraction, documentation, and visualization of the virtual model. However, in this paper, we focus only on the third and fourth stages.

The Grasshopper definition, based on one example developed by Swedish Architect Jesper Wallgren (2020), and made available at his website (*finch3d.com*) allows: a) the design of the building shape or perimeter, such as L, I, U shapes, and several others, in a way it adapts to different site contexts and terrains sizes; b) Subdivision of each floor plan level in different apartment

units, with size solutions ranging from 45m² to the total area of the floor; c) Internal subdivision of each apartment into rooms, according to the size of prefabricated and standard constructions components (drywall, steel-frame, and others); d) the subdivision of each apartment unit into “dry” and “wet” areas, to rationalize the plumbing system, according to the need for solutions of bathrooms, restrooms and kitchens; e) Definition of variations of porch and balconies to all the units; f) A preliminary structural launch, to preview the beams and columns positions, according to the building floor plan; g) Connection to a BIM-based software, to obtain data such as material, standard components, and documentation.

2.1 Parametric modeling

We defined some ground rules to develop the Grasshopper definition:

The units would follow a linear location in the floor plan, which references the perimeter of the building, determined by previous terrain analysis. For this purpose, the designer needs to provide only a curve-type geometry in Rhinoceros, containing the total length of the building and perpendicular to the division. As input, we can select the width of the units, and the code will distribute them in rectangular blocks, combined into different housing units.

To control the areas of each apartment, we used as a reference a subdivision algorithm created by the Swedish architect Jesper Wallgren, (available at *finch3d.com*) that generates adaptative plans. His grasshopper definition works based on the total area of a floor plan, subdivided into different parts according to a numerical factor. Then, we specified some target areas as the sizes we want to reach for each apartment. And then we have a fourth parameter, that randomizes and redistributes the list of targets so that we can verify different organizations for each housing unit. This improvement allows us to test different results for each plan and analyze the distribution according to the building shape or other architectural constraints. In other words, the code can take the divided pieces and merge them accordingly to the areas we provide as targets. In the following step, we can decide the number of levels or floors and adapt the functionalities to the particularities we face in each context.

Each apartment is divided into two parts: one related to wet areas, which concentrates the sanitary facilities and plumbing systems, and the opposite one is destined for areas of personal or social living, such as bedrooms, living rooms, and dining rooms. The sanitary facilities side concentrates the plumbing and is reserved for bathrooms, restrooms, kitchens, and laundries, close to the access and vertical circulation. The other side grants possibilities for balconies and allows more natural lighting and air circulation.

The wall’s surfaces follow an industrial standard drywall structure, 1.5 meters multiplier apart. This modulation of 1.5 meters can fit minimal bathrooms, and laundries, increasing to minimal bedrooms of 3.0 meters by 3.0 meters, and so on, up to larger dimensions for any room. With this starting point

logic, the code can solve the first pre-dimensional steps and subdivide the floor area into multiples of 1.50 meters by 1.50 meters.

As a final step, it is possible to define a preliminary structural system, stating the parameters for the distance and dimensions of columns and beams. However, the code does not allow designing the layouts and furniture of the apartments, which could also be a design decision tool to personalize each housing unit.

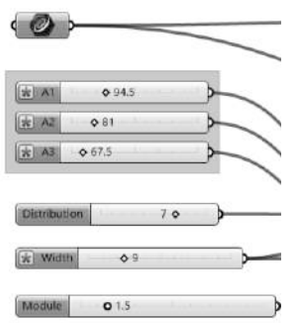

Figure 1. The image illustrates the main parameters as inputs to the algorithm. The geometry component is an input for the guide curve. “A1”, “A2” and “A3” represent the target areas, defined for each apartment. “Distribution” is the randomizer of the list of target areas after quantification. “Width” means the depth of the units. And “module” is the size of the prefab constructive components. Source: the authors.

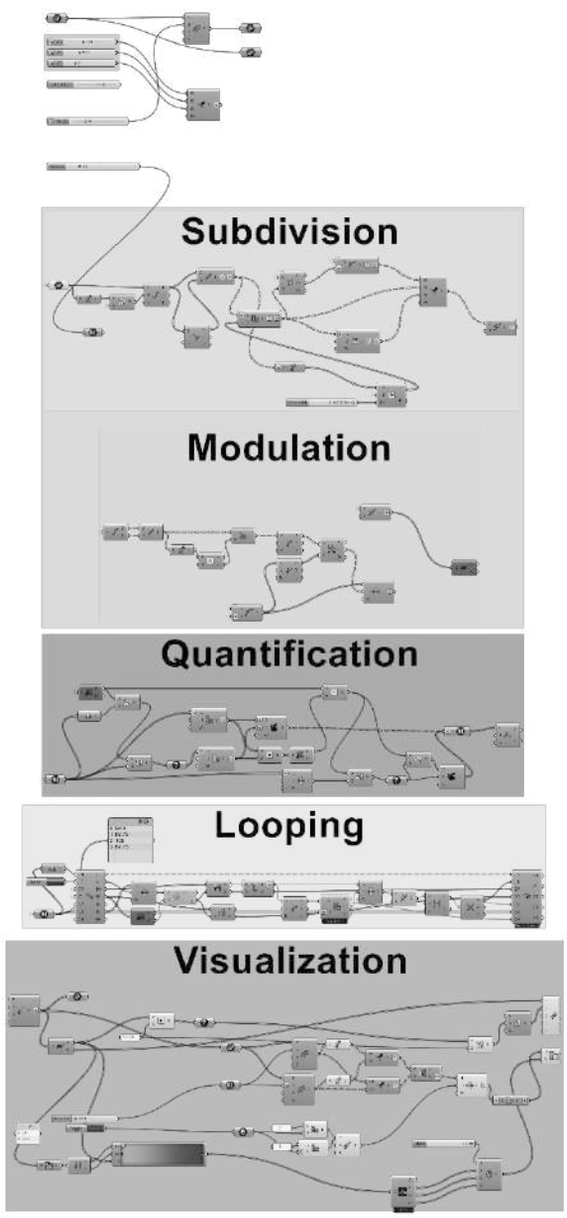

Figure 2. This Grasshopper definition allows the subdivision of each floor plan. The stages defined as subdivision and modulation organize the geometry according to the settings of Width and Module parameters. Quantification and looping derive from Jesper Wallgren's (2020) code. The first sums the target area and relate the number of them it will create in the "looping" stage. "Visualization" is used to define the visual tridimensional appearance of the resulting model. Source: the authors.

Once the base structural system could be defined through the algorithm, being the preliminary positioning of beams, columns, and slabs the main concern, in this case, we can say that this part can define the Support portion of the building, according to Habraken's (1961) and Kendall's (1999) definitions. In their studies, the Support is more than just the concrete portion of the building. It also includes the surroundings, the neighborhood, and the relationship of the residents with these elements (Avalone & Fettermann, 2020; Kendall, 2004). As to the Infill portion, which is not in the scope of this work, we think of it as being possibly solved by standardized solutions available in the construction market, such as drywall, wood, aluminum, and steel, and standard insulation and plumbing systems, as long as they can be easily assembled and disassembled as needed. All of these solutions already appear in other Open Buildings around the world (Kendall, 2017)

2.2 Data transmission to a BIM-Based software (Archicad)

As a means to keep the design process being fed by information concerning material costs and properties, we proposed the use of data transmission between the parametric modeling in Grasshopper to Graphisoft's Archicad, through the plugin Archicad Live Connection, as suggested by Veloso et al. (2018), in their study on the customized layout, due to its friendly interface and easy and fast translation of Grasshopper's code into Archicad's 3D model. As a first approach, to enable a lower-cost fabrication, we chose standard components, such as drywall and steel structures, already available in the construction industry. Even these discrete construction components are not customized, as digital fabrication processes such as 3d printing, the code allows several architectural solutions and combinations. Through this workflow, we can change the whole subdivision on each floor and update it in real time. The BIM model also updates all the information, representation, and statistics. This data transmission allows an interconnected system for sketching, evaluating, analyzing, reconfiguring, adjusting, and verifying every step in this workflow.

3 Results

We placed the building in a high-rise neighborhood, in a Brazilian metropolitan city, as a generative process requires diverse family profiles and specific solutions for the demands. We chose a lot where the legal restraints would allow a building of twenty floors, disregarding the parking and ground floors.

Following the dimensioning and the solar orientation studies, we defined the guide-curve as input into the algorithm, generating the first design possibilities. These possibilities will be directed towards the design of the Support, regarding

Habraken's (1961) Support Theory for Open Building, being considered as Support, in this case, the structural frame and the slabs for each housing unit. The Infill portion will then be able to be analyzed individually for each unit separately, in another stage of the design.

As the strategy is to attend to different family profiles, we tested several numerical values as inputs for the target areas. We decided the lower levels would have more units with smaller sizes, while the upper floors would have fewer units with larger sizes.

For the internal layouts, we defined a strategy to keep the bedrooms on the east side, while the wet areas, which concentrates on the water systems, on the other. All the rooms have natural light and air circulation as a premise. As the last step, we designed a system to create a series of balconies around the whole building, which follows the internal plan variety, on the façade. Following an alternated pattern of 1.5m or 3m advancement, the balconies draw a zigzag around each level, and the boundary angles change on the limits between apartments.

As a result, the algorithm allows us to explore different possible design solutions for the Support portion, within different building shapes. The architect can define the floor boundaries, which means the guide curve, after analyzing the site and the total area. The designer can also explore several possibilities before choosing the best ones according to some constraints or goals.

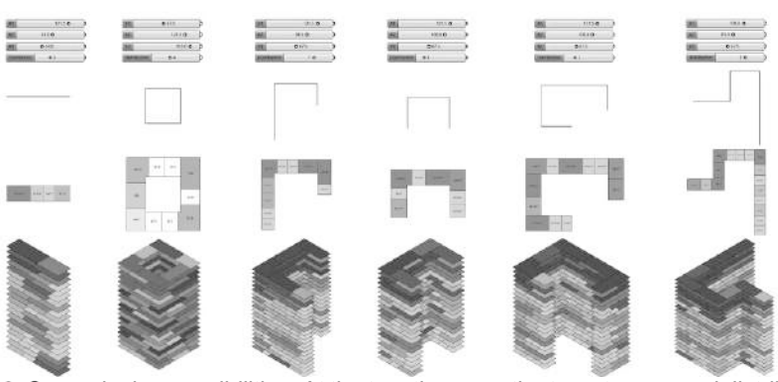

Figure 3. Some design possibilities. At the top, there are the target areas and distribution parameters. Right below it, there is the guide curve as the perimeter of each building. Then, an example of a floor subdivision in apartments and their vertical distribution is stacked in the shape of the building. Each different guide-curve results in different shaped buildings, so that the Support for said building can be studied and defined. After this stage, each unit can have its Infill portion designed individually. Source: the authors.

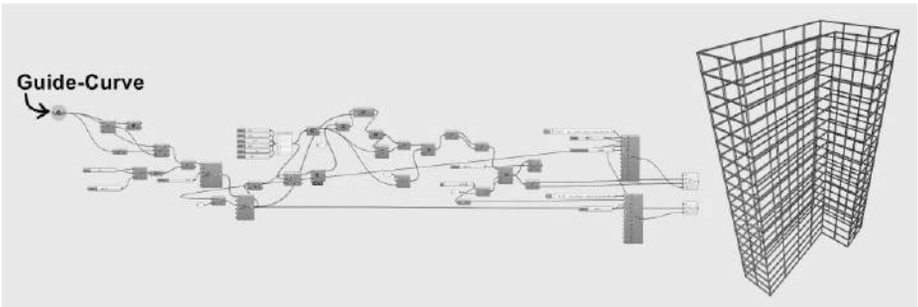

Figure 4. The schema of the structural elements, through the connection to Archicad. In this example, we show the shape of the guide curve for the selected urban context, in an L shape. The pillars and beams in this example are H and I profiles, chosen just as a generic representation of the possibilities. Source: the authors.

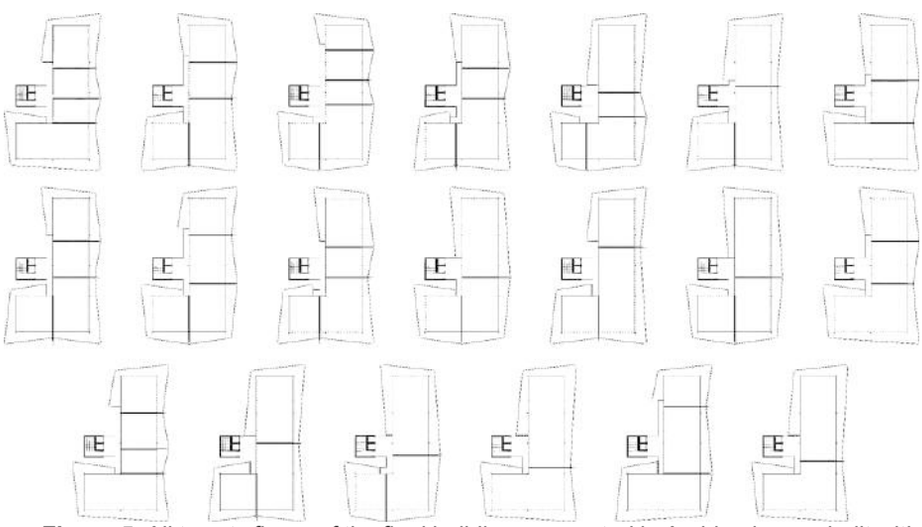

Figure 5. All twenty floors of the final building, generated in Archicad, were built with slabs and walls, and the balconies, were strategically designed to represent the variability of the plan and apartment sizes. Source: the authors.

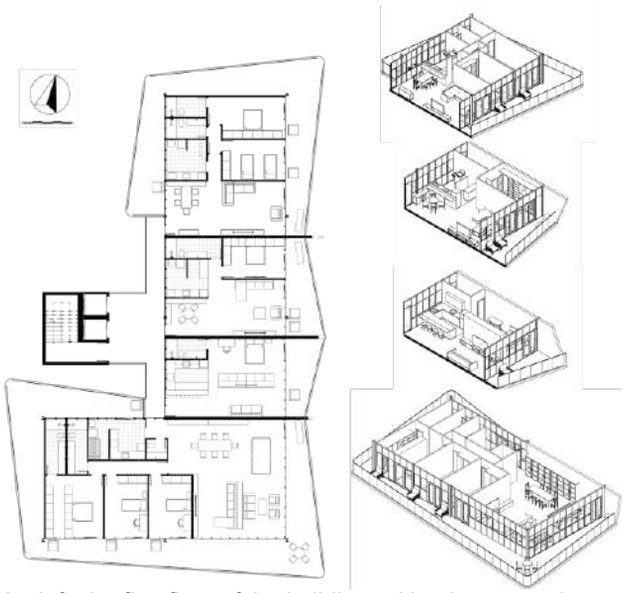

Figure 6. On the left, the first floor of the building, with a layout study, each room with a possible solution according to the unit size, thought to attend to the different family profiles. To the right, perspectives of the apartments for a better understanding of the created space. Source: the authors.

Figure 7. A final perspective of the building and the variability of the terraces, as they follow the floor plans. Source: the authors.

4 Discussion

Far from constituting an answer to the topic, this article aimed to shed light on potential applications, in the conceptual design stage, through an algorithmic process, towards a system that generates guides to possible solutions in architecture. Not as a tool to find a perfect design, but as a tool to help architects to study and analyze more options than what could be achieved manually. In that sense, we believe computational design can improve the decision-making process by helping architects think more about design rules than the design itself.

Placed between the feasibility study and the design of the internal layout, we believe that our code can help architects to visualize several different solutions for vertical buildings, instead of the usual typological plans, that don't work for every family profile, nor every people's needs. And, as an "in-between" stages tool, ours can have its results being used as input for other tools, that generates house and apartment plans, based on an initial geometry of the outline of the unit. Some of these tools are already available as plugins for Grasshopper and can be found at *www.food4rhino.com*. Testing how these tools can be connected to our own is something that we might want to explore in future works.

As a work in progress, there are still some limitations. The first improvement would focus on adding a function to exclude the results that have some problems regarding access, circulation, or openings. Another interesting addition would be a system to draw a preliminary approach to the plumbing system, connecting the "wet" areas and optimizing them.

For future works, we also aim to design a more user-friendly platform to help the decision makings. This platform could also allow architects to manipulate and test the parameters and give visual feedback about the tried solutions.

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References

Avalone, M. C., & Fettermann, D. de C. (2020). Demandas de customização em edifícios residenciais no Brasil: uma análise de agrupamentos empírico-qualitativa com base no sistema Skeleton/Infill. *Ambiente Construído*, *20*(2), 489–503. https://doi.org/10.1590/s1678-86212020000200411

Caetano, I., Santos, L., & Leitão, A. (2020). Computational design in architecture: Defining parametric, generative, and algorithmic design. *Frontiers of Architectural Research*, *9*(2), 287–300. https://doi.org/10.1016/j.foar.2019.12.008

Celani, G., & Frajndlich, R. U. de C. (2016). From prototypical to prototyping: mass-customization versus 20th century utopias in architecture and urban design. *PARC Pesquisa Em Arquitetura e Construção*, *7*(3), 160. https://doi.org/10.20396/parc.v7i3.8647348

Celani, G., & Pupo, R. T. (2008). Prototipagem rápida e fabricação digital para arquitetura e construção: Definições e estado da arte no Brasil. *Cadernos de Pos-Graduação Em Arquitetura e Urbanismo*, 31–41.

Kendall, S. (2004). An Open Building Strategy for Achieving Dwelling Unit Autonomy in Multi-Unit Housing. *Housing and Society*, *31*(1), 89–102. https://doi.org/10.1080/08882746.2004.11430500

Kendall, S. (2017). FOUR DECADES OF OPEN BUILDING Realising Individual Agency in. *Architectural Design*, *87*(Issue 5), 54–61.

Kolarevic, B., & Duarte, J. P. (2019). *Mass Customization and Design Democratization*. Routledge.

Veloso, P., Celani, G., & Scheeren, R. (2018). From the generation of layouts to the production of construction documents: An application in the customization of apartment plans. *Automation in Construction*, *96*(September), 224–235. https://doi.org/10.1016/j.autcon.2018.09.013

Wallgren J. Finch 3D website - Templates for download. Retrieved October 14, 2020, from https://finch3d.com/

A neo-postnatural high resolution aesthetic by Cellular Architecture

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Abstract. The level of detail in architecture is part of our legacy since our discipline has existed as a catalogue of parts, linking art and nature by using concepts of imitation, selection, neatness, and ornament. This research expands the idea of “high resolution” in architecture as a step forward in defining detail and ornament as a way of finally merging the structural and functional dimension of space with the detail and ornamental dimension of a design proposal. In that framework, this work-in-progress research emerges as an opportunity to use Cellular Automata (CA) and its principles to create coherence between different scales in the inhabitable space from a bottom-up approach. CA principles work in both computational levels (as logical machines) and a biological simulator (artificial life), enabling us to cross borders between natural and unnatural in a multi-scale design approach.

Keywords: Generative Design, Detail, High Resolution, Cellular Automata, Multi-scalar

1. Introduction

As a field that began in the Renaissance as a catalogue of components (Alberti, 1450), architecture has a long history of bridging art and nature via the application of notions like imitation, selection, neatness, and adornment. As part of the experimentation-creation-construction process, this final concept is the one that enhances the environment by adding a layer of super-nature to the architectural environment. In this way, the ornament (as a detail) enhances the bare space, assisting in creating "beauty" by mimicking imperfect aspects of nature while also forming nature as a whole.

Architecture, as a proto-discipline before Renaissance, used to be a component of collective creation, like cathedrals or temples from antiquity, where rules and negotiations among various actors governed the building process (Carpo, 2011). At the same time, it was being built and where the

material served as the vehicle to reveal the true nature of a freshly imagined space. As a "little element of the total, yet it has the potential to characterize and identify the complete edifice," the craftsmen were those who were making the "detail" at that time (Weber, 1991). "The whole is to the part as the part is to the whole" in this meaning. Detail and ornament may be viewed as an architectural action on a different scale, one that acts as a constant tactile link between people and their surroundings and fosters diverse interactions with the environment, including emotional ones, because of the presence of evocative language.

Following the Industrial Revolution (Carpo, 2013), standardization procedures eliminated the minimum amount of "porosity" that enables us to produce various contrast levels, light and shadows on multiple scales. This eventually decreased the relationship between detail and occupant. Instead, architecture devolved into a monotonous series of discrete, utilitarian parts unrelated to one another or other aspects of the urban fabric at various scales.

Detail as an ornament (or lack thereof) has always served a purpose connected to aesthetic and cultural factors, representing the era in which the space was conceived (Moussavi, Kubo, 2006). It is a reinterpretation of the environment and its patterns in an exceptionally provocative and logical way, understanding rules, proportions, and connections as information to be transmitted to the inhabitants in touch with the architectural space.

Since modernism, architecture has minimized to the maximum extent possible, causing a critical disconnect between space and user and exacerbating structural and functional factors rather than maintaining them at the same level (or even subordinating them). This situation has persisted in recent architectural developments because "ornamentation" was no longer necessary due to a "more sincere" conception of space. Detail and its reconnection to the building are revisiting Alberti's original definition of architecture in his work, in which detail and its understanding of expression, construction, and materialization processes, as well as discretization, aggregation, behaviors, and growth, are now upgraded.

In a more recent definition, this research widens the notion of "high resolution" in architecture as a development of the meaning of detail and ornament that was previously mentioned and as a means of finally fusing the structural and functional dimensions of space with the detail and ornamental dimension of a design proposal. The qualities of architectural objects and the procedures used to build them have changed qualitatively and quantitatively due to the capacity to make design decisions with more accuracy and resolution. This results in a difference in how such things could be understandably beneficial in a contemporary context.

As a result, every architectural form must-have detail, which comes in a variety of depths and high resolution, works for human perception and frequently for the important organizational traits and performance of a newly constructed space. As in the study of cellular division and its application to design at various scales, high-resolution architectural fabrics are characterized

by fuzzy borders, full of ruptures, similar to those defining the physiology of an organism, but bizarre and unnatural (Andrasek, 2018). Finally, a building's entire shape may be filled with details in the form of color, texture, or patterns in a 2D, 3D, or even more, including time dimension, depending on how the design assembles the specific set of issues or materials, processes, and scales (Figure 1).

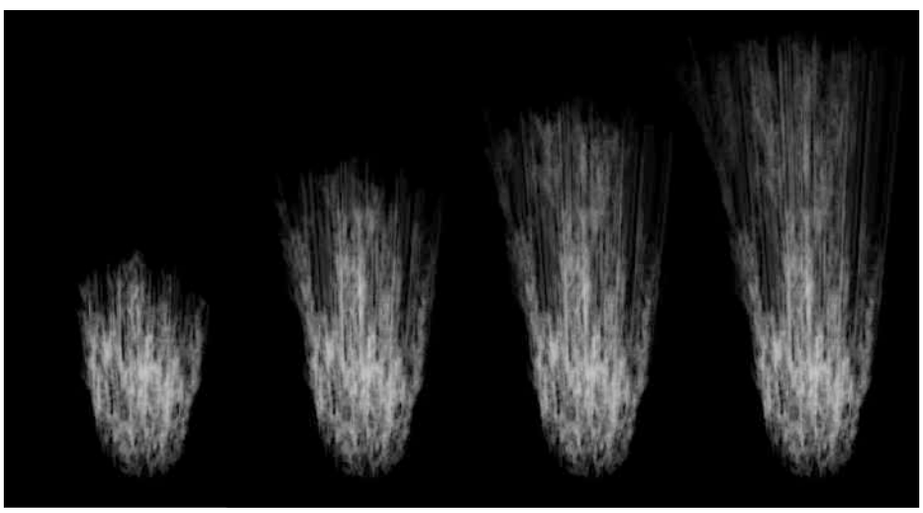

Figure 1: Incremental Cellular Automata column as time based 3d structure after 350 steps (image from the author)

2. A neo-postnatural aesthetic

Cellular Architecture uses Cellular Automata simulations to build architecture as a continuous design process, crossing scales, starting from detail (the seed) to the space (discrete system), using the environment (neighborhood) as a source of raw material to be reshaped into high-resolution spaces. This contrasts with the top-down design methodologies currently used widely in the architectural design profession. Due to this, the primary research framework is based on the transition from computational thinking to architectural design thinking, which involves several stages from the field of mathematics to automation and, ultimately, architecture as a physical manifestation of that theory in the living space.

In that context, this study offers a chance to apply Cellular Automata (CA) and its principles (Wolfram, 2002) (Hoekstra, Et al., 2010) to integrate various

sizes in the inhabitable area by starting at the bottom up. In a multi-scale design approach, CA principles operate at both computational levels (as logical machines) and as biological simulators (artificial life) (Von Neumann, Burks,1966), allowing us to blur the lines between what is natural and what is artificial. These hybrid operations enable us to create artificial bodies (Oosterhuis, 2003) (Langton, 1996) that are a hybrid of nature and technology.

Based on the previous points, it is possible to understand detail as an ornament that adds an artificial pseudo-natural level to the existing space (as an original subtract). Following rules and principles from nature, the original support through the application of design principles comes from the historical pathway that led to the evolution of "the detail" till today, in a discrete way of constructing reality (due to its efficiency since ancient times), adding a higher level of detail (Figure 2).

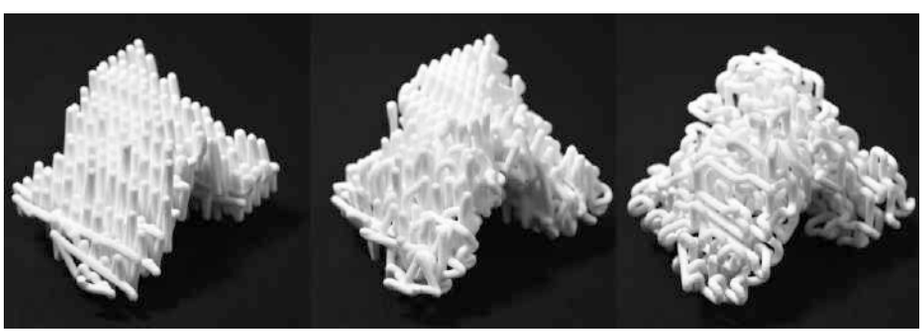

Figure 2: Same collection of Cellular Automata being translated in three different continuous processes (image from the author)

In the Post-Natural perspective, any living entity that humans have purposefully modified through domestication, selective breeding, or genetic engineering, a method of breeding organisms to satisfy a specific cultural requirement, is referred to initially in this concept. As used in cellular architecture, this concept primarily refers to the selected process by which cellular automation, which functions as artificial life and a logical machine, is digitally copied (or self-replicated) to achieve a high degree of detail in the design (as cultural material manifestation). This idea is realized by filling the area with solutions that can improve the current structures (Frazer, 1995). In this way, "the missing link" between the many layers of human-made settings may be developed by cellular architecture, which can read environmental norms and identify a set of potential outcomes to be constructed as the final step.

Last but not least, this research progressively enhances Von Newman's Automata Theory as a chance to create the first logical and physical models based on generative logic with origins in a "seed" cell named "automaton".

In that sense, the concept of "neo" ("new," "recent," "revived," or "changed") has been used as "a new and different form of something that existed in the past" (Britannica, 2022) semantically: cellular architecture follows automatic steps (details) over a discrete field (space), learning from the surrounding contextual data (environment) as well as from itself and providing information about coherence inside/outside different scales, using "neo" as a strategy of revisiting data from the past inside the code.

3. A high level of detail as a research method

This work examines the application of cellular architecture to the built environment in a synthetic approach, which includes a variety of theoretical scales (from neighborhoods to livable spaces). In that sense, incrementing the detail in our cities using a high-resolution multi-scalar approximation could redefine how we view our bodies and the natural world by incorporating highly customized and interactive datascapes.

We do not need an infinite number of distinct machines performing infinitely many different tasks, as Turing noted in 1948. It only needs to be one. The office task of "programming" the universal machine to perform these tasks replaces the engineering challenge of creating different machines for different purposes (Turing, 1948). According to this theory, a cellular automaton solution of a small size must tackle diverse issues on various scales by simply increasing the number of new cells while operating, after which the procedure may be used as an available solution.

The system memory is constructed as a structure that accumulates steps that earlier generations of the same seed were creating over a solution constantly refined on each step as an incremental level of detail resolution. The high-resolution process is not just about the number of steps a CA will run as a generative process (Fernandez, 2022).

Similar to this, the incremental level of resolution can also work as an expansion of Moore machines or Von Newman automata (Koh, 2022) to add precision to the final result of the generative operation, saving steps in the process. In practice, as there is a greater range of neighbors around a seed, fewer generations are required to produce a valid result. In this view, the degree of detail and its increments, together with the incremental memory process, are searching for a more exact outcome, recognizing detail as a remedy for a multi-scalar architectural issue.

The set of experiments that are part of this research is understanding a CA firstly as a "detail generator", working in an asynchronous way in which the rules are the initial catalogue of elements to be distributed during the creation of a structure that initially is working as a digital prototype (Figure 3 - Figure 4).

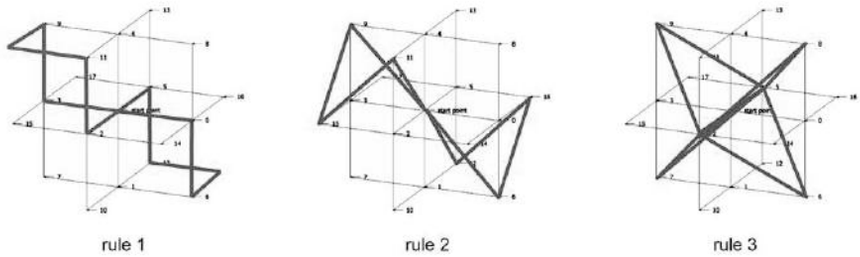

Figure 3: CA Rules as Details to be distributed in an asynchronous mode (image from the author)

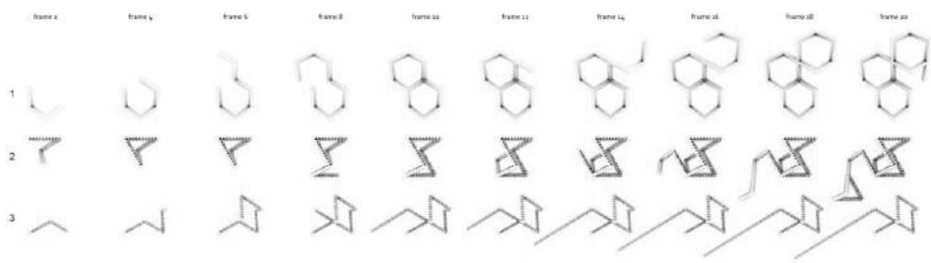

Figure 4: Asynchronous CA starting its first generation after 20 steps (image from the author)

After the first configuration of CA rules as “details”, the preliminary test on a 3d environment defined by a subdivided box of 50x50x50 units gives us the chance to appreciate different possible outcomes without any interaction with other elements than just its self-generated structure. These tests proved an exciting result about continuity and density where the same rule could create structures and forms in a high-density way without any additional help (Figure 5).

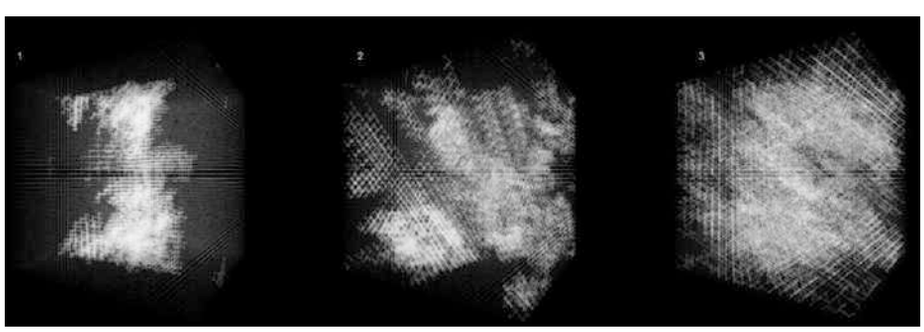

Figure 5: Asynchronous CA after 3000 steps (image from the author)

The third step in this experiment used the first set of rules in a test of interaction with an environmental constraint as a three-dimensional problem to be solved by the CA, creating a restriction that finally tests the resilience of a

system like this one. After 1500 generative steps, the asynchronous CA understood the three-dimensional constraint (yellow vertical masses). From there, it created a structure that disables rules of expansion in X and Y directions and keeps the Z as an available direction to be taken (Figure 6). Finally, the result is a highly dense collection of cells represented as a white point cloud. This test is also genuinely remarkable without the interaction with a constraint in horizontal growing. The structure usually needs around 2500 - 3000 steps to consolidate a high-density point cloud to be translated as voxels for the next step in this experiment.

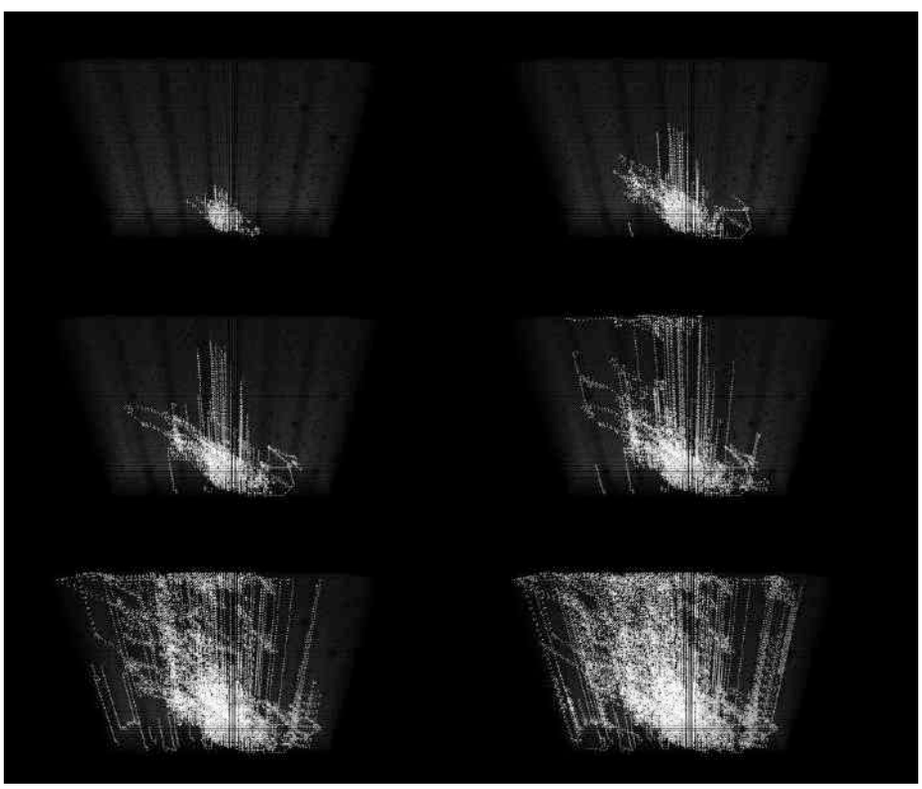

Figure 6: Asynchronous CA after 1500 steps with a three dimensional constrain as yellow mass columns (image from the author)

After all the previous steps, the collection of points is the result of the interaction between a grid as a discrete neighborhood, a seed (100 max) working asynchronously (a cellular automaton can update individual cells independently to the seed), and finally, a constrain in the 3d simulated environment (in this case a bitmap pattern). Creating a higher level of

complexity in this stage relies on the problem to be addressed. According to the principles mentioned in the previous sections, a CA as artificial life and logical machine (a detail) is applying the rules loaded from the initial memory as a deterministic construction mode. Still, with external data interactions, it is possible to enrich the result with more than just one degree of data, creating more complexities and densities, creating a three-dimensional grayscale constraint, and affecting the outcome complexly (Figure 7).

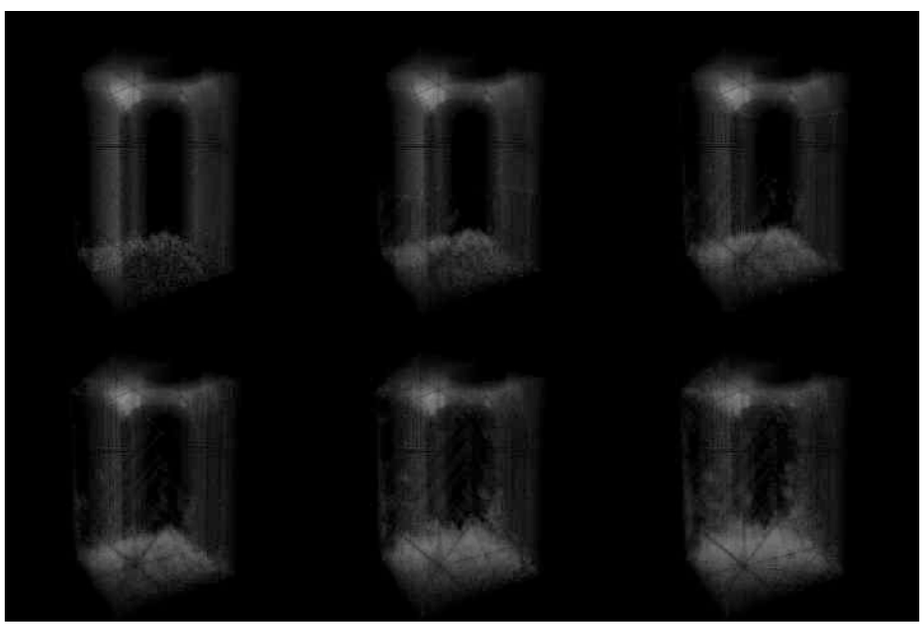

Figure 7: Asynchronous CA after 2000 steps with a three dimensional grayscale constrain on a 100x100x150 subdivided space (image from the author)

4. Conclusions and further steps

From the standpoint of Cellular Architecture, detail has more than just one unique quality; it also offers a different perspective on how an improvement in the generative design process as a degree of resolution may successfully revive earlier notions of detail and their connection to architecture. From that perspective, it is essential to emphasize the development that detail has gone through during its existence in architectural history and its relevance in developing contemporary design strategies.

Cellular Architecture acts as both a qualitative and a quantitative intermediary between the space and its inhabitants, as an additional layer of the spatial notion (working between data and nature). In that sense, the inextricable connection between nature and architecture (as an abstraction process) can now be re-understood as a component of the digital simulation agenda, following the pathway of artificial life and logical machine simulations.

Understanding the process that nowadays science and architecture are sharing (more closely related than ever before in the methods of digital simulation, material experimentation, and spatial expression), we must keep in mind the haptic dimension of the designed space without neglecting its aesthetic dimension and the data before and after that process.

The generative process behind CA as detail to be gradually improved is a concept that emerges as an opportunity in which digital creates new chances to develop the idea of detail, not just as an accessory for architectural space.

As a fundamental part of the space we are building, detail can operate as a building block with rules that find different positions according to the data we use as an environment to be colonized. From there, the concept of high resolution in architecture within a neo-post natural vision of how we are dealing with an aesthetical outcome emerges as an intentionally altered life simulation system that seeks high resolution under the frame of the incremental level of detail.

The previous perspective looks into a more precise generative result for the problems that a CA can face on different scales are two ways that Cellular Architecture is finally expanding the idea of detail. Finally, the keys in the system are: bigger neighborhood + more steps + more seeds = more detail = more accuracy. This research, which is still in progress, explores the increase in the result definition by adding frames to project development and a more comprehensive range of neighborhood interactions.

The following steps for this work will be the process of importing precise data from the environment as images that are breaking the deterministic way of growing a CA, pushing the system's limits into a direct link between detail, gradients, accurate information, and AI, generated based databases, accelerating the generation of various potential solutions to be generated by the same CA simulated seed.

References

Alberti, L. B. (circa 1485), *De re aedificatoria.* Manuscript, Codex Ms 1, Hanna Holborn Gray Special Collections Research Center, University of Chicago Library

Carpo, M. (2011). The alphabet and the algorithm. Cambridge, Mass, MIT Press.

Weber, P. D. (1991).Beyond bolts : architectural details, construction, meaning. Thesis (M. Arch.)--Massachusetts Institute of Technology, Dept. of Architecture.

Whole definition. https://franklloydwright.org/learning-by-doing-part-5-the-whole-is-to-the-part-as-the-part-is-to-the-whole/ last accessed July 5th, 2022.

Carpo, M. (2013). The digital turn in architecture 1992-2012. Chichester: Wiley.

Moussavi F., Kubo M.(2006). Function of Ornament Actar, Harvard University Graduate School of Design.

Andrasek, A. (2018); High Resolution Fabric of Architecture, Melbourne, Australia: RMIT School of Architecture and Design

Wolfram, S. (2002). A new kind of science. Champaign, IL: Wolfram Media.

Hoekstra, A., Kroc, J. and Sloot, P. eds. (2010). Simulating Complex Systems by Cellular Automata. Cham: Springer Nature

Von Neumann, J.. and Burks, A.(1966). Theory of self-reproducing automata. Urbana, University of Illinois Press.

Oosterhuis K.(2003). Hyperbodies : Towards An E-motive Architecture / Kas Oosterhuis. – Basel ; Boston ; Berlin : Birkhäuser

Langton, C.G., (1996). Artificial Life, The Philosophy of Artificial Life, 39-94.New York and Oxford: Oxford University Press

Postnatural concept. https://www.postnatural.org/About last accessed July 2th, 2022.

Frazer, J. (1995). An Evolutionary Architecture , London, England: Architectural Association

Neo definition https://www.dictionary.com/browse/neo last accessed July 1th, 2022.

Neo definition https://www.britannica.com/dictionary/neo- last accessed August 23rd, 2022

Turing, A. (1948). Intelligent Machinery - a report, National Physical Laboratory, London, England.

Fernandez, A. (2022) Cellular Automata, Memory and Intelligence, The 4th International Conference on Computational Design and Robotic Fabrication, College of Architecture and Urban Planning (CAUP), Tongji University

Koh, I. (2022). Voxel substitutional Sampling: Generative Machine Learning for Architectural Design, DCC'22: Tenth International Conference on Design Computing and Cognition, Glasgow Scotland.

Programming Cultures: Machine Learning

Eyes on the Street: Assessing Window-to-Wall Ratios in Google Street Views using Machine Learning

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Abstract. Windows play an important role in 'Eyes on the Street' in Jane Jacobs' theory. However, vital street-level parameters in her theory, most notably windows, are rarely assessed at the urban scale due to imprecise existing datasets. To resolve this challenge, this study proposes an automated computer vision-based methodology to extract the window-to-wall ratios (WWRs) of buildings in the Bronx, New York, using semantic segmentation machine learning. This study brings together machine learning and Google Street View (GSV) to accurately assess WWRs at the urban scale. The WWR distribution results show that street-level WWRs help to analyze with other urban data, with controlled parameters, such as land use and building age. Our WWR assessment can be universally applied to other cities using geotagged street view imagery of GSV. This study can help provide a reference for precise future urban design and management assessments.

Keywords: Machine Learning, Data Analytics, Google Street View (GSV), Visual quality, Window-to-wall ratio

1 Introduction

Street-level window-to-wall ratios (WWRs) have long played a critical role in assessing the visual quality – the visual stimuli that shape our perceptions, attitudes, and general views (Sheikh & Bovik, 2006) – of urban street façades (Li et al., 2020). The measurement of WWRs at an urban scale has been conducted only for building or urban energy assessments (Shi et al., 2020; Szcześniak et al., 2022).

Information on assessing WWRs for urban street-level visual quality is rare. Planners' and managers' ability to plan and manage urban façades effectively and efficiently is, therefore, limited. However, Google Street View (GSV) provides street-level profile views of urban façades (Charreire et al., 2014; X. Li et al., 2015; Rundle et al., 2011; Taylor et al., 2011) and WWRs. Yet, little

research on GSV with WWRs for urban planning exists. With the GSV information, assessed street-level WWR data can be incorporated into urban façade planning and management. Thus, we explore GSV as a street-level, urban WWR assessment tool to understand the visual qualities of the street, such as safety (Raskar et al., 2015; Zhang et al., 2018). We conduct a case study assessment of street façades using GSV images in the Bronx, New York City.

Our methodology involves four steps. First, the GSV Images (400x600 pixels) are collected in two directions vertical to the streets (Tsai & Chang, 2012) using the GSV Image API within the Bronx. Second, based on these large-scale street view image data, the pixel segmentation machine learning model – the Mask R-CNN model (He et al., 2018) trained on our labeled dataset – is used to measure the WWRs in the GSV images at an urban scale automatically. Third, the data predicted by the trained machine learning model are summarized, visualized, and analyzed.

The results reveal that GSV to be suited for assessing street-level WWRs. We suggest that WWRs extracted from GSV can be a relatively objective measurement of street-level visual quality and may be valuable in guiding urban façade planning and management.

2 Related work

In urban design, windows can increase the interaction between people in buildings and on streets. Moreover, Jane Jacobs concludes three necessary qualities that a city street needs to maintain safety as eyes on the street – a clear demarcation, eyes upon the street and sufficient buildings facing streets, and continuous eyes on the street to guarantee effective surveillance (Jacobs, 1961). In her theory, windows are one of the elements that play an essential role in the safety of eyes on the street. She further claims that "Lack[ing] the checks and inhibitions exerted by eye-policed city streets," they can become flashpoints for destructive and malicious behavior. Numerous studies have demonstrated the relationship between eyes on the street and crime rates from theoretical and criminological perspectives (Cozens & Hillier, 2012). However, none of the urban designers has ever demonstrated her theory on how much windows work as eyes on the street to build a safer community using urban data.

Visual quality (i.e., the impacts of visual features on people's feelings, aesthetics, health, etc.) stimulates our perceptions, attitudes, and general views of urban life (Forkenbrock & Sheeley, 2004). Assessing the urban visual quality accurately is important in the design and management of urban environments to demonstrate the theory of Jane Jacobs (1961). Quantitative assessments of urban visual quality aim to automatically measure the quality of images in a perceptually consistent method (Sheikh & Bovik, 2006). However, existing

studies on automated quantitative assessments of street facades are not accurate enough to guide urban design. For instance, many studies that measure urban visual qualities and analyze the possible related factors (Dubey et al., 2016; Zhang et al., 2018) do not accurately measure how much each visual element impacts urban environments.

Window-to-wall ratios (WWRs) of street facades are one of the most important evaluation indicators of visual quality. WWRs are typically estimated based on either the use of 3D laser scanning from street-view or aerial images (Früh & Zakhor, 2003). Although image processing techniques based on machine learning and computer vision have been used to extract façade geometries, they are largely insufficient for precise WWR calculations (C.-K. Li et al., 2020). Moreover, their fundamental weakness is that they depend on rigorous façade styles and quality requirements (Koutsourakis et al., 2009; Riemenschneider et al., 2012; Teboul et al., 2010, 2011) or photographs collected by human labor (Früh & Zakhor, 2003, 2004). These methods are "semi-automatic" and rely on significant human input. Additionally, existing urban image segmentation datasets are noisy with shadows from urban objects such as trees, or some windows are unlabeled. These urban image datasets, such as ADE20K (Zhao et al., 2017; Zhou et al., 2018) and Mapillary (Neuhold et al., 2017), PASCAL VOC (Everingham et al., 2010), and CityScapes (Cordts et al., 2016), cannot segment windows and walls precisely for accurate WWR calculations. Thus, we need a dataset to automatically assess WWRs on the urban scale to improve urban design and management.

To overcome these limitations, our research uses Google Street View (GSV) images (which have continuous street images from the perspective of pedestrians) to assess street-level building façades. GSV, first introduced in 2007, is a library of urban panoramic images captured by cameras on cars (Rundle et al., 2011). The visual quality of GSV is similar to people's experiences on the street by car, bike, or foot.

By stitching the images together, GSV images can create continuous building façade experiences of a streetscape. Thus, the GSV image library has been proposed as an effective potential data source for urban assessments (Rundle et al., 2011; Rzotkiewicz et al., 2018), such as public open space audits (Edwards et al., 2013; Taylor et al., 2011), neighborhood environmental audits (Charreire et al., 2014; Rundle et al., 2011; Odgers et al., 2012; Griew et al., 2013), and building energy audits (Shi et al., 2020; Szcześniak et al., 2022).

While we rarely find any study in the literature using GSV images and machine learning for urban assessment of WWRs, we decide to examine whether or not the application of GSV images with computer vision machine learning for assessing street-level WWRs can work effectively and efficiently. Such an automated assessment can provide a potential method to evaluate the urban environment accurately and to guide urban design.

3 Methodology

3.1 Google street view (GSV) data collection

Our training set contains 500 Google Street View (GSV) images scraped randomly in the Bronx, New York. Our prediction set contains 1874 images in Soundview, a neighborhood in the south of the Bronx, New York City (Fig.1). The street map of the study area was processed and generated based on OpenStreetMap, an editable geographic database.

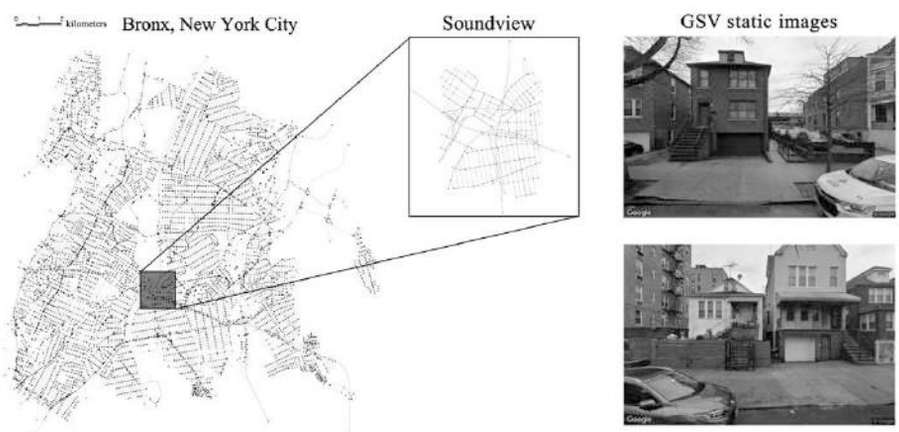

Figure 1. The location, road map, and GSV of a site in Soundview, Bronx, New York. Source: Author, 2022.

Figure 1 shows the GSV of a site in Soundview, Bronx, New York City. The street view is the same as a user sees with GSV panorama (Tsai & Chang, 2012). We collect the GSV images of 400 X 600 pixels in two directions vertical to the streets at intervals of 20m (Tsai & Chang, 2012) using the GSV Image API within the Bronx. To represent the urban WWRs of the study area, 500 sample sites are generated randomly along the road map as the training set from the scraped images.

3.2 Annotation of the training set

We annotate 500 images on the makesense.ai platform. Figure 2 shows an annotated example of our training set. In terms of the selection of labeled facades, we only label the walls and windows facing the camera because the facades with perspective angles cause the miscalculation of the window-to-wall ratio. In terms of the labeled content, the edges of the annotation boxes are the edge of the windows and walls. If a huge tree trunk is encountered, the annotation boxes should not contain the large trunk area; If a small tree branch

is encountered, the annotation boxes should contain the small branch area. The area of the walls includes the area of the windows, but not the area of roofs. Finally, the labeling result is a dataset in Coco format containing two label classes - window and wall.

Figure 2. Annotated training set of GSV in the Bronx, New York. Source: Author, 2022.

3.3 Window and wall area extract from GSV images

The existing trained segmentation models cannot accurately detect the windows from the walls. After testing on the same model of DeepLab (Chen et al., 2017), we found that the reasons include the following 4 biased aspects: noise of the training set, different sources of the datasets, the detection of only glass, and other biases.

Some urban image datasets, such as ADE20K (Zhao et al., 2017; Zhou et al., 2018) and Mapillary (Neuhold et al., 2017), CityScapes (Cordts et al., 2016), have the classes of windows and walls. However, their datasets do not annotate every window of the facades on the street. Thus, the mAP of the window detection is lower than we need for WWR calculation. These noisy dataset annotations result in an imprecise output of specific class detection. Figure 3. shows an output example of the DeepLab model trained on the dataset of ADE20K. From the image, on the right is the GSV image from Soundview; on the left, we can see that the buildings, sky, trees, and cars are well segmented. However, the windows cannot be detected due to the noise of the dataset.

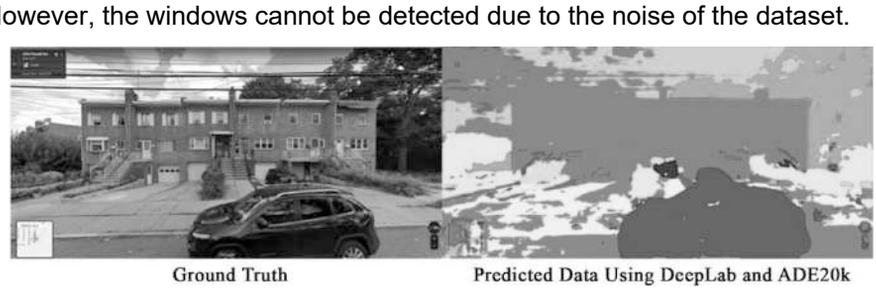

Figure 3. An example of the GSV segmentation results using DeepLab and ADE20k. Source: Author, 2022.

Some datasets are scraped from other media platforms, such as PASCAL VOC (Everingham et al., 2010) from Flickr. The image of these datasets contains different scenes from Google Street View images. For example, Flickr images include more interior, and people view images than street-level images. The training sets of these datasets do not have the same domain as the Google Street View images in the Bronx. Therefore, different databases of image sources lead to different databases suitable for use in different contexts.

Window detection is a key component in many graphics and vision applications related to 3D city modeling and scene visualization. However, some façade parsing datasets can detect the glass in the buildings, such as research by Li (2020). Moreover, these datasets cannot detect all types of windows, and some of them focus on glass detection. Thus, the existing window detection dataset cannot parse the windows in the Bronx effectively. Therefore, we train the pixel segmentation machine learning model – the Mask R-CNN model (Chen et al., 2017) on our dataset for WWR calculations. Then, the output of the trained model can automatically measure the WWRs in the GSV images on an urban scale. Finally, the mean average precision (mAP) is used to evaluate the output of the trained model.

3.4 WWR index calculation

We extract the number of masks of different colors from the image segmentation result. The output results include

- the number of windows,
- the number of walls,
- the number of pixels of windows,
- the number of pixels of walls, and
- the number of pixels in the images.

WWR measures the window area on the total amount of exterior wall area, which is the result of the total number of pixels of windows over the number of pixels of walls. The measured WWR data by machine learning prediction is calculated, mapped. Last, the data predicted by the trained machine learning model are summarized, visualized, and analyzed.

4 Results

4.1 Data augmentation in machine learning model

We use 455 training set and 55 validation set to train the Mask R-CNN model (Chen et al., 2017). In the training process, we augment the images using the augmentation function of imgaug (https://github.com/aleju/imgaug). We utilize the `Gauss. Noise + Contrast + Sharpen, Affine, Crop + Pad` to

augment the street view images to reduce the large number requirement of the training set.

In our case, cropping the image is necessary because the distance of the building facade from the camera varies very much in our dataset. The impact of irrelevant patterns like tree trunk and car can be reduced. Gaussian noise is added to prevent overfitting when our model tries to learn high frequency features are not useful.

4.2 Model hyperparameters and training

Our implementation follows the Mask RCNN paper for the most part, but we adjust several hyperparameters in favor of simplicity and generalization. To support training multiple images per batch we resize all the images to the same size: 384*384. The bounding box are generated based on the smallest box that encapsulate all the pixels of the mask, which is useful for a quick assessment of the result correctness. This makes the model easy to apply images augmentations that would otherwise be harder to apply to bounding boxes.

After several iterations of adjusting hyperparameters, we end up with the 0.001 learning rate, 143 epochs, and 384*384 image size. The mAP of the training is 0.655 in testing the model on 55 validation images, more than 0.5 of the ADE20k datasets. Figure 4. shows the examples of the generated masks. The result shows that we can successfully extract the area of windows and walls to analyze the WWRs further.

Figure 4. The generated masks of google street view using our model. Source: Author, 2022.

Table 1. Sample of window-to-wall ratio output of the predicted images of Google Street View in the Bronx, New York

Date	lat	lon	ang	Window_num	Wall_num	Window_pix	Wall_pix	ratio
2022-02	40.835949	-73.87157	2.454806	12	5	2529	39237	0.064

2022-02	40.834112	-73.874904	7.799306	12	1	9621	39957	0.241
2022-02	40.842859	-73.881411	48.034176	6	1	5955	26715	0.223
2019-11	40.839317	-73.869859	20.287989	2	3	2694	62937	0.043

Source: Author, 2022.

4.3 Data analysis and visualization

Using the WWR index function mentioned above, we are able to calculate the WWRs from the generated mask and the number of windows and walls. The generated data from images are stored in a pandas data frame and then merged with geo-tagged data frame based on the panoID column. Among the 1,874 test images, 97.9% are distributed between 0 to 0.2 (Figure 5. right chart), suggesting a relatively precise result.

The result is mapped for a clear view of the geographical distribution. From Figure 5, we find an interesting phenomenon that main streets have relatively small WWR compared with secondar streets. One possible explanation is that these main streets have higher traffic flow, and the residents prefer smaller WWR to maintain privacy.

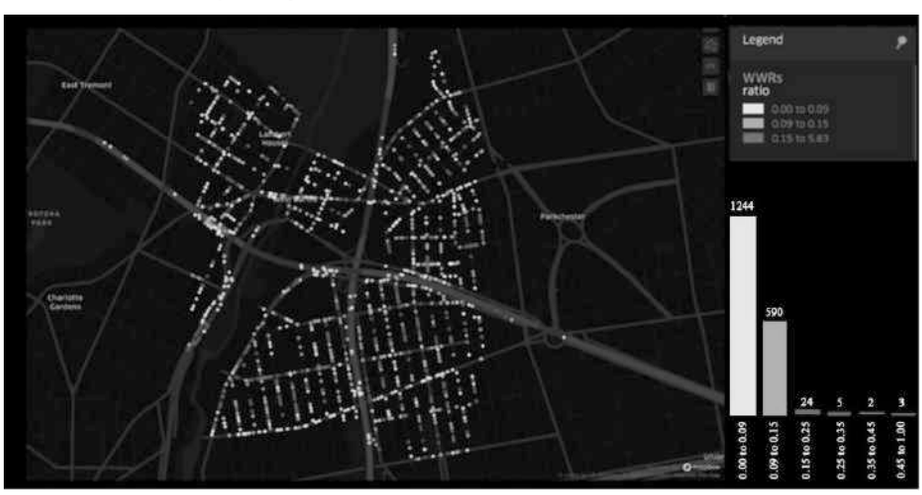

Figure 5. Data visualization and distribution of WWR in the Bronx, New York.
Source: Author, 2022.

5 Discussion

Urban visual data has been generated at an unprecedent speed with the rise of scene segmentation, which opens new opportunities to quantitively investigate

urban physical environment from multiple perspectives. This study provides a method of evaluating WWR by integrating big geo-data from GSV images. We show how GSV along with Mask RCNN can be used efficiently to measure the features of building façade at a large scale.

Our work is limited in several aspects. First, the size of validation set is not quite large, thus may lead to overfitting in the testing set. In future work, we can add more annotated to obtain a larger dataset and achieve a maximum performance of the algorithm. Second, our self-annotated dataset contains only two annotation categories: windows and walls. Third, the segmentation of street corners remains an unsolved problem, since a specific image view does not fit all buildings with different orientations. Inevitably, a high score in the algorithm does not always mean the best state.

This paper serves as the first step in profiling the urban building facade with GSV and scene segmentation. We propose that this line of research can be extended in several ways. In the field of architecture and urban design, WWR is an interesting topic with a wide range of applications. For example, 1) Differences in WWR between cities in different geographic locations, i.e., seaside and inland 2) Differences in WWR between cultures, i.e., Islamic architecture has relatively small WWR compared with catholic buildings. And by calculating WWR on a large scale and quantitatively using google street view and computer vision, we can provide a reference for region or culture based architectural design.

Future works include training a more accurate and generalized model with annotated images from other cities, such as Paris and San Francisco. Our current dataset contains only images in Bronx, NY, where the building facades are quite simple. While considering the variety of building facades in different cities, the current model may not perform well in other cities. With a generalized model, it is possible to compare WWR among different districts of a city and even among different cities and reveal the correlation between WWR and other urban index, like the impact of culture or religion on building design.

6 Conclusion

Our aim is to develop and test an automated computer vision methodology to extract the WWR of building facades in a large scale, using state-of-the-art machine learning techniques and Google Street View (GSV) images. The methodology can be further extended to assess other features of the built environment that shape the visual experience, such as urban architectural style and the relationship between adjacent buildings.

By training the Mask RCNN model, we could achieve a satisfying performance on the annotated validation set, and the mean Average Precision (mAP) reaches 0.66. The result reveals that our model achieves a medium-to-

good performance of calculating WWR, which can shed light on future architectural design and urban development.

The main contributions of our paper are as follows: First, a machine learning model on GSV images for the large-scale and quantitative measurement of WWR, which is one of the key parameters involved with a meaningful understanding of the urban environment.

Second, an annotated GSV dataset that contains 500 GSV images labelled with categories of window and wall. The existing scene-centric datasets include a very limited number of images annotated with the window category and their perspectives are too oriented from the facades, which cause low accuracy of window segmentation.

Third, windows play an important role in 'Eyes on the Street' in Jane Jacobs' theory. However, vital street-level parameters in her theory, most notably windows, are rarely assessed at the urban scale due to imprecise existing datasets. To resolve this challenge, this study proposes an automated computer vision-based methodology to extract the window-to-wall ratios (WWRs) of buildings in the Bronx, New York, using semantic segmentation machine learning. This consistent measured maps on the WWR qualities in Bronx, which can be used for further studies on urban visual environment.

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References

Charreire, H., Mackenbach, J. D., Ouasti, M., Lakerveld, J., Compernolle, S., Ben-Rebah, M., McKee, M., Brug, J., Rutter, H., & Oppert, J.-M. (2014). Using remote sensing to define environmental characteristics related to physical activity and dietary behaviours: A systematic review (the SPOTLIGHT project). Health & Place, 25, 1–9. https://doi.org/10.1016/j.healthplace.2013.09.017

Chen, L.-C., Papandreou, G., Kokkinos, I., Murphy, K., & Yuille, A. L. (2017). DeepLab: Semantic Image Segmentation with Deep Convolutional Nets, Atrous Convolution, and Fully Connected CRFs. ArXiv:1606.00915 [Cs]. http://arxiv.org/abs/1606.00915

Cordts, M., Omran, M., Ramos, S., Rehfeld, T., Enzweiler, M., Benenson, R., Franke, U., Roth, S., & Schiele, B. (2016). The Cityscapes Dataset for Semantic Urban Scene Understanding. ArXiv:1604.01685 [Cs]. http://arxiv.org/abs/1604.01685

Cozens, P., & Hillier, D. (2012). Revisiting Jane Jacobs's "Eyes on the Street" for the Twenty-First Century: Evidence from Environmental Criminology. The Urban Wisdom of Jane Jacobs, 313–344.

Dubey, A., Naik, N., Parikh, D., Raskar, R., & Hidalgo, C. A. (2016). Deep Learning the City: Quantifying Urban Perception at a Global Scale. In B. Leibe, J. Matas, N. Sebe,

& M. Welling (Eds.), Computer Vision – ECCV 2016 (pp. 196–212). Springer International Publishing. https://doi.org/10.1007/978-3-319-46448-0_12

Everingham, M., Van Gool, L., Williams, C. K. I., Winn, J., & Zisserman, A. (2010). The Pascal Visual Object Classes (VOC) Challenge. International Journal of Computer Vision, 88(2), 303–338. https://doi.org/10.1007/s11263-009-0275-4

Forkenbrock, D. J., & Sheeley, J. (2004). Effective Methods for Environmental Justice Assessment. The National Academies Press. https://doi.org/10.17226/13694

Früh, C., & Zakhor, A. (2003). Constructing 3D city models by merging aerial and ground views. IEEE Computer Graphics and Applications, 23(6), 52–61. https://doi.org/10.1109/MCG.2003.1242382

Früh, C., & Zakhor, A. (2004). An Automated Method for Large-Scale, Ground-based City. . . International Journal of Computer Vision, 60(1), 5–24.

He, K., Gkioxari, G., Dollár, P., & Girshick, R. (2018). Mask R-CNN. ArXiv:1703.06870 [Cs]. http://arxiv.org/abs/1703.06870

Jane, J. (1961). The Death and Life of Great American... Book by Jane Jacobs. ThriftBooks. https://www.thriftbooks.com/w/the-death-and-life-of-great-american-cities_jane-jacobs/249572/

Koutsourakis, P., Simon, L., Teboul, O., Tziritas, G., & Paragios, N. (2009). Single view reconstruction using shape grammars for urban environments. 2009 IEEE 12th International Conference on Computer Vision, 1795–1802. https://doi.org/10.1109/ICCV.2009.5459400

Li, C.-K., Zhang, H.-X., Liu, J.-X., Zhang, Y.-Q., Zuo, S.-C., & Fang, Y.-T. (2020). Window Detection in Facades Using Heatmap Fusion. Journal of Computer Science Technology, 35(4), 900–912. https://doi.org/10.1007/s11390-020-0253-4

Li, X., Zhang, C., Li, W., Ricard, R., Meng, Q., & Zhang, W. (2015). Assessing street-level urban greenery using Google Street View and a modified green view index. Urban Forestry & Urban Greening, 14(3), 675–685. https://doi.org/10.1016/j.ufug.2015.06.006

Neuhold, G., Ollmann, T., Bulo, S. R., & Kontschieder, P. (2017). The Mapillary Vistas Dataset for Semantic Understanding of Street Scenes. 2017 IEEE International Conference on Computer Vision (ICCV), 5000–5009. https://doi.org/10.1109/ICCV.2017.534

Raskar, R., Naik, N., Philipoom, J., & Hidalgo, C. (2015). Streetscore—Predicting the Perceived Safety of One Million Streetscapes. IEEE Computer Society Conference on Computer Vision and Pattern Recognition Workshops. https://doi.org/10.1109/CVPRW.2014.121

Riemenschneider, H., Krispel, U., Thaller, W., Donoser, M., Havemann, S., Fellner, D., & Bischof, H. (2012). Irregular lattices for complex shape grammar facade parsing. 2012 IEEE Conference on Computer Vision and Pattern Recognition, 1640–1647. https://doi.org/10.1109/CVPR.2012.6247857

Rundle, A. G., Bader, M. D. M., Richards, C. A., Neckerman, K. M., & Teitler, J. O. (2011). Using Google Street View to Audit Neighborhood Environments. American

Journal of Preventive Medicine, 40(1), 94–100. https://doi.org/10.1016/j.amepre.2010.09.034

Rzotkiewicz, A., Pearson, A. L., Dougherty, B. V., Shortridge, A., & Wilson, N. (2018). Systematic review of the use of Google Street View in health research: Major themes, strengths, weaknesses and possibilities for future research. Health & Place, 52, 240–246. https://doi.org/10.1016/j.healthplace.2018.07.001

Sheikh, H. R., & Bovik, A. C. (2006). Image information and visual quality. IEEE Transactions on Image Processing, 15(2), 430–444. https://doi.org/10.1109/TIP.2005.859378

Shi, X., Wang, C., Wang, M., & Tang, P. (2020). An Innovative Approach to Determine Building Window- To-Wall Ratios for Urban Energy Simulation. Symposium on Simulation in Architecture + Urban Design, 57–60.

Szcześniak, J. T., Ang, Y. Q., Letellier-Duchesne, S., & Reinhart, C. F. (2022). A method for using street view imagery to auto-extract window-to-wall ratios and its relevance for urban-level daylighting and energy simulations. Building and Environment, 207, 108. https://doi.org/10.1016/j.buildenv.2021.108108

Taylor, B. T., Fernando, P., Bauman, A. E., Williamson, A., Craig, J. C., & Redman, S. (2011). Measuring the Quality of Public Open Space Using Google Earth. American Journal of Preventive Medicine, 40(2), 105–112. https://doi.org/10.1016/j.amepre.2010.10.024

Teboul, O., Kokkinos, I., Simon, L., Koutsourakis, P., & Paragios, N. (2011). Shape grammar parsing via Reinforcement Learning. CVPR 2011, 2273–2280. https://doi.org/10.1109/CVPR.2011.5995319

Teboul, O., Simon, L., Koutsourakis, P., & Paragios, N. (2010). Segmentation of building facades using procedural shape priors. 2010 IEEE Computer Society Conference on Computer Vision and Pattern Recognition, 3105–3112. https://doi.org/10.1109/CVPR.2010.5540068

Tsai, V., & Chang, C.-T. (2012). FEATURE POSITIONING ON GOOGLE STREET VIEW PANORAMAS. ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences, I–4, 305–309. https://doi.org/10.5194/isprsannals-I-4-305-2012

Zhang, F., Zhou, B., Liu, L., Liu, Y., Fung, H. H., Lin, H., & Ratti, C. (2018). Measuring human perceptions of a large-scale urban region using machine learning. Landscape and Urban Planning, 180, 148–160. https://doi.org/10.1016/j.landurbplan.2018.08.020

Zhao, H., Shi, J., Qi, X., Wang, X., & Jia, J. (2017). Pyramid Scene Parsing Network. ArXiv:1612.01105 [Cs]. http://arxiv.org/abs/1612.01105

Zhou, B., Zhao, H., Puig, X., Xiao, T., Fidler, S., Barriuso, A., & Torralba, A. (2018). Semantic Understanding of Scenes through the ADE20K Dataset. ArXiv:1608.05442 [Cs]. http://arxiv.org/abs/1608.05442

Palette2Interior Architecture: From Syntactic and Semantic Colour Palettes to Generative Interiors with Deep Learning

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Abstract. Colour palettes have long played a significant role in not only capturing design ambience (e.g., as mood boards), but more significantly, in translating an abstract intuition into an explicit ordering mechanism for design representation and synthesis, whether it is in the discipline of graphic design, interior design or architectural design. Might this difficult process of design synthesis from a low-dimensional colour input domain to a high-dimensional spatial design output domain be computationally mapped? Using today's generative adversarial networks (GANs), the paper aims to investigate this plausibility, and in doing so, hoping to envision an AI-augmented design workflow and tooling. Newly-created datasets are made procedurally and used to train three different types of deep learning models in the specific context of generating living room interior layouts. The results suggest that a combination of syntactic and semantic generative processes is necessary for a critical appropriation of such AI models

Keywords: Machine Learning, Artificial Intelligence, Deep Neural Networks, Colour Palette, Interior Design

1 Introduction

Although there exist many online colour palette generators for designers to create coherent colour schemes given any image or photograph inputs, such as those based on clustering (Lertrusdachakul et al., 2019), those used for image editing (Grogan et al., 2018) and those used for image re-colourisation (Cho et al., 2017), the inverse is not the case. That is, given any colour palette as input, might one generate a design as its output? This one-directional computational extraction of key colours from inspirational images are most commonly used by graphic/web/interior designers to quickly build a colour palette that could then guide the subsequent stages of their design process, such as spatial compositions. It is thus reasonable to think that an inverse

version of the same tool would be of little use. However, one might recall artists like Paul Klee and Sol LeWitt who had used limited set of discrete colour bands as abstraction of semantics and abstraction of syntax respectively. For example, in the striated composition of Klee's 1929 *Fire in the Evening* where the red opaque rectangle semantically suggests a flaming fire in the desert during the evening, and in LeWitt's 1992 *Bands of Color in Four Directions (Within A Square)* where the painting is the literal manifestation of its title and nothing more -- both are inherently generative, though visually reductive as perceptual inputs. Yet, such a process is akin to the inverse version of those aforementioned colour palette extractors. The research aims to explore the question of whether such inversion might be appropriated for the architectural design generative process. The paper will proceed to first lay out the processes used in the creation of the datasets and the implementation of the deep learning models proposed in 'Methodology' section, followed by an illustration and evaluation of the experimental outputs in the 'Results' section, before ending with a discussion on the current and future work in the 'Discussion' section.

2 Methodology

Using interior design as a domain of investigation, the proposed AI-augmented design workflow uses low-dimensional colour inputs in yielding high-dimensional spatial outputs. In generating high-dimensional photorealistically composed interior views, the proposed 'syntactic' palette2interior AI model based on the original GAN (Goodfellow et al., 2014) and the convolutional variant of GAN (Radford et al., 2015), and more specifically cycleGAN (Zhu et al., 2017) or cycle-consistent adversarial network architecture, is trained from scratch with simple inputs of 5 rectilinear colour bands in varying orders and orientations; while the proposed 'semantic' palette2interior AI model also based on the pix2pix or cGAN (Isola et al., 2018) or conditional generative adversarial network architecture trained with complex inputs of 150 possible colours in organic shapes in varying sizes. As part of the generative exploration, a third AI model based on the StyleGAN (Karras et al., 2019) architecture is trained to obtain a latent space for creating a new synthetic dataset of the original interior views. The study consists of dataset preparation, model architecture selection, model training and evaluation, and lastly, design and deployment of an interface application for model inference. The first dataset contains web-scraped interior photographs of living rooms, the second dataset contains automated annotations of the first dataset using a pretrained semantic segmentation model called PSPNet or pyramid scene parsing network (Zhao et al., 2017), and the third dataset contains permutated bands of colours extracted from the first dataset using Google's online colour palette generator.

2.1 Datasets

A total of three corresponding datasets have been created for the experiments, with 80% used as training set and 20% as test set. The first dataset forms the basis on which to derive the other remaining two auto-annotated datasets. Preliminary research in identifying potential sources of imagery containing living room interiors are conducted. Two websites have been found particularly suitable in providing the necessary quality (e.g., without watermarks) and minimal quantity that can be webscraped for the training of the proposed deep learning models. By searching the phrase 'living room interior' on *Unsplash* and the phrase 'interior design living rooms' on *Google Images*, thousands of images are scraped (Fig. 1).

The second dataset is derived by using a colour palette extraction procedure to obtain the five main colours of any given image from the first dataset (Fig. 1). The initial approach is to use the KMeans clustering algorithm to extract the top five colours present in any given image based on their count values. However, the colour palette extracted in this manner does not in fact reflect the actual perceptual colour palette with which a designer or artist would have used in reality. Therefore, the online colour palette extraction capability of *Google Arts & Culture* website is eventually used which indeed yields superior results in effectively representing the five most perceptually dominant colours. The colour information is first stored as hexadecimal value (e.g., #FFFFFF as white) before converting into RGB values (e.g., (255,255,255) as white). The five colours are further converted into an image represented by five discrete horizontal colour bands. Since the order of the horizontal colour bands has no intrinsic meaning in relation to the extraction process, five (instead of all) permutations with/without rotations are further generated as a data augmentation procedure to form an expanded dataset that can be used for training the deep learning models.

The third dataset is derived by using a semantic image segmentation model to obtain the semantic labels to every pixel in any given image from the first dataset. The DeepLabV3 model (Chen et al., 2017) is initially tested on the first dataset, but performed poorly as it fails to recognize several indoor features, such as tables and shelves. The reason is that it has been pre-trained with the Cityscapes dataset (Cordts et al., 2016) which contains only outdoor scenes and streetscapes, rather than indoor environments. Therefore, the pyramid scene parsing network or PSPNet model (Zhao et al., 2017) is eventually used which yields superior results due to the fact that it is pre-trained on the ADE20K dataset (Zhou et al., 2018) that contains both outdoor and indoor scenes.

The last step of the data preparation and annotation generation process is to explore and visualize all three datasets to gain an understanding of their respective distributions and correlations. Fig. 2 shows one of the visualizations that clusters all the indoor interior images from the first dataset based on their respective colour palatte from the second dataset. This is done

by first converting each palette's 5 RGB values into 15-dimensional features, projecting them onto a 2-dimensional plot using principal component analysis (PCA), and finally performing a KMeans clustering with a k-value of 3. It can be observed that cluster 0 (shown as purple points in the scatter plot) gathers interiors with a darker colour palette (i.e., 'Warm' tones), cluster 1 (shown as green points in the scatter plot) gathers interiors with a lighter and warmer colour palette (i.e., 'Neutral' tones), and cluster 3 (shown as yellow points in the scatter plot) gathers interiors with a lighter and cooler colour palette (i.e., 'Cool' tones). In other words, the extracted colour palettes generated for the second dataset is indeed reflective of the first dataset with which they are derived from.

The actual datasets to be used for training the proposed deep learning models consists of different pairing combinations among the three datasets, that is, the first dataset (living room interior imagery) combined with the generated interior images from the second and third datasets, a pair of the first dataset with the second dataset (colour palette), and a pair of the first dataset with the third dataset (semantically segmented interior). The next section will describe the proposed deep learning models used to train on these different datasets.

Figure 1. (LEFT) Dataset 1 containing images of living room interiors; (RIGHT) Dataset 2 generated from Dataset 1 and contains the corresponding colour palettes with the top 5 colours as horizontal bands. Source: Author, 2022.

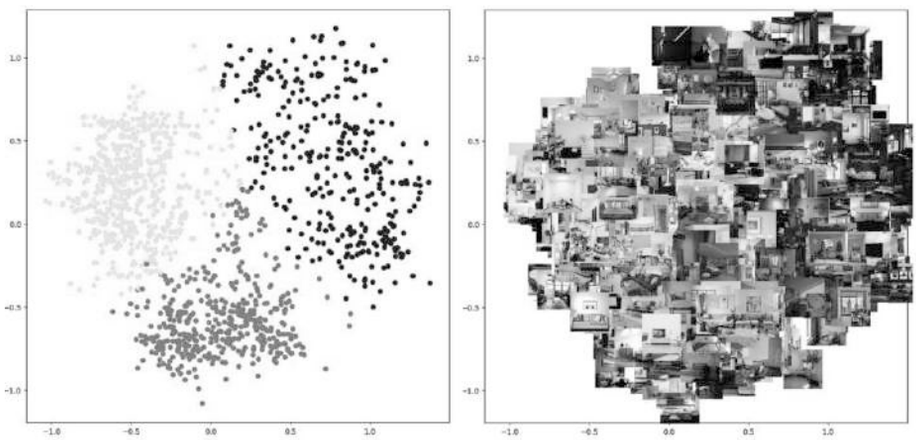

Figure 2. (LEFT) KMeans clustering based on the features of colour palettes from Dataset 2; (RIGHT) Plot of the corresponding living room interior imagery. Source: Author, 2022**.**

2.2 Models

A total of three different deep learning models have been implemented and trained with the aforementioned datasets. All of which are based on variants of the architecture of the generative adversarial networks (GANs). The first model 'syntactic' palette2interior model is an unpaired image-to-image translation convolutional neural network model called cycleGAN (Zhu et al., 2017) that is trained by very loosely pairing the living room interior imagery with its colour palette imagery. The task is to generate a new photorealistic living room interior composition output from a 5-colour palette imagery input (with or without reordering and reorientating the colour bands with permutations and rotation respectively). The model is trained for a total of 195 epochs and restored at epoch 174 without data augmentation (Fig. 3). That is, using only the original extracted horizontal bands of colours. Another model is trained for 123 epochs and restored at epoch 105 with data augmentation (Fig. 4). That is, using reordering of the horizontal bands and reorientation of the bands via orthogonal rotations as the expanded dataset.

The second model 'semantic' palette2interior model is a paired image-to-image translation convolutional neural network model called pix2pix (Isola et al., 2018) that is trained by strictly pairing the living room interior imagery with its semantically segmented imagery. The task is to generate a new photorealistic living room interior composition output from any organically drawn shapes whose pixel colours belong to the set of pixel labels used for training. The model is trained for a total of 210 epochs (Fig. 5).

Finally, as part of the generative exploration, a third AI model based on the StyleGAN (Karras et al., 2019) architecture is trained to obtain a latent

space for creating a new synthetic dataset of the original interior views. Transfer-learning from a StyleGAN model pre-trained on bedrooms is used to avoid having to train from scratch. The model is trained for a total of 1000 epochs and reaches a final FID (Frechet Inception Distance) Score of 25.38.

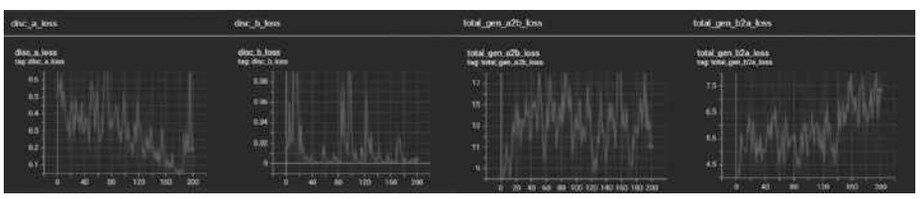

Figure 3. Plots showing the losses (discriminator losses in column 1 & 2 and generator losses in column 3 & 4) during the training of the 'syntactic' palette2interior model with the pairing of the living room interior imagery with its colour palette imagery as dataset. Source: Author, 2022**.**

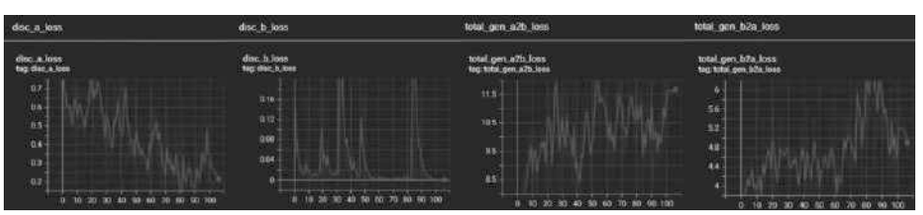

Figure 4. Plots showing the losses (discriminator losses in column 1 & 2 and generator losses in column 3 & 4) during the training of the 'syntactic' palette2interior model with the pairing of the living room interior imagery with its colour palette imagery (with augmentation via reordering and reorientation) as dataset. Source: Author, 2022**.**

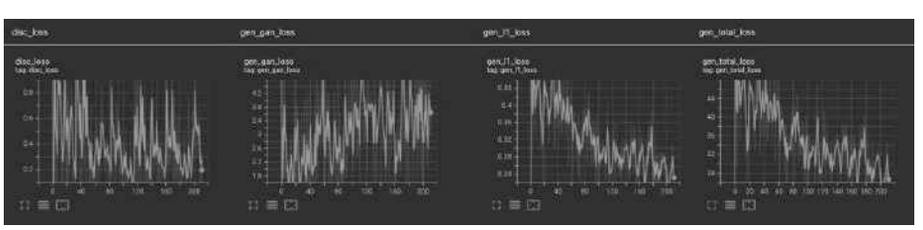

Figure 5. Plots showing the losses (discriminator loss in column 1 and generator losses in column 2, 3 & 4) during the training of the 'semantic' palette2interior model with the pairing of the living room interior imagery with its semantically segmented imagery as dataset. Source: Author, 2022**.**

3 Results

The results from all three models will now be evaluated. In Fig. 6, despite using different colour palettes as inputs to the 'syntactic' palette2interior model, the generated spatial layouts do not seem to vary significantly.

However, it is apparent that the colour palette will still influence the overall colour layout within the interior imagery. More significantly, the reorientated version of the same colour palette will alter both the spatial and colour layouts of the generated outputs. In Fig. 7, even with different colour palettes as inputs to the 'syntactic' palette2interior model, it is observed that the generated spatial layouts do not vary significantly, the overall colour layout do vary substantially. Here, the reorientated colour palette can likewise significantly alter the outputs. In Fig. 8, since the colours are assigned spatially as conditioning pixel label inputs to the 'semantic' palette2interior model, the generated outputs show relatively accurate, realistic and interpretable interior design layouts. In fact, the generated resolution of larger objects improves with further training. However, there is no mechanism to control the desired generated colour palette layout other than the spatial layout. The former is only possible with the previous 'syntactic' palette2interior model. Fig. 9 shows the generated outputs of the third model trained with the StyleGAN architecture. Since the pre-trained model used for the transfer learning is based on a dataset of bedrooms, it can be observed that there are moments when beds morph into sofas in the generated latent walk video.

In general, based on the results from the syntactic model, it is observed that even an abstract spatial composition as that of 5 colour bands could contribute directly to the generated interior spatial composition. However, the placement order of the 5 colour bands within the same palette will only generate differing interior spatial composition if they are perceived as significantly different-looking palettes as images. Since the semantic model is more compositionally descriptive, it is relatively more successful in generating spatially plausible outputs. An interface (Fig. 10) is built to better visualise how such a 'palette2interior' application might be used in real-time with 2 different interactive modes, namely, assigning 5 colours to form an orthogonally composed input palette for the syntactic model, and colouring on a canvas to form an organically composed input palette for the semantic model.

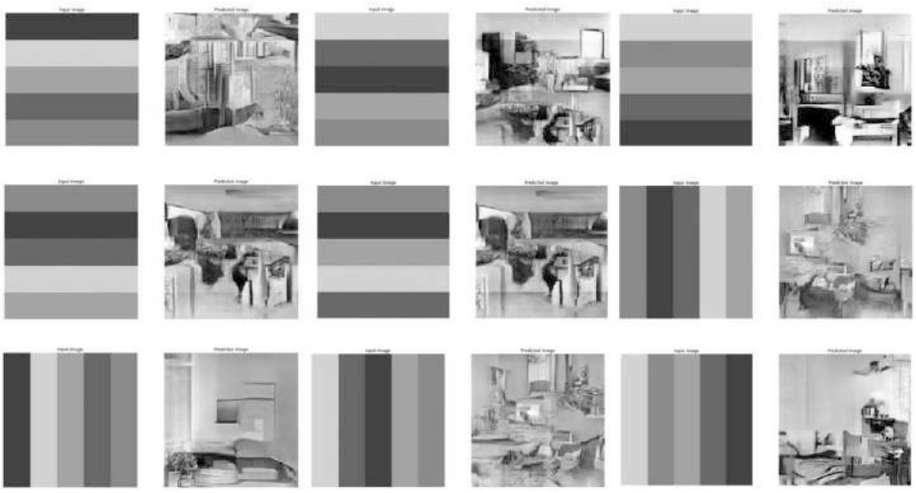

Figure 6. Although the same colour palette when reordered might yield similar spatial layouts with variation mainly in colour layout, it is observed that the position of the darkest colour band can dramatically influence the overall generated outputs. The reorientated colour palette can likewise significantly alter the outputs. Source: Author, 2022.

Figure 7. With different colour palettes as inputs, it is observed that the generated spatial layouts do not vary significantly, although the colour palette will still influence the overall colour layout. The reorientated colour palette can likewise significantly alter the outputs. Source: Author, 2022.

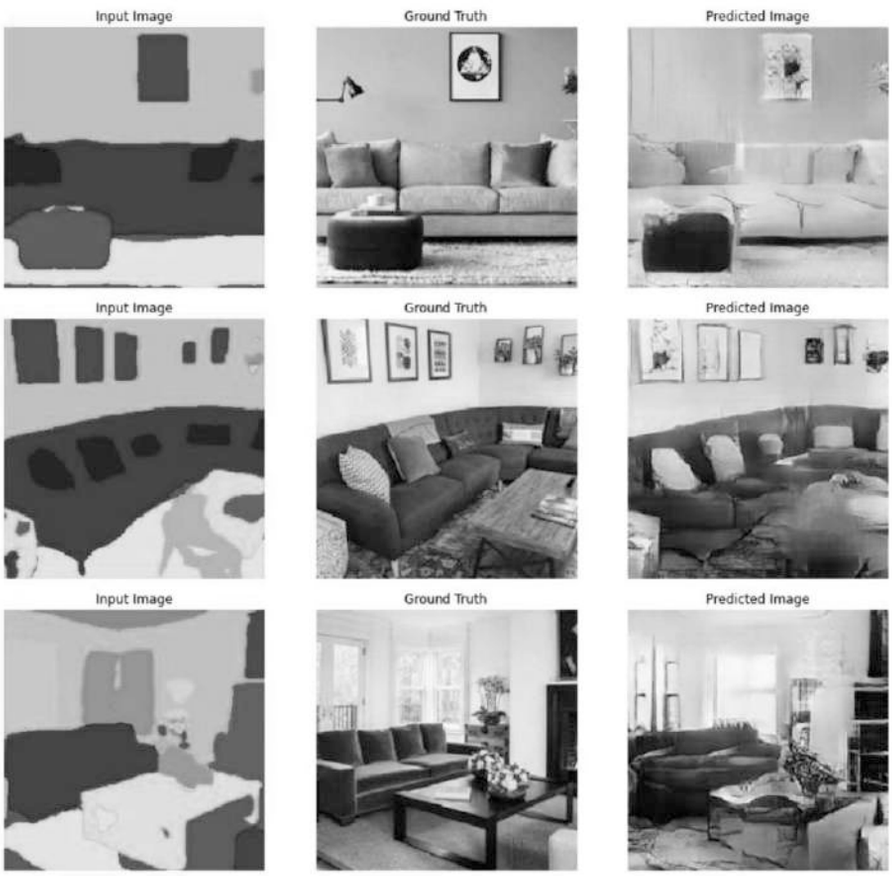

Figure 8. Given that the colours now spatially represent the object semantics, the generated outputs show relatively accurate, realistic and interpretable interior design configurations. Source: Author, 2022.

Figure 9. Samples of the generated outputs of the third model. Transfer-learning is used to quicken the training with the original dataset of living room interiors. See its latent walk video at https://vimeo.com/729465453/3de4c42727. Source: Author, 2022

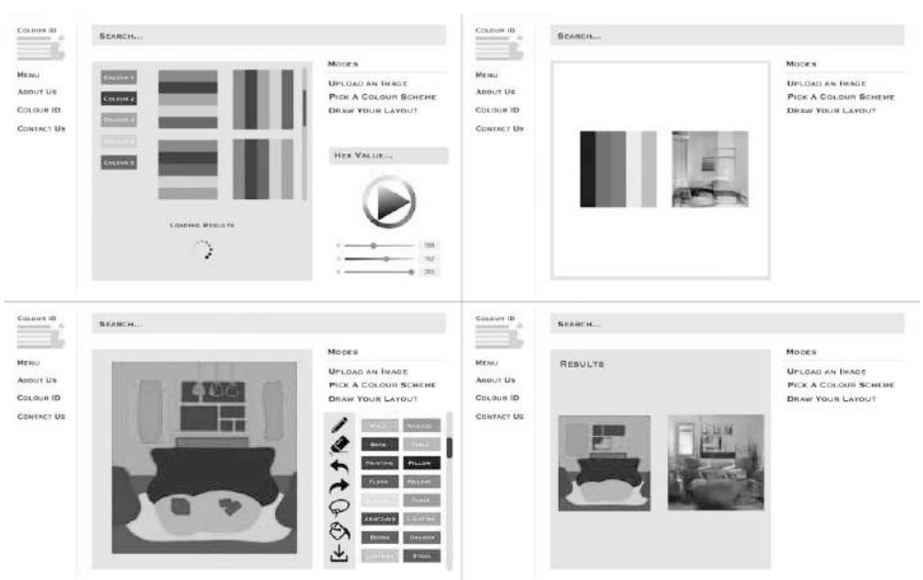

Figure 10. The interface of the proposed 'palette2interior' application with 2 different interactive modes, namely, assigning 5 colours to form an orthogonally composed input palette for the syntactic model, and colouring on a canvas to form an organically composed input palette for the semantic model. See the interactive video recording at https://vimeo.com/698194423/7152d7b5db Source: Author, 2022.

4 Discussion

The paper has contributed to an alternative understanding of the ways in which deep neural networks might be appropriated in inverting the traditional conception of colour palettes as a means towards a semantically and syntactically higher form of design synthesis. There are several limitations to the current work, such as the model inability to accommodate non-orthogonal colour palette representations as shown in Fig. 11. Future work will also combine the 'syntactic' model with the 'semantic' model to better control the colour and spatial layouts simultaneously in a single AI model.

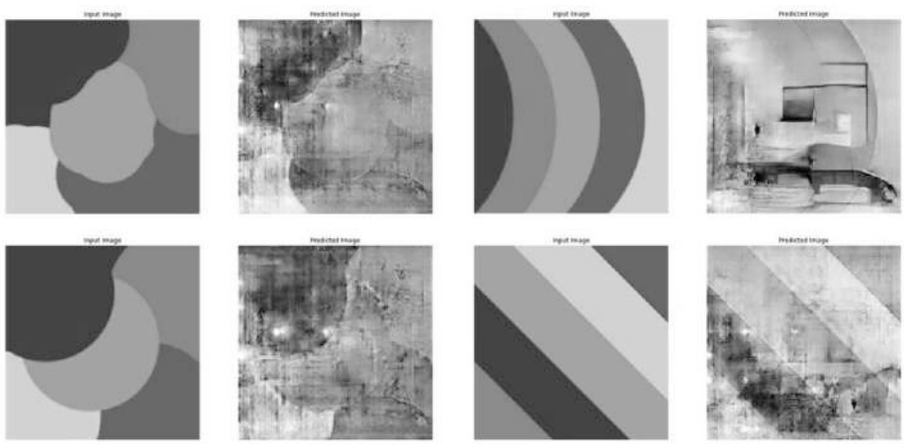

Figure 11. The limitation of the current 'syntactic' palette2interior model in accommodating non-orthogonal colour palette representations can be observed here. Source: Author, 2022.

References

Chen, L.-C., Papandreou, G., Schroff, F., & Adam, H. (2017). *Rethinking Atrous Convolution for Semantic Image Segmentation* (arXiv:1706.05587; Version 3). arXiv. https://doi.org/10.48550/arXiv.1706.05587

Cho, J., Yun, S., Lee, K., & Choi, J. Y. (2017). PaletteNet: Image Recolorization with Given Color Palette. *2017 IEEE Conference on Computer Vision and Pattern Recognition Workshops (CVPRW)*, 1058–1066. https://doi.org/10.1109/CVPRW.2017.143

Cordts, M., Omran, M., Ramos, S., Rehfeld, T., Enzweiler, M., Benenson, R., Franke, U., Roth, S., & Schiele, B. (2016). *The Cityscapes Dataset for Semantic Urban Scene Understanding* (arXiv:1604.01685). arXiv. https://doi.org/10.48550/arXiv.1604.01685

Goodfellow, I. J., Pouget-Abadie, J., Mirza, M., Xu, B., Warde-Farley, D., Ozair, S., Courville, A., & Bengio, Y. (2014). Generative Adversarial Networks. *ArXiv:1406.2661 [Cs, Stat]*. http://arxiv.org/abs/1406.2661

Grogan, M., Hudon, M., McCormack, D., & Smolic, A. (2018). Automatic Palette Extraction for Image Editing. *Undefined*. https://www.semanticscholar.org/paper/Automatic-Palette-Extraction-for-Image-Editing-Grogan-Hudon/fb1b4d4c49c28f2ba3134c07dd190ad891572357

Isola, P., Zhu, J.-Y., Zhou, T., & Efros, A. A. (2018). Image-to-Image Translation with Conditional Adversarial Networks. *ArXiv:1611.07004 [Cs]*. http://arxiv.org/abs/1611.07004

Karras, T., Laine, S., & Aila, T. (2019). A Style-Based Generator Architecture for Generative Adversarial Networks. *ArXiv:1812.04948 [Cs, Stat]*. http://arxiv.org/abs/1812.04948

Lertrusdachakul, T., Ruxpaitoon, K., & Thiptarajan, K. (2019). Color Palette Extraction by Using Modified K-means Clustering. *2019 7th International Electrical Engineering Congress (IEECON)*, 1–4. https://doi.org/10.1109/iEECON45304.2019.8938867

Radford, A., Metz, L., & Chintala, S. (2015). Unsupervised Representation Learning with Deep Convolutional Generative Adversarial Networks. *ArXiv:1511.06434 [Cs]*. http://arxiv.org/abs/1511.06434

Zhao, H., Shi, J., Qi, X., Wang, X., & Jia, J. (2017). Pyramid Scene Parsing Network. *ArXiv:1612.01105 [Cs]*. http://arxiv.org/abs/1612.01105

Zhou, B., Zhao, H., Puig, X., Xiao, T., Fidler, S., Barriuso, A., & Torralba, A. (2018). *Semantic Understanding of Scenes through the ADE20K Dataset* (arXiv:1608.05442). arXiv. https://doi.org/10.48550/arXiv.1608.05442

Zhu, J.-Y., Park, T., Isola, P., & Efros, A. A. (2017). Unpaired Image-to-Image Translation using Cycle-Consistent Adversarial Networks. *ArXiv:1703.10593 [Cs]*. http://arxiv.org/abs/1703.10593

Performance predictive metamodel for dynamic facade shading

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Abstract. Dynamic shading compositions present a challenge for computer simulation of illuminance performance still in the design phase of the project. Such architectural elements have a conflicting function, shading without blocking natural light. The evaluations of these dynamic elements present an infinity of parameters and several combinations, resulting in compositional complexity and making it difficult to read and understand the performance. The objective of this research is to identify the optimized positioning of dynamic facade shading elements. The dependent variable to be analyzed is the annual average illuminance. The algorithm that creates the shape of the Shoebox and manipulates the independent variables is the same that performs the annual daylight assessment. Simulation results are the metamodel input data, Machine Learning is used for the optimization. The contribution of this research is to test the set of results of the independent variables, training an algorithm capable of replacing the simulation.

Keywords: Machine Learning, Metamodel, Dynamic Shading, Performance Evaluation.

1 Introdução

As envoltórias dos edifícios foram progressivamente transformadas em envelopes com multicamadas leves e transparentes, resultando em uma diminuição da massa térmica, portanto, com menor valor de isolamento (Konstantoglou & Tsangrassoulis, 2016). A materialidade da construção, em especial, a que constitui os componentes construtivos da envoltória, podem afetar consideravelmente o desempenho energético e o conforto do edifício (Kheiri, 2018). Uma vez que a envoltória é uma barreira primária entre interior e o exterior de uma edificação, é necessário enfatizar as vantagens de se usar estratégias passivas ou ativas para redução da demanda energética, como melhorar o aproveitamento de luz natural para amenizar a necessidade por iluminação artificial (Kheiri, 2018).

O sistema passivo de sombreamento de envoltórias é um meio bioclimático eficaz para manter o equilíbrio entre a demanda visual e térmica. No entanto, estudos mostraram que os elementos de sombreamento estáticos são notavelmente incapazes de responder completamente às condições

climáticas variáveis (Al-Masrani & Al-Obaidi, 2019). Os avanços tecnológicos computacionais, tanto em programas (software) e máquinas (hardware), incitaram os projetistas a mesclar necessidades ambientais e simulações computacionais para desenvolver envoltórias de construção dinâmicas que respondem a condições variáveis climáticas (Al-Masrani & Al-Obaidi, 2019). Os exigentes requisitos para a construção de sistemas inteligentes de fachada estão ligados às conquistas tecnológicas, formando sistemas adaptativos ou responsivos. Sua atuação visa tanto contrabalançar fenômenos antagônicos, sombreamento e iluminação, quanto atuar como moderadores ambientais (Konstantoglou & Tsangrassoulis, 2016). Quando se projeta um sistema de fachada dinâmica, para coletar a luz do dia com mais eficiência, o projeto deve incorporar o uso de softwares de projeto paramétrico, projeto algorítmico e simulação dinâmica, de maneira a validar a importância da computação para aproveitar e projetar questões de complexidade de desempenho (el Sheikh & Gerber, 2011).

Existem diferentes formas para realizar simulações computacionais de predição de iluminação natural, inicialmente com métodos simples utilizando diagramas, modelo em escala, fórmulas matemáticas e com regras obtidas por experimentos (Reinhart et al., 2006). Atualmente, simulações de iluminação natural podem ser aplicadas para diferentes propósitos e variam em escala e em complexidade, seja para espaços internos, envoltórias de edificações ou em contextos urbanos(Ayoub, 2020). Contudo, mesmo com os computadores e softwares atuais, as simulações diurnas são demoradas e caras do ponto de vista computacional (Ayoub, 2020). Conjuntos arquitetônicos, como uma envoltória, podem formar um sistema complexo com uma variedade de parâmetros. Portanto, simular tal sistema de envoltória, sua propriedade geométrica, bem como os impactos ambientais pode ser um processo intensivo e exigente em termos computacionais(Sebestyen & Tyc, 2020).

A adoção de métodos de projeto paramétrico possibilita integrar os dados das simulações ainda em fases iniciais da concepção (Ayoub, 2020). Isto, pois geralmente as simulações eram feitas em etapas mais avançadas do projeto, em que as alterações no projeto são mais difíceis, custosas e limitadas (Østergård et al., 2016). Métodos de otimização de luz do dia devem ser integrados ainda nas fases iniciais do processo de projeto. Os estágios iniciais são caracterizados por um grande número de parâmetros e possibilidades de projeto, mas, apesar dos avanços nas ferramentas de simulação de desempenho, essas ferramentas normalmente fornecem resultados determinísticos que avaliam o projeto ao invés de orientá-lo de forma proativa (Østergård et al., 2017). Conhecer o desempenho das soluções desde os momentos iniciais pode contribuir para uma melhor tomada de decisões.

Na forma convencional de projeto, se o projetista quiser mudar qualquer parâmetro, todo o processo tem de ser repetido. Em um projeto paramétrico alterar e melhorar o projeto é um processo automático que imediatamente atualiza o modelo, permitindo então um controle absoluto sobre a forma, em todas as etapas do projeto (Eltaweel & SU, 2017). Apesar de a modelagem paramétrica permitir testar variáveis e comparar soluções facilmente, isso ainda não é o bastante para avaliar o excesso de dados que é

criado. E, por isso, recorre-se a algoritmos de otimização, como Inteligência Artificial (IA) na Aprendizagem de Máquina (AM).

Segundo Poole et al. (1998), a IA é o estudo de “agentes inteligentes", representados por qualquer sistema que percebe seu ambiente e executa ações que maximizam a hipótese de atingir seus objetivos. Segundo Russell & Norvig (2013), o campo da IA objetiva construir entidades inteligentes. A IA pode ter o enfoque nos processos do pensamento e raciocínio ou procura imitar o comportamento humano por máquinas. Busca-se fidelidade ao desempenho humano ou da racionalidade.

A IA com o enfoque na ação por máquinas de forma humana aborda o processamento de linguagem natural, a representação do conhecimento, o raciocínio automatizado, a visão robótica, a robótica e o AM (Russell & Norvig, 2013). O AM é a capacidade das máquinas de aprender e trabalhar em novas dimensões de problemas sem serem explicitamente programadas para isso (Kumar, 2017). Para tal, os programas computacionais que realizam o AM são alterados à medida que são expostos a novos dados e cenários.

1.1 Metamodelo

Tarefas de modelagem também podem tirar proveito de abordagens de AM, seja na simplificação de modelos de simulação de edifícios, ou na geração automática de soluções de projeto baseadas em imagens, ou descrições textuais de edifícios (Belém et al., 2019). Fachadas dinâmicas, pode-se tirar proveito das ferramentas de arquitetura paramétrica, com integração de simulações de desempenho e a análise de resultados utilizando AM. Deste modo, torna-se possível a implementação de estratégias de otimização de desempenho, com soluções baseadas nos resultados obtidos das simulações (Østergård et al., 2017), avaliando quais variáveis impactam mais, removendo as que impactam menos, e consequentemente reduzindo o conjunto de soluções possíveis e o tempo de simulação necessário.

A metamodelagem é um método de construção de modelos acelerado e concentrados que correlacionam entradas a resultados obtidos por modelos matemáticos mais complexos (Østergård et al., 2017). Os metamodelos podem ser desenvolvidos por meio de diferentes métodos, utilizando técnicas de AM. Uma de suas vantagens é a capacidade de realizar uma previsão a partir de um número reduzido de parâmetros e com menor tempo de execução. Um metamodelo é capaz de substituir um processo complexo de simulação (Bracht et al., 2021). Tais modelos têm a capacidade de prever as ações e influências das variáveis, tornando-o capaz de tomar decisões que privilegiam a otimização do desempenho (Østergård et al., 2017). Tais funções de otimização e suas consequências não são capazes de qualificar a estética da edificação, estas ficam a cargo do projetista. A Figura 1 apresenta um fluxograma com a estrutura conceitual de um metamodelo.

Figura 1. Fluxograma que expressa o conceito de funcionamento de um metamodelo. Fonte: os autores.

2 Metodologia

O problema abordado nessa pesquisa é a multiplicidade de parâmetros e combinações associadas ao posicionamento das aletas, que é representado pelo total de possibilidades de horários e orientações, gerando um conjunto geral de iluminâncias. O objetivo é identificar o posicionamento otimizado de elementos dinâmicos de fachada, com aletas horizontais foscas de posicionamento vertical e giro axial automatizado, ainda no processo de concepção do projeto. A otimização visa o desempenho de iluminância em ambiente interno.

Os objetivos específicos são: integrar os algoritmos de geração do modelo, de simulação ao metamodelo e a concepção e comprovação da aplicação do metamodelo. A primeira hipótese a ser destacada é verificar a integração do algoritmo que gera a forma da *Shoebox,* aplica as combinações das variáveis independentes, realiza a simulação computacional, integrando a estes o metamodelo de otimização de posicionamento, a segunda hipótese é a comprovação do metamodelo, comparando os resultados relativos aos valores obtidos inicialmente.

O método de pesquisa será experimental. A pesquisa experimental requerendo determinar o um objeto de estudo, selecionar as variáveis que conseguiriam influenciá-lo, definir as formas de controle e observação dos efeitos que a variável produz no objeto (Gil, 2002). Na pesquisa experimental, a operacionalização das variáveis exige que se considerem as condições de mensuração, sobretudo para serem selecionados os instrumentos apropriados. O objeto de estudo definido para esta pesquisa é a *Shoebox*, que é adotada como padrão típico para simulação de desempenho de edificação, para mostrar o impacto dos principais parâmetros de design (Reinhart et al., 2013). As dimensões do *Shoebox* de formato retangular adotadas foram 3,60 m de largura, 8,20 m de profundidade e pé direito de 2,80 m. Em uma das faces existirá uma abertura, localizada a 1,00 m do piso, com 1,50 m de altura e 3,00 m de largura. A *Shoebox* será locada em Campinas, SP, Brasil. A Tabela 1 apresenta o conjunto de variáveis independentes adotadas.

Tabela 1. Variáveis independentes e as combinações possíveis.

Variável	Orientação	Posicionamento Vertical Brises	Posicionamento Axial Brises	Hora/ Data Ocupadas	TOTAL
Quant.	4	3	5	4745 (horas 6:00-18:00)	1.067.625

Os Brise foram gerados na abertura criada em uma das laterais. A abertura tem 3,00 metros de largura com 1,50 metros de altura e distância do piso de 1,00 metro. Os elementos de sombreamento são formados por aletas planas e retangulares. O design das aletas não é o foco desta pesquisa.

Uma das variáveis independentes é a orientação da abertura, os quatro posicionamentos estão representados na Figura 2 orientação da *Shoebox*, a faixa indica a abertura para entrada de iluminação solar, são quatro variações de posicionamento. Os *Brises* são elementos dinâmicos e apresentam duas formas de movimento: a rotação axial de suas aletas e o posicionamento vertical das aletas.

Na Figura 2 estão representadas as formas de controle para variar a influência dos *Brises* na *Shoebox*. São cinco posicionamentos verticais estimados e as três possíveis rotações das aletas.

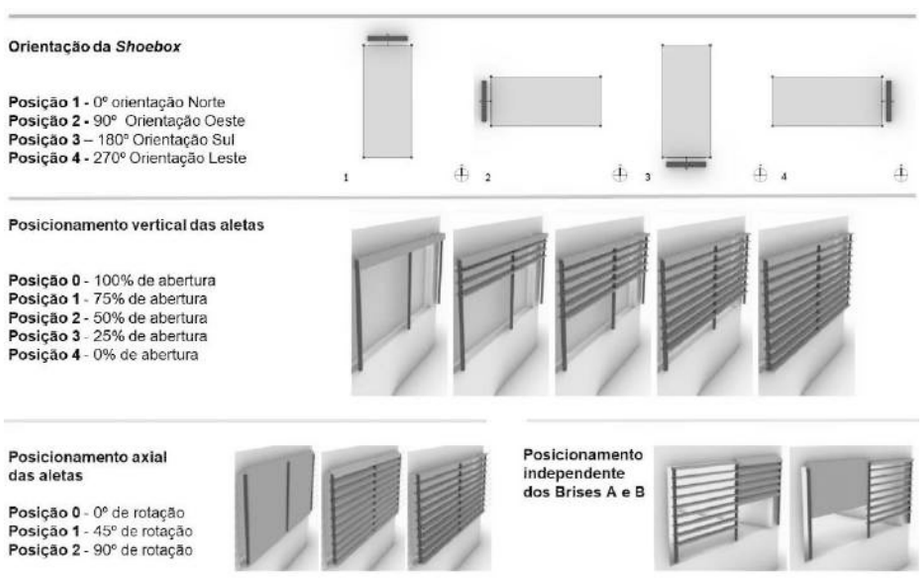

Figura 2. Operacionalização das variáveis independentes. Fonte: os autores.

Os movimentos verticais vão até as aletas chegarem no topo, onde se encaixam. Já os movimentos de rotação são realizados nos eixos de cada uma das aletas. Neste estudo são dois os Brises, denominados A e B, com tamanhos iguais. São conjuntos de aletas com movimentos independentes. O ambiente desta pesquisa experimental é computacional, realizada em ambiente virtual com o controle das variáveis, já que este ambiente permite a maximização do efeito das variáveis independentes sobre a dependente.

O fluxograma de definição do ambiente segue a lógica de *softwares* e *plugins* utilizados, como representado na Figura 3. Todo o projeto da *Shoebox* e dos *Brises* foi desenvolvido no *Rhinoceros* (Mcneel, 2022) e *Grasshopper* (Davidson, 2022). Todas variáveis independentes foram criadas em um mesmo algoritmo, seguindo uma linha de lógica paramétrica que permite a exploração de todas as combinações.

O *Climate Studio* (Solemma, 2021) é um plugin para o *Rhinoceros*, desenvolvido para realizar simulações computacionais avançadas de iluminação natural e simulação de gasto de energia. Foi construído com base nos motores de simulação validados, denominados *EnergyPlus* e *Radiance*. Destaca-se pela velocidade de cálculo e por apresentar resultados precisos. O cálculo a ser realizado será de disponibilidade de luz do dia. Essas métricas avaliam as distribuições de iluminância interna devido à incidência de luz natural, durante o ano todo.

A coleta de dados na pesquisa experimental é feita mediante a manipulação de certas condições e a observação dos efeitos produzidos. O Climate Studio funciona avaliando uma designada superfície, denominada *grid*. A superfície a ser observada precisa ser definida pelo usuário. O *grid* de observação é dividido seguindo um padrão geométrico, e com número de sensores definido, como pode ser observado na Figura 4.

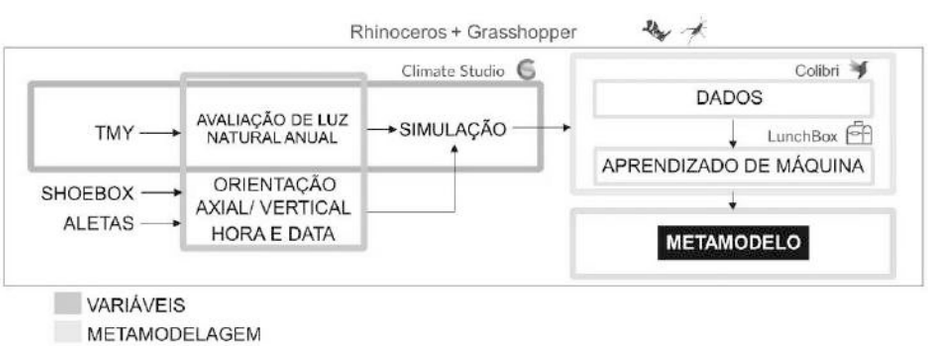

Figura 3. Fluxograma de definição do ambiente. Fonte: os autores.

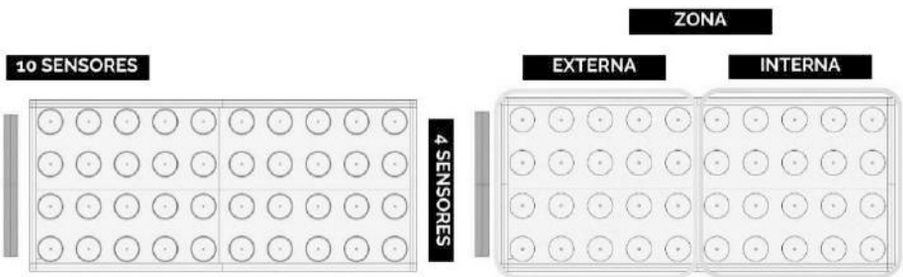

Figura 4. Grids para avaliação da Iluminância. Fonte: os autores.

Os sensores são observados individualmente, quanto maior o número de sensores, maior a precisão da avaliação e o maior o tempo de cálculo. No caso desta pesquisa foram definidos quarenta sensores, em fileiras equidistantes com quatro linhas e dez colunas. Para melhor avaliar os resultados, foi decidido dividir o *grid* em duas partes iguais, um setor com vinte sensores localizados mais próximos ao caixilho, denominado Zona Externa, e uma Zona Interna, com os mesmos vinte sensores, mas localizada distante do caixilho.

3 Resultados

Os resultados da avaliação de luz natural anual, foram apresentados em valores de iluminância média das horas ocupadas anuais de uma *Shoebox*, considerando apenas as horas ocupadas, das 6:00 até 18:00, para uso de escritório. O *Grid* foi definido com 40 sensores (divididos em 20 *grids* externos e 20 *grids* internos) e os resultados da simulação para os sensores tipo *timestep do Climate Studio,* foram separados por data e hora [lux] [wh/m²].

3.1 Metamodelagem

A metamodelagem foi realizada no *Grasshopper,* na Figura 5 a seguir estão descritos os passos do algoritmo para chegar ao resultado. Os algoritmos foram separados e todos têm funções específicas, a separação ocorreu devido ao peso computacional. O primeiro passo foi o algoritmo de geração do modelo de informação para fachada dinâmica em uma *Shoebox*, com aletas horizontais foscas de posicionamento vertical e giro axial, denominado Shoebox+CS 01.

Neste mesmo arquivo em que o modelo foi gerado, o algoritmo tem continuidade com a simulação de desempenho utilizando o *Climate Studio* e o componente de avaliação de lux natural anual, apenas as horas ocupadas.

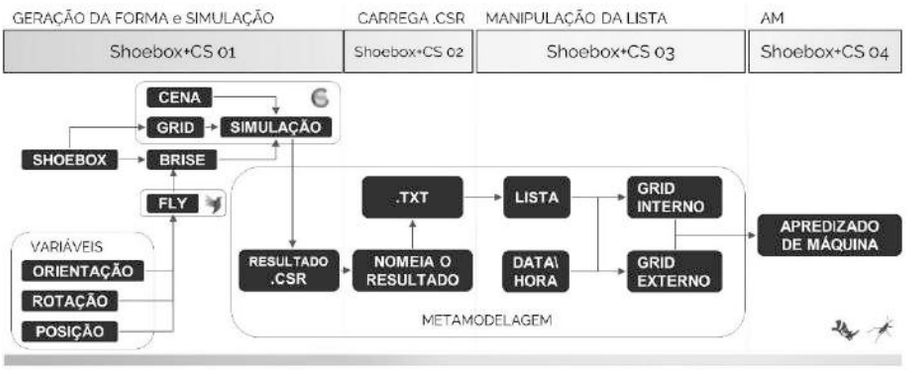

Figura 5. Processo de metamodelagem, definição de função dos arquivos de Grasshopper. Fonte: os autores.

A configuração do *grid*, dos materiais para a cena, configuração das aberturas estão todos no mesmo arquivo. Os resultados da simulação são exportados e salvos em uma pasta, arquivos em formato .CSR. Os resultados das simulações dos posicionamentos em .CSR precisam ser reinseridos no *Grasshopper* para que possam ser organizados e nomeados, passo seguinte representado no arquivo de nome Shoebox+CS 02. O algoritmo organiza os dados e exporta as listas em formato .TXT, para posteriormente explorar as diferentes combinações das variáveis, para realizar tal tarefa de forma automatizada foi utilizado o plugin do Grasshopper Colibri.

O próximo passo é a importação das listas em formato .TXT, geradas a partir dos arquivos de simulação, realizada no arquivo Shoebox+CS 03. O processo de organização das listas permite a aplicação de algoritmo de AM, classificando o desempenho da solução na concepção, e possibilitando diferentes arranjos e combinações das variáveis.

3.2 Aplicação de Aprendizado de Máquina

Foi aplicado algoritmo de otimização denominado *k-Nearest Neighbor (k-NN)* de AM para a classificação dos posicionamentos otimizados de iluminância das aletas. Os arquivos em .TXT são importados, eles já estão separados em três arquivos, as zonas internas, zonas externas e as *strings*. A lógica do algoritmo é importar os TXT's, organizá-los e combiná-los, para então encontrar o valor do posicionamento otimizado com o k-NN, Figura 6.

Os valores das zonas são designados como eixo X e Y e formam um ponto. Estes pontos são os valores de iluminância e variam entre 0 e 10.000 lux. Estes valores, em lux, são remapeados para números entre 0 e 1, todas as horas do ano são testadas individualmente, para todas as combinações das variáveis independentes de cada horário. Então é adicionado um ponto de referência, o valor de otimização definido pelo autor. Neste projeto, foram adotados os valores de referência 500, 1.000, 1.500 e 2.000 lux.

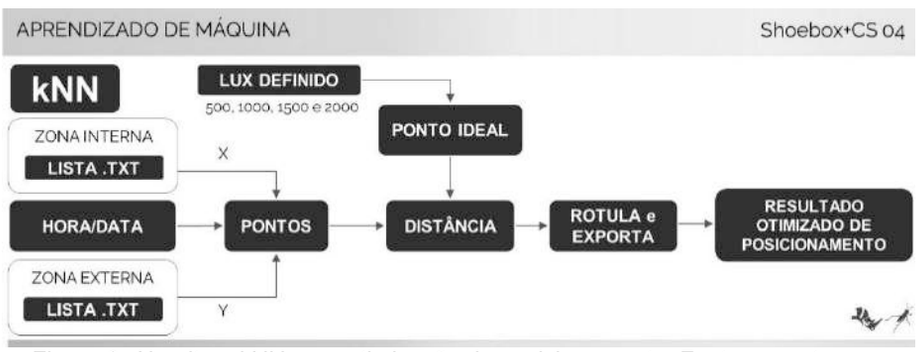

Figura 6. Algoritmo kNN para otimização de posicionamento. Fonte: os autores.

O k-NN calcula o vizinho mais adequado, neste caso utilizando a distância como definição de adequação. Entre os 225 valores para os posicionamentos e combinações das aletas, ele encontra o mais próximo e o define como o candidato ideal. O restante do algoritmo avalia todas as horas ocupadas no ano, as rotula e exporta para uma planilha, com as informações completas das combinações. Os resultados do processo de metamodelagem geraram o conjunto de posicionamentos para os Brises da *Shoebox*. Eles foram separados em planilhas de Excel de acordo com faixas de conforto determinadas pela quantidade de Lux. Essas faixas de iluminância foram definidas seguindo a premissa de Nabil e Mardaljevic (2006). O exemplo representado na Figura 6 é do funcionamento de um algoritmo de k-NN. O código tem início com a extração de valores do banco de dados, neste caso são os resultados das simulações de iluminância. Os valores estão separados em zona interna e externa, e podem ser extraídos por hora do ano. Com estes dados são criados pontos em um plano cartesiano, remapeados de 0 a 1,0. É inserido neste plano um ponto ideal, em vermelho, neste caso o ponto é de 2.000 Lux. O valor máximo de 2.000 lux não foi atingido em nenhuma média mensal. São medidas todas as distâncias entre os pontos criados e o ponto ideal, as linhas verdes da Figura 6. O ponto com a menor distância, neste caso o ponto B, é o ponto selecionado.

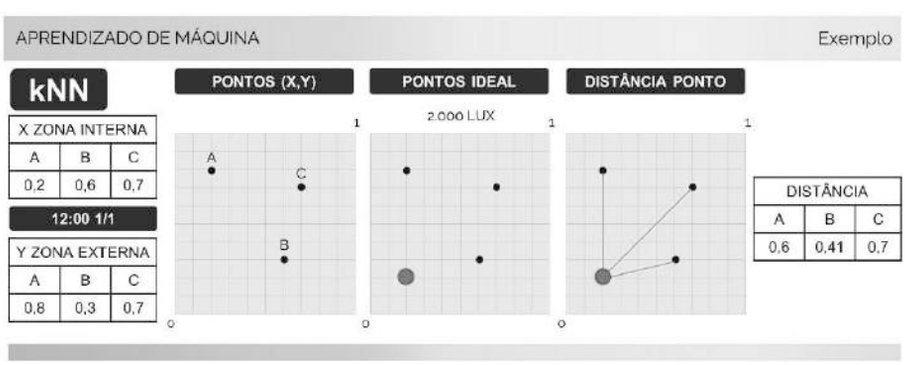

Figura 7. Algoritmo kNN para otimização de posicionamento. Fonte: os autores.

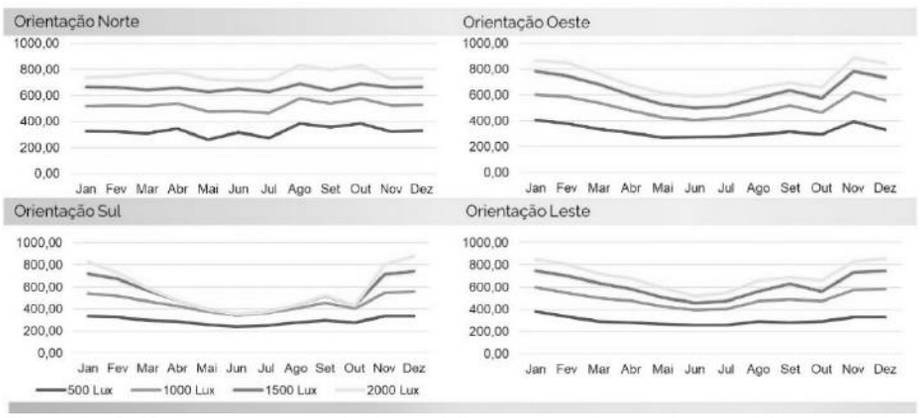

Figura 8. Gráficos com os resultados médios para cada um dos cenários avaliados. Fonte: os autores.

A análise dos resultados foi realizada a partir dos valores médios de cada um dos cenários avaliados, de maneira que possam ser comparados. Na Figura 8 os gráficos representam avaliações dos metamodelos, separadas por orientação e por valor de otimização em Lux. São valores de iluminância média mensal calculados após a otimização de posicionamentos das aletas. Observa-se que na localização deste experimento simulado para a orientação sul qualquer otimização de posicionamento das aletas na abertura resulta luminância máxima de 400 lux entre os meses de abril e outubro. Diferentes cenários existem para ampliar a atuação do metamodelo e possibilitar a adaptação dos posicionamentos. A Figura 9 apresenta os gráficos com os posicionamentos mais comuns, para os diferentes cenários analisados.

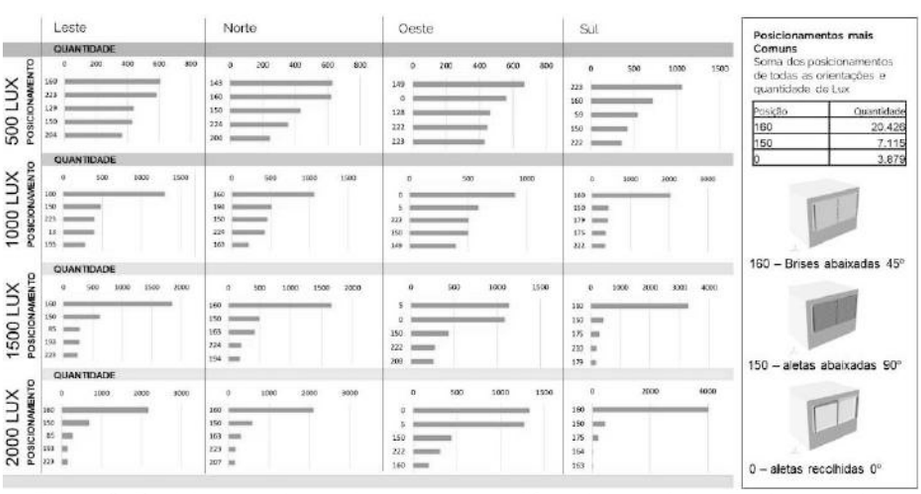

Figura 9. Posicionamentos mais comuns nos diferentes cenários. Fonte: os autores.

Os levantamentos representados nos gráficos da Figura 9 foram separados pela orientação e para cada um dos cenários em Lux, somando as quantidades de aparições de cada um dos 225 diferentes posicionamentos possíveis em todas as horas ocupados do ano. São 4.745 possíveis posicionamentos para cada um dos cenários, eles foram numerados seguindo a lógica de combinação apresentada no código, por isso não existe uma relação expressa entre a numeração dos posicionamentos os números seguintes. Os posicionamentos das aletas mais comuns foram: número 160, com as aletas abaixadas e em ângulo de 45º, número 150, com as aletas abaixadas e em ângulo de 90º e número 0, com as aletas recolhidas, foram encontrados somando todos os cenários possíveis, 4 orientações da fachada e quatro cenários em Lux, num total de 75.920 posicionamentos.

4 Considerações Finais

A contribuição desta pesquisa é gerar o conjunto dos resultados das variáveis independentes capacitando a proposição de um metamodelo para substituir a simulação. Essa é uma pesquisa em andamento e o processo de metamodelagem sofrerá provável alteração, com o intuito de verificar sua eficiência e precisão. Serão revistas técnicas de AM a serem utilizadas.

Agradecimentos. Meus sinceros agradecimentos a Prof.ª Dr.ª Ana Lúcia Harris (em memória), sem a qual este trabalho não teria início, nem meio e muito menos fim.

Al-Masrani, S. M., & Al-Obaidi, K. M. (2019). Dynamic shading systems: A review of design parameters, platforms and evaluation strategies. Automation in Construction, 102(March), 195–216. https://doi.org/10.1016/j.autcon.2019.01.014

Ayoub, M. (2020). A review on machine learning algorithms to predict daylighting inside buildings. Solar Energy, 202(March), 249–275. https://doi.org/10.1016/j.solener.2020.03.104

Belém, C. G., Leitão, A. M., Santos, L., & Leitão, A. M. (2019). On the Impact of Machine Learning: Architecture without Architects ? CAAD Futures 2019, June, 247–293.

Bracht, M. K., Melo, A. P., & Lamberts, R. (2021). A metamodel for building information modeling-building energy modeling integration in early design stage. Automation in Construction, 121(September 2020), 1–19. https://doi.org/10.1016/j.autcon.2020.103422

Davidson, S. (2022). Grasshopper (No. 2022). https://www.grasshopper3d.com

el Sheikh, M., & Gerber, D. J. (2011). Building skin intelligence: A parametric and algorithmic tool for daylighting performance design integration. Integration Through Computation - Proceedings of the 31st Annual Conference of the

Association for Computer Aided Design in Architecture, ACADIA 2011, November 2011, 170–177.

Eltaweel, A., & SU, Y. (2017). Parametric design and daylighting: A literature review. Renewable and Sustainable Energy Reviews, 73(October 2016), 1086–1103. https://doi.org/10.1016/j.rser.2017.02.011

Gil, A. C. (2002). Como Elaborar Projetos de Pesquisa. In Editora Atlas (Ed.), Como Elaborar Projetos de Pesquisa (4º Edição).

Kheiri, F. (2018). A review on optimization methods applied in energy-efficient building geometry and envelope design. Renewable and Sustainable Energy Reviews, 92(March), 897–920. https://doi.org/10.1016/j.rser.2018.04.080

Konstantoglou, M., & Tsangrassoulis, A. (2016). Dynamic operation of daylighting and shading systems: A literature review. Renewable and Sustainable Energy Reviews, 60, 268–283. https://doi.org/10.1016/j.rser.2015.12.246

Kumar, R. (2017). Machine Learning and Cognition in Enterprises. In Machine Learning and Cognition in Enterprises. Apress. https://doi.org/10.1007/978-1-4842-3069-5

Mcneel, R. (2022). Rhinoceros 3d (7 SR14 & 7.14.22010.17001. 2022). https://www.rhino3d.com

Østergård, T., Jensen, R. L., & Maagaard, S. E. (2016). Building simulations supporting decision making in early design - A review. In Renewable and Sustainable Energy Reviews (Vol. 61, pp. 187–201). Elsevier Ltd. https://doi.org/10.1016/j.rser.2016.03.045

Østergård, T., Jensen, R. L., & Maagaard, S. E. (2017). Early Building Design: Informed decision-making by exploring multidimensional design space using sensitivity analysis. Energy and Buildings, 142, 8–22. https://doi.org/10.1016/j.enbuild.2017.02.059

Poole, D. (1998). Computational intelligence: a logical approach. Choice Reviews Online, 35(10), 35-5701-35–5701. https://doi.org/10.5860/choice.35-5701

Reinhart, C. F., Jakubiec, J. A., & Ibarra, D. (2013). Definition of a reference office for standardized evaluations of dynamic façade and lighting technologies. Proceedings of BS 2013: 13th Conference of the International Building Performance Simulation Association, 3645–3652.

Reinhart, C. F., Mardaljevic, J., & Rogers, Z. (2006). Dynamic daylight performance metrics for sustainable building design. LEUKOS - Journal of Illuminating Engineering Society of North America, 3(1), 7–31. https://doi.org/10.1582/LEUKOS.2006.03.01.001

Russell, S., & Norvig, P. (2013). Inteligência Artificial. Elsevier.

Sebestyen, A., & Tyc, J. (2020). Machine Learning Methods in Energy Simulations for Architects and Designers. ECAADe 38, 1(MAKING THROUGH CODE), 613–622.

Solemma. (2021). Climate Studio (ClimateStudio_1.6.8014.23580 nov. 2021.). https://www.solemma.com/climatestudio

Programming Cultures: Parametric Analysis

Form Finding with Flexible Concrete Materialization with Addition of Agro-Industrial Pozzolans

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Abstract. This research is based on the problems faced by designers in the execution of models generated with the "Form-finding" design technique, due to the low or non-existent market proposal regarding the quality of materials capable of withstanding the stresses to which a model with complex curvatures is subjected; therefore, the use of agro-industrial pozzolans (sugarcane bagasse ash) is proposed as a 20% substitute for Portland cement to obtain flexible concrete, with the intention of evaluating the physical-mechanical behaviour and its application to geometries based on force systems (catenaries) obtained from mesh relaxation through digital simulation, following the form-finding technique, resulting in a 16% superiority in compression tests of concrete with pozzolans compared to conventional concrete (control).

Keywords: cane bagasse ash, pozzolana, concrete, form finding, catenary

1 Introducción

El diseño computacional, conforme avanza la tecnología, ofrece mayores funciones que permiten a los diseñadores predecir el comportamiento de estructuras en el mundo físico; sin embargo, las variables aumentan en función de la complejidad de las formas creadas digitalmente. Por lo tanto, es necesario conocer el comportamiento en el mundo físico.

Esta investigación parte de la inquietud de proponer un concreto capaz de materializar formas complejas sin depender de cálculos matemáticos de la estructura para la ejecución de modelos a escala objeto y que estos sean resilientes a las cargas axiales a las cuales se someten estas formas con curvaturas variables; es decir, "fuerzas a través de la geometría" (Block, 2018) en donde se utiliza la técnica de diseño *form-finding* para la búsqueda de

catenarias capaces de absorber cargas de flexión y compresión. Para ello, es necesario que el material, en este caso el concreto con ceniza de bagazo de caña (CBC), cuente con la capacidad de soportar estas cargas destructivas. Según un estudio referente a la innovación del concreto, la mezcla de concreto con CBC superará al concreto convencional en las pruebas de tensión y flexión en un 13% y 16%, respectivamente (Villicaña, 2015).

1.1 Descripción del problema

El diseño no se refiere únicamente a la generación de formas que obedecen al capricho del diseñador, pero se entiende que responden a un resultado del proceso de trabajo en sinergia con la materialización de este; pues el solo "especular" no genera innovación, sino hasta la comprobación de su eficiencia.

El diseño genera formas que se pueden alejar de la geometría euclidiana, en las que las rectas son ausentes, donde lo perpendicular se convierte en líneas oblicuas, donde la doble curvatura es la constante de las formas, pero ¿con qué material pueden ejecutarse las formas que obedecen a un diseño generado por métodos de diseño como el *form-finding* con características curvas que resistan las cargas axiales?

Aunado a esta problemática, según datos de la Cámara Nacional del Cemento (Canacem), por cada tonelada de cemento producido, se genera una tonelada de dióxido de carbono (CO_2), sabiendo que la construcción es una de las industrias con mayor actividad contaminante en el mundo.

1.2 Objetivo

Experimentar, explorar y diseñar modelos físicos con la técnica de *form-finding* asistido por un *software* que simule el comportamiento de mallas y líneas afectadas y/o deformadas por fuerzas de gravedad, materializándolos con concreto adicionado con puzolanas agroindustriales, con la finalidad de evaluar la resistencia de los modelos fabricados, si son aptos de su réplica y si obedecen a un diseño digital eficiente en el mundo físico.

Concreto

El concreto (hormigón) es básicamente una mezcla de dos componentes: agregados y pasta. La pasta, compuesta de cemento Portland y agua, une los agregados, normalmente arena y grava (piedra triturada, piedra machacada, pedrejón), creando una masa similar a una roca. Esto ocurre por el endurecimiento de la pasta, en consecuencia, de la reacción química del cemento con el agua (Portland Cement Association, 2004).

Cemento. El cemento Portland está compuesto principalmente por silicatos hidráulicos de calcio. Los cementos hidráulicos fraguan y endurecen por la reacción química con el agua. Durante la reacción, llamada hidratación, el cemento se combina con el agua para formar una masa similar a una piedra, llamada pasta. Cuando se adiciona la pasta (cemento y agua) a los agregados (arena y grava, piedra triturada, piedra machacada, pedrejón u otro material granular), la pasta actúa como un adhesivo y une los agregados para formar el concreto, el material de construcción más versátil y más usado en el mundo (Portland Cement Association, 2004).

Agregado grueso. Frecuentemente, la variación de la resistencia del concreto puede explicarse con el cambio de la relación a/c; no obstante, existe evidencia en la literatura que este no siempre es el caso. Además, por consideraciones teóricas, independientemente de la relación a/c, las características de las partículas del agregado, como el tamaño, la forma, la textura de la superficie y el tipo de mineral, influyen en las características de la zona de transición y, por lo tanto, afectan la resistencia del concreto (Mehta & Monteiro, 1998).

Agregado fino. En el agregado fino, hay dos elementos que deben ser considerados, por un lado, el módulo de finura (MF) y, por el otro, la continuidad en los tamaños, ya que algunas arenas pueden tener módulos de finuras aceptables (entre 2.2 y 3.1) y carecer de alguna clase granulométrica. Si consideramos únicamente el módulo de finura, pueden obtenerse dos condiciones desfavorables: una de ellas existe cuando el módulo de finura es mayor de 3.1 (arena gruesa), donde puede ocurrir que las mezclas sean poco trabajables, faltando cohesión entre sus componentes y requiriendo mayores consumos de cemento para mejorar su trabajabilidad; la otra condición es cuando el módulo de finura es menor de 2.2 (arena fina), en este caso puede ocurrir que los concretos sean pastosos y que haya mayores consumos de cemento y agua para una resistencia determinada, y también una mayor probabilidad de que ocurran agrietamientos de tipo contracción por secado (Uribe, 1991).

Puzolana (ceniza de bagazo de caña). Newman (Newman & Choo, 2003) y Kosmatka (2004) (Kosmatka, Kerkhoff, Panarese, & Tanesi, “Diseño y Control de Mezclas de Concreto”, boletín de ingeniería EB201, Portland Cement Association, PCA, serial 2797, ISBN 0-89312-233-5, 2004) describen las aportaciones de los principales materiales puzolánicos que se usan de forma común en la fabricación de concreto: ceniza volante, escoria granulada de alto horno, humo de sílice y puzolanas naturales (dentro de estas las más usadas son el metacaolín y la piedra caliza; sin embargo, actualmente, existen otros materiales que también han sido muy estudiados, tales como la ceniza de bagazo de caña y la ceniza de cascarilla de arroz) (Marquez-Montero *et al*., 2010; Águila, 2008; Hernández, 2010). Estos materiales podrían clasificarse dentro de las puzolanas artificiales de origen agrícola o agroindustrial.

La CBC es el subproducto del sector de ingenios azucareros y alcoholeros, y este se considera un residuo, ya que pasa por varias fases industrializadas: quema de la hoja de caña para su cosecha, transporte de la caña a los ingenios, proceso de molienda de la caña para la extracción del jugo, triturado de la caña y este ser cristalizado para la producción de azúcar o fermentado para la producción de alcohol. De esta etapa se genera un subproducto llamado bagazo de caña, el cual es calcinado para calentar las turbinas de los ingenios y producir energía eléctrica. De este paso resulta la CBC, que es un material inerte, pues se somete a más de 600 ºC. Su recolección es sencilla, pues se encuentra en bancos donde la conservan en grandes montículos.

1.3 Form- finding

Form-finding es el término bajo el cual se agrupan las diferentes técnicas de generación formal basadas en principios biológicos y físicos, dando como resultado formas estéticamente bellas, aparentemente inspiradas en la naturaleza, pero, además, funcional y estructuralmente óptimas (Patiño, 2018).

El termino *form-finding* fue empleado por primera vez por el arquitecto Frei Otto, quien logró sistematizar y parametrizar las leyes físicas que rigen estas técnicas para lograr transformaciones formales significativas en sus proyectos (Schumacher, 2008); sin embargo, antes de tomar el nombre de *form-finding*, ya algunos arquitectos buscaban inspiración en la naturaleza para sus construcciones, tal es el caso de Antoni Gaudí, quien afirmaba que “el arquitecto del futuro se basará en la imitación de la naturaleza, porque es la forma más racional, duradera y económica” (Universidad Nacional del Nordeste, 2014).

La técnica de diseño de *form-finding* consiste en la instrumentalización de la deformación elástica como propiedad del material para estabilizarse y autoconformarse (Lienhard, 2014). Dicha técnica permite lograr figuras con comportamiento eficiente respecto al material, en donde con el mínimo de área se pueden lograr cuerpos envolventes, cubiertas y formas que son estables por sí mismas, tal como se observa en la figura 1. En esta, se expone la comparativa de un arco a dos puntos que es cruzado por una curva catenaria de manera eficiente, ya que cubre las zonas críticas por donde cruzan las fuerzas a través de la geometría.

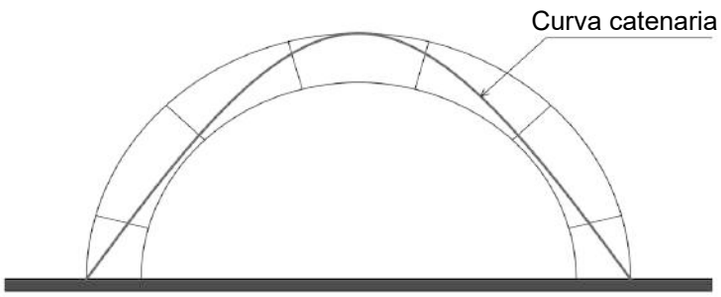


Figura 1. Arco a dos puntos en comparativa con una curva catenaria

Es necesario resaltar que, pese a la carencia de cálculos complejos, la construcción de las catenarias se ejecutaba gracias a modelos a escala que predeterminaban el comportamiento de las futuras estructuras a una mayor escala. Uno de los modelos catenarios más famosos es el modelo colgante de invertido de la iglesia la Colonia Güell (figura 2). Dicha estructura fue creada por el arquitecto Antonio Gaudí en el siglo XX, en donde este modelo de cuerdas colgantes se invierte para ejecutar en mayor escala, ya que la forma lograda predice la estabilidad de las curvas encontradas por la técnica de relajación de las cadenas y, también, permite dibujar la forma creada para la elaboración de los planos de esta iglesia.

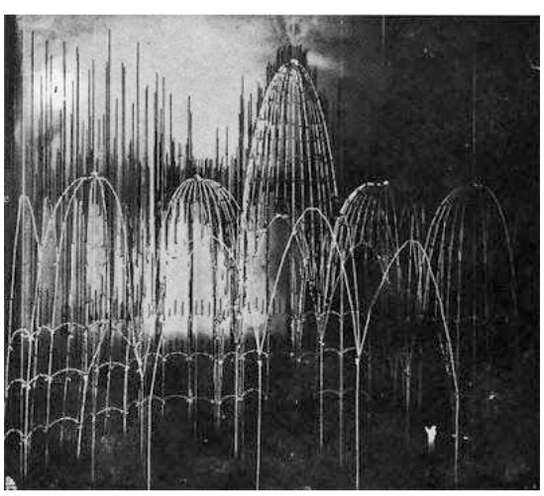


Figura 2. Modelo colgante (invertido) usado por Gaudí para dibujar los planos de la iglesia de Colonia Güell (Huerta, 2013)

2 Metodología

Esta metodología es rescatada de estudios de *form-finding* analógico, que consiste en la determinación de escalar de la forma a través de la replicación de las condiciones materiales y contextuales del mundo físico, que apunta a optimizar la geometría respecto al comportamiento material y su desempeño estructural. Existen estudios de experimentación, en este caso, apoyados por investigaciones científicas y ejemplos construidos, incluso antes del uso generalizado del diseño computacional en arquitectura, aun así continúa aportando una lectura esencial para la innovación e investigación en diseño (Gronda & Chiarella, 2017).

Para el desarrollo de esta investigación, se procede al diseño de un algoritmo en el *software* de diseño asistido por computadora Rhino 7, con lenguaje de programación llamado Grasshopper, que es un *plug-in* dentro de este *software*. En este lenguaje se instala un motor de simulación física (Kangaroo) para obtener cubiertas estructurales de autoorganización y, con estas, iterar la forma hasta lograr una aproximación a los objetivos establecidos en esta investigación (figura 3).

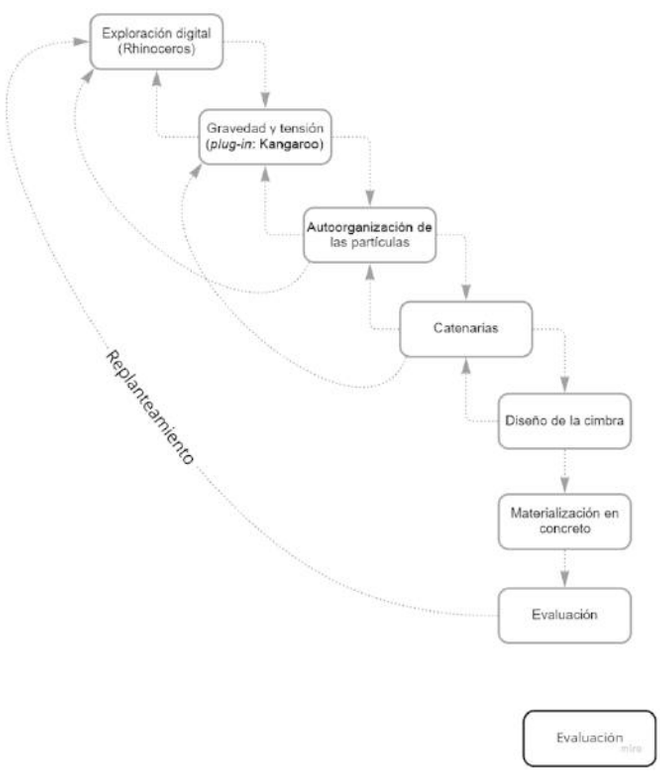


Figura 3. Metodología propuesta, basada en el trabajo de Gronda y Chiarella (2017)

2.1 Fases

La técnica de diseño *form-finding* analógica se divide en tres fases, la primera consiste en la exploración de la forma digital, incluyendo el principio de la ideación de la cimbra con los diferentes materiales antes mencionados; la segunda fase es la materialización en concreto, en la cual se considera el colado y el fraguado del concreto, que va desde la fabricación de la mezcla, pasando por el proceso de fraguado de acuerdo con las normas NMX C-161-ONNCCE-2013 y NMX-C-160-ONNCCE-2004 hasta llegar al descimbrado. Subsecuente a esta etapa, se realizan observaciones físicas y, de ser necesario, un replanteamiento hasta llegar al modelo físico, el cual se somete a una prueba de compresión simple (figura 4).

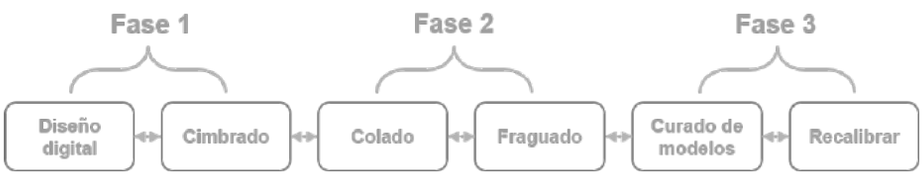


Figura 4. Fases del proceso de experimentación

2.2 Materiales

Los materiales que se utilizarán para la elaboración de la mezcla se dividen en materiales para contener (recipientes cerámicos con capacidad de contener un litro), vaso medidor, báscula al gramo, agitadores, cuchara metálica de albañilería; insumos, cemento Portland, grava, arena, agua, fluidificante, ceniza de bagazo de caña; y cimbra, tela de algodón, tela de nylon, tela de algodón 50% y nylon 50%.

El concreto es el material de la construcción más utilizado a nivel mundial y uno de los más estudiados; sin embargo, dado al origen pétreo, desde el cemento Portland (aglutinante) hasta los agregados tanto finos como gruesos, son componentes que elevan el peso específico del hormigón. Esto conlleva un uso limitado en estructuras complejas y de claros largos en proporciones largo-esbeltez de cada elemento en donde es aplicado, ya que el agrietamiento por la patología de "contracción plástica" está directamente ligado con la pérdida abrupta de humedad en el fraguado, sin descartar las diversas patologías de dicho material.

2.3 Técnica de diseño computacional

En esta investigación, se ha implementado la técnica de diseño de *form-finding* de mallas en relajación aplicado en el programa de diseño Rhino 7, en el cual

se realiza una serie de simulaciones. “Toda masa aumenta su volumen según su grado de inclinación” (Newton, 1703). Partiendo de este principio de la física, se puede predecir que se generará un cambio de dimensiones tanto en la parte interna como en la parte externa de la línea a afectar, tan solo por la relajación de esta línea. En la figura 5, se muestra la afección ante la aplicación del concreto internamente, y cómo la cimbra responde ante la autoorganización de las partículas del concreto, que busca rellenar este espacio para dar paso a un colado monolítico.

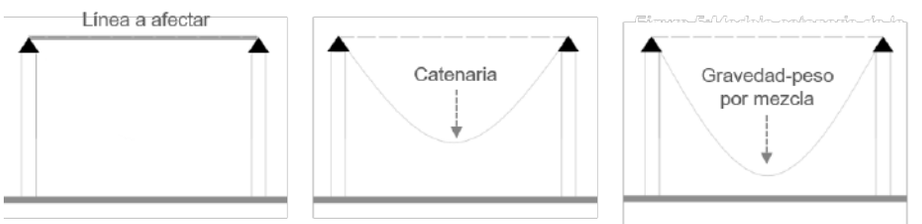


Figura 5. Comportamiento de curva catenaria

Como base a la complejización de las catenarias, se comienza el diseño con el principio de organización de partículas de Voronoi limitado por una circunferencia, en donde la distribución de las líneas se hace de manera que la intersección de las líneas con perpendiculares, respecto al cruce de cada punto interno dado en el programa computacional Rhino 7, genera una figura en planta con líneas en diferentes direcciones (figura 6).

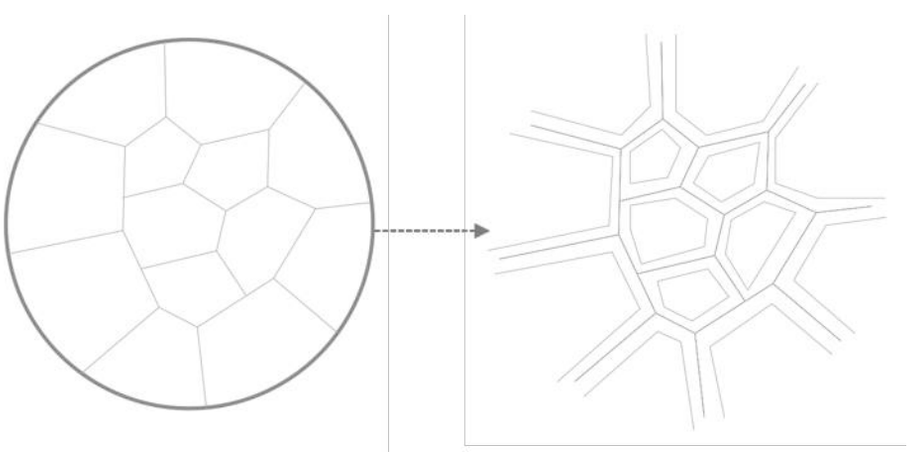


Figura 6. Voronoi como base de líneas en relajación

Después de haber obtenido las líneas base a las cuales se aplicará la relajación, se realiza un fenómeno de desfase perpendicular paralelo para obtener una tubería en dos dimensiones. Esta se convierte en una malla con la intensión de introducirla al lenguaje de Grasshopper, cuya finalidad es someterla a fuerzas de tensión, que servirá como base para imprimir en tela de caucho para llevarla a la materialización (figura 7).

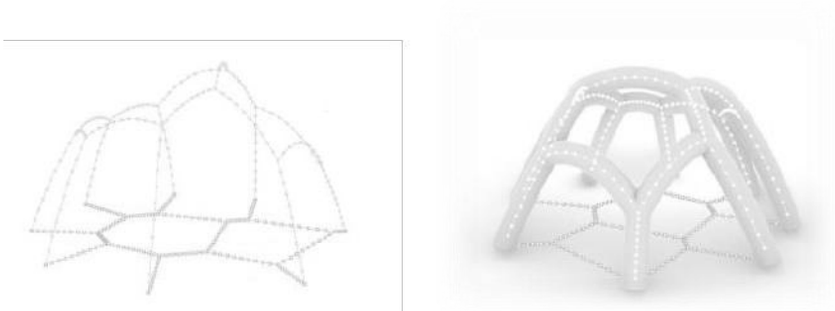


Figura 7. Relajación de líneas y mallas simuladas con el *plug-in* Kangaroo

Una vez obtenido el diseño digital, este es llevado al mundo físico, haciendo efectiva la aplicación del *form-finding* híbrido. El diseño parte de la planta establecida en el diseño digital, la cual delimita el comportamiento que esta tomará al someterse en relajación por efecto de gravedad, y está compuesta por ocho vectores, cuyo inicio se estabiliza con un anillo de acero inoxidable y abrazaderas que contienen la tela que guarda la mezcla a manera de tubo. La malla se coloca en puntos de anclaje por cada brazo vector, y esta se adapta a la deformación demandada por los esfuerzos provocados por la gravedad y, posteriormente, por las cargas de la mezcla colada, como se observa en la figura 8.

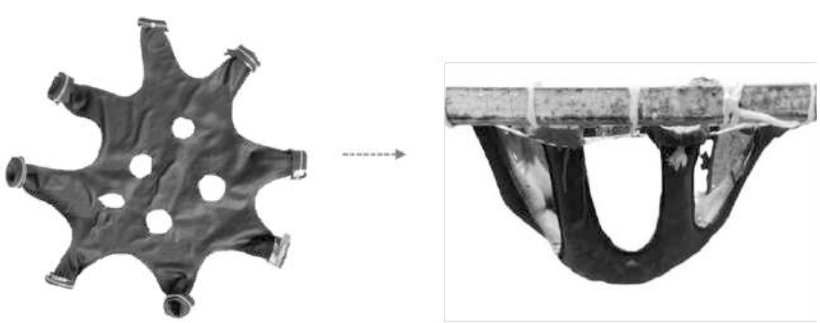


Figura 8. Aplicación del diseño digital en el mundo físico con telas de algodón y nylon

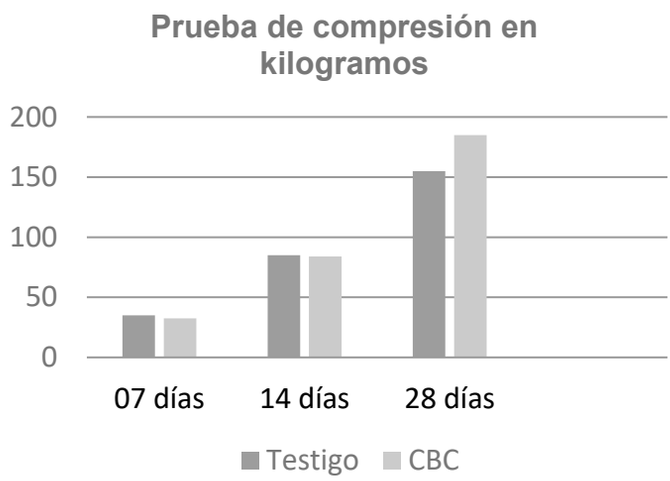
Resultados

De acuerdo con la normatividad mexicana (NMX C-161-ONNCCE-2013), el proceso de descimbrado debe ser después de las 24 horas de colado. Sin embargo, para granizar la pérdida de humedad por fraguado y obtener un modelo monolítico, se opta por retirar la cimbra a los siete días, pues se garantiza una mayor estabilidad del modelo por experiencia obtenida en esta investigación. De lo contrario, ya que los poros de esta cimbra son cerrados respecto a los otros tipos de cimbra utilizados, el proceso de fraguado es mayor, y las piezas anteriores se desprendían en ciertos puntos por efecto de un fraguado deficiente. Por ello, se descimbra con mayor tiempo posterior al colado (figura 9).

Figura 9. Modelo de concreto creado con la técnica *form-finding*

Como exigencia para evaluar este modelo, obedeciendo al método comparativo, se ha optado por la prueba de compresión comparando modelos fabricados con concreto convencional y concreto con CBC, y que estos sean probados como lo marca la norma (7, 14 y 28 días de fraguado) para obtener resultados propios de un rigor metodológico (tabla 1).

Tabla 1. Prueba de compresión directa con resultados en kilogramos



Como se puede observar en esta tabla, los modelos fabricados con concreto con CBC obtuvieron resultados favorables en un 16% en la prueba de compresión; sin embargo, con esta prueba, dado que los modelos cuentan con curvas en diferentes direcciones y brazos que actúan como soportes complejos, se puede afirmar que el concreto también trabaja a flexión para disipar o absorber las cargas hasta su punto máximo de ruptura.

3 Discusión

Esta investigación aporta una solución práctica a los retos de los diseñadores y constructores para la ejecución de formas complejas, ya que propone un material que es resistente a la flexocompresión, superior a un concreto convencional en un 16%. Así, se ha demostrado en este trabajo que puede ser aplicado en figuras de curvaturas complejas, ofreciendo una opción viable técnica y sustentablemente, pues este concreto es fabricado con residuos de la agroindustria, aprovechando un subproducto que se desecha en cantidades industriales en las localidades cercanas a los ingenios azucareros y alcoholeros. Entonces, este concreto genera un impacto positivo en el campo de la arquitectura y del diseño en general, puesto que no se limita a una sola escala ni a una sola diciplina.

Referencias

Águila, I. (2008). *Evaluación química de cenizas de cascarillas de arroz, bagazo de caña.*

Gronda, L. & Chiarella, M. (2017). Materialidad digital. Análisis de estrategias performativas transferibles al diseño resiliente. *SIGraDi 2017 [Proceedings of the 21th Conference of the Iberoamerican Society of Digital Graphics]*, 22-24.

Hernández, T. (2010). *Efecto de una puzolana de desperdicio agrícola y el tiempo de curado en la corrosión del ferrocemento* [Tesis de maestría, Instituto Politécnico Nacional].

Lienhard, J. (2014). *Bending Active Structures, Form-Finding Strategies Using Elastic.* Stuttgart: University Of Stuttgart.

Marquez-Montero, S. (2010). *Efecto de la sustitución parcial del cemento Portland por CBC.*

Mehta, K. & Monteiro, P. (1998). *Concreto, estructura, propiedades y materiales IMCYC.* IMCYC.

Patiño, E. & Maya, J. (2018). Construction of a Repertoire of Analog Form-Finding. En A. Liapis, J. Romero & A. Ekárt (Eds.), *Computational Intelligence in Music, Sound, Art and Design* (pp. 50-63). EvoMUSART.

Portland Cement Association. (2004). *Diseño y control de mezclas de concreto*. Portland Cement Association.

Uribe, R. (1991). El control de calidad en los agregados para concreto, 3.ª parte. *Construcción y Tecnología* (40).

Huerta, S. (2013). El cálculo de estructuras en la obra de Gaudí. En S. Tarragó, *Miscel.lània* (pp. 133-162). Universitat Politècnica de Catalunya.

Universidad Nacional del Nordeste. (2016). *Docencia*, *investigación, extensión y gestión*. *Comunicaciones científicas y tecnológicas anuales*. Universidad Nacional del Nordeste.

Villicaña, M. (2015). *Innovación en el diseño de concreto; empleo de puzolanas para incrementar la durabilidad.* Universidad Nacional del Nordeste. Universidad Michoacana de San Nicolás de Hidalgo.

Parametric modeling applied to landscape design: simulation as a tool for defining tree stratum

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Abstract. This experiment demonstrated how the use of a process aided with computational tools, similar to the multi-criteria performative model, contributes to the learning of architecture and urbanism students in the development of designing urban and landscape projects. The study seeks to bring students closer to multi-criteria analysis in project training activities. The method used is guided by a case study that allows simulated data referring to radiation, visual permeability, and percentage of visible sky. The results were collected through the analyzes and comparisons found in the final project of the discipline, verified through the observation of the design decisions based on the simulations. This allowed us to identify the potentialities of the process in the understanding of the students in using different criteria in the initial launch of the architectural project and also to recognize the points and negatives of the use of the process.

Keywords: Parametric Analysis, Simulation, Multicriteria Analysis; landscaping

1 Introduction

Esta pesquisa intenciona verificar como a utilização de um modelo semelhante ao de formação performática (OXMAN, 2005 e 2006), pode contribuir no ensino e aprendizagem de estudantes de arquitetura e urbanismo nas primeiras fases de concepção de projetos urbanísticos e paisagísticos. O desenvolvimento desse estudo aproxima os estudantes das simulações e análises multicritérios nas atividades de formação de projetos. Visto que a utilização adequada no ensino pode apresentar uma melhora na interpretação dos fenômenos ligados às simulações, além de facilitar a visualização dos seus resultados (REINHART, et al.,2015; REINHART, et al.,2012). O entendimento dessas análises é de suma importância para o desenvolvimento profissional, pois projetos que trazem acesso a condições mínimas de conforto, garantem aos ocupantes aspectos suficientes para o

seu bem-estar (LUCA, NABONI e LOBACCARO, 2021; REINHART, et al., 2015; LUCA, 2020).

Contudo, ainda são raros os cursos que integram corretamente as ferramentas de simulação do ambiente e a análise de desempenho aos projetos arquitetônicos e urbanísticos. A separação entre o projeto e a simulação não possibilita o real entendimento do desempenho do projeto, bem como o aprofundamento de questões relacionadas ao seu desempenho. Esse distanciamento entre o ensino das disciplinas de simulação e projetos em ateliê é uma das principais limitações no atual cenário do ensino de arquitetura (REINHART, et al.,2015; LUCA, 2019).

A integração correta, no ambiente do ensino acadêmico ou profissional — entre os processos de projeto e simulações — já foi averiguada em projetos arquitetônicos e urbanísticos, e permitem que seja interpretado e selecionado as melhores ideias e composições conforme um determinado ideal. A aplicação das simulações em disciplinas voltadas ao urbanismo mostrou-se eficiente ao promover projetos pensados no conforto e eficiência, como no uso correto da luz do dia, fluxos, sombreamento, consumo de energia, conforto térmico externo. Isso pode ocorrer mesmo utilizando exemplos arquitetônicos e urbanos, onde as possibilidades de alternativas ainda permitem diferentes testes (LIMA e DUARTE, 2021ª e 2021b).

Dispondo deste contexto como premissa, o estudo de caso apresentado neste artigo tem como experimento de método, a aplicação de simulações e análises de projeto na disciplina de urbanismo II. Nessa disciplina incentiva-se que os estudantes proponham espaços públicos que dêem suporte a atividades de lazer e aprendizado. O projeto engloba o desenvolvimento de plano de massas, definição dos espaços livres e construídos. Assim, a pesquisa é iniciada ao final da terceira de quatro etapas, no anteprojeto, onde as ferramentas paramétricas e de simulação foram experimentadas pelos estudantes e buscou-se apresentar como poderiam influenciar no processo de decisão durante a definição do estrato arbóreo.

Nessa aplicação os alunos foram estimulados a utilizarem componentes desenvolvidos em linguagem de programação visual e escrita, que permitem simular e interpretar suas decisões relacionadas a escolha das características da vegetação e composição do projeto. A visualização disponibilizada pelas simulações pode auxiliar a tomada de decisão no lançamento do estrato arbóreo paisagístico e em aspectos urbanísticos. A visualização de características como sombreamento, insolação e permeabilidade visual, resultantes de diferentes arranjos e tipos, formas e tamanhos de copas, pode orientar decisões nas atividades da disciplina.

O processo e componentes desenvolvidos permitiram identificar as potencialidades da utilização das simulações computacionais aplicadas no desenvolvimento do projeto. A pesquisa também demonstra que a absorção do conhecimento, aplicação e adaptação a diferentes demandas com enfoque na aprendizagem, é potencializada, e possibilita o entendimento de uma estrutura para um processo de projeto computacional que auxilia a compreender e utilizar critérios no lançamento inicial das características da vegetação arbórea e aspectos compositivos nos projetos urbanísticos.

2 Simulação computacional e o processo de projeto

O desenvolvimento de um projeto arquitetônico que apresenta uma boa solução para um problema, acontece segundo Bentivegna (2019), pela associação de diferentes requisitos conectados a um contexto, tais como: as propriedades e características sociais; econômicas; físicas; simbólicas; técnicas; funcionais; culturais; e outras. Tais características têm suas soluções validadas ou não pelo uso e sensação dos usuários, que circundam ou habitam o espaço após sua construção. Fatinanzi e Micelli (2019) acrescenta haver diferentes formas de se obter essa avaliação, podendo ser: requisitos relacionados ao funcionamento e eficiência vinculados ao uso prático do objeto; e o impacto que as características do projeto podem ter na qualidade do ambiente urbano e territorial no mesmo se insere.

A utilização de ferramentas digitais e de simulação computacional está cada vez mais presente na formação acadêmica de arquitetos e urbanistas, e tende a se popularizar cada vez mais. Sua utilização adequada no ensino já apresenta uma melhora na interpretação dos fenômenos ligados às simulações, além de uma facilitar a interpretação do impacto das características do projeto (REINHART et al., 2015). Contudo, a proficiência dos estudantes de arquitetura ainda é baixa ao final do curso quando relacionada ao desenvolvimento de simulações climáticas e análises. O resultado desses processos ainda necessita de melhoramentos para uma aplicação correta das simulações. Isso, entre outras causas relacionadas ao tempo de formação, estrutura, etc., pode ser resultado da insuficiência de experiências na geração de projetos que tentam adequar-se a um determinado nível de desempenho. Isso pode ser confirmado pela pouca capacidade de arquitetos formados realizarem simulações de desempenho ou interpretarem resultados corretamente (REINHART et al., 2012).

Ainda são poucos os cursos que integram suficientemente o uso de ferramentas de simulação do ambiente, análise de desempenho e projetos arquitetônicos e urbanísticos (SZENTESI-NEJUR, LUCCA e NEJUR 2021). A separação entre o projeto e a simulação pode dificultar o real entendimento do projeto, assim como não amparar o aprofundamento de questões relacionadas ao desempenho de características da arquitetura. Esse distanciamento entre o ensino das disciplinas de simulação e os projetos em ateliê é uma das principais limitações no atual cenário do ensino de arquitetura, que acabam por ocasionar uma falta de integração e aprendizagem entre o que está sendo projetado e seu real desempenho (CHARLES, E THOMAS, 2009).

Outra abordagem que não integra a utilização das simulações no contexto do processo é o uso de soluções prontas para a aplicação. O emprego de projetos anteriormente concluídos pelos alunos tem como consequência a não compreensão do potencial do uso de simulações para orientar decisões de projeto nas fases iniciais do processo criativo. Justamente no momento em que há mais liberdade de manipulação da forma e possibilidade de visualizar o impacto das escolhas de suas composições. Estudos já realizados mostram que alunos tendem a aprender com maior facilidade e

eficiência quando conseguem associar as tarefas referentes a construção do "design" formal de seus projetos com o seu consequente desempenho (IBARRA e REINHART, 2009).

A seleção do estrato arbóreo vegetal considera uma variedade de condicionantes e conhecimentos específicos relacionados a categoria de espécie selecionada. A escolha, posição e composição da vegetação depende de uma série de particularidades de cada família, como hábitos de crescimento, origem, adaptação com o entorno, e processos biológicos. Também é necessário compreender tópicos contextuais do ambiente como sistemas hidrológicos, precipitação, temperatura, vento e solo. Sendo que algumas dessas características, quando não bem definidas, podem gerar resultados críticos ao espécime escolhido ou ao entorno (SECKIN, 2018).

É comum que, no início da elaboração de projetos de paisagismo, lide-se com tipos vegetais ao invés de espécies propriamente ditas. Este modo abstrato de trabalhar com a vegetação facilita sua utilização como fator de estruturação plástica e ordenamento da paisagem. A especificação da espécie pode ser deixada para uma fase posterior do projeto, quando então se torna imprescindível considerar os aspectos naturais de cada trecho da área a ser tratada. Tendo como principais atributos a serem considerados em um primeiro momento, e irão influir decisivamente na escolha: as categorias de solo, variações de idade e iluminação (SALVATTI,1993).

No projeto de arquitetura de paisagismo, principalmente em grandes áreas, o estrato arbóreo é um elemento importante que ajuda a estruturar espaços arquitetonicamente, colaborar com a formação de áreas sombreadas, reduzir efeitos de ilha de calor, entre outras contribuições. As estratégias para a inserção destes elementos no projeto podem estar relacionadas a aspectos compositivos, arranjos volumétricos, densidade, funcionais e ambientais (GONÇALVES; BARBASSA; PEREIRA, 2016), sendo que muitas métricas podem estar envolvidas neste processo.

2.1 Ferramentas Computacionais

Como base para o desenvolvimento e visualização da programação, o ambiente de modelagem Rhinoceros 3D (versão 7) foi utilizado como ferramenta para a instalação de componentes e plugins que estruturam a criação das simulações utilizadas na pesquisa. A construção do algoritmo foi realizada em duas linguagens de programação. A primeira delas, com estratégia de programação visual, foi o editor de algoritmos Grasshopper, um módulo de extensão para modelagem paramétrica do Rhinoceros. Que, por coordenadas, produz geometrias simples que se assemelham a diferentes copas. A segunda, baseada em uma linguagem de scripting, foi feita com utilização de componente Grasshopper que permite programar um algoritmo a partir da linguagem de alto nível Python. Nessa parte eram geridas as coordenadas onde são inseridas as geometrias, e permite afastar, aproximar, randomizar, alinhar, tais pontos. O Grasshopper fornece uma gama de operações e comandos matemáticos e geométricos, podendo alterar o modelo digital construído. Essas operações e componentes podem ser

criados também em linguagens escritas, como o próprio Python, permitindo a ampliação ou simplificação de suas funções (RHINOCEROS, 2018).

Quando finalizadas, foram agrupadas em um único componente para facilitar o manuseio por parte do usuário. As simulações, que utilizam informações de saída do componente, foram organizadas por meio do plugin Ladybug. Este módulo de extensão de código aberto do Grasshopper, possibilita explorar e avaliar o desempenho ambiental relacionado a uma determinada coordenada geográfica. Para essa análise o plugin importa arquivos meteorológicos padrão do EnergyPlus (.EPW) que apresentam uma série de dados capazes de fornecer uma variedade de gráficos interativos 3D, que apoiam o processo de tomada de decisão durante o projeto. A sua utilização possibilita que haja um acoplamento dinâmico entre a “interface” de programação visual flexível baseada em componentes do Grasshopper e conjuntos de dados ambientais validados e mecanismos de simulação. (SADEGHPOUR, PAK, 2013).

2.2 Métricas

As simulações e análises permitem que os estudantes interpretem diferentes características do ambiente e possam visualizar o impacto de suas decisões e intenções de projeto. Os resultados são apresentados visualmente na “interface” do Rhinoceros 3D, e gerados por meio da manipulação de componentes pré-ajustados no Grasshopper, de modo a facilitar o seu manuseio. Assim, o usuário final responsabiliza-se apenas em conectar a geometria a ser analisada e o contexto base da simulação. Para essa pesquisa as análises foram focadas em três percepções: visual, térmica e lumínica. A escolha dessas métricas dentro do plugin Ladybug foi feita, pois, são métodos de rápida execução em geometrias simples, com pouca complexidade de parâmetros, pois não consideram características como: reflexão, absorção, cor e outros (SADEGHPOUR e PAK, 2013).

Figure 1. Uma amostra do resultado das simulações disponibilizadas, sendo: porcentagem de visibilidade; porcentagem visual; máscara do céu; radiação anual incidente; e quantidade de horas de Sol durante um ano. Fonte: Os autores, 2022.

Tais percepções do ambiente foram separadas em diferentes análises controladas por componentes independentes e disponibilizadas em cinco componentes: "Visibility Percent” (Porcentagem de Visibilidade); "View Percent” (Porcentagem visual); "Ski Mask" (Máscara do céu); "Incident Radiation" (Radiação incidente); e "Direct Sun Hours" (Horas de sol diretas). Cada uma dessas métricas têm sua descrição apresentada no próprio plugin e tem uma amostra de seus resultados apresentados pela Figura 1. As suas caracterizações podem ser descritas por:

1) Porcentagem de Visibilidade: avalia a porcentagem de visibilidade da geometria para um conjunto específico de pontos que podem ser escolhidos pelo usuário. Esses cálculos são usados para se entender a visualização de um determinado ponto de referência, podendo identificar os principais visuais e obstruções em um ambiente ao ar livre (SADEGHPOUR e PAK, 2013).
2) Porcentagem visual: avalia a porcentagem de visualização para o exterior ou para o céu por um contexto. Esses cálculos podem ser usados para estimar a qualidade de uma vista para o ao ar livre a partir de um determinado local. Também podem ser usados para avaliar a abertura de passeios ou ruas para o céu. (SADEGHPOUR e PAK, 2013).
3) Máscara do Céu: Permite que se possa visualizar a parte da cúpula do céu mascarada pela geometria de contexto ou sombreamento em torno de um determinado ponto. Malhas separadas são geradas para diferentes partes da cúpula do céu, as que estão mascaradas e as visíveis (SADEGHPOUR e PAK, 2013).
4) Radiação incidente: calcula a radiação incidente na geometria usando uma matriz de céu do "Cumulative componente Sky Matrix", um componente que obtém uma matriz contendo valores de cada pedaço de uma cúpula do céu (SADEGHPOUR; MOSTAPHA, 2019) Sendo úteis para avaliar o impacto da orientação da implementação de uma determinada arquitetura para o uso da carga térmica, tamanho e na identificação dos espaços onde há uma maior incidência cumulativa durante o ano. O componente utiliza um "Weather file" (EPW) que identifica a localidade da simulação e importa os dados pertinentes para essa análise (SADEGHPOUR e PAK, 2013).
5) Horas diretas de sol: possibilita calcular e visualizar o número de horas de luz solar direta recebida pela geometria usando os vetores obtidos do componente "LB SunPath". Esses cálculos diretos do sol podem ser usados para estudos de sombra de ambientes externos ou para estimar o potencial de ofuscamento do sol direto no interior. (SADEGHPOUR e PAK, 2013)

3 Desenvolvimento do método

Visando testar as simulações implementadas durante a pesquisa, foi proposta uma atividade com estudantes do quinto período, matriculados na disciplina de Urbanismo II, em que os participantes pudessem manipular o componente desenvolvido para essa pesquisa. Esse elemento foi criado por meio do Grasshopper, uma ferramenta do modelador tridimensional Rhinoceros 3D (versão 7) e por plugins de simulação. A construção do algoritmo foi realizada em duas linguagens: (1) programação visual, pelo editor de algoritmos Grasshopper; e (2) baseada em uma linguagem de scripting, a partir da linguagem de alto nível Python. Ambas foram agrupadas em um único componente para facilitar o manuseio por parte do usuário. O

seu uso possibilita simular e interpretar suas decisões relacionadas a escolha das características da vegetação e composição do projeto.

Esta cadeira introduz conceitos de arquitetura paisagística por meio da elaboração de um projeto de uma área livre pública, sendo que o desenvolvimento do trabalho é dividido em quatro etapas:

1) **Memorial de intenções:** leitura, interpretação e análise da área de intervenção e seleção de uma referência como estudo de caso;
2) **Diagrama conceitual:** criação de um diagrama da proposta, contendo aspectos físicos, funcionais e categorias de lazer que deverão estar presentes na proposta;
3) **Anteprojeto geral:** representa as propriedades totais de um lugar, buscando transmitir o conceito do projeto;
4) **Aproximação:** recorte de uma área onde a escala de trabalho será mais detalhada e definida, possibilitando maior especificação dos elementos que compõem o espaço.

Na etapa de anteprojeto são também introduzidos aspectos básicos de trabalho com a vegetação, contudo sem um foco nas espécies e sim na estruturação espacial, principalmente com a utilização do estrato arbóreo. Sendo assim, observa-se a necessidade da interpretação, por parte dos estudantes, dos diferentes efeitos que o porte, forma e densidade vegetal podem causar ao ambiente urbano. Com a chegada da quarta e última etapa da disciplina, em uma escala mais aproximada, os estudantes devem rever o resultado da composição arbórea, tentando relacionar com as diferentes funções do espaço. Como resultado, no início desta etapa optou-se por reservar uma aula para introduzir as ferramentas paramétricas e de simulação e como estas poderiam influenciar no processo de decisão durante a definição do estrato arbóreo.

A atividade não foi realizada com todos estudantes matriculados na disciplina, pois a maioria não teve experiências prévias com as ferramentas utilizadas no experimento, o que dificultaria o acompanhamento, por parte do tutor, das dúvidas que surgissem no processo. Como resultado, de um a dois membros das equipes de projeto foram selecionadas para participar da oficina. Dos seis grupos formados na disciplina, quatro apresentaram interesse em utilizar o componente. Cada equipe possui de cinco a seis integrantes e, desses, um ou dois envolveram-se diretamente no experimento. Utilizaram-se os computadores disponibilizados pelo laboratório de mídias digitais da Universidade Federal de Santa Catarina durante o horário das aulas do ateliê.

Para interpretar o mecanismo de funcionamento do componente desenvolvido no Grasshopper uma apresentação inicial foi efetuada, explicando os principais comandos utilizados dentro do Rhinoceros 3D e Grasshopper. Nessa primeira exposição foi explicado as duas principais funções, sendo: (1) selecionar parte da área utilizada pela disciplina; e (2) como criar as formas e curvas no Rhinoceros. Essas formas e linhas são projetadas diretamente no terreno, podendo ser feitas em duas dimensões e sendo adequado automaticamente a topografia. Tal mecanismo faz com que

caminhos e áreas preenchidas pelos maciços vegetais sejam recriadas com facilidades pelos estudantes, sem a necessidade de um nível avançado de conhecimento em ambos os programas. Isso pode ser visualizado pela figura 2, que apresenta a projeção das linhas do Rhinoceros e o terreno modelado digitalmente para a disciplina.

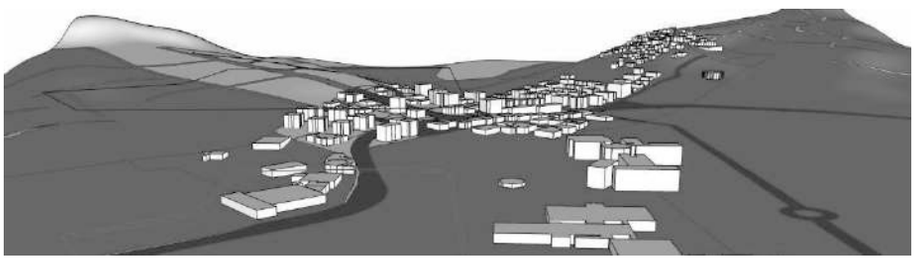

Figure 2. Apresentação da área de intervenção da disciplina, que se inicia na rua inferior esquerda e segue até a comunidade à direita. Fonte: Os autores, 2022.

Na sequência, foram demonstrados os comandos básicos de como utilizar o componente desenvolvido no Grasshopper e os parâmetros das simulações, tanto para o entendimento do resultado das simulações quanto o funcionamento dos seus controladores. Como a programação apresentada já estava completa, a interação com o ambiente deu-se pelo preenchimento e alteração de valores nos controladores pré-ajustados, de modo a facilitar o seu manuseio. Assim, para a manipulação, o usuário necessita: conectar qual superfície do terreno ele quer analisar; o espaço que será preenchido pelo estrato; caminhos — caso existam —; e qual as propriedades físicas das árvores. As análises simuladas permitem que os estudantes interpretem as diferentes características do ambiente geradas por uma determinada composição do estrato arbóreo. O resultado das simulações e das composições são repassados visual e graficamente para a “interface” do Rhinoceros 3D.

O processo de modelagem da vegetação para simulação parte da geração aleatória de pontos (P) como método de inserção do elemento no projeto. Os algoritmos desenvolvidos em Python empregam quatro modos de geração: (1) elemento atrator que emprega uma curva (c) como delimitador da distância máxima (dl) de alocação da vegetação sobre o terreno descrevendo, por exemplo, arborização ao longo de um caminho (passo A→B→C); (2) elemento repulsor, onde a distância dl torna-se o limite de aproximação e, no passo B, as áreas Ai e Ae são invertidas; (3) sobreposto, onde os pontos devem estar sobre a(s) curva(s) ($P \cap c$); e (4) aleatório, os pontos são gerados sobre At, tendo apenas o passo C como critério. A Figura 3 apresenta o componente desenvolvido e seus parâmetros de entrada e saída no Phyton e no Grasshopper.

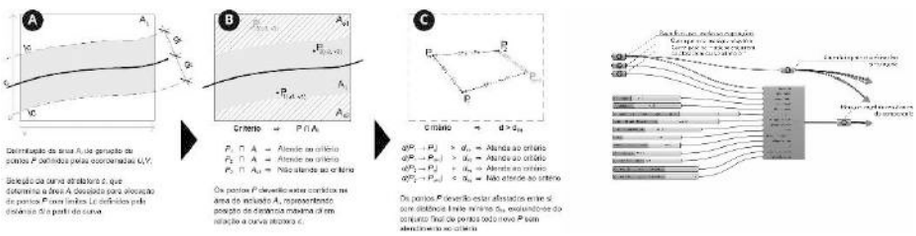

Figura 3. Regras e critérios de geração de pontos para alocação de vegetação empregando o modo “elemento atrator e uma amostra do componente desenvolvido para a programação em linguagem visual e escrita. Fonte: Os autores, 2022.

Durante a utilização do programa os alunos foram instruídos a salvarem imagens das simulações e estratos. Essas imagens, efetuadas com a captura da tela, permitiram que os resultados fossem utilizados para a criação de um acervo, que permite analisar como e se os alunos compreenderam a utilização da ferramenta, e se os resultados impulsionaram a escolha da vegetação.

4 Resultados

Os resultados coletados e apresentados nesse artigo ainda não são os finais, visto que, como comentado no desenvolvimento do método, até o momento os alunos puderam utilizar o componente desenvolvido na terceira etapa da disciplina. Mesmo apresentando soluções preliminares, a experimentação e resultados ainda podem ser ampliados com a utilização do componente em um contexto de escala mais aproximado, em que os estudantes possam analisar o comportamento de decisões fundamentais do projeto, como inserção de arquiteturas, mudanças de topografia, entre outros. Uma amostra do resultado da utilização do componente pelos alunos pode ser observada na figura 4. Nela, é possível observar um conjunto dos resultados visuais das simulações coletadas por cada equipe.

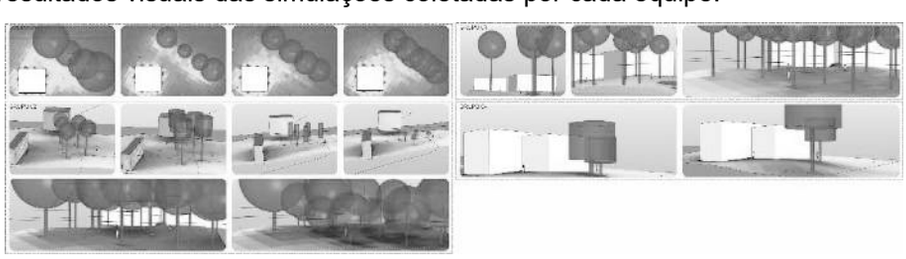

Figura 5: Uma amostra da utilização dos alunos com o componente desenvolvido. Fonte: Os autores, 2022.

Contudo, diferentes informações já puderam ser coletadas. Em um aspecto geral, os alunos conseguiram utilizar com facilidade o componente e os comandos básicos tanto do Rhinoceros quanto do Grasshopper. Os participantes acabaram por simular e analisar aspectos particulares referentes aos seus projetos, já direcionando as primeiras simulações para análises que apresentavam interesses particulares. Cada grupo testou as simulações que apresentaram uma maior conexão com o conceito aplicado no projeto. Como ao utilizarem a ferramenta de porcentagem de visibilidade e a de porcentagem visual, para verificar diferentes ordenações da vegetação, o diálogo entre o caminho e os eixos visuais, e possíveis perspectivas que gostariam de utilizar. Em outros grupos, foram testadas simulações como a radiação incidente e horas diretas de Sol, buscando identificar as composições geométricas da vegetação, como elementos em ritmo, agrupamentos, proporção ou espaços heterogêneos.

A avaliação dos diferentes critérios pelos alunos não foi induzida a nenhum método já validado, como o uso de algoritmo ou Pareto, foi feita por uma análise comparativa dos resultados gráficos visuais. A orientação para esse tipo de análise foi feita, pois nessa pesquisa não utilizaram da coleta de dados quantitativos que poderiam ser usados para análises mais complexas. As escolhas das características das vegetações foram feitas por meio de observações visuais e comparativas, pois dois resultados de simulações diferentes poderiam rapidamente aparecer e serem comparadas. E para aspectos da característica dos maciços vegetativos podem ser ajustados de modo rápido e fácil devido aos controladores

5 Discussões

O desenvolvimento, uso e análise do componente possibilitou identificar três questões que podem ser discutidas nesse artigo, sendo: a compreensão do funcionamento das simulações e a aplicação dos resultados; o entendimento do uso de simulações como um instrumento de tomada de decisão; e o interesse dos estudantes em continuarem a utilizar o componente devido à facilidade no manuseio.

A identificação das formas dos maciços arbóreos e dos elementos isolados foi uma das principais simulações realizadas pelos estudantes. Os testes foram feitos principalmente com a mudança de porte, composição — heterogêneas e homogêneas, posicionamento referente a uma determinada curva — afastada, aproximada e sobre a linha. A organização dos estratos em ritmo foi bastante avaliada, mas principalmente para questões visuais e a relação que a sombra gerada por essa linearidade pode ter com o caminho. Contudo, um ponto negativo observado dentro desse tópico foi dificuldade na manipulação de alguns comandos básicos devido a pouca familiaridade com a instrumentação. Tendo em vista que o controle não planejado de alguns dos parâmetros acabaram por ocasionar travamentos nos computadores, por uma simulação ser desativada para que outra fosse executada. Entretanto,

tais dificuldades foram rapidamente superadas, e podem ser aprimoradas com um período curto de treinamento nos programas.

O entendimento do uso das simulações foi positivo, a percepção do resultado do comportamento da radiação, insolação ou permeabilidade visual — entorno e céu — pode ser direcionado para algumas características do projeto. Tal percepção das simulações foi facilitada pela simplificação do processo, pois os estudantes não precisavam modificar um número elevado de parâmetros nos componentes para obterem resultados. Isso os conduziu a estarem mais concentrados nas mudanças de parâmetros que modificam as características do estrato arbóreo do que na alteração de componentes que mudavam resultados das simulações.

Tal facilidade no manuseio e visualização dos resultados fez com que os estudantes não se defrontassem com todas as dificuldades existentes no desenvolvimento de programações, como o entendimento da linguagem ou a "interface". Isso se evidenciou como um incentivo a continuar o uso das simulações no processo, além de estimular a utilização de programas paramétricos. Considera-se que com a continuidade da disciplina, o uso das simulações e do componente sejam ainda mais efetivos. Espera-se que para a entrega final do artigo, mais resultados visuais possam ser apresentados, reforçando as discussões apresentadas.

Para a continuidade da pesquisa e pesquisas futuras pretende-se refinar alguns dos parâmetros existentes no componente e realizar mais experimentos em diferentes fases de projeto. Ainda é observado a possibilidade de aprimoramento da programação, atribuindo mais características às geometrias, como permeabilidade das copas e mais padrões de organização.

References

Bentivegna V. (2019). The quality of the architectural works: the relational aspects, in Rivista SIEV, Valori e Valutazioni, Vol. 23, DEI, Roma, pp. 23-29.

Fattinnanzi E., Micelli E. (2019). Ezio. Evaluating the architecture project. Valori e Valutazioni, Roma, n. 23, p. 3-13.

Ibarra D. I., Reinhart C. F. (2009) Daylight Factor Simulations: How Close Do Simulation Beginners 'ReallyGet? In: Eleventh International IBPSAn 11., Glasgow. Proceedings of Eleventh International. Building Simulation, p. 196-203.

Lima, F. N. B., Jose D. (2021) a. Urban Design Optimization: Generative Approaches towards Urban Fabrics with Improved Transit Accessibility and Walkability - Generative Approaches towards Urban Fabrics with Improved Transit Accessibility and Walkability. Projections, 719–28.

Lima, F. N. B., José P. D. (2021) b. A Grammar-Based Optimization Approach for Walkable Urban Fabrics Considering Pedestrian Accessibility and Infrastructure Cost." Environment Planning and B.

Luca, F. de. (2019) Learning Performance-driven Design. Students Approach Integrating Urban Form Studies and Building Performance Analysis. In: 16 th IBPSA, 16. p. 1-9.

Luca, F. de. (2020) A Case Study of Teaching Method and Students' Learning Experience in Integrating Urban Design and Performance Simulations for Climate Conscious Design in Estonia. Acta Architecture Naturalis, v. 1, n. 6, p. 44-63.

Luca, F. de., Naboni, E., Lobaccaro, G. (2020) Tall buildings cluster form rationalization in a Nordic climate by factoring in indoor-outdoor comfort and energy. Energy And Buildings, v. 238. http.10.1016/j.enbuild.2021.110831

Gonçalves, L. M., Barbassa, A. P., Pereira, T. R. D. S. (2016). O projeto paisagístico como elemento integrador e identificador de técnicas compensatórias de drenagem. In: congresso internacional towards green cities, Mérida. p. 1-10.

Oxman, R. (2005) The conceptual content of digital architecture.: a content analysis in design. Arquitetura Revista, p. 1-16.

Oxman, R. (2006) Theory and design in the first digital age. Design Studies, 27, n. 3, p. 229-265. Elsevier BV. http://dx.doi.org/10.1016/j.destud.2005.11.002.

Reinhart, C. F. et al. (2012). Learning by playing – teaching energy simulation as a game.Journal Of Building Performance Simulation. 5, n. 6, p. 359-368, http://dx.doi.org/10.1080/19401493.2011.619668.

Reinhart, C. F. et al. (2015). Lessons Learned from a simulation-based approach to teaching building science to designers. In: Building Simulation, 14. Hyderabad. Proceedings in Conference of International Building Performance Simulation Association. Hyderabad: p. 1126-1133.

Rhinoceros (2018). Disponível: <https://www.rhino3d.com/>. Acesso em: 15 mar. 2018

Sadeghipour R., M., Pak, M., (2013). Ladybug: a parametric environmental plugin for grasshoppers to help designers create an environmentally conscious design. In: Proceedings of the 13th International IBPSA Conference Held in Lyon.

Sadeghpour R., M., Pak M. (2019). Cumulative Sky Matrix. Disponível em: https://docs.ladybug.tools/ladybug-primer/components/2_visualizedata/cumulative_sky_matrix. Acesso: 15 jun. 2022.

Salvati, E. J. (1993). Tipos vegetais aplicados ao paisagismo. Paisagem e Ambiente, n. 5, p. 9. Universidade de São Paulo, Agência USP de Gestão da Informação Acadêmica (ÁGUIA). http://dx.doi.org/10.11606/issn.2359-5361.v0i5p9-45.

Seckin, N. P. (2018). Environmental control in architecture by landscape design. A/Z: ITU journal of Faculty of Architecture, v. 15, n. 2, p. 197-211, LookUs Bilisim A.S. http://dx.doi.org/10.5505/itujfa.2018.90022.

Szentesi-Nejur, S., Luca., F. de., Nejur, A. (2021) Integrated Architectural and Environmental PerformanceDriven Form-Finding: a teaching case study in montreal. In: ECAADE 39, Novi Sad. Proceedings in Education and Research in Computer Aided Architectural Design in Europe. Novi Sad v. 2, p. 105-114.

Investigation of indoor daylight performance of the two-sided roof monitor system solution space

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Abstract. The present study evaluated levels of zenith daylight and the incidence of solar radiation in an indoor environment with two-sided roof monitor system opening using a parametric geometric model, numerical simulations and machine learning techniques. It was used a climatic database from a locality with a hot and humid tropical climate, at low latitude in Brazil. The daylight performance was analyzed using the Useful Daylight Illuminances and the incident solar radiation with annual and daily maximum results. The study included analyzes with the zenith openings oriented to North-South and East-West, considering the photosensitive sensor meshes on the walls and floor. The results presented that the modeling process used can help the architectural design process in its dimension of natural illuminance and incidence of solar radiation in internal environments, showing optimized configurations for the room size and for the zenithal opening geometry.

Keywords: Predictive Modeling, Parametric Modeling, Radiation, Zenithal Daylight, Indoor Environment.

1 Introdução

A entrada demasiada de radiação solar em ambientes arquitetônicos internos, quando não controlada, pode prejudicar o conforto térmico dos usuários e pode gerar desconforto visual através do ofuscamento. Além do excesso de iluminância ou calor, pode haver também a falta de luminosidade natural, influenciando o consumo energético. Nesse sentido, o dimensionamento e distribuição das aberturas dos ambientes internos para o ambiente exterior devem ser bem planejadas, de modo a captar quantidade de luz diurna adequada para atividades (SILVA et al. 2019). Em geral, os sistemas de iluminação natural zenitais com superfícies transparentes horizontais apresentam maiores ganhos térmicos e maior possibilidade de ofuscamento por reflexão, principalmente em localidades de baixa latitude.

O método da Iluminância útil de luz natural, conhecido também como *UDI* (*Useful Daylight Illuminance*), é usado para avaliar o tempo em que os níveis de iluminância da luz do dia estiveram dentro de uma faixa de iluminância especificada, em um intervalo de permanência estipulado (Nabil e Mardaljevic, 2006). Esta avaliação realiza análises que empregam um modelo de céu realista e variável com o tempo para prever níveis horários de iluminância absoluta da luz do dia. A parâmetro de desempenho *UDI* não informa apenas sobre os níveis úteis de iluminância da luz diurna, mas também sobre os níveis excessivos de luz do dia que estão ligados ao desconforto visual do usuário e o ganho térmico indesejado.

Neste artigo é apresentado um estudo de iluminação natural em um ambiente arquitetônico composto por uma sala de planta quadrilateral e uma dupla abertura zenital. A tipologia de abertura utilizada nesse estudo foi o lanternim, modelado parametricamente para que fosse obtido o espaço de soluções desta tipologia e, identificar as melhores configuração dos parâmetros geométricos que definem a sua forma, dada uma localidade geográfica. Nesta investigação foi considerada uma base de dados climática de uma localidade de clima quente e úmido, de baixa latitude de modo a verificar se há situações que possam ser obtidos bom nível de iluminação natural zenital sem causar superaquecimento no ambiente devido ao excesso de radiação solar.

2 Materiais e métodos

As investigações de desempenho do ambiente interno foram realizadas considerando o modelo conhecido como modelo de “caixa de sapatos” (*shoebox model*) (REINHART et al., 2013). Este modelo consiste em um ambiente em formato cuboide com o fechamento superior que, neste caso, possui uma abertura zenital do tipo lanternim.

2.1 Modelo geométrico paramétrico

O modelo geométrico paramétrico foi concebido no ambiente CAD (*Computer Aided Design*) *Rhinoceros* v.7 em conjunto com a interface de programação visual *Grasshopper*. Na Figura 1 podem ser observados os parâmetros definidores do modelo geométrico do ambiente com o acoplamento do lanternim, definido por 9 parâmetros: Largura do ambiente (Larg); Profundidade do ambiente (Prof); Altura do ambiente (Altura); Altura do lanternim (Alt_L); Proporção da largura do lanternim em relação à largura do ambiente (Prop_L); Proporção horizontal da abertura de entrada de luz em relação a profundidade do ambiente (Prop_h); Proporção vertical da abertura

de entrada de luz em relação à altura do lanternim (Prop_v); Extensão da marquise de proteção (Marq); e a Espessura da laje da marquise (Esp). Também podem ser observadas no canto inferior esquerdo da Figura 1 as duas orientações deste ambiente em relação ao Norte, consideradas nas análises realizadas: Norte 1, onde as aberturas de entrada de luz são voltadas para o Norte-Sul; e Norte 2, onde as aberturas de entrada de luz são voltadas para o Leste-Oeste.

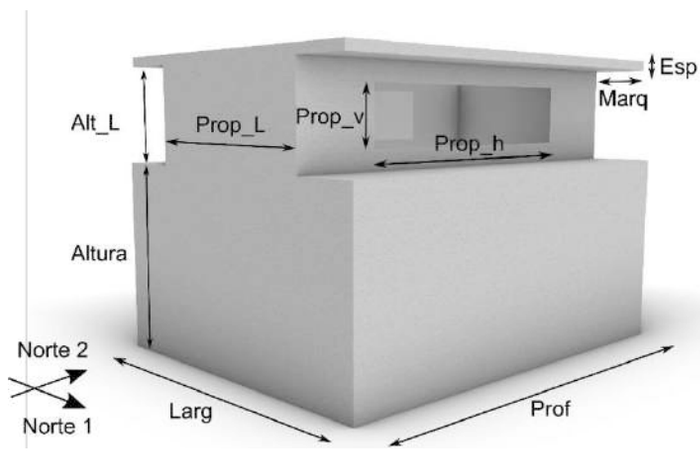

Figura 1. Modelo geométrico e seus parâmetros definidores. Fonte: Autores, 2022

2.2 Simulações de radiação solar e iluminância natural

As simulações de radiação e iluminância foram realizadas no *Grasshopper* através da biblioteca *Honeybee*, proveniente do pacote *Ladybug tools*, que por sua vez, consiste em uma interface programada em *python script* que administra o software *Radiance* que contém o motor de cálculo para esta simulação. O método numérico de cálculo de radiações e iluminância que esta ferramenta usa é o *raytracing* (AYOUB, 2019), considerando como fonte de luz o sol e, captadores sensíveis a essa luz modelados por um *grid* de pontos localizados onde se pretende avaliar o desempenho. Foi considerado um *grid* de pontos com espaçamento entre si de 0,5 m, sendo ilustrado na Figura 2 a distribuição destes no piso e nas paredes do ambiente modelado. Adicionalmente, foi considerado o pacote *Acelerad*, que permite que o *Radiance* realize cálculos de *raytracing* usando o processador da *GPU* (*Graphical Processing Unit*) para realizar os cálculos, diminuindo substancialmente o tempo de processamento da simulação de radiação e iluminância de cada instância do modelo paramétrico.

Na simulação da propagação da luz/radiação pelo *raytracing*, os vetores que representam os raios de luz irão se refletir ao entrar em contato com as superfícies das paredes, teto e piso do ambiente, sendo influenciados pelas propriedades de cor e rugosidade que essas superfícies possuem. Para isso,

foram consideradas propriedades fixas padronizadas segundo a Instrução Normativa Inmetro para a Classificação de Eficiência Energética de Edificações Comerciais, de Serviços e Públicas (INI-C, 2021), onde os índices de refletâncias utilizados foram de 70% para o teto, 50% para as paredes internas e 20% para o piso. O vidro das aberturas também é um ponto de influência de como a radiação e iluminação penetra no ambiente, sendo considerada a propriedade física para as simulações de 84% de transmitância para o vidro simples.

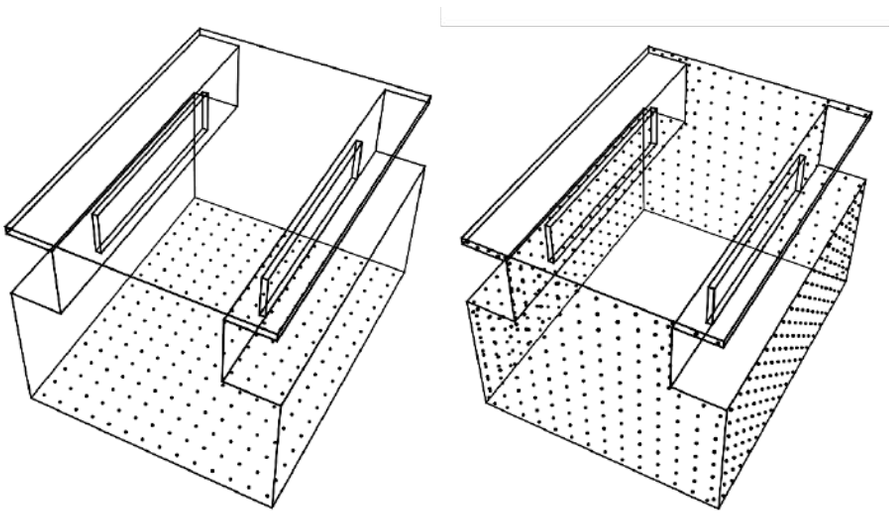

Figura 2. Posicionamento dos sensores de captação de radiação e iluminância: esquerda: sensores no piso; direita: sensores nas paredes. Fonte: Autores, 2022

A avaliação do desempenho lumínico diurno foi realizada com os valores de *UDI* (*Useful Daylight Illuminance*), que consiste em um percentual de tempo que o valor da iluminância esteve dentro da faixa especificada, considerando uma janela temporal de acordo com a ocupação (*schedule*). Neste estudo, foi considerada uma janela de tempo diária entre 8:00h às 16:00h e a faixa de iluminância entre 150 lux e 2000 lux. Esta faixa de iluminância em lux está dentro da faixa sugerida pela literatura (NABIL, MARDALJEVIC, 2006; CHI et al., 2018), onde este limite superior em lux viria a prevenir o superaquecimento do ambiente e a eventual ocorrência de desconforto por ofuscamento pela luz excessiva.

Os índices de desempenho que foram considerados neste presente estudo foi o valor da radiação máxima e de *UDI* mínimo apresentados pelo sensor de cada instância analisada. Para estas análises foi considerada a localidade da cidade de João Pessoa (Lat.: 7,1º Sul; Long.: 34,9 Oeste), usando a base de dados meteorológica pelo arquivo *.epw com dados coletados pelo INMET (Instituto Nacional de Meteorologia), disponível no site climate.onebuilding.org.

Foi usado para esse processamento um computador exclusivamente dedicado a estes processamentos com configuração de processador de 6 núcleos e 12 *threads*, 32 GB RAM e GPU GTX1060.

2.3 Espaço de soluções e Meta-modelo

Na modelagem geométrica deste ambiente, foram adotadas para as três dimensões do ambiente um domínio que compreende sugestões providas pela literatura (ACOSTA et al., 2013; GARCIA e PEREIRA, 2019; SILVA et al., 2019; TABADKANIA et al., 2019). A geração do espaço de soluções discretizado foi realizada considerando subdivisões dos domínios dos parâmetros definidores da geometria, apresentado na Tabela 1. Foram consideradas duas orientações ao Norte, paralelos às duas dimensões da planta do ambiente em estudo (Figura 1). Este espaço de soluções, para cada situação de posicionamento dos sensores (piso e paredes) e, para cada uma das duas orientações ao Norte, corresponderam a 45.927 instâncias em cada um desses quatro casos estudados (duas orientações ao Norte, sensores no piso e nas paredes), totalizando 183.708 instâncias geradas com avaliações advindas de simulações numéricas. As saídas simuladas numericamente com resultados de radiação e iluminância captados pelos sensores corresponderam a valores anuais, alimentando uma tabela de dados que corresponde ao espaço de soluções simulado.

Tabela 1. Domínios dos espaços de solução do modelo geométrico

Dimensões	Domínio discretizado simulado	Domínio discretizado meta-modelo
Larg / Prof / Altura	3,0 m; 6,0 m; 9,0 m	3,0 m; 4,0 m; 5,0 m; 6,0 m; 7,0 m; 8,0 m; 9,0 m
Alt_L	0,50 m; 0,75 m; 1,00 m; 1,25 m; 1,50 m; 1,75 m; 2,00 m	0,50 m; 0,75 m; 1,00 m; 1,25 m; 1,50 m; 1,75 m; 2,00 m
Prop_L	25%; 50%; 75%	25%; 35%; 45%; 55%; 65%; 75%
Prop_v / Prop_h	30%; 60%; 90%	30%; 40%; 50%; 60%; 70%; 80%; 90%
Marq	0,5 m; 1,0 m; 1,5 m	0,5 m; 0,6 m; 0,7 m; 0,8 m; 0,9; 1,0 m; 1,1 m; 1,2 m; 1,3 m; 1,4 m; 1,5 m
Esp	0,1 m; 0,2 m; 0,5 m	0,1 m; 0,2 m; 0,3 m; 0,4 m; 0,5 m

Fonte: Autores, 2022.

A tabela de dados gerada que representa o espaço de soluções deste sistema foi usada para treinar uma rede neural para obter um modelo

generalizado a partir de um uma regressão. Os dados de entrada desta regressão são os valores de configuração da geometria e, os dados de saída, os valores de radiação máxima e *UDI* mínimo. Com a disponibilidade de um meta-modelo (*meta-model*), também conhecido como modelo substituto (*surrogate model*), valores de desempenho de instâncias foram obtidos com tempo de processamento menor e com configurações intermediárias não simuladas numericamente.

A configuração desta rede neural para obter este meta-modelo considerou uma função de ativação do tipo *ReLu* com número de camadas intermediárias e quantidade de neurônios a ser definida inicialmente a partir de um processo de otimização de modo a minimizar o erro quadrático médio da etapa de treinamento e teste. A construção dessa rede neural foi realizada com as bibliotecas *Tensorflow-Keras* que possui métodos de aprendizado de máquina (*Machine Learning*) e, para o processo de otimização da configuração desta rede neural foi usada a biblioteca de algoritmos genéticos *PyGAD*, ambas disponíveis na linguagem de programação *python script*.

O conjunto de dados de treinamento e de teste da rede neural foi gerado a partir de uma seleção aleatória usando a função *sample* da biblioteca *Pandas*, aplicando uma normalização deste conjunto de dados para melhor desempenho no treinamento da rede neural. A taxa de separação do conjunto de dados foi de 80% para o subconjunto de treinamento e 20% para o conjunto de teste. A quantidade de épocas foi obtida por um controle automático provido pela biblioteca *Keras*, considerando os valores de perdas (*loss*).

Um novo espaço de soluções discretizado foi gerado a partir do modelo generalizado pelo meta-modelo, considerando uma discretização mais refinada do que a tabela de dados inicialmente gerada por simulações. Ao invés de 45.927 instâncias, este novo espaço de soluções contém 38.824.170 instâncias, considerando maiores subdivisões dos domínios definidos pela Tabela 1.

O espaço de soluções foi analisado graficamente através da plotagem de pontos em *plots* bidimensionais que relacionam as dimensões do ambiente e do lanternim entre si e valores de radiação máximo e *UDI* mínimo. A visualização gráfica do espaço de soluções em instanciações com valores elevados de *UDI* mínimo tem o objetivo de apresentar quais as combinações de dimensões de ambiente e configuração geométrica do lanternim que demonstraram melhor desempenho.

Devido à dificuldade que multidimensionalidade do problema acarreta à análise, foi considerada a técnica do algoritmo *k-means* para separar os melhores quatro grupos de instância que apresentaram melhor desempenho. Esta implementação do algoritmo *k-means*, técnica de aprendizado de máquina não supervisionado que separa grupos de pontos de dados com características mais próximas, foi realizada usando a biblioteca *Scikit-learn* na linguagem de programação *python script*.

3 Resultados e Análises

A rede neural otimizada consistiu em três camadas com 128 neurônios. O processo de treinamento das redes neurais para a geração da regressão que consistem nos meta-modelos para cada caso de orientação ao norte, apresentaram na fase de teste valores de erro absoluto e quadráticos médios considerados baixos. Estes valores estão em torno de 1,0 relativo ao erro absoluto médio e 9,0 para o erro quadrático médio para as medidas de *UDI* mínimo; em torno de 0,5 relativo ao erro absoluto médio e 4,0 para o erro quadrático médio para as medidas de radiação máxima.

3.1 Visualização do espaço de soluções a partir do meta-modelo

Para visualizar o espaço de soluções gerado pelo meta-modelo foi considerada um uma separação deste em quatro grupos através do algoritmo *k-means* e plotados em gráficos bidimensionais de pontos que representam as instâncias, contornados por curvas tracejadas, gerando regiões que contém cada agrupamento de pontos. Nas Figuras 3 a 6, são apresentados esses gráficos que relacionam o desempenho deste sistema relacionando o *UDI* mínimo anual com as dimensões do ambiente e a relações entre as medidas do lanternim.

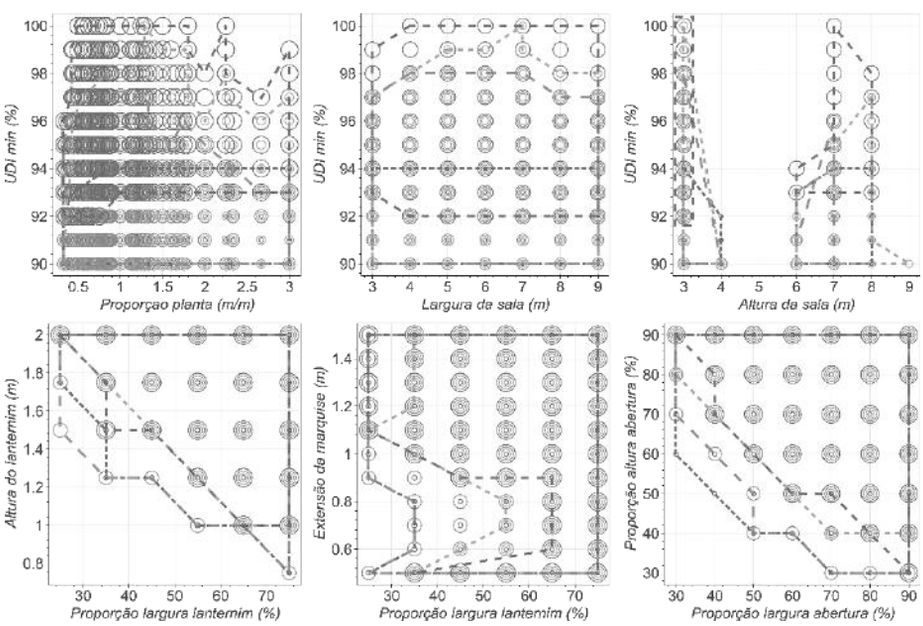

Figura 3. Relação entre dimensões do ambiente e do lanternim com os valores de *UDI* mínimo para o piso: aberturas voltadas para o Norte-Sul. Fonte: Autores, 2022

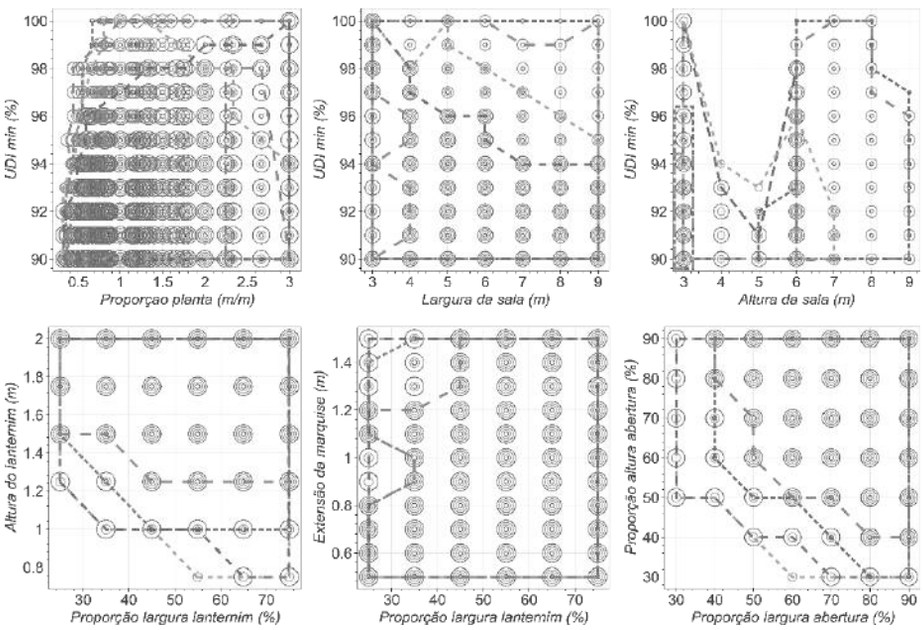

Figura 4. Relação entre dimensões do ambiente e do lanternim com os valores de *UDI* mínimo para o piso: aberturas voltadas para o Leste-Oeste. Fonte: Autores, 2022

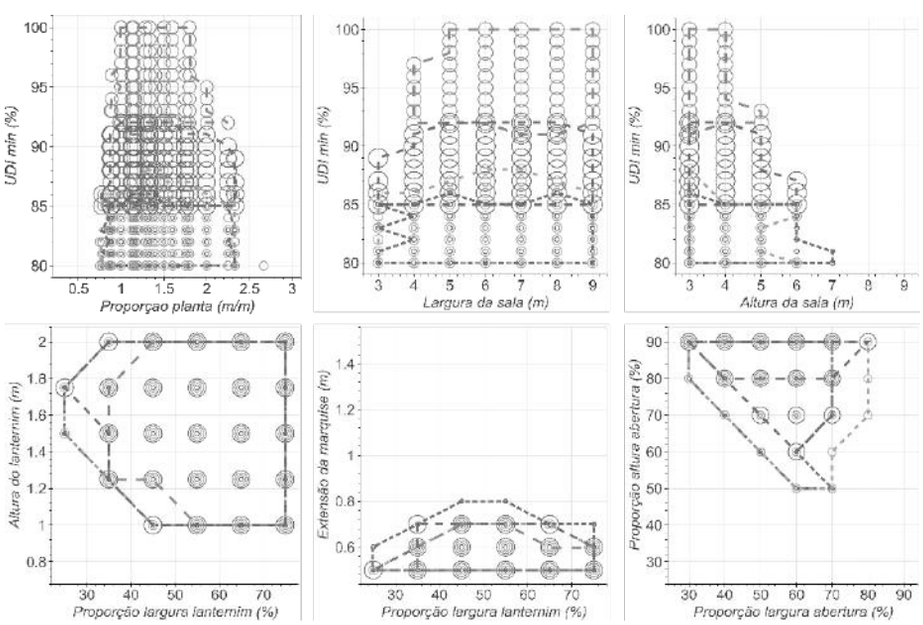

Figura 5. Relação entre dimensões do ambiente e do lanternim com os valores de *UDI* mínimo para paredes: aberturas voltadas para o Norte-Sul. Fonte: Autores, 2022

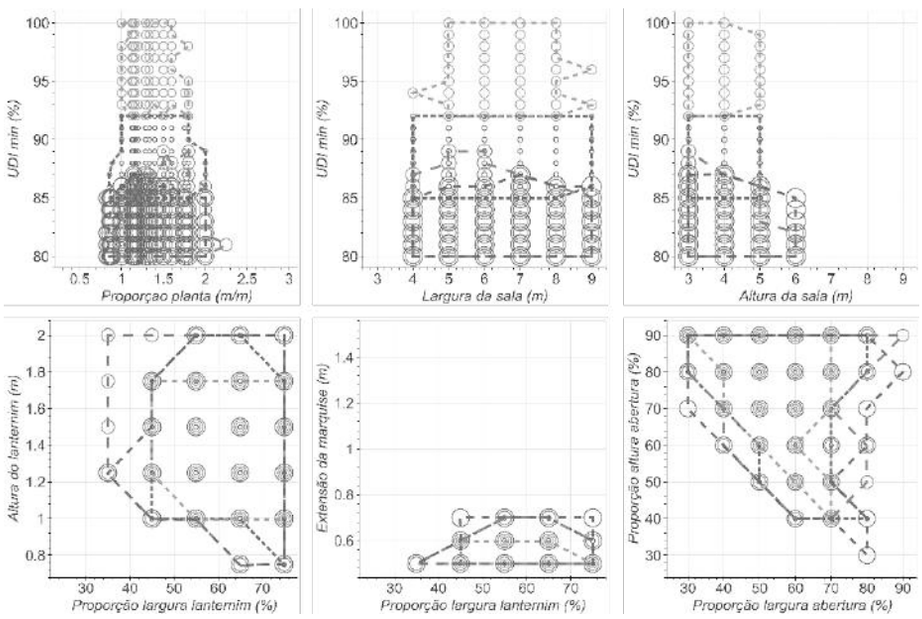

Figura 6. Relação entre dimensões do ambiente e do lanternim com os valores de *UDI* mínimo para paredes: aberturas voltadas para o Leste-Oeste. Fonte: Autores, 2022

Os pontos que representam as instâncias do espaço de soluções foram ilustrados por círculos (Figs. 3 a 6) para melhor visualizar as sobreposições em grupos diferentes, diferenciando-os por cor e diâmetro desses círculos. O algoritmo *k-means* separou o espaço de soluções em quatro grupos com cores diferentes, o que auxiliou a identificar quais configurações do lanternim estão associadas a um índice de UDI mínimo anual mais elevado: grupo vermelho na Figura 3; grupos verde e azul na Figura 4; grupo verde na Figura 5 e grupo laranja na Figura 6.

Estes resultados mostram que o desempenho de iluminância na localidade analisada depende da configuração do tamanho e proporção da sala, das dimensões da abertura de entrada de luz e da relação destes parâmetros com a extensão da marquise. Nestas figuras, observa-se que os desempenho do piso foi superior em relação às paredes, apresentando opções mais abrangentes da configuração das dimensões da sala e do lanternim e sem grandes limitações da altura da sala frente ao desempenho.

A orientação das aberturas ao Norte-Sul aparentaram ter menor desempenho em relação à Leste-Oeste, sobretudo no decrescimento de desempenho do piso em salas com altura entre 4 m e 6 m, e das paredes em salas com altura maior do que 4 m. A orientação Norte-Sul apresentou um desempenho melhor quando associada a proporções menores de larguras do lanternim em relação à largura da sala e, a maiores extensões da marquise, demonstrando uma necessidade maior de proteção do interior.

3.2 Investigação detalhada de uma instância com bom desempenho

Para exemplificar uma situação de projeto, foi escolhida a partir dos gráficos do espaço de soluções (Figuras 3 a 6) uma instância com configuração de ambiente e de lanternim com as aberturas orientadas Norte-Sul.

Na Figura 7 são apresentados em falsa-cor os resultados anuais deste ambiente, que tem as dimensões da sala com 5 m x 5 m x 3 m, e as dimensões do lanternim com 60% da largura do ambiente, altura de 1,2 m, 0,75 m de extensão da marquise, e com proporções de abertura horizontal e vertical, respectivamente a 50% do comprimento do ambiente e 90% da altura do lanternim. O espaço de soluções indicou que esta configuração do ambiente e do lanternim representou um desempenho anual de UDI mínimo de acima de 80% para o piso (Figura 3) e para as paredes (Figura 5), confirmado pelo resultado simulado (Figura 7).

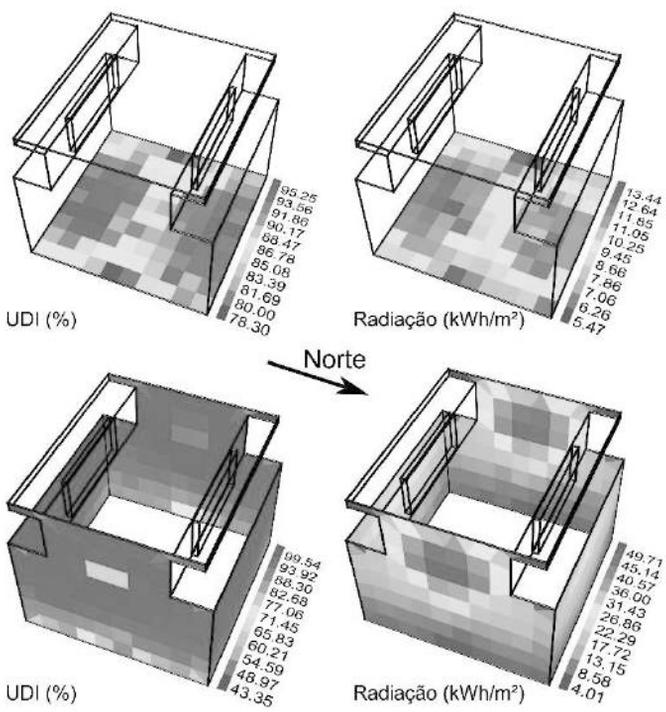

Figura 7. Resultado de valores anuais de *UDI* e Radiação acumulada em piso e paredes com aberturas do lanternim voltadas para o Norte-Sul. Fonte: Autores, 2022

Pode-se observar na Figura 7uma relação entre a situação do dos valores mais baixos de *UDI* tanto com regiões de excesso quanto com falta de radiação. No piso, os menores valores de UDI estão associados a uma menor radiação enquanto que, nas paredes, os menores valores de UDI estão na base das paredes Leste-Oeste por baixa radiação e, no topo destas paredes

por excesso de radiação. No entanto, estes resultados mostram que tanto para o piso quanto para as paredes os valores de *UDI* anual mínimo absoluto foi de aproximadamente 80% para o piso e também para a maior parte das regiões das paredes.

A Figura 8 (inferior) ilustra o valor máximo de irradiância horária da instância selecionada, traçando um gráfico ao longo do ano, podendo-se comparar a flutuação desse desempenho com o valor máximo de 50 W/m², recomendado por Garcia e Pereira (2019). Ainda, foram extraídos os valores de UDI mínimo, obtendo assim a variação desse desempenho ao longo do ano (Figura 8, superior). Observa-se que um decréscimo de desempenho no período do meio do ano, em uma época de menor incidência de radiação na região analisada. Apesar disso, este decréscimo de UDI ocorreu por excesso de radiação.

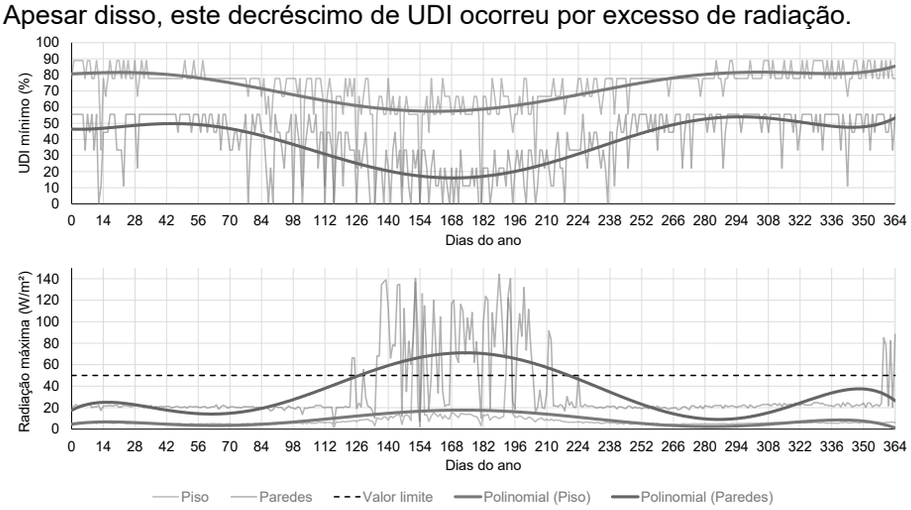

Figura 8. Variação ao longo do ano de *UDI* mínimo diário e radiação máxima horária. Fonte: Autores, 2022

Nestes gráficos da Figura 8 foram consideradas curvas de tendências polinomiais para suavizar a variação desse desempenho. É evidente que a instância selecionada (Figura 7) apresenta um desempenho do piso superior ao das paredes ao longo do ano ao verificar a sua variação ao longo do ano.

4 Discussões e Conclusões

Os resultados obtidos neste estudo mostram que o uso de meta-modelo para refinar a discretização de um espaço de soluções com respostas de radiação solar e nível de iluminância se demonstrou viável e útil na avaliação da tipologia de lanternim. Os gráficos das Figuras 3 a 6 indicam dimensões do lanternim e do ambiente com maior desempenho a UDI e evidenciando alguns aspectos de dependência destes parâmetros entre si. As figuras 7 e 8 mostram

uma avaliação mais específica de uma instância selecionada a partir do modelo generalizado por rede neural, apresentando graficamente a distribuição do desempenho de radiação e iluminância deste ambiente, além de mostrar a variação deste desempenho ao longo do ano com valores máximos de radiação e de UDI mínimo.

Este modelo generalizado dá subsídios para se ter respostas rápidas do desempenho deste sistema frente à grande variabilidade de configurações possíveis da sala e do lanternim. Esta rápida resposta sobre o desempenho lumínico facilita a busca da otimização multiobjetivo do desempenho em projeto de arquitetura, contribuindo para o desenvolvimento sobre o conhecimento sobre tecnologias que podem ser aplicadas ao processo de projeto.

Referencias

Acosta, I., Navarro, J., & Sendra, J. J. (2013). Daylighting design with lightscoop skylights: Towards an optimization of shape under overcast sky conditions. Energy and Buildings, 60, (pp. 232-238). doi:10.1016/j.enbuild.2013.01.006

Ayoub, M. (2019). 100 Years of daylighting: A chronological review of daylight prediction and calculation methods. Solar Energy, 194, (pp 360–390). https://doi.org/10.1016/j.solener.2019.10.072

Chi, D.A., Moreno, D., & Navarro, J. (2018). Correlating daylight availability metric with lighting, heating and cooling energy consumptions, Building and Environment. doi: 10.1016/ j.buildenv.2018.01.048.

Garcia D. L. R., & Pereira, F. O. R. (2019). Análise anual da exposição à incidência solar direta, ao ofuscamento e aos níveis de iluminação natural em ambiente com proteções solares internas. In: Anais do XV Encontro Nacional de Conforto no Ambiente Construído e XI Encontro Latino-Americano de Conforto no Ambiente Construído (pp. 2574-2583).

Instituto Nacional de Metrologia, Qualidade e Tecnologia. Instrução Normativa INMETRO para a Classe de Eficiência Energética de Edifícios Comerciais, de Serviços e Públicos (INI-C). São Paulo, 2021.

Nabil, A., & Mardaljevic, J. (2006). Useful daylight illuminances: A replacement for daylight factors. Energy and Buildings. v.38, (pp.905-913). London: Elsevier.

Reinhart, C. F., Jakubiec, J. A., & Ibarra, D. (2013). Definition Of A Reference Office For Standardized Evaluations Of Dynamic Façade And Lighting Technologies. 13th Conference of IBPSA, (pp. 3645–3652).

Silva, J. T., Medeiros, R. C. B., Lima, R. C., & Santos, J. P. L. (2019). A influência das orientações das aberturas e condições de céu nos níveis de iluminação natural em um ambiente hospitalar. In: Anais do XV Encontro Nacional de Conforto no Ambiente Construído e XI Encontro Latino-Americano de Conforto no Ambiente Construído (pp. 2554-2563).

Tabadkania, A., Shoubib, M. V., Soflaeic, F., & Banihashemid, S. (2019). Integrated parametric design of adaptive facades for user's visual comfort. Automation in Construction, 106. https://doi.org/10.1016/j.autcon.2019.102857.

A Parametric Approach to Efficient Implementation of Green Infrastructure in the Urban Field

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Abstract. Water availability has a key role in their process of occupation. However, accelerated urbanization had several detrimental impacts, increasing the vulnerability of urban communities. Because of the limitations of traditional planning, an alternative approach is emerging to respond to the constant changes in the landscape. Now, green infrastructure (GI), an ecosystem-based approach (EbA), is being used combined with traditional solutions to increase the resilience of the cities. In this paper, we proposed the use of an algorithm to determine the best place to implement GI. The algorithm used the inputs to develop a multi-criteria analysis capable of translating urban complexity. Results show that the GI solution can't be efficiently implemented without context evaluation. However, the algorithm has the potential to become an informative tool in the decision-making process of urban planning.

Keywords: Parametric Analysis, Bioretention, Sustainable Design, Green Infrastructure, Water Resources.

1 Introduction

The environment is a major factor in the formation of cities, and water availability has a key role in their process of occupation. Historically, cities started in the proximity of water sources, because without them, life in the cities could not be sustained. Hence, managing water wisely is a key prerequisite for the existence of cities. (Novotny et al., 2010) However, the accelerated growth and the urban soil degradation (caused by imperviousness, compaction, erosion, and contamination) had several detrimental impacts on welfare (Ferreira et al., 2018). The occupation of river beds and floodable areas instigates this degradation process, creating conflicting relationships between the urban area and the environmental systems. This made the local

communities more vulnerable to natural hazards and the impacts of climate change, leading to inundations and floods becoming common in many urban areas across the world.

Currently, flood risk is dealt with through the improvement of drainage infrastructure to remove stormwater as fast as possible - within the Latin American context, most urban drainage interventions tend to be applied as punctual strategies (Horne et al., 2018). This is a characteristic of the ruling paradigm that treats the systems as isolated from each other, seeking its efficiency and optimization (Walker & Salt, 2006). Despite the technological advancements, the limitation of this current paradigm was perceived and, for the last two decades, professionals have seen a paradigm shift that requires them to respond to the dynamic characteristic of the landscape. Now, the landscape is understood as a complex temporal and constantly changing medium, composed of social and natural systems (Novotny et al., 2010; Steinitz, 2016).

Ecosystem-based adaptation (EbA) is a strategy defined as “the use of biodiversity and ecosystem services as part of an overall strategy to help people adapt to the adverse effects of climate change”. It is a people-centric approach, focused on reducing vulnerability and increasing resilience. In cities, it is commonly used to refer to green and blue infrastructure solutions as a way to adapt to climate change. These solutions consist of a network of natural or semi-natural areas that are combined with gray infrastructure (traditional infrastructure), to deliver a wide range of ecosystem services (benefits) at lower costs and to make the city more resilient (Browder et al., 2019; Capps et al., 2016; United Nations Environment Programme, 2021). However, the use of green infrastructure (GI) can only be effective within the context of a network of equipment, which allows for achieving the water performance needed to solve the problems of each city (Pereira et al., 2021).

In an era of such perspective change and with the increase of urban areas, it has become a challenge for researchers to find the best places for the application of GI. Given the problems of investment and the political, economic, and social issues this solution could hardly be applied extensively. The advance in technology and the development of mathematical and computational models have provided a new approach (Cantrell & Holzman, 2015) that combines graphics and data, making it possible for us to simulate options and adjust for possible outcomes, creating a more informed and easier to understand decision-making process strongly supported by information (Aminpour et al., 2022; Cantrell & Holzman, 2015; Eastman et al., 2008; Steinitz, 2016; Walker & Salt, 2006).

Based on this, the current work presents research on the development of a parametric algorithm capable of interrelating different data and urban aspects, to find out in which places the application of GI for stormwater management would be more efficient considering the complexity of the urban mesh. The impact of this study is to generate a parametric approach that helps in decision making, to favor the implantation of these types of facilities in the places where

they are most needed, that is, to reallocate the urban green to the areas of the city in which it is more required. This impact will be reflected in a more strategic and viable approach to applying GI in the urban environment.

2 Methodology

Within the context of climate change, EbA is a form of adaptation system to tackle the vulnerabilities of at-risk people, and GI is an important tool for the enhancement of urban hydrology (Pereira et al., 2021; Woroniecki et al., 2019). Once vulnerabilities are inside of a multifaceted context, solutions focused on place can help clarify important issues and identify potential values (Potschin & Haines-Young, 2013).

For this study, Bioretention cells (e.g. rain garden, bioswale, shallow dish) were the GI solutions selected to be implemented in the public areas of the study site (Figure 1). We chose these solutions due to the potential they have to be executed in small areas. As a benefit, they can help manage the volume of urban runoff through infiltration and temporary retention, treating it with bioremediation, and improving, thus, the overall quality of permeated water. This kind of solution, however, requires previous geography, pedology, and local climate examination. Therefore, a multicriteria analysis was made, using not only the local characteristics but also the best place conditions for Bioretention cells as parameters for the algorithm that was developed using Rhinoceros and Grasshopper software.

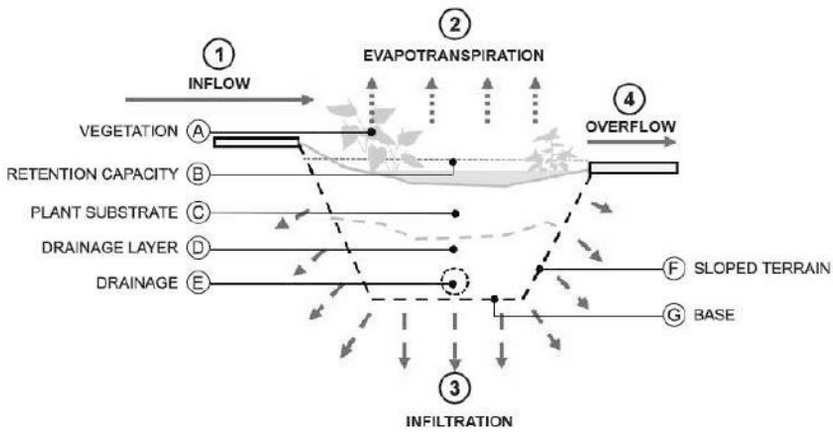

Figure 1. Simplified section of a generic Bioretention cell. Source: Pereira et al., 2021.

2.1 Algorithm Development

We composed computational reasoning to interrelate practical, measurable urban parameters that could be used on a collective database toward a traceable result. Understanding an algorithm as a sequence of steps was essential in the development of this study.

At first, we defined what would be the inputs - the necessary data - to identify the best locations for GI, based on their efficiency. We chose georeferenced data (shapefiles), collected from the city's database. These types of data contain related geometric and tabular information, allowing us to design a greater range of studies and manipulations. The shapefiles used as inputs were: topography, roads, lots, buildings, and blocks.

After the input definition, the algorithm was constructed using three phases: (1) initial analysis; (2) data processing, and (3) multicriteria analysis. In the end, we found a map that identified the most efficient places to implement GI according to the data provided (Figure 2).

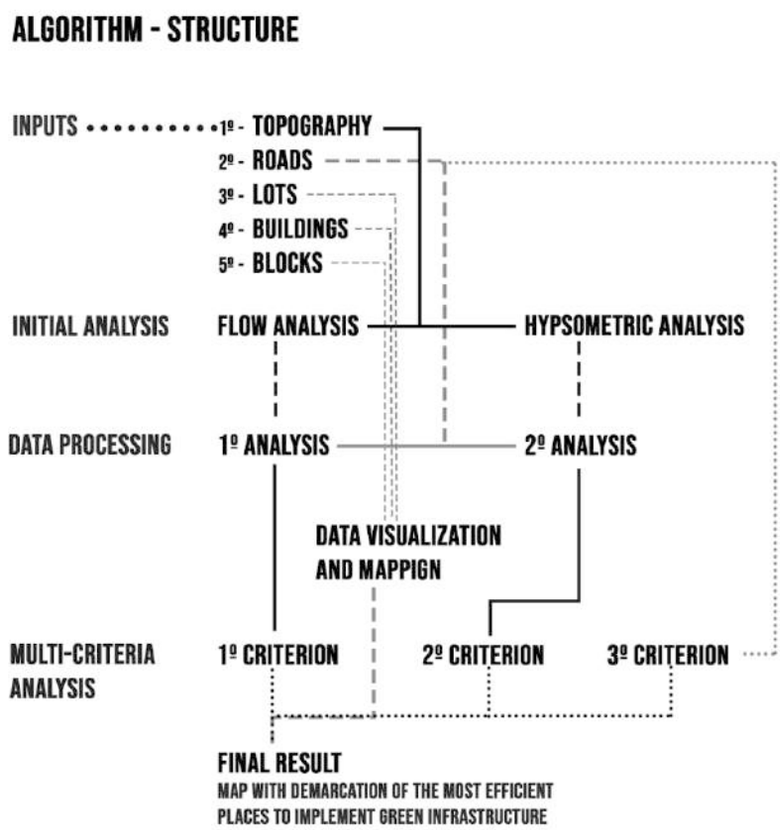

Figure 2. Algorithm structure/workflow process. Source: Authors, 2022.

In the first phase, the topography datum was the elementary input for the algorithm, and with it, we made two initial analyses. Initially, we made water flow analysis using the “Groundhog” plugin developed by Philip Belesky, Landscape Architecture professor at RMIT University in Melbourne, Australia (Figure 3). This helped us to understand its runoff behavior in the area, identifying where it is greater and where the water potentially accumulates. Then, we did a hypsometric analysis (Figure 4) to map the higher and lower-level heights of the land.

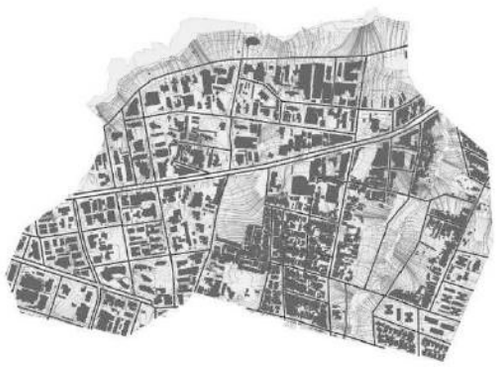

Figure 3. Water flow analysis map. Source: Authors, 2022.

Figure 4. Hypsometric analysis map. Source: Authors, 2022.

The second phase comprised crossing data, adding road information to the results found in the first phase. Starting from it, we made our first analysis: we determined the number of intersections between water runoff lines and road lines. This aimed to create retention potential criteria through the identification of the water flow behavior. So, we made an average intersection index - a mathematical evaluation necessary because the roads have different dimensions - calculated by the number of total runoff intersections divided by the extension of the respective road.

The second analysis of this phase was the data processing between hypsometric and roads through their geometric projection. This investigation pointed to mapping the average level heights of each road so we could classify them in origin, middle, or bottom areas. The classification considered the average height level across the road, qualifying the execution potential. For this criterion, we consider the roads on middle-level heights (yellow colors) would be the most appropriate locations for the setting of GI. This occurred because since the middle areas receive water from the origin areas, they have the potential of functioning as interruptions to the natural water runoff, preventing flooding in the bottom areas, where the water and its washed pollutants concentrate

The two initial phases allowed us to identify two different criteria for the choice of the best place for GI. To make the multi-criteria analysis more practical, we created a third parameter, based on the road hierarchy. We considered that an arterial road, for example, has more possible intervention areas for GI than a local road. Therefore, we determined a score for each road hierarchy, valuing with higher scores the ones that had more capacity of having Bioretention cells.

The established three criteria were used to develop a variable score system that aimed to search different scenarios. The criteria function as variables that can be modified and manipulated in different ways. The resulting map is a demarcation of the roads that got the best score, the demarcation works from a gradation of colors for the visual identification of the GI execution potential: red for roads with higher potential; yellow for roads with intermediary potential, and blue for roads with low potential (Figure 5).

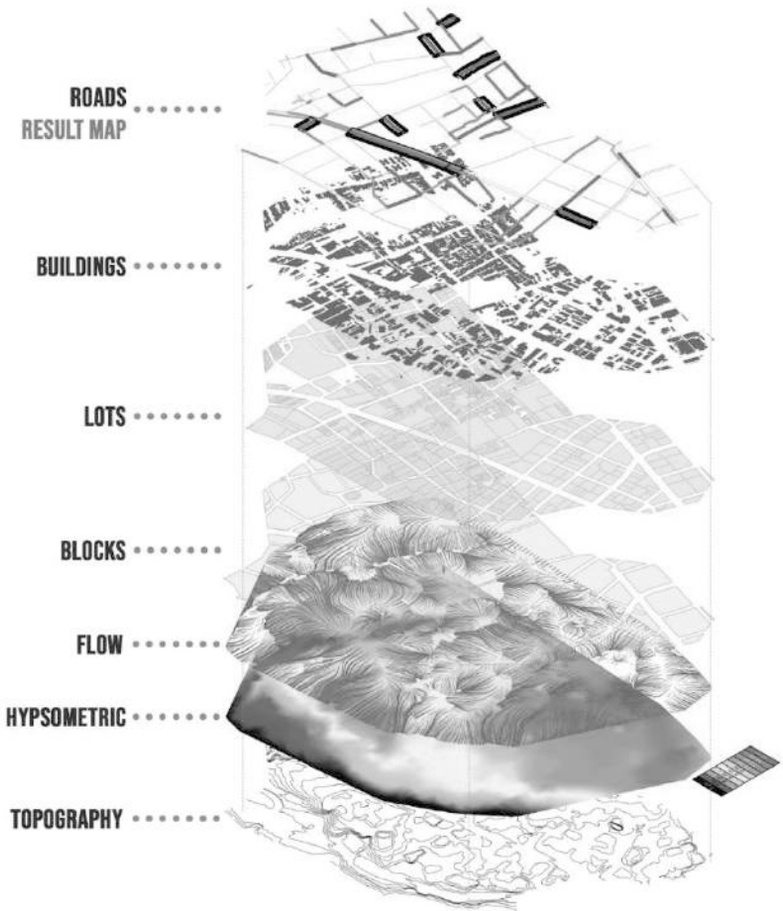

Figure 7. Superposition of the generated maps and information. Source: Authors, 2022.

3 Results

We built the map through a visual approach that used the inputs as data for the graphics. That allows the reader a better understanding of the area and facilitates the comprehension of the behavior of water in a complex urban mesh. The focus is that we have enough information to make a more oriented decision.

Results show that a road has different classifications throughout its extension. Hence, the same solution will have different performances when

used without considering the context. This emphasizes the need for previous analysis.

On both maps, results show that, with the input used, the higher potential areas are scarce, but the number of road sections with intermediary potential is very high. Comparing the two maps, however, we can see that there are areas that remain with the same potential classification, besides the change in criteria score. This occurs because of the good operation on all three criteria.

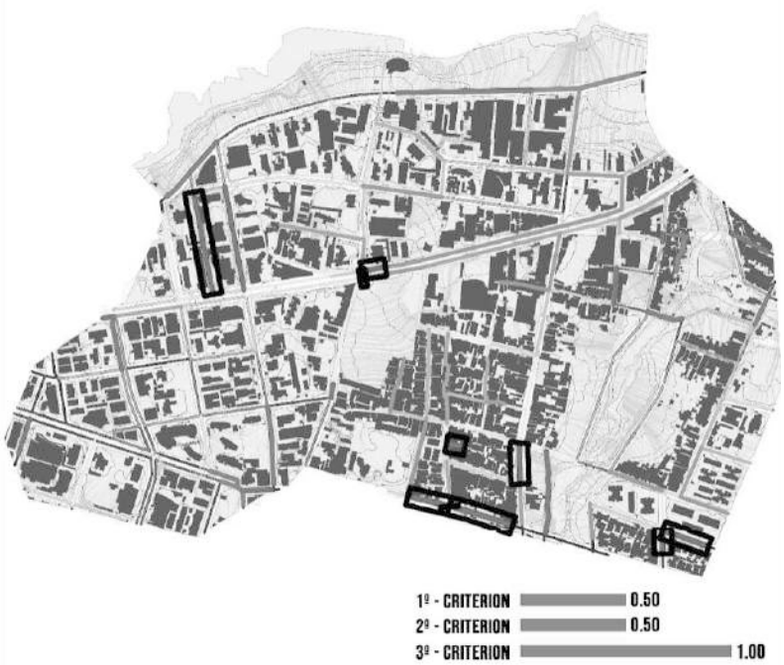

Figure 6. Result map with emphasis on road hierarchy (3rd criterion). Source: Authors, 2022.

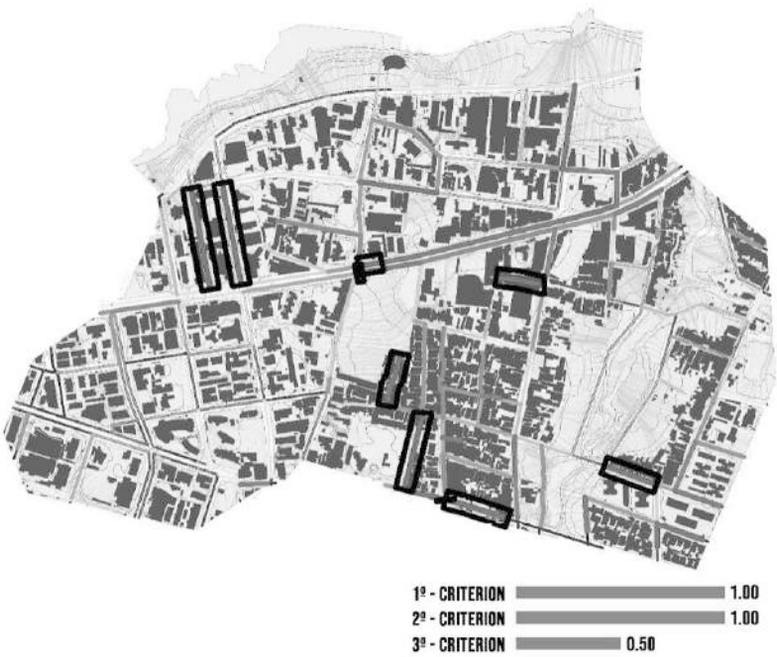

Figure 7. Result map with emphasis on water runoff and road lines intersection (1st criterion) and middle-level heights (2nd criterion) Source: Authors, 2022.

4 Discussion

4.1 Quotes

Quotes must be in italics.

Our analysis explored the use of an algorithm to determine the best places for the execution of GI in an area of a city. The algorithm was based on local data and considered three criteria that were used as a scoring system to evaluate each road section, serving as a tool for better visualization of urban complexity. This kind of visualization creates a new way of intervention in the landscape, based on a greater complexity of systems connecting and operating on different scales (Cantrell & Holzman, 2015; Walker & Salt, 2006).

The different scenarios produced showed us how important each criterion was. Their variations exemplified the impact of different approaches. With it, we

could anticipate the sites with better potential for solutions and a range of alternatives, making more informed urban interventions for the future. However, our inputs were limited, considering aspects of urban morphology. This might be problematic from a socio-economic perspective. The lack of this information disregards the local citizens' benefits and the potential cultural impact of the interventions. Also, we didn't incorporate the different Bioretention cells. This was a reflex of our choice for testing the viability of the tool in generating generic scenarios.

This research has proposed a novel way of approaching a multi-criteria analysis for the best place to implement GI. For that, we tested a tool that integrated morphology aspects with the water dynamics, integrating different knowledge and giving the water a key role, leaving the background in urban decisions. Our research represents a step further for the development of a tool that helps in decision making, by the use of physical, behavioral, and geometric inputs. However, there is a complex context of social and cultural needs that influence the choice of these decisions, as there are other variables that are subjective to the urban planner's perception that wasn't considered for this study that must always be taken into consideration in the planning process. In this way, it is not only performance and efficiency that must determine the intervention sites, but an in-depth study of the area. The algorithm works as a qualitative analysis to validate and assist in this process, opening new possibilities to explore the GI elements within the urban environment.

The results obtained were an innovative way of relating different data, by using georeferenced files, which facilitates the selection and direction of the algorithm's workflow. Therefore, using the Rhinoceros and Grasshopper software was an assertive choice to visualize the data and generate different overlapping geometric analyses (Figure 8). The great advantage of working with a parametric approach is that its structure is the same, so the input data modification will generate a new analysis. The algorithm will work using the same method, generating a standardized dynamic and interactive scenario analysis. Thus, it could be used as a tool for adaptive planning.

For the near future, the present work seeks to incorporate more city variables to create a more complete form of analysis that can fit within the limitations of urban databases, incorporating new criteria to validate potential areas, so we can elaborate a more context-specific parametrization utilizing optimization systems and data managing.

References

Aminpour, P., Gray, S. A., Beck, M. W., Furman, K. L., Tsakiri, I., Gittman, R. K., Grabowski, J. H., Helgeson, J., Josephs, L., Ruth, M. & Scyphers, S. B. (2022). Urbanized knowledge syndrome—erosion of diversity and systems thinking in urbanites' mental models. Npj Urban Sustainability, 2(1), 1–10. https://doi.org/10.1038/s42949-022-00054-0

Browder, G., Ozment, S., Bescos, I. R., Gartner, T. & Lange, G.-M. (2019). Creating Next Generation Infrastructure.

Cantrell, B. E. & Holzman, J. (2015). Responsive Landscapes. In Angewandte Chemie International Edition (1st ed., Vol. 6, Issue 11). Routledge. https://doi.org/10.4324/9781315757735

Capps, K. A., Bentsen, C. N. & Ramírez, A. (2016). Poverty, urbanization, and environmental degradation: Urban streams in the developing world. Freshwater Science, 35(1), 429–435. https://doi.org/10.1086/684945

Eastman, C., Teicholz, P., Sacks, R. & Liston, K. (2008). BIM Handbook. John Wiley & Sons, Inc. https://doi.org/10.1002/9780470261309

Ferreira, C. S. S., Walsh, R. P. D. & Ferreira, A. J. D. (2018). Degradation in urban areas. Current Opinion in Environmental Science and Health, 5, 19–25. https://doi.org/10.1016/j.coesh.2018.04.001

Horne, J., Tortajada, C. & Harrington, L. (2018). Achieving the Sustainable Development Goals: improving water services in cities affected by extreme weather events. International Journal of Water Resources Development, 34(4), 475–489. https://doi.org/10.1080/07900627.2018.1464902

Novotny, V., Ahern, J. & Brown, P. (2010). Water Centric Sustainable Communities: Planning, Retrofitting, and Building the Next Urban Environment. John Wiley & Sons, Inc.

Pereira, M. C. S., Gobatti, L., Soares, M. C., Leite, B. C. C. & Martins, J. R. S. (2021). Soluções baseadas na natureza: quadro da ocupação da cidade de São Paulo por células de biorretenção. Revista LABVERDE, 11(1), 95–120. https://doi.org/10.11606/issn.2179-2275.labverde.2021.189292

Potschin, M. & Haines-Young, R. (2013). Landscapes, sustainability and the place-based analysis of ecosystem services. Landscape Ecology, 28(6), 1053–1065. https://doi.org/10.1007/s10980-012-9756-x

Steinitz, C. (2016). Um Framework para o Geodesign: Alterando a Geografia através do Design. eSRI.

United Nations Environment Programme. (2021). Guidelines for Integrating Ecosystem-based Adaptation into National Adaptation Plans: Supplement to the UNFCCC NAP Technical Guidelines. www.un.org/Depts/Cartographic/english/htmain.htm

Walker, B. & Salt, D. (2006). Resilience thinking: sustaining ecosystems and people in a changing world. In Coral Reefs. Island Press. http://books.google.com/books?hl=en&lr=&id=NFqFbXYbjLEC&oi=fnd&pg=PR5&dq=Resilience+thinking+Sustaining+Ecosystems+and+People+in+a+Changing+World&ots=6mKX0y_WO6&sig=NuTgjG7gBj9X5DN-k6l2Lu0dvO4

Woroniecki, S., Wamsler, C. & Boyd, E. (2019). The promises and pitfalls of ecosystem-based adaptation to climate change as a vehicle for social empowerment. Ecology and Society, 24(2). https://doi.org/10.5751/ES-10854-240204

Open-source responsive solar tracker performance evaluation: a comparative study

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Abstract. Due to the current energy crisis in Brazil and in the world, it is important to explore renewable energy sources, such as photovoltaic systems. Considering this, this research analyzes a responsive capture system called Girassol, which seeks better efficiency in energy production. Tests were performed on the mechanism to assess the advantages and disadvantages of using the solar tracker compared to fixed systems. The tests were carried out using the physical prototype and computational tools to compare the results. The methodology used was Design Science Research, which has to develop and improve affordable solutions, based on experiments and computational simulations. Compared to the physical prototype it was possible observe that there is a greater energy upgrade of the Girassol mainly in the initial and final moments of the daylight hours.

Keywords: Parametric Analysis, Solar tracker, Ladybug, Energy efficiency, Responsive system

1 Introdução

A atual crise energética que vem se agravando com o passar dos anos e se mostra um grande desafio a ser enfrentado para arquitetos e urbanistas. A energia solar é uma das fontes alternativas mais promissoras, por estar disponível praticamente em todos os lugares geográficos. Sistemas fotovoltaicos foram desenvolvidos como alternativa para fornecer energia limpa e renovável para diversos usos, a partir da conversão da luz do sol em energia elétrica (Tirmikci & Yavuz, 2015). A presente pesquisa traz os resultados do projeto de um seguidor solar de código-aberto que utiliza sensores fotossensíveis e programação responsiva para manter as placas solares permanentemente direcionadas para o sol, visando o aumento da

eficiência energética do sistema. A pesquisa tem grande relevância científica devido ao grande potencial de geração de energia solar no Brasil e a importância de atender a agenda ambiental relativa ao uso de energia limpa e renovável, em especial em regiões carentes e isoladas que não tem acesso à energia elétrica (Bondarik et al, 2018).

Esta pesquisa parte do pressuposto de que energia solar fotovoltaica é produzida a partir da corrente elétrica gerada pela radiação solar ao atingir módulos fotossensíveis, e que quanto maior for a radiação solar incidente nos módulos, maior será a energia elétrica produzida. A pesquisa utilizou dados quantitativos de radiação incidente coletados tanto em modelo físico quanto digital para determinar o volume de energia a mais produziria por um seguidor solar em comparação com um módulo fixo.

Foram utilizados componentes de plataformas Arduino e peças customizadas impressas em 3d e cortadas a laser para a produção do modelo físico e recursos do plugin Ladybug (Grasshopper) para a simulação dos dados no modelo digital. Trata-se de pesquisa aplicada que avança nas análises de etapas publicadas em Rocha et al (2020) trazendo dados sobre os testes de funcionamento do sistema e a coleta de dados relacionados à geração de energia.

2 Metodologia

A metodologia utilizada foi inspirada na Design Science Research (Van Aken, 2004) caracterizada por sua natureza prescritiva e projetual com o objetivo de desenvolver soluções práticas ou aprimorar soluções para artefatos e sistemas existentes (Dresch et al, 2015). Os resultados desta pesquisa avançam sobre etapas de desenvolvimento anterior já publicadas (Rocha et al, 2020) e contribuem para o entendimento das possíveis contribuições práticas deste tipo de mecanismo responsivo. Neste sentido, o propósito da metodologia adotada é produzir sistemas que ainda não existem, ou que não estão disponíveis ou acessíveis para a realidade e o contexto em que será instalado. Os procedimentos adotados têm objetivo prescritivo e utilizam como suporte fundamental o desenvolvimento projetual de futuras versões do mecanismo. Por meio do projeto, espera-se com esta metodologia desenvolver artefatos que permitam soluções satisfatórias para problemas práticos da realidade brasileira, em se tratando de geração autônoma de energia elétrica. Os resultados foram avaliados qualitativamente e quantitativamente tendo em vista o desenvolvimento de aplicações e experimentos que permitam não apenas compreender a realidade do equipamento, mas transformá-lo em versões melhoradas. A aplicação da metodologia inclui três etapas: estruturação do projeto, construção do protótipo e da simulação computacional incluindo ciclos de aprimoramento, e a análise dos resultados. A seguir serão descritos os dois processos de etapa

de construção do protótipo e simulação computacional destacando os procedimentos e configurações adotadas.

3 Desenvolvimento dos Protótipos

3.1 Protótipo Digital

Nesta etapa de análise da eficiência de produção de energia solar do Girassol foi realizada a simulação digital de modelo tridimensional produzido no software *Rhinoceros/Grasshopper* e seu *plugin Ladybug*. O objetivo foi obter dados relacionados à diferença na produção de energia em diferentes situações de exposição à radiação solar. O *Ladybug* é uma extensão do *Grasshopper* que auxilia nas análises ambientais, importando arquivos de informações climáticas para criação de diagramas, cartas solares, análises de radiação, quantidade de insolação em simulações paramétricas (Sadeguipour Roudsari & Pak, 2013). Para o desenvolvimento da simulação foi utilizado modelo 3d em formato *SKP* (*Sketchup*) importado para o software *Rhinoceros*/*Grasshopper*. Após o referenciamento do modelo na interface Grasshopper foi realizada a separação dos eixos de rotação, para que o movimento do equipamento fosse idêntico ao movimento do modelo físico. Assim, a divisão dos eixos de movimento do modelo 3D foi programada para atender aos mesmos requisitos do protótipo físico.

Para analisar a quantidade de radiação que as placas solares receberiam foi necessário utilizar o arquivo EPW (*Energy Plus Weather*), um formato que carrega informações climáticas de diversas regiões do planeta que facilitam sobremaneira a operacionalização de simulações climáticas. O arquivo EPW é a base de informações a partir de onde o *plugin Ladybug* retira os dados necessários para cada tipo de análise. O arquivo utilizado nesta pesquisa foi do INMET Vitória.

Para fazer com que o modelo simulado acompanhasse a posição solar referente à localização geográfica desejada foi utilizado o componente *SunPath*, que recupera os dados retirados do arquivo EPW e gera um diagrama de carta solar que fornece a posição exata do sol. Essa posição foi utilizada como referência para a orientação do movimento de giro do Girassol, simulando a característica heliotrópica (Rocha et al, 2020) adaptativa do seguidor solar. Para a análise da radiação incidente nas placas foi utilizado o componente *GencumulativeSkyMtx*. Ele possui uma função denominada *Radiance's GendayMtx* para especificamente calcular a radiação em cada hora do dia, durante todo o ano. O *GendayMtx* utiliza o *Perez All-Weather Sky Model*, um modelo matemático usado para descrever a

quantidade de emissão de luz que ultrapassa ou é refletida por uma superfície. Trata-se de um modelo elaborado para cálculos relacionados à iluminação diária composto por dados reais reunidos em estações climáticas ao redor do mundo. Com o emprego do componente *SelectSkyMtx* é possível definir um período de análise de acordo com um horário, dia e mês específicos. Essa etapa foi decisiva para a implementação dos cálculos de simulação de incidência solar porque trouxe definições científicas comprovadas nos períodos selecionados. O componente *Radiation Analysis* permitiu calcular a quantidade de radiação (Kwh) que incide nas placas solares do modelo digital em um momento específico de insolação definido pelo componente *SelectSkyMtx*, e ainda em sincronia com o direcionamento do Girassol para a posição ótima baseda no *SunPath* (Fig. 1).

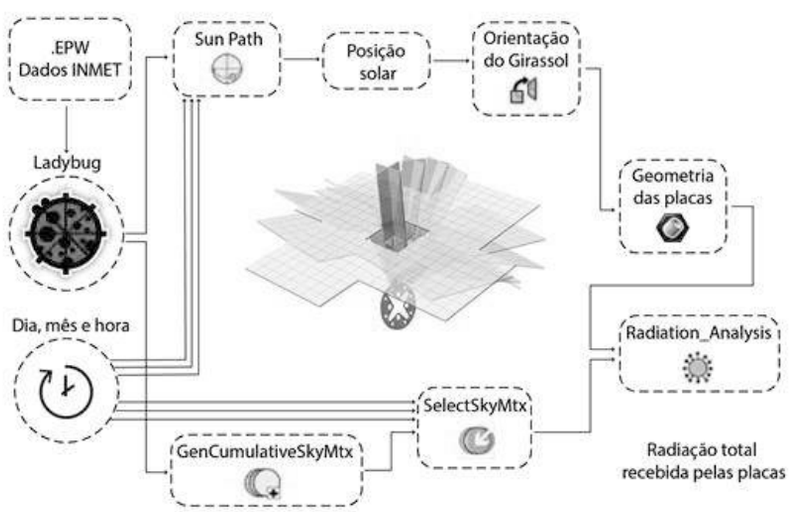

Figura 1. Diagrama ilustrativo da programação desenvolvida no *Grasshopper*. Fonte: Produção do próprio autor, 2021.

O cálculo inicial foi realizado durante os solstícios e equinócios de verão e inverno entre as 8 (oito) e 18 (dezoito) horas. Primeiramente foi realizada a coleta de dados considerando o sistema ativo, ou seja, com as placas sempre orientadas perpendicularmente aos raios solares. Em seguida, nas mesmas datas, foram coletados os dados com o sistema passivo, em conformidade com a orientação comumente adotada pelo mercado comercial que é inclinação correspondente à latitude (20 graus no caso da cidade de Vitória) e orientadas em direção N (norte).

Para determinar a diferença entre os valores entre os dois modos, foi elaborado o valor do coeficiente de aproveitamento que é a proporção no ganho de radiação total nas placas, medidos em kWh/m², entre o sistema ativo (Rd_{ativo}) e o sistema inativo ($Rd_{inativo}$), resultando em uma medida de porcentagem. O cálculo realizado considerou os valores coletados pelo sistema passivo como sendo 100% do recebimento de luz em cada dia, e os relacionou diretamente com os valores coletados pelo sistema ativo para determinar o coeficiente de aproveitamento ($Coef_{aprov}$), conforme a equação:

$$\boldsymbol{Coef_{aprov}}(\%) = \frac{\mathbf{100} \times (\boldsymbol{Rd_{ativo}})}{(\boldsymbol{Rd_{inativo}})} \quad (1)$$

O resultado obtido pelo cálculo é a quantidade de radiação total a mais recebida pelas placas do sistema ativo proporcionalmente ao passivo, sendo qualquer acréscimo aos 100% interpretado como ganho no aproveitamento.

Reunindo os valores dos coeficientes de aproveitamento nos dias dos solstícios e equinócios, percebe-se, conforme ilustrado Fig. 2, que o coeficiente de aproveitamento foi maior no sistema ativo (linha em laranja) do que em relação ao sistema passivo (linha em azul), em grande parte dos horários estudados, em especial nos períodos iniciais e finais. Assim, observamos que nos períodos entre 8 (oito) e 10 (dez) horas da manhã e entre 14 (quatorze) e 17 (dezessete) horas houve ganho comprovado de eficiência para os painéis ativos. Nos períodos entre 11 (onze) e 13 (treze) horas o coeficiente de aproveitamento apresentou valores relativamente equivalentes e ganhos pouco expressivos em relação aos módulos passivos.

É importante explicar que as simulações digitais mensuraram a proporção na quantidade de radiação solar recebida pelas superfícies do modelo tridimensional e não a quantidade de energia gerada, pois a conversão da radiação em corrente elétrica depende de outras variáveis intrínsecas às configurações dos módulos fotovoltaicos, que não foram realizadas por estarem fora do escopo desta etapa. A figura a seguir apresenta informações sobre o comparativo entre a quantidade de radiação (kWh/m²) ao longo do dia para ambos os sistemas, ativo e passivo (inativo), bem como um comparativo único entre ambos de forma resumida.

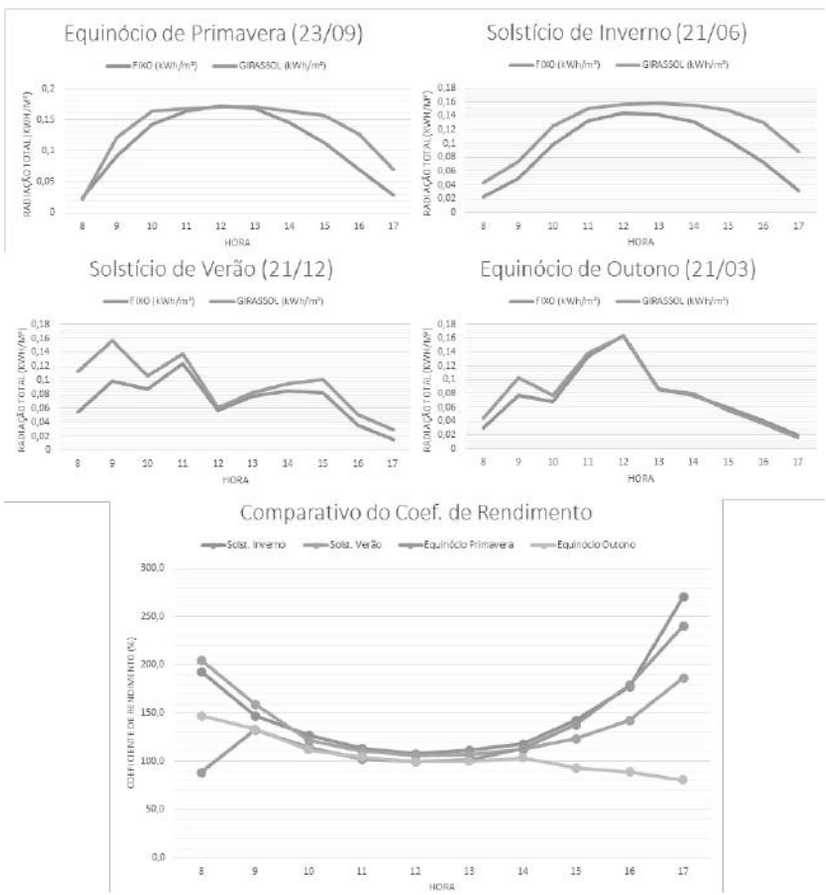

Figura 2. Radiação total recebida pelas placas na data do solstício de inverno, equinócio de primavera, solstício de verão, equinócio de outono e Comparativo dos coeficientes de aproveitamento para as datas analisadas. Fonte: Produção do próprio autor.

Os resultados obtidos durante o equinócio de primavera e solstício de inverno mostram as curvas dos gráficos mais constantes, sem grandes picos ou vales, e com diferenças mais sutis entre os dois modos, ativo e passivo. Os resultados do solstício de verão e do equinócio de outono apresentaram variações alternadas nas linhas dos gráficos. Em termos gerais, é possível afirmar que o seguidor solar ativo demonstrou, em grande parte dos períodos de aferição, um ganho de eficiência na coleta de radiação que não deve ser desprezado, mas sim explorado. Com base no ganho de radiação recebida, pode-se afirmar que a probabilidade de ganho também na produção de energia elétrica se confirmaria.

3.2 Protótipo físico

A estrutura utilizada para a coleta de informações no modelo físico foi elaborada com base no sistema responsivo desenvolvido anteriormente. Este sistema foi objeto de desenvolvimento em etapa anterior desta pesquisa, publicado em Rocha et al (2020) e encontra-se em estágio funcional. No entanto, em função de seu tamanho reduzido, não suportou o peso das placas fotovoltaicas adquiridas e portanto houve a necessidade de recriar sua funcionalidade em um novo protótipo conforme ilustrado abaixo (Fig. 3).

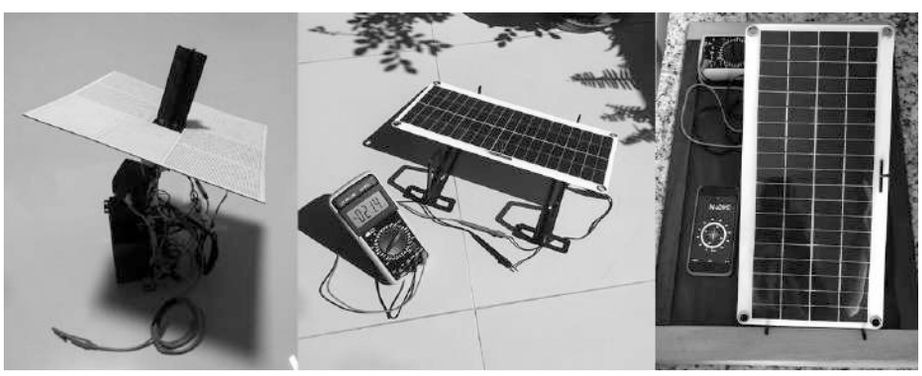

Figura 3. (a) sistema responsivo original, (b) módulo novo (c) módulo novo. Fonte: Produção do próprio autor

Para a aferição da corrente elétrica geradas pelas placas fotovoltaicas foi elaborado um novo sistema independente composto pelos seguintes componentes: 01 módulo fotovoltaico de 20 watts, dimensões (40 x 15 cm), 01 multímetro e estruturas de suporte impressas em 3D (PLA cor preta). O processo de avaliação comparativa da performance entre o sistema ativo e passivo considerou a diferença na corrente elétrica (Volts) produzida pelo módulo fotovoltaico ao longo de um período de 9 horas em intervalos de 15 minutos. A medição do modo ativo foi feita de forma analógica com o uso de uma haste de referência indicativa da posição análoga ao sistema em funcionamento. O período de realização adotado foi o equinócio de primavera. Os resultados das medidas realizadas, bem como os gráficos comparativos dos resultados podem ser encontrados na tabela 1 e na Figura 4 que se seguem:

Tabela 1. Registro dos valores de corrente elétrica produzidos (volts) no sistema ativo e inativo. Fonte: Produção do próprio autor.

h / Sistema	7:00	7:15	7:30	7:45	8:00	8:15	8:30	8:45	9:00	9:15	9:30	9:45	10:00	10:1
ATIVO	22.4	22.1	22.2	22.2	22.0	22.2	22.2	22.2	21.7	21.6	21.6	21.5	21.3	21.1
INATIVO	6.2	6.4	6.8	20.7	20.6	21.6	21.5	21.6	21.3	21.2	21.3	21.2	21.1	21.0
Ganho %	+361	+345	+326	+7,24	+6,79	+2,77	+3,25	+2,77	+1,87	+1,88	+1,40	+1,41	+0.94	+0,4
h / Sistema	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45	13:00	13:15	13:30	13:4
ATIVO	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1
INATIVO	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0
Ganho %	+0,47	+0,47	+0,47	+0,47	+0,47	+0,47	+0,47	+0,47	+0,47	+0,47	+0,47	+0,47	+0,47	+0,4
h / Sistema	14:00	14:15	14:30	14:45	15:00	15:15	15:30	15:45	16:00	16:15	16:30	16:45	17:00	17:1
ATIVO	22.1	21.8	22.1	22.2	21.9	21.7	21.6	21.7	21.5	21.2	20.8	x	x	x
INATIVO	21.8	21.6	21.8	21.8	21.4	21.1	20.9	20.9	20.7	20.2	6.8	x	x	x
Ganho %	+1,37	+0.92	+1,37	+1,83	+2,33	+2,84	+3,34	+3,82	+3,86	+4,95	+305	x	x	x

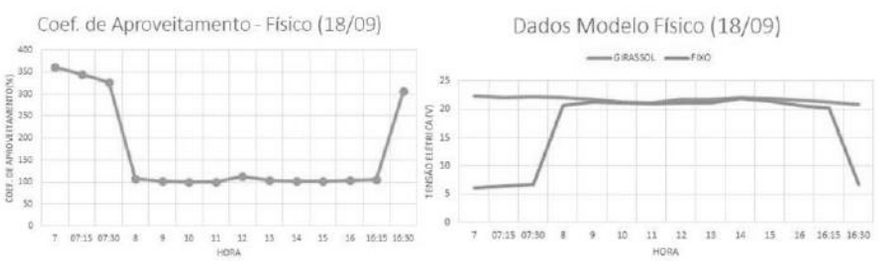

Figura 4. Dados comparativos (esquerda) e coeficiente de aproveitamento (direita).
Fonte: Produção do próprio autor.

Foram adotados os mesmos princípios para o cálculo do coeficiente de aproveitamento utilizados no modelo digital, ou seja, a mesma posição de 20 (vinte) graus para o sistema passivo (linha laranja) e um intervalo de tempo semelhante que vai desde o início da manhã e o final da tarde.

4 Análise dos resultados e conclusões

Comparando os gráficos do coeficiente de aproveitamento tanto do modelo digital quanto do modelo físico, constata-se haver uma semelhança no desenho dos resultados, que indicam um ganho de rendimento relevante principalmente no início da manhã e final de tarde. Durante os demais períodos, entre as 10 (dez) e 14 (quatorze) horas, a diferença indicada no coeficiente foi relativamente baixa em comparação ao sistema passivo, com

uma alteração média de 5%. Esta diferença maior existente nos períodos do início da manhã e final de tarde era esperada uma vez que nos parece lógico que uma maior diferença no ângulo de incidência dos raios solares nas placas fotovoltaicas gera uma perda proporcional de geração de corrente. No entanto, algumas considerações importantes devem ser feitas para aprofundar nas particularidades destas diferenças.

O cálculo da inclinação recomendada para as placas solares de 20 graus (ou o valor correspondente da latitude) sugerida pelos fabricantes de placas é calculado para otimizar a produção de energia (Torsoni et al, 2015). No entanto, esta fórmula é uma aproximação genérica que está sujeita a ajustes em função da variação angular dos raios solares durante todo o ano.

Os resultados da simulação indicam que é justamente nos períodos mais afastados ao verão que o ganho de produtividade do seguidor solar é mais contínuo, como pode ser visto no gráfico correspondente ao solstício de inverno (21/06) na Fig. 2. Neste período, a necessidade de uma correção das placas é maior e o ganho em realizar este procedimento é mais visível ao longo de todo dia. O comparativo de coeficientes comprova esta informação, e demonstra que é neste período que há diferenças maiores presentes nos extremos dos horários de sol.

Embora a medição no modelo físico tenha sido realizada somente em um dos quatro períodos utilizados no modelo digital, o desenho do gráfico respeitou desenho semelhante, indicando maiores diferenças nos extremos dos horários de insolação. Se por um lado o modelo físico demonstrou uma diferença significativa em extremos maiores do gráfico (antes das 8 e depois das 16h, contrário ao modelo digital que indicou antes das 10h e após as 14h, para o mesmo período do equinócio de primavera), por outro lado, os valores do coeficiente de aproveitamento foram bem mais altos, indicando ganhos entre 300% e 400% (enquanto no modelo digital os ganhos encontram-se entre 70% e 270%).

Foi possível perceber durante as experiências com o modelo físico que não há uma correspondência direta e proporcional entre o ângulo de inclinação dos raios solares nas placas fotovoltaicas e a perda de rendimento. Isso significa que as placas conseguem produzir uma quantidade estável de corrente elétrica mesmo havendo diferenças na incidência da luz sobre elas. Os resultados do modelo físico indicaram que quando expostas diretamente à luz solar no período estudado (equinócio de primavera), a diferença de corrente entre o horário das 8h e 16:30h foi de apenas 7%, o que significa que as placas podem manter seu rendimento alto mesmo sob diferenças razoáveis no ângulo de incidência do sol sobre elas. No entanto, nos horários mais extremos de insolação (antes das 8h e depois das 16:30h), nos quais a inclinação atinge valores mais expressivos, há uma queda abrupta no rendimento de mais de 70%, momentos estes em que se justifica atuar no reposicionamento das placas por meio de um seguidor solar.

Durante o equinócio de primavera (23/09) o coeficiente de rendimento permanece maior nos extremos do gráfico e torna-se equitativo nos horários próximos ao meio-dia.

Ao final, considerando o intervalo de coleta de informações e as diferenças de valores mensuradas durante todo o período, podemos afirmar que o modelo físico trouxe um ganho médio de 35%, considerando todas as aferições. No entanto, cabe salientar que os ganhos mais substanciais se concentram nos extremos dos horários de iluminação natural (início da manhã e final de tarde). Nos demais períodos, a proporção média de ganho foi de 5%.

References

Bondarik, R., Horst, D, J., & Pilatti, L, A. (2018) Uma Visão Geral Sobre o Potencial De Geração de Energias Renováveis no Brasil.Interciencia.43. p.680-688. https://www.redalyc.org/journal/339/33957861002/html/

Dresch, A., Lacerda, & D., Miguel, P. (2015) A Distinctive Analysis of Case Study, Action Research and Design Science Research. Revista brasileira de gestão de negócios, Vol.17(56),1116-1133. DOI:10.7819/rbgn.v17i56.2069

Roudsari, M. S., & Pak, M (2013). Ladybug: A parametric environmental plugin for grasshopper to help designers create an environmentally-conscious design. Proceedings of BS 2013: 13th Conference of the International Building Performance Simulation Association. 3128-3135. DOI:10.26868/25222708.2013.2499

Tirmikci, C. A., & Yavuz, C. (2015) Comparison of Solar Trackers and Application of a Sensor Less Dual Axis SolarTracker.Journal of Energy and Power Engineering. 9 (6). DOI:10.17265/1934-8975/2015.06.006

Torsoni, G. B., Miranda, J. K., & Aparecido, L. O. (2019). Influência da direção de placa solar na geração de energia. Encontro Internacional De Gestão, Desenvolvimento e Inovação (EIGEDIN), 3(1). https://desafioonline.ufms.br/index.php/EIGEDIN/article/view/8597

Van Aken, J., Chandrasekaran, A. & Halman, J. (2016) Conducting and publishing design science research. Journal of Operations Management, 47-48: 1-8. https://doi.org/10.1016/j.jom.2016.06.004

Rocha, B, M, Celestino, R., Silva, K., & Galimberti, I. (2020) Digital Sunflower: the potential of eco-oriented responsivity in the design process", p. 918-923 In: Congresso SIGraDi 2020. São Paulo: Blucher. ISSN 2318-6968, DOI 10.5151/sigradi2020-124

Parametric evaluation of urban compactness in Brazil: a computational study in Juiz de Fora

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Abstract. This paper presents an application of parametric techniques and tools to assess urban compactness in the city of Juiz de Fora, Brazil. A literature review identifies the objective metrics' role in urban design and how they are associated with the urban compactness paradigm. The case study provided results that characterize aspects of the built urban density and the mix of uses in the samples, exploring how parametric resources can help urban design. This research shed some light on how metrics can assist parametric urban design allowing performance measurement in the early design stages. It also highlights potentials, future studies, and challenges, establishing discussions about developing this field of knowledge in Brazil and even in Latin America.

Keywords: Urban Design, Parametric Urban Design, Computer-aided Urban Design, CityMetrics, Architectural Design

1 Introduction

Parametric tools have improved designers' work since their introduction in architectural tasks, with algorithmic languages reaching urban design from many perspectives (Kotnik, 2010; Leach, 2009a; Schumacher, 2009). This technique gained prominence for its architectural applications, with limited use in urbanism. Some authors argue that most parametric urban design methods have only the appearance of morphology and lack a deep understanding of the principles of urban structure formation (Çalışkan, 2017; Leach, 2009b; Yuhan, Zhenying & Yulong, 2020).

The often-used idea of complexity to study the evolution of urban components and create models based on the emergence of several shapes and structures is recurrently used by designers (Schumacher, 2009). On the other hand, this basic overlay of factors neither proves nor explains the nature of the interactions among urban elements (Leach, 2009b).

Some researchers highlight a need for new techniques that address the urban space supplying a demand for sustainability, innovation, and dynamic management, considering the context of urban population growth and the impact caused by cities on our planet. The environmental conditions of public spaces and buildings shape how people use external and internal spaces in their routines, and urban design is crucial to reverse this scenario, restoring the balance of the built environment so that it sustains more quality of life (Amorim, 2015; Bereitschaft & Debbage, 2013; Chokhachian *et al*., 2020; Farr, 2007).

Characterizing and evaluating urban areas in the initial design stages is essential to promote evidence-based / performance-based urban design actions. This paper identifies a possibility in which new tools/techniques can be inserted to increase efficiency and streamline management activities and urban design, justifying this research and outlining its objectives. We intend to contribute to the Computer-aided Architectural Design (CAAD) field, presenting a fruitful application of a parametric model to assess urban compactness indicators and establishing discussions about developing this field of knowledge in Brazil.

2 Methodology

This research applies the inductive method, outlining itself as applied research with a quali-quantitative approach with two and three-dimensional surveys of the urban form in three study areas. This approach consists of two main techniques: parametric modeling and algorithmic logic, and the methodological procedures were distributed in two steps within the workflow. In the first stage, a literature review identifies the metrics' role in urban design and how they are associated with the urban compactness paradigm. The review also identifies tools, parameters, and objective indicators that could be incorporated into the case study. The second stage corresponds to the parametric evaluation implementation in the study's samples. The evaluation sought to objectively characterize aspects of the built-up urban density and the diversity of uses. The *Rhinoceros3D* software and its generative plugin, *Grasshopper,* were adopted as our primary digital tool.

We selected three urban fabric samples from three neighborhoods to compose this research case study. We used components from the *CityMetrics* toolbox (Lima, 2017, Lima *et al*., 2017), chosen to assist in carrying out a parametric analysis of the *Mixed-use Index* (Hoek, 2008) and the Berghauser Pont & Haupt (2010) *Spacematrix* indicators. Then, a second scenario was structured based on the Hillier & Hanson (1984) *Social Logic of Space* theory, analyzing the axial axes' influence in each sample and addressing how they relate to the other metrics evaluated in the first scenario.

For the modeling stage and the following objective evaluation, the procedures performed were, in short:

a) definition of the three samples used in the research;
b) data harvest and treatment of files;
c) implementation of *CityMetrics* (inputs) to evaluate the indicators identified in the bibliographic review stage;
d) list the results obtained (outputs).

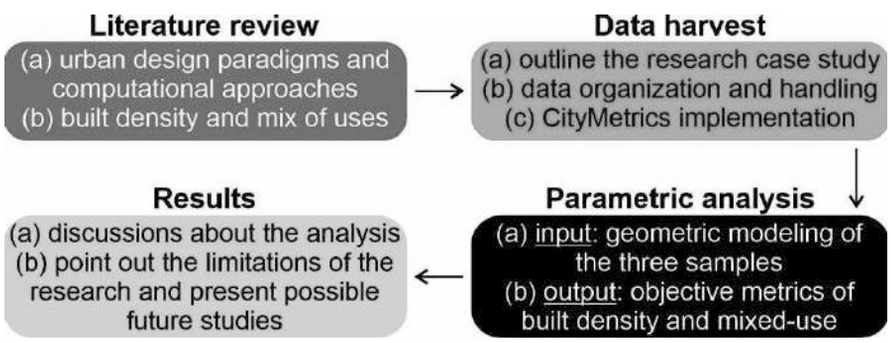

Figure 1. Summary of methodological procedures. Source: Authors, 2022.

2.1 *CityMetrics* - parametric toolbox for analysis and optimization of urban configurations

CityMetrics (Lima, 2017; Lima *et al.*, 2017) is a set of tools that articulates *Grasshopper3D* components associating metrics for performance evaluation based on algorithmic-parametric logic. The purpose of the toolbox is to assist in analysis and urban planning tasks, even enabling optimizations in different aspects related to the degree of efficiency and the possibilities of operation of geometric and algebraic configurations of an urban area. According to his developer, the model was designed to evaluate and optimize the performance of urban settings through metrics related to measurable principles derived from the *Transit-oriented Development* (TOD) paradigm, using the logic of the *Visual Programming Language* (VPL) to build *Generative Systems*. Among all the components available in the toolbox, only two were used in the case study reported by this research: the one for calculating the *Mixed-use Index* (MXI) and the one for calculating the indicators of built density *Spacematrix*.

2.2 The *Mixed-use Index* (MXI) and the *Spacematrix* indicators

Hoek (2008) developed the *Mixed-use Index* (MXI) to establish a relationship between the total residential and non-residential built areas in a given sample. The MXI approaches the total sum of the entire area in all buildings, including all floors above ground level (street level). The index aims to verify the balance of uses in the sample. Hoek (2008) states that when the ratio between the residential and non-residential areas approaches the

balance, the urban diversity is close to the ideal. Consequently, the greater the diversity of uses in the area.

Berghauser Pont & Haupt (2010) presented a set of indicators that characterize some of the essential aspects of built density. We evaluated three fundamental indicators proposed by the authors: (i) total land covered by buildings (*Ground Space Index* - GSI; (ii) vertical use in areas where the soil is occupied (*Floor Space Index* - FSI) and (iii) density of the street network (*Network Density* – N). The GSI represents a relationship between the sample and the projections of buildings on the ground. It can be obtained through a ratio between the total area and the sum of the building's soil areas. The FSI represents how much the projections of buildings in the sample are used, which can be obtained by dividing the total constructed area (also considering the vertical floors) and the sample area. The network density N is defined as the length of the network per square meter of base area (m/m2) and is calculated as the sum of the entire network of internal roads and half the length of the network of external roads (perimeter of the sample).

3 Urban compactness and the role of parametric tools in designing sustainable neighborhoods: a short review

Rogers (1998) pointed out that the survival of a society depends on the balance between population, natural resources, and the environment. One of the problems addressed in his work Cities for a Small Planet is the current pattern of urban development and how cities compromise environmental balance, destroying ecosystems and threatening human survival on a planet whose natural resources are finite. Farr (2007) identified that in this context of global urbanization, soil, water, and energy scarcity concerns sustainability. Amorim (2015) understood that these new concerns were allied to a demand for new services, the expansion of consumption patterns, the incorporation of parts of the populations that were previously not served or were marginalized, the fight against pollution and climate change, and the environment protection. These new demands also significantly increase economic and financial costs to enable a series of essential services to face these challenges.

Hoek (2008) stated that social changes are one of the most relevant forces that drive urban transformation and development, as well as the definition of urban design characteristics. In the 20th century, the economy shifted from industrial production and distribution to knowledge-based services and creation. The rapid development in modern times of economy and technology has increased the scale of operation from a local to a global scale. In contrast, Ascher (2005) highlights that contemporary urbanization processes are determined by de-industrialization and the reinvention of the concept of modernity, de-traditionalizing the typical industrial society. Hoek (2008) states that these processes accompany a reassessment of urban uses, aiming to

stimulate diversity and, consequently, an ideal scenario to promote urbanity, economic development, and consumption of products.

It is important to reinforce that the high urban density paradigm assumes that its benefits can only be fully viable through an adequate infrastructure, or as Chakrabarti (2014) defines, the infrastructure of opportunity: schools, cultural centers, hospitals, health centers, parks, and other fundamental social facilities that enable social aspirations such as employment, education, leisure, and health. In summary: urban compactness contributes to sustainability by bringing the houses closer to the work buildings and leisure areas, in a logic where the car becomes expendable, given that the distances between spaces become accessible by walking (Farr, 2007, Frey 2003, Lima, 2017, Rogers, 1998, Talen, 2011).

Rauws, Moroni & Cozollino (2020) identified that the main reason for the ineffectiveness of some current urban design actions is that they aim, in most cases, to order the growth of cities and control all the agents that interact there through prescriptive actions. Rauws & De Roo (2016) highlighted that cities spontaneously develop a capacity for adaptation — identified by the authors as the capacity for self-organization — which produces, in parallel, a challenging scenario for orthodox urban design actions.

The definition of parametric design, as presented by Woodbury (2010) and Jabi (2013), presents it as a design process based on algorithmic thinking in order to allow the expression of well-defined parameters and rules that, together, determine, encode and establish a relationship between the proposal and the project response. Beirão *et al*. (2010) understand that within the field of urban planning, the paradigm of computational tools meant a possibility to quickly visualize the impact of changes in the panorama of the shape of the city — such as aspects of density or diversity.

Through parametric design, it is possible to manipulate and adjust parameters such as soil utilization, the ratio between heights, and the percentage of open space, among other aspects. This technique would allow managers to make decisions based on a database related to different scenarios, aiming at incorporating an infinity of variables into a cohesive system and evaluating the dynamic effects of different parameters on each other and the shape of cities. Thus, it is possible to state that using parametric tools in urban design is a growing and relevant technique. This technique should be understood as an aid to processes in which it is possible to insert objective metrics in the initial stages of design, allowing fast production, visualization, modification, and evaluation of possible solutions.

4 The case study and the results

As criteria for selecting research samples, three neighborhoods were chosen in the city of Juiz de Fora (Brazil): São Pedro (Sample 1), Benfica

(Sample 2), and Centro (Sample 3). The three neighborhoods are located in the most populous regions of the city. They are of great importance for the structure of the city's urban fabric, playing a central role in both economic and historical aspects. Through empirical perception, the three samples also presented a recent scenario of intense morphological transformations, arousing our interest in objectively evaluating them. Three sections of the urban fabric were established and spontaneously defined based on the selection of blocks in the most central part of each sample: in the São Pedro neighborhood, the blocks adjacent to Avenida Presidente Costa e Silva were selected; in the Benfica sample, the blocks adjacent to Rua Martins Barbosa were selected; and in the Centro sample, the blocks that make up the region popularly known as the "expanded central triangle" were selected. Figure 2 illustrates the 3D modeling of the three samples evaluated.

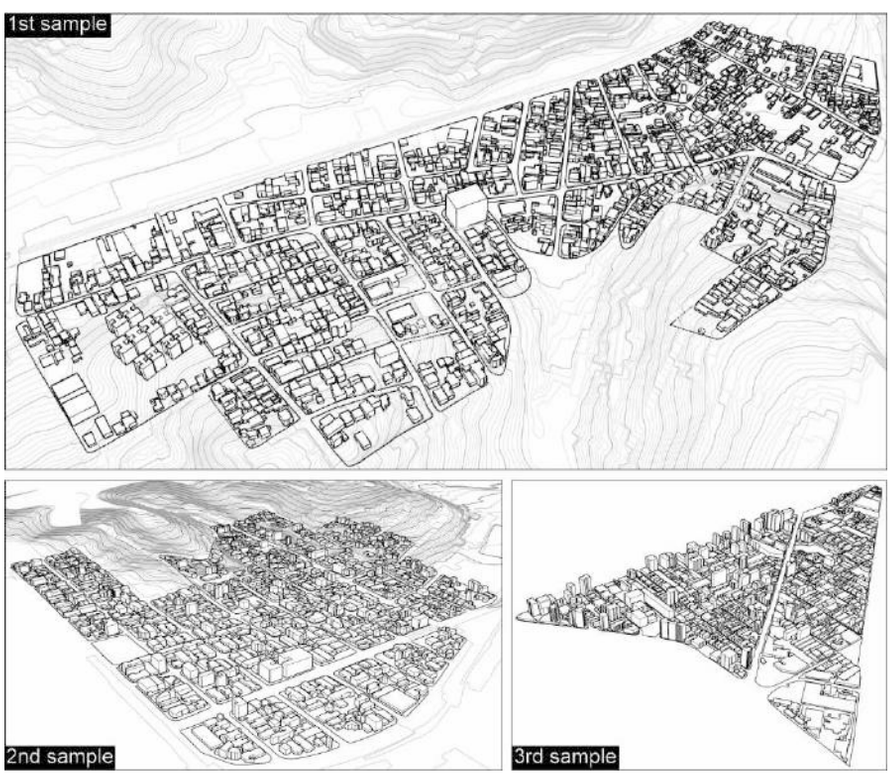

Figure 2. 3D modeling of the samples inside *Rhinoceros3D*. Source: Authors, 2022**.**

The objective metrics related to the aspects evaluated (built density and mix of uses) were collected from the modeling stage, evaluating the three samples in two different scenarios. Regarding the mix of uses in the samples in the first scenario, Samples 1 and 2 present an excessively monofunctional panorama

(greater residential use), with a low supply of services/non-residential uses; Sample 3 has a slight imbalance. Figure 3 illustrates the uses in the three evaluated areas, and Figure 5 presents the results objectively in a graphic. The metric characterization of the built density is presented in Table 1.

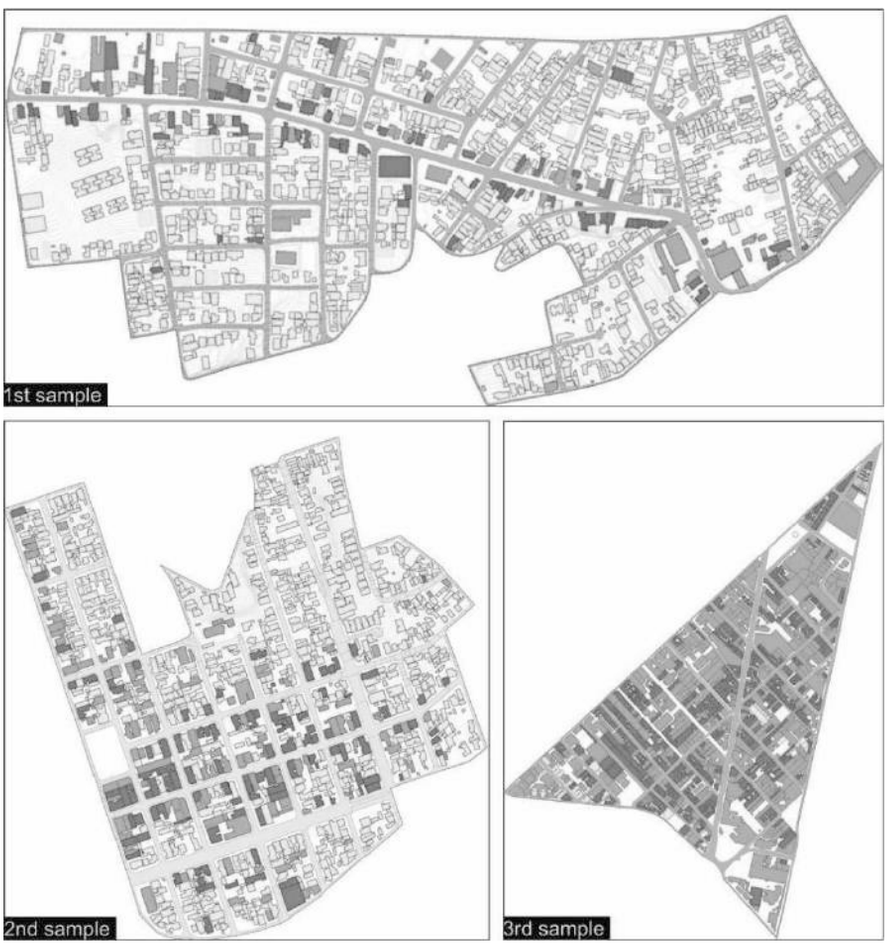

Figure 3. Map of buildings uses of the three samples. In yellow, residential use; orange, non-residential use; light red, mixed-use. No scale. Source: Authors, 2022.

After the first analysis, we organized a new scenario (Scenario 2) to evaluate how the sample's main street impacts urban compacity metrics. In Scenario 2, verifying the uniformity of the urban configuration in the three samples was also possible. A significant variation in the values of the indicators addressed means that the uniformity of the urban configuration is low, pointing out that the morphological characteristics of the main street differ drastically from the rest of the sample. Figure 3 illustrates Scenario 2, identifying uses and buildings not

considered in the objective assessment. Figure 5 can also be used to query the MXI graphic results. The second part of Table 1 presents the metric characterization of the built density in both scenarios, allowing a comparison of the results.

Figure 4. Maps identifying the disregarded buildings in scenario 2 (in black). In yellow, residential use; orange, non-residential use; light red, mixed-use. No scale. Source: Authors, 2022.

In Sample 1, the results varied considerably concerning MXI and built density (GSI and FSI), which suggests that the neighborhood concentrates the highest services and buildings on its main street. In Sample 2, the slight drop in the indicators points to a significant presence of services on the main street, keeping part of the non-residential uses distributed in the rest of the sample. The buildings on the main street of this clipping had a reasonable impact on the GSI and FSI indicators, suggesting that in the central portion of the sample, the

buildings occupy more land and have a higher utilization coefficient. Sample 3 had a uniform drop in the MXI, GSI, and FSI indicators values, remaining close to those obtained in Scenario 1, indicating a very uniform distribution of uses and the pattern of occupation and land use.

Table 1: Results of the objective evaluation in both scenarios.

Scenario 01	*Mixed-use Index* (%)		*Spacematrix* indicators		
	Res	non-Res	GSI	FSI	N
Sample 1	84	16	0.33	0.68	0.015
Sample 2	77	23	0.40	0.81	0.018
Sample 3	42	58	0.62	2.04	0.016
Scenario 02	*Mixed-use Index* (%)		*Spacematrix* indicators		
	Res	non-Res	GSI	FSI	N
Sample 1	95	5	0.27	0.38	N/A
Sample 2	83	17	0.35	0.65	
Sample 3	47	53	0.57	1.8	

Source: Authors, 2022.

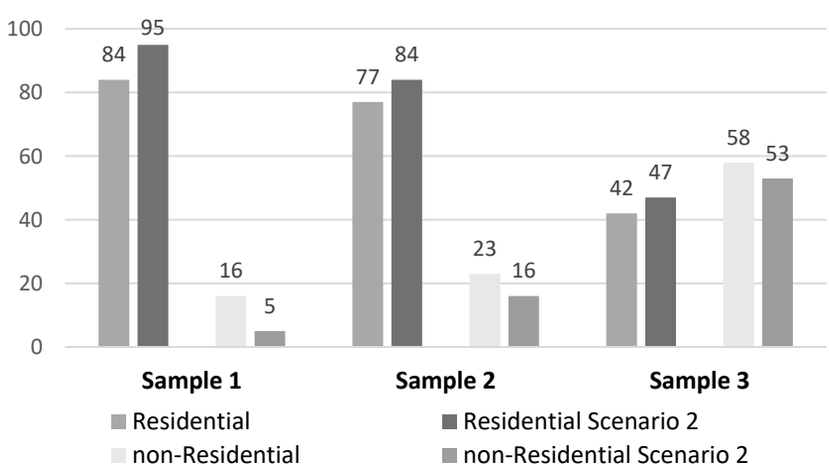

Figure 5. Illustration of the MXI variation in both scenarios. Source: Authors, 2022.

Regarding the built density (Table 1), in Scenario 1, the evaluation showed that Sample 2 has a higher land occupation than in Sample 1 and is smaller than in Sample 3. The values found for the GSI indicator indicate that samples 1 and 2 can still increase total land use within the maximum legislated potential (GSI = 0.60). In Sample 3, the value of this indicator is already a little above the ideal. Regarding the floor area ratio, the FSI result showed that the three samples have low average use of the soil, especially in samples 1 and 2. Regarding the street network density (N), the result was positive for the sample from the Benfica neighborhood (Sample 2), which has the highest network

density. The region proved well-served by streets and suggested a good scenario for walkability/adoption of alternative transport. The São Pedro neighborhood sample (Sample 1) has the lowest network density among the three samples, which can be explained by the presence of dispersed and large blocks in its urban fabric. The sample from the Centro neighborhood (Sample 3) presents an average network density among all the three samples evaluated by this research.

In Scenario 2, the mix of use (MXI) and built density (GSI and FSI) indicators of Sample 1 varied a lot, revealing that the neighborhood concentrates the services and buildings of greater size and occupation of the land in front of Avenida Presidente Costa e Silva. Sample 2 showed a slight drop in the indicators, pointing to a large concentration of services on the main street, but still maintaining a good distribution in the rest of the sample. The buildings on the main road of this clipping had a reasonable impact on the GSI and FSI indicators, suggesting that along the central street axis, the buildings occupy more land and have a higher utilization coefficient. Sample 3 had a uniform drop in the MXI, GSI, and FSI indicators, which remained close to those obtained in Scenario 1. This result means that the mix of uses is uniform in this segment and the pattern of use and land occupation. This indicator (N) was not evaluated in Scenario 2 since no changes were proposed in the configuration of the streets.

5 Discussions

Evaluating the urban space is a task that deals with tangible and intangible aspects: as Christopher Alexander has taught us, the city does not have the structural simplicity of a tree. Although it is hard to measure sensations such as insecurity, well-being, or happiness among people who inhabit cities, it is known that these sensations can be associated with specific and measurable characteristics of the urban space. As presented in the short review, compact cities optimize public transport and encourage alternative transportation, reducing the impact caused by cars and even supporting a healthier life. From the social perspective, compactness allows the inhabitants to create a relationship of intimacy with the urban space, increasing the flow of people and the possibilities of meeting and coexistence between them. It also creates more opportunities for social development and a more significant stimulus for establishing small businesses: an impulse for several exchanges that encompass social, human, and financial capital.

This research highlights the relevance of metric approaches to investigating cities at different scales: the evaluation allowed a quick visualization that the most effective use of the soil is related to regions with the most diversity of uses in the three samples, which promotes more urbanity. We shed some light on how parametric evaluation can support the urban design and how quality

indicators can be converted into metrics that enable objective analysis and more efficient design proposals within a specific scope. The adoption of urban metrics must be understood as an essential aspect of more sustainable urban planning because they allow performance measurement in the early design stages, providing a quick evaluation even in simple experiments, as in the case study presented in this paper.

Thus, this paper intends to stimulate the use of computational resources as the primary technique to deal with information modeling tasks and the physical characterization of cities, associated with approaches that can evaluate urban performance through objective indexes and metrics. Characterizing the aspects of built urban density and the mix of uses is an essential step towards designing more sustainable neighborhoods and cities, favoring the development of urban spaces with balanced social dynamics.

This article also emphasizes the importance of carrying out specific studies on performance metrics contextualized with Brazil's social reality, impacting the development of an identity for Brazilian parametric urban design, highlighting the cultural aspects of cities, and supporting the design of a better urban space. Looking ahead, one possibility that seems to us to be very fruitful is using parametric techniques to articulate metrics that can guide urban densification based on the potential for urban transformation, aiming for more sustainable and socially balanced cities.

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References

Amorim, A. (2015). Discutindo City Information Modeling (CIM) e conceitos correlatos. Gestão & Tecnologia de Projetos, 10 (2), 87-100. DOI: https://doi.org/10.11606/gtp.v10i2.103163

Ascher, F. (2005). La société hypermoderne. La Tour-d'Aigues: Editions de l'Aube.

Beirão, J., Duarte, J., Montenegro, N. & Gil, J. (2010). Monitoring urban design through generative design support tools: a generative grammar for Praia. Architecture and modern information technologies, 2 (11), 1-25.

Bereitschaft, B. & Debbage, K. (2013). Urban form, air pollution, and CO^2 emissions in large US metropolitan areas. The Professional Geographer, 65 (4), 612-635. DOI: https://doi.org/10.1080/00330124.2013.799991

Berghauser Pont, M. & Haupt, P. (2010) Spacematrix: space density and urban form. Rotterdam: NAi Publishers.

Çalışkan, O. (2017). Parametric Design in Urbanism: a critical reflection. Planning Practice & Research, 32 (4), 417-443. DOI: 10.1080/02697459.2017.1378862

Chakrabarti, V. (2014). A country of cities: a manifesto for an urban America. New York: Metropolis Books.

Chokhachian, A., Perini, K., Giulini, S. & Auer, T. (2020). Urban performance and density: generative study on interdependencies of urban form and environmental measures. Sustainable Cities and Society, 53 (1). DOI: https://doi.org/10.1016/j.scs.2019.101952

Farr, D. (2007). Sustainable Urbanism: urban design with nature. New Jersey: John Wiley & Sons.

Frey, H. (2003). Designing the city: towards a more sustainable urban form. London: Taylor & Francis.

Hillier, B. & Hanson, J. (1984). The social logic of space. Cambridge: Cambridge University Press.

Hoek, J. (2008). The MXI (mixed-use index): an instrument for anti-sprawl policy? In: ISOCARP CONGRESS, 44., 2008, Dalian. Proceedings [...]. China, Dalian, 2008.

Jabi, W. (2013). Parametric design for architecture. London: Laurence King.

Kotnik, T. (2010). Digital Architectural Design as Exploration of Computable Functions. International Journal of Architectural Computing, 8 (1), 1-16. DOI: https://doi.org/10.1260/1478-0771.8.1.1

Leach, N. (2009a). Digital Cities. Architectural Design, 79 (4), 6-13. DOI: https://doi.org/10.1002/ad.911

Leach, N. (2009b). Swarm urbanism. Architectural Design, 79 (4), 56-63. DOI: https://doi.org/10.1002/ad.918

Lima, F. T. A. (2017). Métricas Urbanas: Sistema (para)métrico para análise e otimização de configurações urbanas de acordo com métricas de avaliação de desempenho (Doctoral dissertation, Faculty of Architecture and Urbanism, Federal University of Rio de Janeiro). https://repositorio.ufjf.br/jspui/handle/ufjf/7009

Lima, F., Montenegro, N., Paraizo, R., Kos, J. (2017). Urbanmetrics: an algorithmic-(para) metric methodology for analysis and optimization of urban configurations. In S. Geertman, A. Allan, C. Pettit, & J. Stillwell (Eds.), Planning Support Science for Smarter Urban Futures (pp. 47–64). Springer International Publishing. DOI: https://doi.org/10.1007/978-3-319-57819-4_3

Rogers, R. (1998). Cities for a small planet. New York: Basic Books.

Schumacher, P. (2009). Parametricism: a new global style for architecture and urban design. Architectural Design, 79 (4), 14-23. DOI: https://doi.org/10.1002/ad.912

Talen, E. (2011). Sprawl retrofit: sustainable urban form in unsustainable places. Environment and Planning B, 38 (6), 952-978. DOI: https://doi.org/10.1068/b37048

Yuhan, S., Zhenying, X. & Yulong, L. (2020). Research on Algorithm-based Urban Design: a case study in Chefoo Bay. Journal of Digital Landscape Architecture, 5 (1), 81-93. DOI: 10.14627/537690009

Woodbury, R. (2010). Elements of parametric design. New York: Routledge.

Pertinence and Possibility(s) of Ontological Approaches in Parametric Digital Design Procedures

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Abstract. A research article is presented that seeks to reflect on the relevance and possibility(s) of the incorporation of ontological approaches in the methodological articulation of parametric procedures in architectural design, having as object of study the algorithmic modeling for the digital fabrication of a laminar roof materialized with wood by sub-products from the production of national industries. Such methodological implementation makes possible, as research results, a conceptualization -through a taxonomic structuring supported by relevance- and a systematization by means of a meta-script framed in the universe of possibilities of the ontological approach. The debate problematizes the question of critical appropriation (the convening topic of the present edition of the Sigradi Congress) of methodologies that, arising in realities different from the Ibero-American one, have quickly had an impact in our environment to conclude on the need to emphasize the context parameter in the conceptualization of specific meta-scripts.

Keywords: parametric analysis, ontologies, digital design, digital fabrication, algorithmic design

1 Introducción

El siguiente artículo de investigación tiene como objetivo reflexionar en torno a la problemática vinculada a la implementación de procedimientos paramétricos en los procesos de diseño arquitectónico y se articula a partir de la pregunta de investigación asociada a la pertinencia y posibilidad(es) de la aplicación de enfoques ontológicos que permitan estructurar dichos procedimientos por medio de una operación denominada metaguión. Esta se encuentra basada en la lógica procedimental de explicitación y vinculación de constantes con variables

dependientes e independientes a través de restricciones de distinta índole (matemática, geométrica, lógica, topológica, etc.), a la que se excluye su capacidad performativa y se potencia la trazabilidad y la semántica de sus componentes.

El artículo está estructurado a modo de ensayo de investigación, en el sentido de que seguramente deje planteadas más interrogantes que respuestas en torno a la problemática abordada. Además, (o más allá) de intentar responder a la pregunta de investigación estructurante, se pretende develar los diferentes tópicos vinculados a la complejidad de la temática seleccionada. Complejidad entendida desde la perspectiva oportunamente planteada por Edgard Morin (1990) como "aquello que está tejido en conjunto, como una trama de constituyentes heterogéneos inseparablemente asociados, que presenta la paradoja de lo uno y lo múltiple".

Como se verá a lo largo del relato planteado, la implementación de los procedimientos paramétricos, en diseño y arquitectura, presenta una doble dificultad; por un lado, su conceptualización fuertemente vinculada a la construcción epistemológica sobre la que se estructura, así como el *background* sustentante; y, por otra parte, su instrumentalización asociada a los aspectos operativos presentes en las estrategias de diseño que, de forma implícita o explícita, se aplican y desarrollan *ad-hoc*.

La gestación y gestión de procedimientos paramétricos en las diferentes etapas de la arquitectura implica, necesariamente, reflexionar sobre el modo en que la práctica del diseño arquitectónico experimenta un profundo cambio a partir de la inclusión y desarrollo de las tecnologías de información y comunicación. Castells (2010) afirma que la tecnología digital proporciona un momento de transformaciones en la sociedad caracterizado por una revolución centrada no solo en el conocimiento en sí, sino en su aplicación para generar nuevos conocimientos, además de los dispositivos de procesamiento/comunicación, completando así un *loop* acumulativo entre la innovación y el uso de dichas innovaciones.

La computación tiene un profundo impacto tanto en la percepción como en la realización de la forma, el espacio y la estructura arquitectónica. Según Menges (2015), "cambia la manera de percibir la forma, la manera de proponerla y la manera de producirla". La computación en el diseño representa una acumulación de conceptos multicapa que van desde la teoría de sistemas y la cibernética pasando por la morfogénesis, la teoría de la transformación, la biología del desarrollo, las leyes de la termodinámica (Germán, 2010), en el que "el diseño, en tanto disciplina transversal a todos los procesos de cambio, adquiere una inédita dimensión de complejidad" (García Amen, 2019). Asimismo, en la historia de la arquitectura, la llegada de nuevas tecnologías de fabricación y construcción siempre ha sido un catalizador de la innovación en el diseño, y el próximo cambio

de paradigma latente facilitado por la introducción de sistemas de producción ciberfísicos no será una excepción; la emergencia de la Cuarta Revolución Industrial posibilitará el cambio de la fabricación basada en el comportamiento según Brugnaro (2015).

Concomitantemente la palabra *ontología* es polisémica, ya que es utilizada con diferentes sentidos en diferentes disciplinas: filosofía, inteligencia artificial, web semántica, ingeniería de sistemas, ingeniería de *software*, informática biomédica, bibliotecología, arquitectura de la información, entre otras. La mayor diferencia en su significación se produce entre el sentido filosófico, en donde tiene una procedencia atávica en la metafísica a partir de la consideración y reflexión acerca de las "entidades", y el sentido computacional, que surge en los estudios de cibernética a mediados del pasado siglo, se expande en los últimos años en la comunidad de la ingeniería del conocimiento alrededor de una definición de las ontologías (computacionales) como "especificaciones explicítas de conceptualizaciones" (Gruber, 1992). Así, se estructura la transformación de la información en conocimiento de máquinas-herramientas que comienzan a disponer de "conocimiento" habilitadas por el internet de las cosas y la implementación de algoritmos de inteligencia artificial.

De este modo, la(s) ontología(s) permite(n) representar el entendimiento común y compartido de un dominio, facilitando la comunicación entre los miembros de una comunidad y/o entre sistemas computacionales posibilitando, simultáneamente, la conceptualización e instrumentalización de un procedimiento paramétrico aplicado en la fabricación digital de cubiertas laminares utilizando productos derivados de la madera de procedencia nacional.

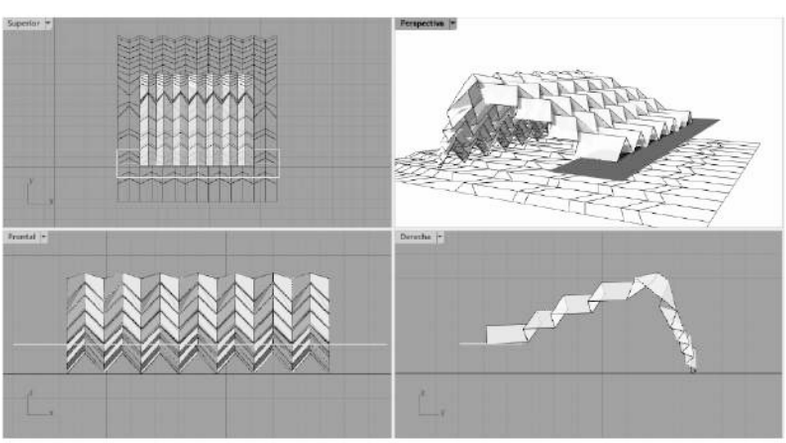

Figura 1. Modelo digital de cubierta plegada. Fuente: Piñeyro, 2022.

Las cubiertas laminares son dispositivos arquitectónicos de cerramiento/envolvente horizontal que salva grandes luces con pequeños espesores, fundamentalmente por su configuración morfológica que le permite soportar las diferentes solicitudes estructurales mediante un comportamiento de cáscara, canalizando la respuesta de la reacción a través de esfuerzos normales de compresión y/o tracción, así como tangenciales uniformes en el espesor de la superficie de la cubierta. Esos criterios las convierten en elementos aptos para implementar procesos de búsqueda de forma a partir del control explícito del control de parámetros geométricos (exploraciones morfológicas vinculadas a configuraciones tectónicas plegadas), así como para involucrar procedimientos paramétricos de fabricación digital.

1.1 Pregunta e hipótesis de investigación

Todas las cuestiones anteriores plantean el terreno fértil para la reflexión del artículo alrededor de la pregunta sobre la que se articula el presente ensayo, que se refiere a la pertinencia y posibilidad(es) de la utilización de construcciones ontológicas en la configuración de procedimientos paramétricos en el diseño arquitectónico. Además, se apoya en la siguiente hipótesis de trabajo: los procedimientos paramétricos, en tanto instancias particulares de pensamiento algorítmico, y por lo tanto configurables (programables) en el mundo de la computación, posibilitan la aplicación de ontologías, entendidas estas últimas como “especificación formal y explícita de una conceptualización compartida”.

Figura 2. Fabricación digital del objeto de estudio. Fuente: Pereyra, 2022.

2 Metodología

A partir de la definición de Gruber, es posible identificar las características que constituyen su impronta, así como las herramientas metodológicas empleadas para la consecución de los fines planteados.

- Conceptualización. Como referencia abstracta de algún fenómeno del mundo del que se busca representar los conceptos más relevantes. Esta singularidad propicia la "representación" a través de grafos de conocimiento, mapas conceptuales o por medio de una operación que he denominado metaguión, para referirla concretamente al uso de *scripts* en la implementación de procedimientos paramétricos (planteado en términos de "guion del guion"; de ahí la terminología empleada).

- Explícita. Se refiere a la necesidad de detallar de forma extensiva los diferentes conceptos de la ontología. Esta característica propicia la utilización de taxonomías, sistemas clasificatorios que faciliten la operatividad de la(s) ontología(s) aplicándola(s) en la materialización de prototipos mediante fabricación digital.

- Formal. Relacionado con el hecho de que se debe utilizar un lenguaje de representación formalizado para su especificación. El *script* algorítmico basado en programación gráfica, implementado en Grasshopper, es la herramienta utilizada para la formalización del procedimiento paramétrico.

- Compartida o consensuada (condición fundamental para la desambiguación del conocimiento aceptado en el dominio). Se instrumentaliza, metodológicamente, a través de diferentes versiones de glosarios controlados de acuerdo con el subdominio de actuación involucrado; fabricación digital, programación gráfica, cálculo estructural, construcción con madera, etc.

De este modo, se implementan dos instancias metodológicas a partir del enfoque ontológico: en tanto conceptualización y en cuanto modelización e instrumentalización. A continuación se analizan ambas instancias.

2.1 En tanto conceptualización

Se procedió a identificar, clasificar, conceptualizar y relacionar aquellos tópicos que participan en la construcción de la cuestión, y que se develan en torno a la pregunta ontológica fundamental: ¿qué es una definición paramétrica en arquitectura? De tal modo es posible problematizar, con fundamento taxonómico, en torno a los siguientes ítems: (a) contexto, (b) autoría, (c) condición, (d) instancia, (e) razón, (f) finalidad, (g) configuración, (h) estrategia y (i) entrada/salida.

2.2 En tanto instrumentalización

Dado que uno de los principales objetivos de las ontologías (Gruninger & Fox, 1995) es aumentar el entendimiento compartido en un dominio dado, eliminando así las diferencias, solapamientos y malentendidos en conceptos, estructuras, terminologías, etc., las ontologías pueden funcionar como marcos de trabajo que unifican distintos puntos de vista y mejoran la comunicación a través del empleo de herramientas complementarias a la conceptualización taxonómica. Además, incorporan glosarios controlados y/o modelizaciones en tanto instrumentalización que, permitiendo la "especificación formal y explicíta de una conceptualización compartida", posibiliten estructurar procedimientos paramétricos *ad-hoc*.

3 Resultados

De acuerdo con lo que se anticipó en líneas anteriores, se habilita la obtención de resultados —utilizando un enfoque ontológico— a través de cuatro instancias vinculadas: modelo conceptual, metaguión, procedimientos taxonómicos y gráfico síntesis. A continuación se desarrollan cada una de las instancias explicitadas.

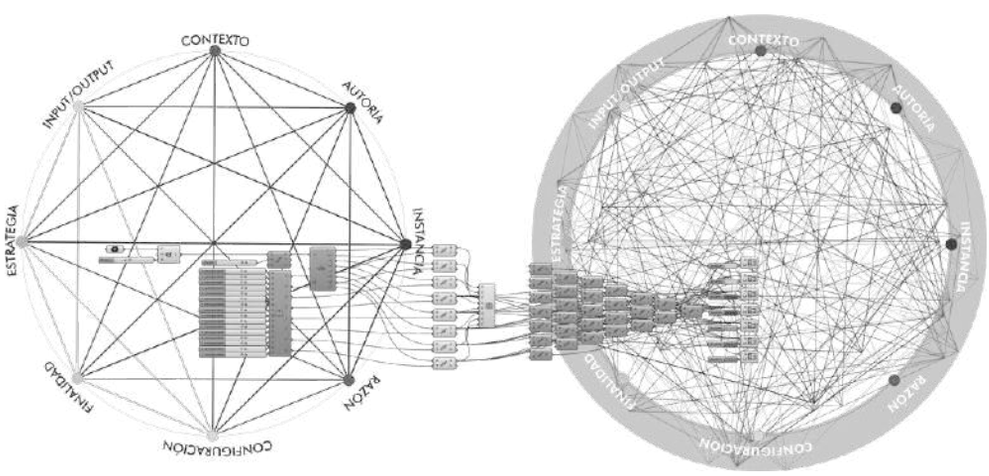

Figura 3 Modelo conceptual. Fuente: Paulo Pereyra, 2022.

3.1 Modelo conceptual

Identifica y estructura la significación de las variables intervinientes a través de un primer resultado esperado, un gráfico algorítmico que parametriza y vincula las relaciones entre variables identificadas, con fundamento taxonómico, en el marco metodológico alrededor de los siguientes tópicos:

• Contexto. Dónde, lugar o situación implementación; en este caso, nos referimos al proyecto que propicia su estructuración.

• Autoría. ¿Quién(es) lo realizan? Esta cuestión se vincula a aspectos de agenciamiento, en el sentido deleuziano que relaciona multiplicidad de heterogeneidades de distinta naturaleza, contrapuesta a la concepción humanista de "creación".

• Instancia. ¿Cuándo se ejecuta el procedimiento?, ¿en qué etapa del diseño arquitectónico es necesaria su implementación? Los procedimientos paramétricos se pueden aplicar, en forma aislada o conjunto, en las instancias de ideación, evaluación, calibración, simulación, racionalización, documentación y otras que puedan integrar el "mundo posible".

• Razón. ¿Por qué se implementa ese procedimiento?, ¿cuál es la causa/problema que motiva o se quiere resolver con su estructuración?

• Finalidad. ¿Para qué se vincula con la utilidad que se espera de la implementación del procedimiento paramétrico, conceptualización/evaluación/materialización?

• Configuración. ¿Cómo se implementa? Referida a la sintaxis del procedimiento, es decir, las reglas que controlan el modo de ordenación y combinación de las variables bajo una impronta algorítmica que posibilite un "continuum digital" característico del *file-to-factory*.

• Estrategia. ¿Cuál es el criterio con el que se plantea el procedimiento paramétrico? Los diferentes enfoques se agrupan en dos grandes estrategias: *bottom-up o top-down*.

• Entrada/salida. ¿Qué objeto/concepto necesitamos para "alimentar" al procedimiento de modo que sea operativo? y, concomitantemente, ¿qué objeto/concepto buscamos obtener como resultado de la implementación del procedimiento paramétrico?

3.2 Metaguión

Se implementa para la consecución del segundo resultado esperado, un mapa conceptual denominado metaguión (figura 3), que, explicitando y

visibilizando las intenciones generales de la autoría, posibilita la edición, sistematización, articulación y disponibilización del proceso *ad-hoc* que se enmarca en el universo de posibilidad(es) del enfoque ontológico.

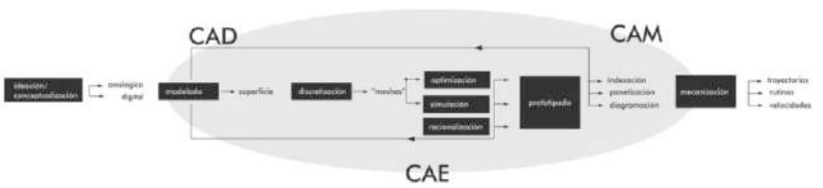

Figura 4. Mapa conceptual: metaguión. Fuente: Pereyra, 2022.

3.3 Procedimientos taxonómicos

La materialización de un prototototipo a escala necesario para el estudio de fabricación, montaje y cálculo estructural implica procedimientos de indexación que, además de los objetivos de identificación de cada elemento, propician una capacidad tectónica, en el sentido de que, a partir de la lógica del detalle, favorezca el diálogo entre estructura/materia y construcción; sin embargo, es necesario realizar un intenso proceso taxonómico, facilitado por el enfoque ontológico, para la clasificación y anidación de componentes intervinientes.

3.4 Gráfico síntesis

Otro producto obtenido, el gráfico síntesis, indica los hitos articuladores del procedimiento paramétrico devenido en protocolo, en particular los *inputs* fundamentales y los *outputs* que posibilitan informar los procesos de materialidad digital.

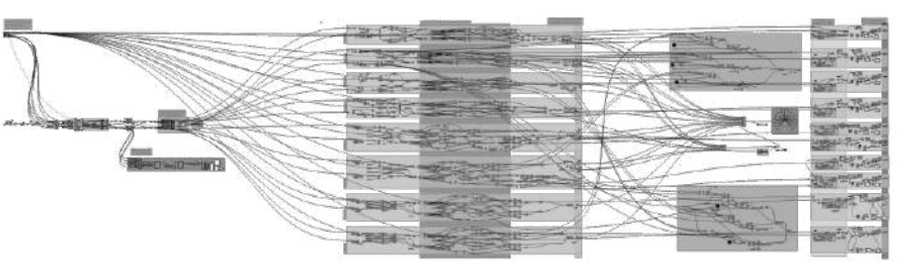

Figura 5. Síntesis. Fuente: Pereyra, 2022.

4 Discusión

Dentro de las innumerables consideraciones vinculadas a la utilización de procedimientos paramétricos en las diferentes instancias del diseño en general, y del proyecto arquitectónico en particular, está la cuestión de "apropiación crítica" de unas metodologías que, surgiendo en contextos y realidades diferentes a la iberoamericana, rápidamente han impactado en nuestro medio. Esto debido a que la globalización y el desarrollo exponencial de las TIC es un argumento "sólido" de quienes defienden su uso, y en sus antípodas se esgrimen causales tan disímiles como el alejamiento de la arquitectura de sus "fuentes" o la no consideración del "lugar" como insumo de proyecto. Sin embargo, no es esta la discusión que se busca al problematizar la cuestión en torno a la pregunta asociada a la pertinencia y a las posibilidad(es) de las ontologías, sino, justamente, cómo el enfoque ontológico permite, al conceptualizar y sistematizar procedimientos paramétricos, la apropiación crítica de una metodología que al plantear una "especificación formal y explicíta de una conceptualización compartida" (Gruber,1992) posibilita modelar definiciones de términos específicos del campo de una determinada disciplina. Entonces, se facilita la producción de la información, así como la comunicación de los distintos actores (humanos y no humanos) involucrados en los procesos de convergencia físico digital del diseño arquitectónico.

En tal sentido, la(s) posibilidad(es) planteadas por la incorporación de enfoques ontológicos en la estructuración de procedimientos paramétricos está(n) vinculada(s) a la disponibilidad de recursos epistemológicos con la finalidad de crear, gestionar (categorizar), editar (modificación/ transformación) y transmitir conocimiento a partir de la implementación de procedimientos paramétricos.

• Con relación a la creación, el sentido de "conocimiento" no está relacionado con un conjunto de creencias que son apodícticamente verdaderas, sino a la construcción de un conocimiento hipotético que debe ser justificado, o rechazado, en el transcurso del proceso de una implementación paramétrica. Según Ortega (2009), "el proceso ya no es una representación de un proceso mental, sino que es un proyecto en sí mismo que condiciona la manera de pensar. Se cuestiona la linealidad del orden pensamiento-representación-producción y se plantea un sistema cíclico de retroalimentación entre el pensamiento y su representación en unos bucles constantes de interacción".

• Vinculadas a la gestión, las posibilidades ontológicas articulan y despliegan procedimientos taxonómicos que facilitan la racionalización, el control, la iteracción y el análisis de *inputs/outputs*. Si bien los procedimientos paramétricos son difíciles de estructurar, según Jabi (2013), "la buena noticia para los diseñadores que desean emplear técnicas paramétricas es que, por lo

general, precisan resolver un problema de diseño pequeño y acotado (al contrario de los desarrolladores de software y gestores de inteligencia artificial) en un espacio de soluciones predefinidos".

• Asociados a la edición, los sistemas de diseño paramétrico modelan un diseño como una colección restringida de diagramas. Los diseñadores trabajan en estos sistemas a dos niveles:

- La definición de los diagramas y las restricciones
- La búsqueda de hitos dentro de tal taxonomía de diagramas

Para Aish y Woodbury (2005), "los sistemas basados en la propagación producen algoritmos eficientes que son completos dentro de su dominio, requieren la especificación explícita de un grafo de restricciones acíclico dirigido y permiten estrategias de depuración relativamente sencillas basadas en los antecedentes y los consecuentes. El requisito de ordenar las restricciones parece ser útil para expresar las intenciones específicas del diseñador y para desambigüar la interacción". Una característica clave de estos sistemas en la práctica parece ser la necesidad de tener múltiples puntos de vista sobre el modelo de restricciones y la interacción simultánea entre varios puntos de vista.

• Contingente a la transmisión de conocimiento, la sistematización de la información que plantean los enfoques ontológicos implícita y explícitamente posibilita la participación de actores humanos / no humanos en los procedimientos en los que la autoría de los mismos no es del todo clara y genera una permeabilidad de responsabilidades, o como lo plantea Donna Haraway (1983) "el límite es permeable entre herramienta y mito, instrumento y concepto, sistemas históricos de relaciones sociales y anatomías históricas de cuerpos posibles, incluyendo objetos de conocimiento". A su vez, en la transmisión del conocimiento interviene la mediación, una variable que, contraponiéndose al determinismo tecnológico, posibilita un enriquecimiento mutuo entre humanos / no humanos y entre ciencia/cultura, tal como lo propone el sociólogo Bruno Latour (2008).

5 Consideraciones finales

El aporte que brinda la incorporación de enfoques ontológicos en la estructuración de procedimientos paramétricos está vinculado a la reflexión en torno a la nueva condición tecnológica, en el sentido de que las nuevas implementaciones tecnológicas de la información y comunicación han traspasado el umbral de ser simples "esclavos" que facilitan un procedimiento determinado para pasar a ser actores principales en la conformación de los conocimientos que habilitan un determinado *know-how*. En particular, los sistemas de inteligencia artificial posibilitan unos modos de conocimiento (entendido como transformación

de la información y no como “verdad”) que, articulados por prácticas algorítmicas y diseminados a través de la web semántica (favorecida por la tecnología 5G), constituyen la urdiembre de la cuarta revolución industrial enmarcada en la crisis ambiental/energética/sanitaria sin precedentes que caracteriza la eclosión del Antropoceno como clara consecuencia de la acción humana. En tal sentido, Sadin (2020) plantea lo siguiente:

"La causa (y no la consecuencia) de la pregnancia del fenómeno de la inteligencia artificial es un cambio de estatuto de las tecnologías digitales: de ser prótesis acumulativas e intelectivas –porque permiten el almacenamiento, la indexación y el tráfico veloz de información–, han pasado a ser entidades de las que se espera que enuncien una verdad a partir de la interpretación automatizada de situaciones... Así, gracias a este poder de enunciar una verdad que los humanos no podemos ver, la tecnología deja de ser protésica para devenir antropomórfica. La autonomía de decisión de los sistemas de inteligencia artificial termina de cerrar el círculo de este cambio radical, enfrentándonos por primera vez con el estadio del tecno-logos de la técnica: no un logos sobre la técnica producido por los humanos sino humanos modelados por una técnica capaz de producir discurso o verdad. En este nuevo régimen, sin réplica posible, se juega la vocación humana primordial de habitar el mundo”.

Justamente ese es el desafío que plantea la apropiación crítica, que seamos los humanos quienes poseamos el fuego de la verdad.

6 Referencias

Aish, R. & Woodbury, R. (2005). Multi-level Interaction in Parametric Design.

Brugnaro, G. (2015). Cyber-physical construction system for woven spaces.

Castells, M. (2010). Comunicación y poder.

Davis, D. (2013). Modelled on Software Engineering: Flexible Parametric Models in the Practice.

Eco, U. (1964). Apocalípticos e integrados.

García, F. (2019). El diseño y la geometría; apostillas a la praxis del diseño paramétrico y su incipiente hegemonía.

Germán, J. G. (2010). De lo mecánico a lo termodinámico; por una definición energética de la arquitectura y del territorio.

Gruber, T. R. (1992). Toward Principles for the Design of Ontologies Used for Knowledge Sharing.

Gruninger, M. & Fox, M. S. (1995). *Methodology for the Design and Evaluation of Ontologies*.

Haraway, D. (1983). *Manifiesto cyborg*.

Jabi, W. (2013). *Parametric Design for Architecture*.

Latour, B. (2008). Reensamblar lo social: una introducción a la teoría del actor-red.

Menges, A. (2015). Material Synthesis: Fusing the Physical and the Computational.

Morin, E. (1990). Introducción al pensamiento complejo.

Ortega, L. (ed.) (2009). La digitalización toma el mando.

Sadin, E. (2020). La inteligencia artificial o el desafío del siglo. Anatomía de un antihumanismo radical.

Programming Cultures: Predictive Modeling

City information modeling (CIM) applied to urban planning: the urban indicator of reachness

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Abstract. This work is part of an extension and investigation project dedicated to studying solutions related to urban, social and economic innovation with the purpose of developing a Health Innovation District (HID). Purposing to define the HID's intervention area, a group of urban indicators was developed and categorized in four layers: reachness, integrability, use diversity and social validation. This article will explain the first layer: reachness. To achieve this, it aims to appropriate a generic framework that incorporates 1) a Relational Database Management System (PostgreSQL), 2) a Geographic Information System (QGIS) and 3) a CAD software associated to an algorithmic modelator (Rhinoceros3D + Grasshopper3D), associated to computer solutions to assess if the shortest way possible between the residential lots and the points of interest has an adequate distance.

Keywords: City Information Model, Urban Planning, Urban Indicators, Parametric Analysis

1. Introdução

O planejamento urbano atento reconhece no projeto um instrumento de manifestação do fenômeno urbano, cuja complexidade é intrínseca aos agentes, lugares, circunstâncias e acontecimentos (Ascher, 2010). Como parte de um projeto que delimita uma área de intervenção para a implantação

de um distrito de inovação em saúde em Fortaleza, Brasil, Viva@Porangabussu, a pesquisa a seguir trabalha os aspectos lugar e circunstância, constituindo uma investigação sobre como a modelagem da informação da cidade (CIM) ampara o planejador urbano na elaboração de uma ferramenta que estuda o deslocamento na malha urbana.

Partindo de Ascher (2010), é considerado que é necessário uma reformulação da arquitetura institucional e da elaboração de dispositivos estatais com escalas flexíveis - o autor afirma que a modernização, a partir da substituição progressiva da tradição pela razão nas tomadas de decisão, conduz a uma "refletividade" que exige a análise constante das práticas sociais, a partir de informações produzidas delas. Tal referência traduz-se, neste trabalho, na demanda de uma ferramenta que delimite a área do projeto embasada por dados. Assim, como uma maneira de converter dados em informação, o desenvolvimento de um indicador é apontado como solução. Para Jannuzzi (2017), os indicadores sociais permitem a operacionalização de uma demanda e apontam termos operacionais às dimensões sociais de interesse a partir de escolhas realizadas anteriormente.

A formalização do indicador é amparada, fundamentalmente, nos conceitos (1) da sintaxe espacial de Hillier e Hanson (1984) - que busca descrever a ordenação urbana e as relações público privado através de análises quantitativas elucidando características urbanas como a acessibilidade e o uso do solo; (2) do Spatial Capital de Marcus (2007; 2010) - que constitui um processo de medir variações na urbanidade como uma categoria socioespacial buscando aferir o quanto aquela diversidade local pode ser acessível à cidade; (3) e o iCam 2.0, índice de caminhabilidade proposto pelo Instituto de Políticas de Transporte e Desenvolvimento (ITDP Brasil) em parceria com o Instituto Rio Patrimônio da Humanidade (IRPH) e a Pública Arquitetos, voltado para a análise da qualidade dos passeios para os pedestres, avaliando questões como segurança viária, atração, qualidade das calçadas, mobilidade, meio ambiente e segurança pública (ITDP, 2016).

O trabalho apresentado é parte de uma pesquisa de mestrado que visa a construção de um indicador composto para aferir a atratividade do espaço urbano para a implantação de Distrito de Inovação da Saúde (DIS) que, para fins didáticos, é dividido em quatro etapas, e são elas: alcançabilidade, integrabilidade, diversidade de usos e validação social.

Antes de abordar o trabalho em si é necessário definir o que é um Distrito de Inovação, para tal adotaremos o conceito de Mineiro & Castro, 2020 que define Distrito de Inovação como um habitat voltado para a interação entre empresas, universidade, Poder Público e comunidade com a intenção de gerar inovação tecnológica. No caso do estudo apresentado, o Distrito é voltado exclusivamente para inovações em saúde, recebendo a terminologia de Distrito de Inovação da Saúde (DIS).

O trabalho em questão irá abordar a construção e formalização da alcançabilidade, onde os autores buscam se apropriar de um framework genérico associado a soluções computacionais para aferir se o menor percurso possível entre os lotes residenciais e pontos de interesse possui

uma distância adequada de percurso, através de análises críticas de métricas de pesquisadores já consagrados como Gehl (2013), Moretti (1997), Gouvea (2008), Ferraz (2004) e Pitts (2007), além de aferir, também, a qualidade e segurança dos passeios que compõem os percursos.

Para a aferição das distâncias entre dois pontos, é preciso determiná-los: as origens serão os lotes dentro de um raio de análise; já os destinos, serão constituídos por pontos de interesse coletivo compostos por equipamentos, instalações e áreas verdes. A aferição proposta acontece dentro de um framework que incorpora (1) um Sistema Gerenciador de Banco de Dados Relacional (PostgreSQL), (2) um Geographic Information System (QGIS) e (3) um software CAD associado a um modelador algorítmico (Rhinoceros3D + Grasshopper3D). Dentro desse modelador, o complemento Carcará, desenvolvido pelo Laboratório de Experiências Digitais (LED_UFC), possibilita a estruturação de um algoritmo que manipula os dados geométricos da cidade, realiza os cálculos de distância e os armazena como tabela no banco de dados para futuras iterações.

Após a produção e tratamento desses dados, é possível empregá-los na elaboração de mapas de calor que apresentam a alcançabilidade dos pontos de interesse, oferecendo a possibilidade de visualizar lacunas de cobertura na forma de lotes desprovidos de acesso segundo as métricas adotadas.

Por fim, é discutido como as soluções computacionais podem ser relevantes ao planejamento urbano, como elas podem ressignificar não apenas o papel do planejador, mas ainda suas competências, e como essas soluções podem nos distanciar da atuação fundamentada em experiências prévias nem sempre tão correlatas.

2. Materiais e Métodos

1. Condições do estudo

O trabalho em questão foi desenvolvido em 2021 e surgiu da necessidade de delimitar um perímetro para o desenvolvimento do Distrito de Inovação da Saúde de Fortaleza, que irá se estabelecer nas imediações do bairro Porangabussu – conhecido por abrigar o campus de saúde da Universidade Federal do Ceará (UFC).

É importante destacar que durante o período de desenvolvimento da pesquisa, o mundo passava por períodos de lockdown devido à pandemia de COVID-19, o que inviabilizou as coletas de dados em campo. Desse modo, a aferição dos elementos qualitativos realizada pelos pesquisadores nem sempre pôde contar com dados de levantamentos direcionados, seja porque eles não foram realizados pelo poder público ou porque seus resultados não chegaram a ser disponibilizados por tal. As fontes dos dados obtidos compreenderam as secretarias municipais responsáveis e os próprios autores, através da manipulação conjunta dos dados primários para obter novos dados e informação.

2. Conceitos

O indicador de alcançabilidade analisa, dentro de um padrão mínimo de qualidade, a acessibilidade do lote a pontos de interesse (POI) predeterminados e categorizados como no quadro 1.

Quadro 1. Organização dos POI por classe e categoria, com alcances adequados.

Classe	POI	Raio	Fonte
Instrução	ens. infantil	500m	Moretti (1997)
	ens. fundamental	800m	Moretti (1997)
	ens. medio	3000m	Gouvea (2008)
	ens. superior	1250m	Plano de Paris
Saúde	atenção primária	1000m	Gouvea (2008)
	atenção secundária	2000m	Moretti (1997)
	atenção terciária	regional	Moretti (1997)
Instalação	serviço	500m	Gehl (2013)
	comércio		
	templo		
Mobilidade	ponto de ônibus	300m à 500m	Ferraz (2004)
	estação de metrô		
	estação bicicletar		
Lazer	praça e jardim	600m	Gouvea (2008)
	parque municipal	2400m	Gouvea (2008)
	equip. desportivo	2000m	Pittis (2004)

Fonte: Elaborado pelos autores, 2021.

A análise é executada na escala dos lotes, através do traçado dos percursos que ligam o lote em questão aos representantes do POI sendo analisado, respeitando a malha viária – o caminho de dimensão mais curta é selecionado e avaliado em comparação ao raio de cobertura do POI, definido pelos pesquisadores com base em autores de referência.

3. Ferramentas

Para Beirão e Cardoso (2018), a espacialização de um conjunto sólido de dados, além da sua correta utilização, condiciona a execução de análises do espaço urbano. A espacialização da informação necessária a essas análises é possível através de um Sistema de Informação Geográfica (SIG), mas não faz parte do seu desenvolvimento técnico o registro das transformações e operações de projeto. Para essa demanda, surge o CIM (city information modeling), um modelo digital da cidade que estaria apto a simular aspectos e fenômenos da cidade (Khemlani, 2016). Beirão e Arrobas (2013), com contribuições de Sousa (2018), descrevem CIM essencialmente como um framework, composto por um sistema gerenciador de banco de dados (SGBD) informando um SIG e por uma interface de modelagem que surge a partir da associação entre um software CAD e uma interface visual de programação (IVP) (Fig. 1).

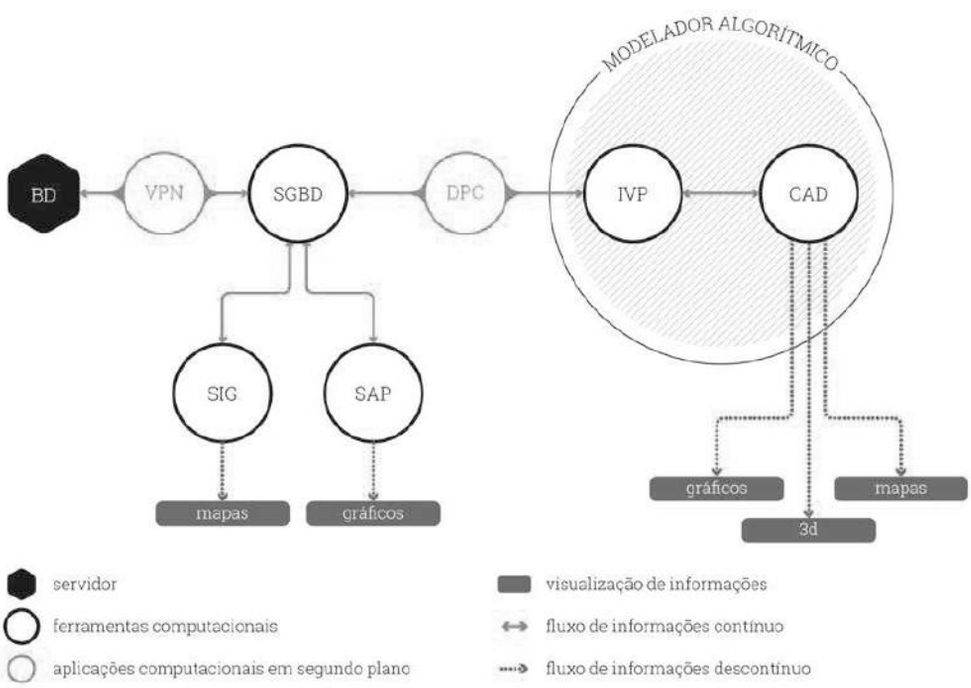

Figura 1. Estrutura do framework descrito. Fonte: Adaptado de Sousa (2018).

O SGBD centraliza todos os dados coletados, além de possuir funções que facilitam a gestão de projetos – a partir dele, é possível acessar os dados local ou remotamente, definir permissões específicas para usuários que acessam o banco, realizar consultas e análises de maneira nativa, além de poder incorporar dados de diferentes tipos que podem ser coletados por diferentes fontes (Gil et al., 2011). A plataforma utilizada, PostgreSQL, é uma ferramenta que possui código aberto e conta com uma conexão nativa com o QGIS, a ferramenta SIG adotada pelos autores (também de código aberto) que permite a execução de análises simples e a elaboração de mapas. A infraestrutura para a construção e segurança do banco é garantida pela Secretaria de Tecnologia da Informação (STI) da Universidade Federal do Ceará (UFC) e o acesso remoto seguro é viabilizado através de uma virtual private network (VPN).

O modelador algorítmico, no framework dos autores, é composto pelo software CAD Rhinoceros 3D e sua IVP nativa, Grasshopper 3D. Dentro da IVP, o plugin Carcará desenvolvido pelo LED_UFC é capaz de se comunicar com o banco de dados e oferece uma série de funções de consulta e manipulação de dados que ajudam a suprir a necessidade de programar em SQL.

4. Método

Para diversos autores como Spolidoro (1997), Lunardi (1997), Audy (2017), dentre outros, a relação com as universidades é fundamental para o sucesso de um distrito de inovação. Para Audy (2017) as Universidades assumem o papel de atuarem como vetores do desenvolvimento econômico e social da sociedade, ampliando suas missões básicas, de ensino e pesquisa. Assim, devido ao grande papel desempenhado pelas universidades foi estabelecido que a área de influência seria traçada a partir dos edifícios universitários ligados à saúde – por se tratar de um ambiente de inovação da saúde.

O passo seguinte foi estabelecer uma métrica e para tal foi destacado o conceito de cidades caminháveis trabalhados em diversos planos municipais como o Plano de Paris com “ville de quart d'heure" e o Plano Fortaleza 2040 que prevê uma série de benefícios com cidades acessíveis a uma caminhada de 15 ou 10 minutos respectivamente. Dessa maneira foi estabelecido um raio de 1250m – equivalente a 15 minutos de caminhada (Figura 2).

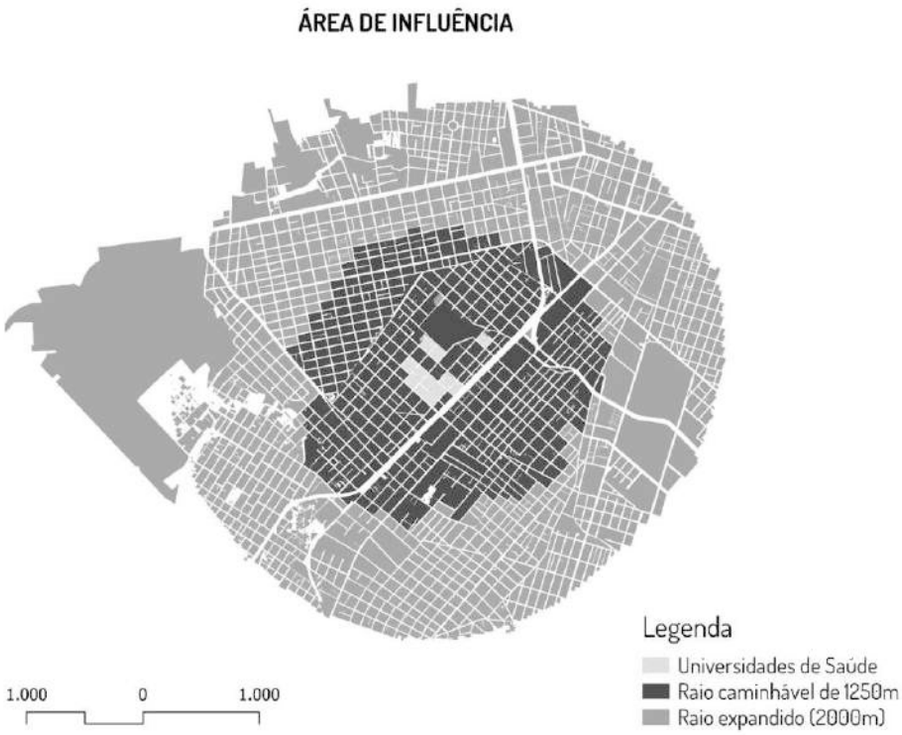

Figura 2. Delimitação do raio de influência do objeto. Fonte: Elaborado pelos autores, 2021.

Após a definição da área de influência é iniciado o cálculo das distâncias através do framework adotado. O algoritmo utilizado transforma os eixos das vias em vértices de grafos e determina, primeiramente, o menor caminho do lote selecionado para *todas* as ocorrências do POI em análise – com todas as distâncias medidas e ordenadas, é possível selecionar a mais curta e, consequentemente, ocorrência do POI mais próxima.

Com a coleta dos dados e sua sintetização em uma planilha foram classificados os percursos aceitáveis, atribuindo 1 para adequado e 0 para inadequado, dentro das distâncias estabelecidas anteriormente e realizado uma média aritmética por grupo (educação, saúde, mobilidade, institucional e lazer) e finalizando com a alcançabilidade quantitativa que resulta na somatório das notas parciais (de cada categoria dos POI) dividido por cinco:

$$\text{Alc quanti} = (\sum \text{Alc parc})/5$$

Onde:
Alc quanti: Alcançabilidade quantitativa;
∑Alc parc: Somatório da alcançabilidade por segmento dos POI

Após o cálculo dos aspectos quantitativos foram adicionados alguns elementos para aferir algum grau de qualidade dos percursos calculados. Nesse ponto é investigado o alcance dos lotes dentro de um padrão mínimo de qualidade dos percursos. Para isso foi buscado no iCam 2.0 (ITDP, 2016) métodos e métricas para tal cálculo das condições do espaço urbano através da ótica do pedestre.O índice é dividido em seis categorias que atribuem uma pontuação de 0 à 3 (insuficiente à otimo) de acordo com as condições encontradas no percurso.

Para aplicação do iCam em sua totalidade é necessário coleta de dados em campo, entretanto, devido às especificidades do trabalho e a extensão do recorte, o estudo em questão se deteve a dados já existentes e disponibilizados pelas secretarias municipais de Fortaleza, acarretando no uso do índice apenas como uma referência.

Dessa maneira, ao considerar a composição do iCam 2.0 e os dados disponibilizados foi selecionado como elementos qualitativos relacionados à alcançabilidade a presença de calçada, presença de iluminação pública e arborização nas calçadas, pois de acordo com índice de caminhabilidade do ITDP tem relação direta com a segurança viária, segurança pública e ambiente.

Após o processamento desses dados foi atribuído 1 para presença dos elementos e 0 para ausência dos mesmos para a realização de uma média aritmética entre os elementos (calçada, iluminação e arborização):

$$\text{Alc quali} = (\text{Pres cal} + \text{Pres ilu} + \text{Pres arb})/3$$

Onde:
Alc quali: Alcançabilidade qualitativa;
Pres cal: Presença de calçada
Pres ilu:Presença de iluminação pública
Pres arb: Presença de arborização nas calçadas

Nesse ponto é importante salientar que o trabalho apresentado é parte de um indicador composto que visa aferir a atratividade em DIS, assim, para o estudo, aspectos qualitativos e quantitativos possuem o mesmo peso. Dessa maneira é realizada uma média aritmética entre Alcançabilidade quantitativa e Alcançabilidade qualitativa para encontrar o indicador Alcançabilidade.

3. Resultados

A seguir é apresentado o resultado gráfico da Alcançabilidade que pode variar de 0 à 1, onde 0 indica o pior nível de alcançabilidade possível e 1 indica alcançabilidade plena (Figura 3).

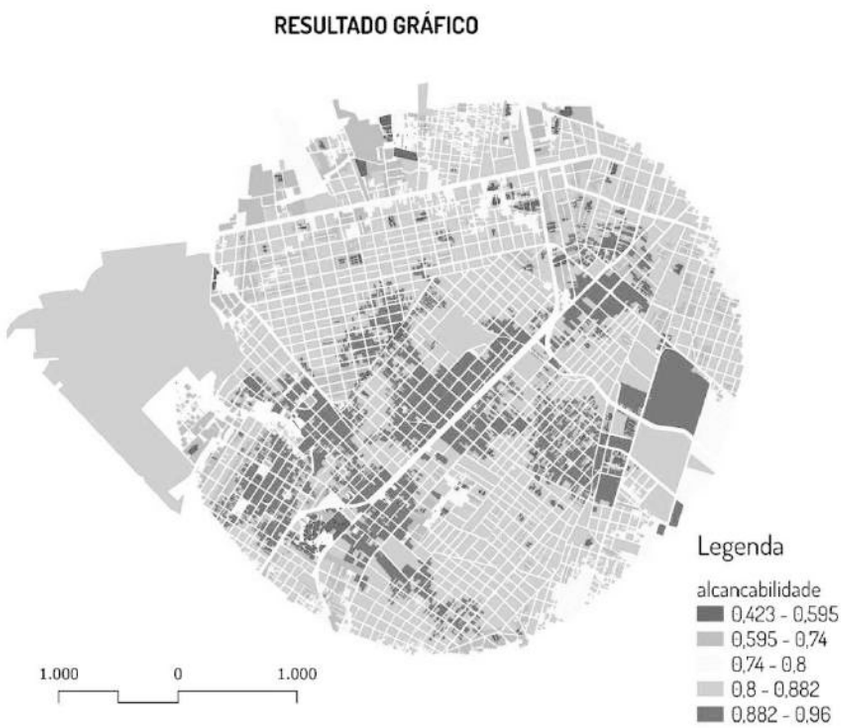

Figura 3. Resultado gráfico Alcançabilidade. Fonte: Elaborado pelos autores, 2021.

Após a configuração do indicador, com o objetivo de estabelecer o perímetro para o DIS, a equipe realizou um recorte que será sobreposto aos recortes das outras etapas (integrabilidade, diversidade de usos e validação social) para enfim delimitar a área de implantação do DIS. A Seguir será demonstrado como foi realizada tal seleção.

Para se alcançar a excelência de um ambiente de inovação é primordial a facilidade de acesso aos POI com o intuito de minimizar viagens realizadas em modais não sustentáveis. Para tanto foi estabelecido como nota de corte a alcançabilidade 0,8, visto que nem todos os habitantes e frequentadores do DIS precisarão acessar todas as classes de POI, dessa maneira cada lote com alcançabilidade menor que 0,8 não estará apto para o perímetro caso se encontrem nas extremidades do polígono, ou permaneceram com indicação

de construção de novos POI que serão destacado ao concluir o estudo. Prezando a uniformidade do polígono serão excluídas as quadras da extremidade da poligonal com a maioria de lotes com a alcançabilidade menor que 0,8 (Figura 4).

$$\text{Se Alc} \leq 0{,}8, \subset qe \therefore eq; \subset li \therefore ir$$

Onde:
Alc total: Alcançabilidade total;
qe: quadra de extremidade;
li: lote interno;
eq: exclusão da quadra;
ir: indicação de reforma.

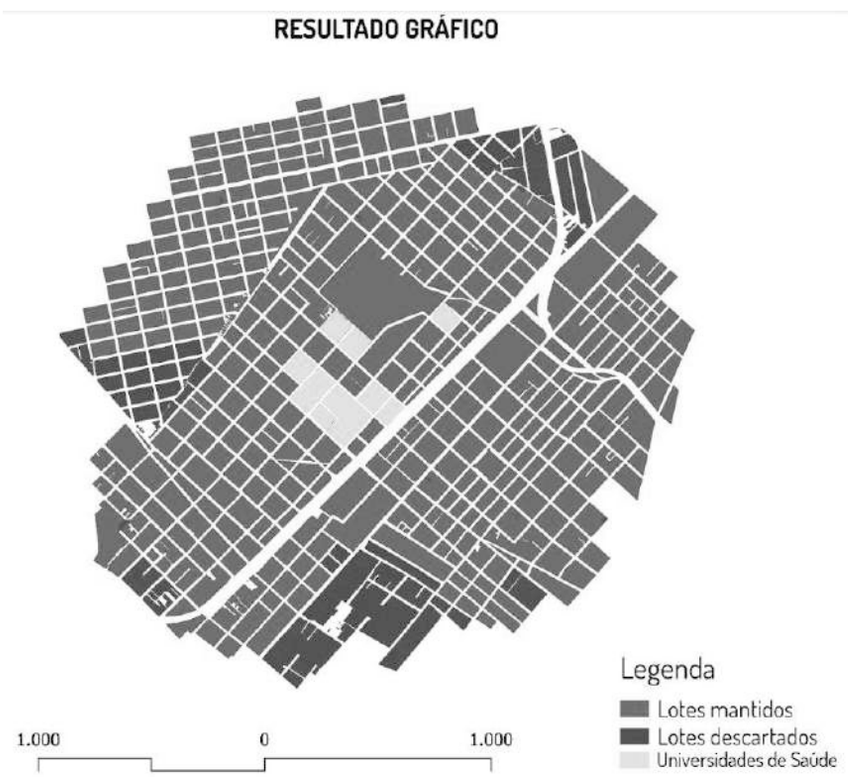

Figura 4. Resultado gráfico pós nota de corte. Fonte: Elaborado pelos autores, 2021.

4. Conclusão

O trabalho aqui demonstrado tratou-se de uma etapa para construção de um *indicador de atratividade* para delimitação de um DIS - decomposto em *Alcançabilidade, Integrabilidade, Diversidade e Validação Social* - e somente ao final de todo processo é possível delimitar o perímetro do objeto em estudo e traçar parâmetros comparativos para ambientes semelhantes.

Mesmo se tratando de uma janela parte de uma pesquisa maior, a formulação do *indicador Alcançabilidade* demonstrou a possibilidade de um planejamento para cidade através do CIM, ao manipular, processar e armazenar dados urbanos, além de registrar todo o processo para futuras iterações através do plugin Carcará.

O estudo também contribui com o debate sobre a viabilidade do CIM em políticas públicas. A aplicação do indicador, apesar de ainda inicial, já corresponde a uma evolução em relação às decisões de projeto, já que, diferente de outros casos ocorridos dentro do próprio desenvolvimento do DIS, utiliza-se de parâmetros técnicos para a definição do perímetro.

Além disso, o *indicador Alcançabilidade* aponta um esforço para uma construção de parâmetros, índices e indicadores que contemplem tanto aspectos quantitativos como qualitativos imersos em um ambiente CIM. Porém é importante ressaltar que não somente a Alcançabilidade, mas também o *indicador de atratividade*, são passiveis de ensaios para extenuar possíveis dúvidas de viabilidade e replicação.

Concluindo, a modelagem de informação da Cidade (CIM) voltada para distritos de inovação é um caminho longo e repleto de desafios. O estudo ilustrou que a aferição da qualidade urbana em distritos de inovação, através da modelagem da informação é uma matéria complexa, que integra, relaciona e atravessam diferentes segmentos profissionais, cada um deles com desafios e contribuições únicas para a construção do modelo computacional, principalmente pela necessidade de conversão de dados ligados à percepção e à cognição, para dados mensuráveis, passíveis de transpor para um sistema algorítmico e matemático.

Referências Bibliográficas

Ascher, F. (2010). Os novos princípios do urbanismo. São Paulo: Romano Guerra Editora, 2010. 104 p. ISBN: 978-85-88585-25-6

Audy, J. (2017). A inovação, o desenvolvimento e o papel da Universidade. Estudos avançados, 31, 75-87. https://doi.org/10.1590/s0103-40142017.3190005

Beirão, J., & Arrobas, P. (2013). Interactive urban parametric design. In Stouffs, Rudi and Sariyildiz, Sevil (eds.), Computation and Performance – Proceedings of the 31st eCAADe Conference – Volume 1, Faculty of Architecture, Delft University of Technology, Delft, The Netherlands pp. 291-299. https://doi.org/10.52842/conf.ecaade.2013.1.291

Beirão, J., & Cardoso, D. (2018). Modelos de Simulação para a Medição e Espacialização do Capital Criativo. V ENANPARQ - V Encontro Da Associação Nacional de Pesquisa E Pós-Graduação Em Arquitetura E Urbanismo.

Brasil, I. T. D. P. (2016). Instituto de Políticas de Transporte e Desenvolvimento. Índice de Caminhabilidade. Retrieved July 22, 2021, from http://itdpbrasil.org/wp-content/uploads/2019/05/Caminhabilidade_Volume-3_Ferramenta-ALTA.pdf

Erika, C., & Rojas, Á. G. (2014, December). *Caracterização dos Distritos de Inovação no Desenvolvimento Regional do Estado de Santa Catarina*. XIV COLÓQUIO INTERNACIONAL DE GESTÃO UNIVERSITÁRIA – CIGU, Florianópolis.

Gehl, J. (2013). Cidades para pessoas. São Paulo: Perspectiva.

Gil, Jorge, Almeida, J. & Duarte, J.P. (2011). The backbone of a City Information Model (CIM): Implementing a spatial data model for urban design. In Proceedings of the Conference eCAADe 2011. Ljubljiana. pp.143-151.

Hillier, B. & Hanson, J. (1984). Social Logical of Space. Cambridge: Cambridge University Press.

Jannuzzi, P. de Martino (2017). Indicadores. Sociais no Brasil. Conceitos, Fontes de Dados e Aplicações. (6. ed.) Campinas: Alínea

Khemlani, L (2016). City information modeling: Aecbytes. City Information Modeling; AECbytes. Retrieved March 03, 2022, from https://www.aecbytes.com/feature/2016/CityInformationModeling.html

Marcus, L.(2010) Spatial capital. The Journal of Space Syntax 1.1 (2010): 30-40.

Marcus, L. (2007). Spatial capital and how to measure it: an outline of an analytical theory of the social performativity of urban form. Sixth international space syntax symposium (pp. 5-1). Istanbul Technical University. ISBN: 978-975-561-304-8

Mineiro, A. A. da C., & Castro, C. C. de. (2020). A Hélice Quádrupla e sua relação com a visão de futuro dos Parques Científicos e Tecnológicos consolidados no Brasil. *Revista de Administração, Sociedade E Inovação*, *6*(2), 71–89. https://doi.org/10.20401/rasi.6.2.422

Moretti, Ricardo de Souza. (1997) Normas Urbanísticas para habitação de interesse social: recomendações para elaboração. – São Paulo: Instituto de Pesquisas Tecnológicas.

Sousa, E. (2018). Modelando a Percepção: o ambiente do patrimônio cultural edificado na regulação da forma urbana. Fortaleza: Universidade Federal do Ceará.

Spolidoro, R. (1997). A sociedade do conhecimento e seus impactos no meio urbano. Parques tecnológicos e meio urbano. Brasília: Anprotec.

Spolidoro, R., & Audy, J. (2008). *Parque científico e tecnológico da PUCRS: TECNOPUC*. EDIPUCRS.

Programming Cultures: Shape Grammars

From Shelter to Home: Transformation Grammar of Housing Units in Irbid Refugee Camp

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Abstract. This paper presents research on the design challenges in refugee camps where “temporary" shelters often evolve into permanent homes and larger communities. These transformations convey an informal design process, a phenomenon evident in Irbid Camp for Palestinian refugees in Jordan. To study this site and design process in detail, shape rules based on the transformation of ten individual housing units are developed, with consideration of area and growth limitations inside the refugee camp. The Irbid Camp Grammar reveals a modular, grid-based logic at play in the incremental and spontaneous design of refugee housing from temporary shelters to permanent homes. This study is one step forward in helping us understand how formalizing this growth logic can contribute to the design of better emergency housing interventions in the future.

Keywords: Shape grammars, Emergency housing, Refugee housing, Housing transformation, Informal settlements.

1 Background and Research Problem

More than 70 years have passed since the Arab-Israeli war in 1948. However, Palestinian refugee camps in Jordan, Palestine, Syria, and Lebanon are politically defined as "temporary settlements” today, even though those camps still exist. Following the Arab-Israeli war in 1948, Palestinian refugee camps in Jordan were first initiated as emergency settlements for exiled Palestinians. Some of the camps were installed in areas that later became neighborhood-like settlements within the urban envelope of host cities. The “temporary status” of refugee camps did not stop camp inhabitants from practicing their daily life and developing their livelihoods and physical built environments (Al Husseini, 2010; Hanafi, 2010). According to UNRWA (2021), Jordan hosts ten official camps for Palestinian refugees, accommodating nearly 370,000 Palestinian refugees, or 18 percent of the country’s total. These Palestinian refugee camps are now established as permanent

neighborhood-like settlements within their host cities. The ten camps in Jordan evolved through a long process of incremental transformations from their initial state as emergency settlements to their current state as permanent neighborhood-like communities (Abu-Aridah, 2016).

To analyze and understand the design challenges of emergency housing interventions and their long-term implications, this research studies the transformation of individual refugee housing units in Jordan using shape grammars. More specifically, the focus is on ten houses from the Irbid Camp, which is one of the ten camps for Palestinian refugees in Jordan that has evolved into a permanent community over the last 70 years. The Irbid Camp grammar interprets the transformation of the housing units in abstracted two-dimensional plan and three-dimensional massing representations that convey the major spatial relationships that evolve from one phase of informal development to another.

The major research questions shaping this work are: (1) how can shape rules documenting spatial relations and their change over time help designers understand the informal transformation process of housing units in Irbid Camp; and (2) how the formal interpretation of these design moves might help progress the design of emergency housing interventions in the future.

2 Methodology

2.1 Shape Grammars

Shape grammars are a rule-based formalism characterized by visual computations that was first launched by Stiny and Gips in 1972. The primitives in shape grammars are shapes rather than symbols, and the relationships and operations on shapes are all spatial rather than symbolic. Therefore, shape grammars use rules that are shape specific rather than property specific, allowing designers to describe, interpret, and evaluate spatial relationships with geometric algorithms (Gips, 1999; Stiny & Gips, 1972).

Shape grammars can be broadly divided into two categories: analytical grammars that are developed to analyze existing designs and original grammars that are concerned with the creation of new and original designs (Colakoglu (2005). This work is concerned primarily with analysis and how that analysis can inform future designs. To that end, transformation grammars specified with parametric shape rules are used to study the informal design of housing units in the Irbid Camp. Transformation grammars are a unique class of grammars focused on how languages of designs change over time or from one language to another (Knight, 2014; Knight, 1994). Parametric shape rules use parametric shapes to formalize rules that can adapt to a range of possible geometries and related constraints as specified in the rule (Stiny, 1980).

2.2 The Case Study: Irbid Camp for Palestinian Refugees

The Irbid camp for Palestinian refugees is in the downtown area of Irbid city, north of Jordan. The camp was set up in 1951 on an area of 0.24 square kilometers. Fig. 1 shows the aerial image of the camp two years after its establishment (left) and a second aerial image of the current situation of the camp (right). The camp originally housed 4,000 refugees in emergency tents that were set up on 8x8 meter land plots. The camp now houses more than 28,000 registered Palestine refugees (UNRWA, 2021).

Fig. 1. Aerial Photo for Irbid Camp in 1953 and 2016 (Image by Author)

The primary data used for this research was collected to explore the patterns of physical and socioeconomic integration of the two major Palestinian refugee camps in Irbid city in Jordan (Abu-Aridah, 2016). The refugee housing units in Irbid Camp have gone through many alterations and replacements during the 70 years of the camp's existence (Abu-Aridah, 2016; UNRWA, 2021). Based on the categorization of shelter types by IFRC (2013), the following transformation stages of the refugee housing units in Irbid camp are defined (as illustrated in fig. 2):

- **The emergency phase:** this phase comprised the setup of tents on 8x8 meter land plots that were assigned to refugees upon their arrival at the camp.
- **The temporary phase:** this phase witnessed the building of one room using temporary building materials of mud block and bamboo.
- **The transitional phase:** In this phase, refugees added kitchens and toilets to the initial rooms that were built during the temporary phase.
- **The core unit phase:** during this phase, some refugees demolished the residential units that were built during the temporary and transitional phases and replaced them with permanent building materials, and illegally enlarged their land plots by occupying parts of the adjacent streets. Other refugees added extra rooms to their residential units without destructing the rooms that were built using mud blocks and bamboo.

- **The vertical expansion phase:** this phase documents the evolution to a more permanent housing construction as some refugees added extra floors to their core units.

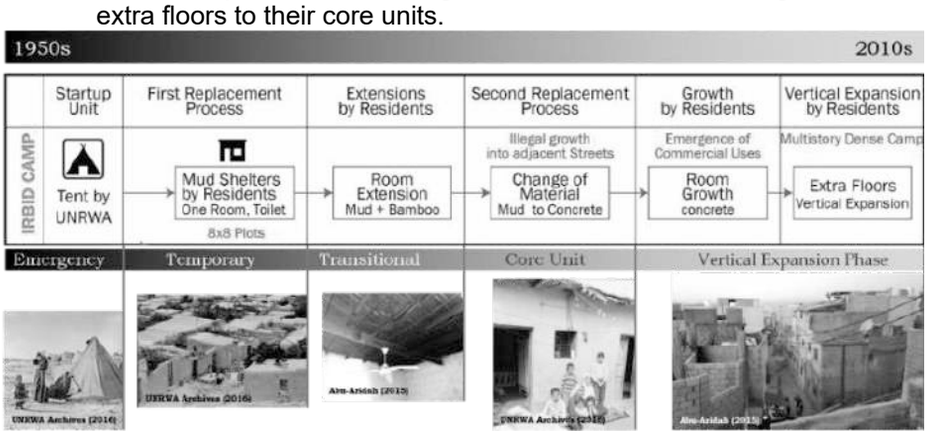

Fig. 2. Transformation of Housing Units in Irbid Camp (Image by Author)

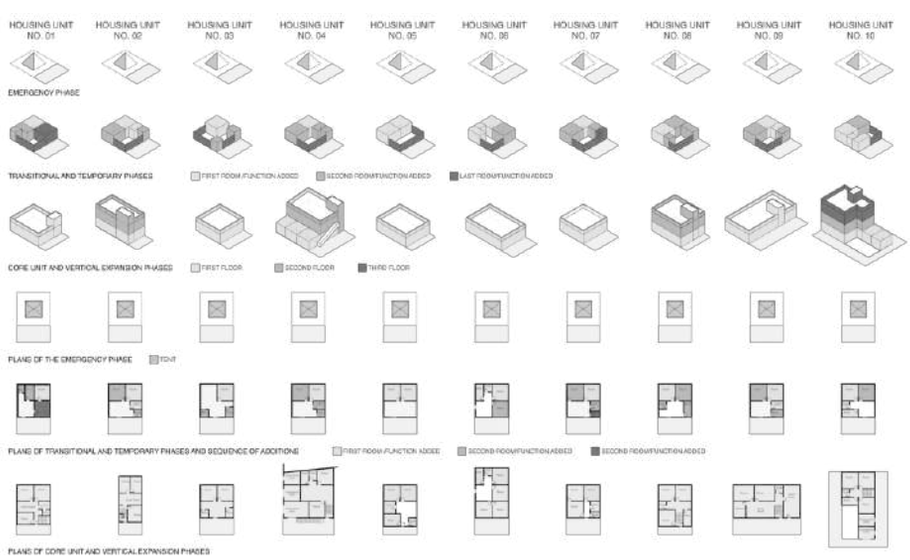

Fig. 3 Housing Units 1 – 10 (Image by Author)

The housing units selected for the scope of this study belong to key residents and informants who settled in Irbid camp from the early years of its establishment and performed significant transformations in their residential units since then. This base corpus consists of ten housing units which are illustrated in detail in Fig. 3. This figure depicts the transformation process for each of these units over all five phases in two-dimensional plans and an overall three-dimensional massing. The ten housing units all started as a

small tent. They each maintained a single-story, rectilinear enclosure limited by their land plot during the transitional and temporary phases, which is associated with having smaller households at the beginning that maintained a similar character within the camp community. During these two stages, housing units were composed of basic living spaces including bedrooms, kitchens, and toilets. However, each housing unit evolved in a very different way when the households started to grow, adding more spaces to suit their unique social and economic needs, such as guest rooms, commercial shops, and gathering areas.

3 The Irbid Camp Grammar

The Irbid Camp Grammar is a transformation grammar developed to analyze and explain the informal transformation of refugee housing units. The grammar interprets this process in five transformation stages, each related to a specific phase of development in the refugee settlement discussed in the previous section. These transformation stages are each defined with parametric shape rules to develop an understanding of how the designs change from one phase of the settlement to the next (Knight, 2014; Knight, 1994; Stiny, 2006). The research builds on the existing knowledge of the Irbid Camp and provides a visual analysis and generative specification to formalize the transformation of the refugee housing units over their 70-year existence.

The creation of the Irbid Camp Grammar encompasses the following steps: (1) analyze the spatial layouts and relationships of the ten existing housing units as they evolved from their initial conditions to their current design; (2) define a shape vocabulary that the houses and their transformations can be described with; (3) design a parametric rule set to describe the transformations of the housing units step by step; and (4) apply the rules to generate a sample design to test the validity of the grammar.

3.1 Analysis of Spatial Relationships of the Housing Units

To analyze the corpus of houses in each phase of the transformation process, a tree diagram is developed (Fig. 4). The tree diagram serves several purposes: (1) to depict primary spatial relations for the selected cases, (2) to establish a shape vocabulary that can be used in the shape rules, and (3) to synchronize the growth and transformation of refugees' housing units with the growth phases of the camp as a settlement. The tree diagram reveals many common features between the examined housing units that informed the design of the shape rules, especially during the emergency and the temporary phases. The ten housing units evolved from three basic layouts that are illustrated in the temporary phase. The transitional phase also demonstrated functional and organizational similarities. During this phase,

kitchens, and toilets were the two main spaces that are added to the original layout, but with different locations and sizes. The core unit and the vertical expansion phases introduce the addition of more functions and spaces in a modular way. This analysis shows how the aggregation of spaces in each phase follows an informal grid-like organization, based on each new space relating to the previous construction. This incremental logic inspired the creation of a flexible yet modular parametric shape grammar to further interpret this design process.

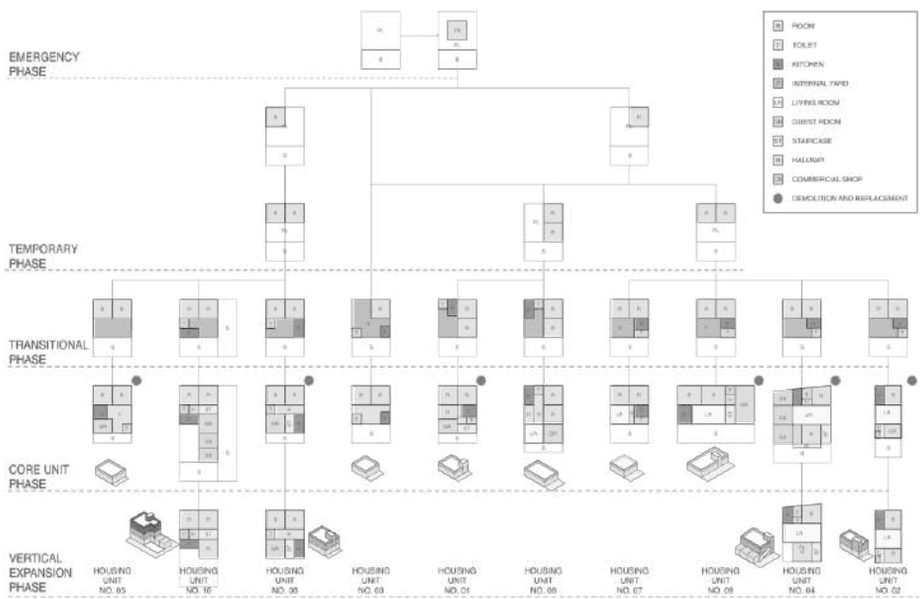

Fig. 4 Tree Diagram showing the evolution of ten housing units at Irbid Camp (Image by Author)

3.2 Definition of Shape Vocabulary

The primary shape vocabulary of the Irbid Camp Grammar, illustrated in Fig. 5, is developed based on the analysis of the plans' spatial elements that are extracted from the tree diagram. The shape vocabulary consists of polygons that represent the spatial functions in the refugees' housing units at any phase of the transformation process. From top left in the figure, the largest shape is the plot (PL), which specifies the boundary given for each housing unit. Moving to the right, the next shape is the tent (TN), other shapes in the top of the figure represent the primary spatial functions that were added during the temporary and transitional phases, including rooms (R), toilet (T), kitchen (K), and yards (Y). The shapes in the bottom of the figure represent the spatial functions added to the housing units during the core unit and

vertical expansion phases including the staircase (ST), living room (LR), commercial store/shop (CS), hallway (H), and guest room (GR).

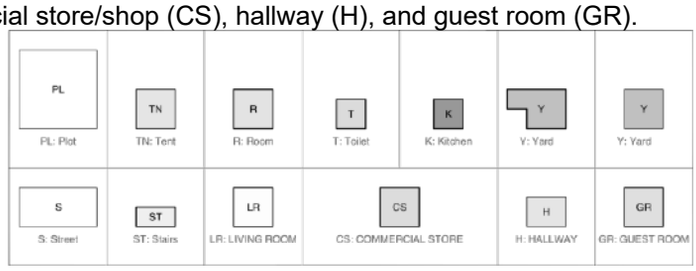

Fig. 5 Shape vocabulary elements of the Irbid Camp Grammar (Image by Author)

3.3 Shape Rule Design

The shape rules of the Irbid Camp Grammar are parametric shape rules describing spatial relations of the refugee housing in terms of transformable polygons. A limited number of rules are represented using rule schemata to capture emergent variability that follows a clear logic but resists the definition of a parametric shape rule (Economou & Kotsopoulos, 2015; Ligler & Economou, 2018; Stiny, 2006). Key conventions used in the grammar include parameters and labels. Labels are used in the graphic definition of rules to contextualize and control the application of rules. For example, the rule in Fig. 6 shows a dot label which orients the addition of the new shape to the top right of the initial shape. Parameters are used to indicate the height and width of each function in the housing unit and are also used to indicate the position of each added function with reference to a previously added function. Dashed lines are used to help illustrate the spatial relations of each newly added function, and the determining distances are defined as parameters as illustrated in Fig. 6. For example, the width of a room is indicated using the parameter Xr and the height is indicated using the parameter Yr. The horizontal distance between each added function and the previously added function is indicated using the parameter Xn and the vertical distance is indicated using the parameter Yn. When applying these rules, the designer specifies the values of these variables to ensure the proper application of each rule. Similar parameters are defined for all shape rules described hereafter.

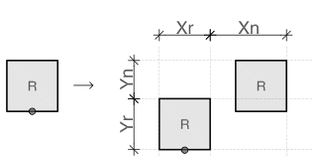

Fig. 6 Parametric Definition and Position of Functions (Image by Author)

Rule schemata are also utilized in the grammar to specify rules using irregular polygons that result from the cumulative relations of the regular polygons of the shape vocabulary. For example, the rule that defines the internal court is presented in rule schemata as shown in Fig. 7.

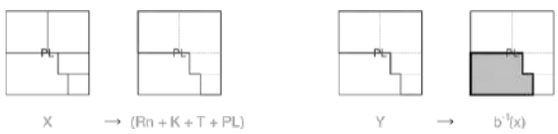

Fig. **7** Example of Applying Rule Schemata (Image by Author)

The first part of the rule represents the Boolean union of the shapes that are formed by rooms, kitchens, and toilets, the Boolean union of those shapes is indicated as (X) while the second part of the rules, indicated as (Y), represents the inverse boundary of the shape (X) with reference to the plot boundary.

The Irbid Camp Grammar includes 32 parametric shape rules in five stages. Each rule defines a new function, determines the dimensions of that new function with specific parameters, and adds it to the existing spatial form that is generated through the sequential application of rules for each housing unit.

The five transformation phases and associated rules include:

Phase (1) is the emergency phase and the starting phase (rules 0 to 1.2). This phase includes three rules that represent the assignment of a fixed 8x8 meter land plot, setting up the emergency 4x4-meter tent, and removing the tent at a later stage as shown in Fig. 8.

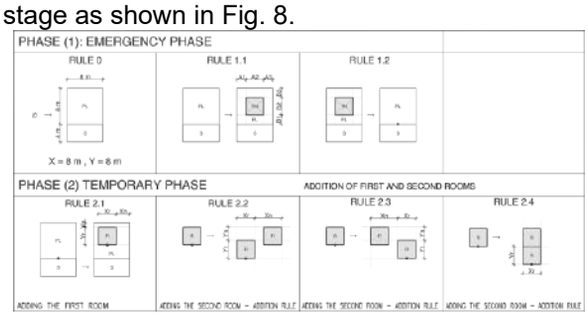

Fig. 8 Shape Rules for Phase (1) and Phase (2) (Image by Author)

Phase (2) is the temporary phase (rules 2.1 to 2.4). This phase describes the process of building one room and adding another room using temporary building materials. This stage is represented using four rules in which the first one (rule 2.1) defines the first room, its height, and width and determines its position within the land plot. The remaining rules represent the addition of the second room and determine its spatial relationship with the first room (Fig. 8).

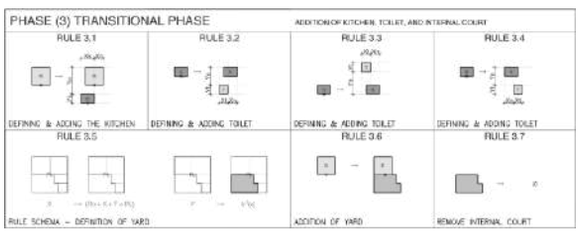

Fig. 9 Shape Rules for Phase (3 (Image by Author)

Phase (3) is the transitional phase, which is a continuation of the temporary phase (rules 3.1 to 3.7). This phase includes the addition of the basic functions of kitchens and toilets and the definition of the internal yard as the remaining space within the plot boundary after adding the kitchen and toilet functions. This phase is described in seven rules. The first rule of this phase is used to define the kitchen (rule 3.1). The next three rules represent the addition of the toilet, its location, and dimensions with reference to the kitchen (rules 3.2, 3.3, 3.4). Two rule schemata are defined to add the internal courtyard (rules 3.5, 3.6) and one more rule is defined to remove this courtyard (rule 3.7). All rules for this phase are illustrated in Fig. 9.

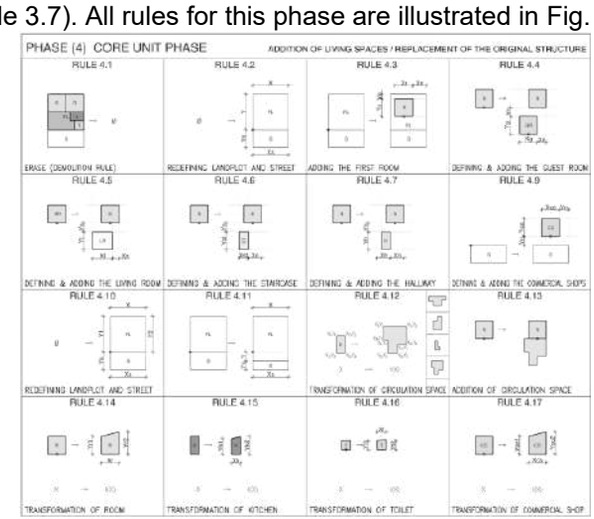

Fig. 10 Shape Rules for Phase (3) (Image by Author)

Phase (4) is the core unit phase (rules 4.1 to 4.17). This phase describes the definition of new functions and in some cases the replacement of some housing units that were built up to the end the transitional phase. This phase includes 17 shape rules which are shown in Fig. 10. Rule 4.1 indicates the demolition of the housing unit entirely. Rules 4.2 and 4.10 indicates the definition of the land plot with parameters to represent the expansion of the original land plot that was performed by some refugees as described earlier in

this article. Rule 4.11 is used to indicate the expansion of the original plot in one or two dimensions without demolishing the original housing unit.

Rule 4.3 is used to define the first room that is added after the destruction of the original housing unit, it defines the room's height and width and determines its position within the land plot. Rules 4.4 to 4.9 define the functions of the guest room, living room, staircase, hallway, and commercial shop, respectively. Rule 4.12 is a rule schema that represents the transformation of the shape that indicates the hallway, and rule 4.13 determines the position of the hallway that is generated using rule 4.12. Rules 4.14 to 4.17 are also rule schemata that indicate the transformation of the shapes of the room, toilet, kitchen, and commercial shop functions.

Phase (5) is the vertical expansion phase or permanent housing phase, consisting of rules 5.1 to 5.3. This phase represents the addition of extra floors which can be found in some housing units inside the camp. This phase includes three shape rules. The first rule (rule 5.1) defines the shape transformation from 2D to 3D, the second rule (rule 5.2) represents the addition of the second floor as a typical one, and the third rule (rule 5.3) presents the addition of the third floor as a typical floor as well. All rules for this phase are illustrated in Fig. 11.

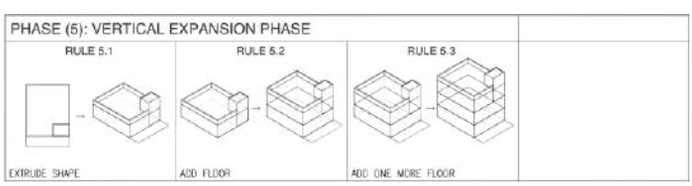

Fig. 11 Shape Rules for Phase (5) (Image by Author)

3.4 Generating Irbid Camp Designs

To further articulate the Irbid Camp grammar, a derivation showing the detailed application of shape rules to generate housing unit no. 02 from its temporary state to its current state is illustrated in Fig. 12. The following rules are applied to produce this design: starting from rule 0 in the emergency phase, a 4x4 meter tent (rule 1.1) was placed in the center of the 8x8 meter original plot, and the tent was removed using rule 1.2. Moving to the temporary phase, one room was added to the upper right side of the land plot using rule 2.1 and a second room was added next to the first room using rule 2.2. The values of all parameters for these rule applications are shown in Fig. 12.

In the transitional phase, rule 3.1 is applied to add the kitchen, rule 3.2 is used to add the toilet, and rules 3.5 and 3.6 define the internal courtyard. This housing unit was demolished after the transitional phase and the dimensions of the land plot are changed. Refugees claimed the extra space by expanding into the adjacent streets. Thus, for the core unit phase, rule 4.1 is applied to

demolish the housing unit entirely and rule 4.2 is applied to reshape the land plot which became 11 meters in height and 5.5 in width. Rule 4.3 is applied to add the first permanent room of concrete. Rule 3.1 is applied to add the kitchen and rule 3.4 is applied to add the toilet, which happened to be below the staircase. Rule 4.4 is applied to add the guest room and rule 4.6 is applied to add the staircase. Then, rule 4.5 is applied to add to the living room. In the vertical expansion phase, rule 5.1 transforms the two-dimensional layout to a three-dimensional representation. Rule 5.2 is applied to add a second typical floor based on the layout of the lower level.

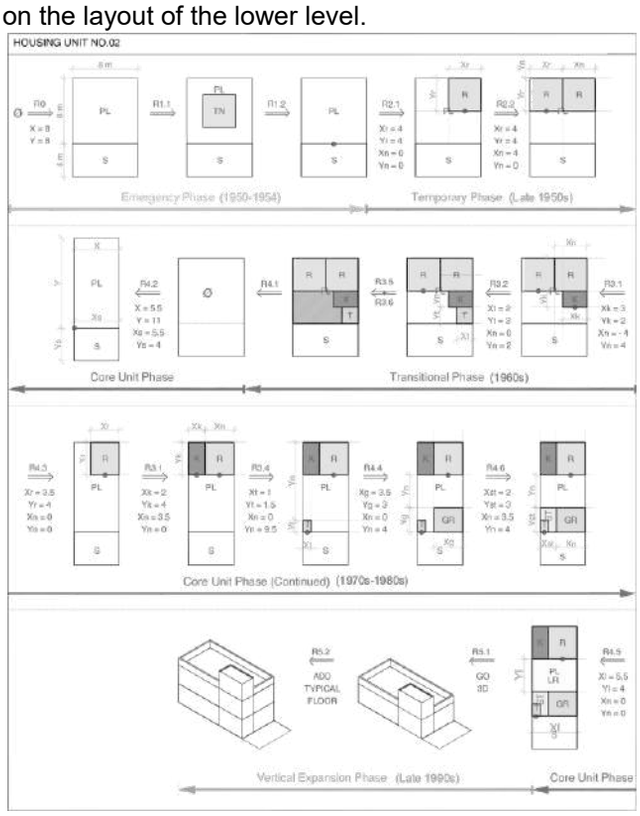

Fig. 12 Application of Shape Rules for Housing Unit No.2 (Image by Author)

4 Findings and Conclusions

The parametric shape grammar presented in this paper interprets the long-term transformation process of refugee housing at Irbid Camp as a series of design modifications. Parametric shape rules are specified to formalize the spontaneous growth and transformation of ten housing units over time. The rules foreground the modular-like evolution of the houses that were originally

achieved informally as a self-build process unique to each refugee housing unit. The rules also demonstrate a correlation between the growth phases and the evolving spatial configuration of the housing unit. The clarification of the modular growth system suggests the opportunity for further interventions in refugee housing design to mediate these transformations and utilize the grammar as a basis for responding to housing emergencies with design solutions that acknowledge the potential permanence of the community. The Irbid Camp Grammar provides a basis for designing these new strategies, focusing on the concepts of flexibility, adaptation, and modularity to anticipate the self-build process. Learning from the Irbid Camp Grammar, future work will aim to investigate the social and economic aspects that impacted each phase of the camps' growth and to develop a computational model that can be further utilized in designing refugee housing systems for different locations and geographies.

References

Abu-Aridah, D. (2016). *Exploring Patterns of Integration Emergence for Palestinian Refugee Camps in Irbid* [Master's Thesis, German Jordanian University]. Amman. Jordan.

Al Husseini, J. (2010). UNRWA and the Refugees: A Difficult but Lasting Marriage. *Journal of Palestine Studies*, *40*(1), 6-26.

Colakoglu, B. (2005). Design by Grammar: An Interpretation and Generation of Vernacular Hayat Houses in Contemporary Context. *Environment and planning. B, Planning & design.*, *32*(1), 141-149. https://doi.org/10.1068/b3096

Economou, A., & Kotsopoulos, S. (2015). From shape rules to rule schemata and back. In *Design Computing and Cognition'14* (pp. 383-399). Springer.

Gips, J. (1999). Computer Implementation of Shape Grammars. NSF/MIT Workshop on Shape Computation,

Hanafi, S. (2010). *Governing Palestinian Refugee Camps in the Arab East: Governmentalities in Search of Legitimacy* (Working Paper Series #1 Issue.

IFRC. (2013). *Post-Disaster Shelter: Ten Designs* (J. Ashmore & C. Treherne, Eds. Second Edition ed.). International Federation of Red Cross and Red Crescent Societies.

Knight, T. (2014). Regarding rules: from Rimini to Rio. *Joelho Journal of Architectural Culture*(5).

Knight, T. W. (1994). *Transformations in design: a formal approach to stylistic change and innovation in the visual arts* (Vol. 8). Cambridge University Press Cambridge.

Ligler, H., & Economou, A. (2018). Entelechy revisited: On the generative specification of John Portman's architectural language. *Environment and Planning B: Urban Analytics and City Science*, *45*(4), 623-648.

Stiny, G. (1980). Introduction to shape and shape grammars. *Environment and Planning B: Planning and Design*, *7*(3), 343-351.

Stiny, G. (2006). *Shape: talking about seeing and doing*. MIt Press.

Stiny, G., & Gips, J. (1972). *Shape Grammars and the Generative Specification of Painting and sculpture* Information Processing 71, Amsterdam: North-Holland.

UNRWA. (2021). *WHERE WE WORK*. Retrieved October 12, 2021 from https://www.unrwa.org/where-we-work/jordan

A multilingual grammar for 'The International Style', and its hybrid grammar

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Abstract. This paper describes the proposal and results of a multilingual shape grammar to describe the designs of three architects, precursors of the 'International Style'. A shape grammar is a generative process that allows the recreation of designs that follow a language. Grammars are useful mechanisms to describe patterns and generative processes that can be used for analysis or design exploration. Most grammars represent one language. This study focuses on three independent languages within the same movement. The proposed grammar is parametric and allows the independent recreation of each independent design. Its difficult application can be linked to the difficult evaluation process. This research proposes a quantitative and a qualitative method of grammar evaluation, using respectively Principal Components Analysis (PCA) and user questionnaires. The results are then discussed and assessed using hybrids that fall in between languages and help delineate parametric spaces.

Keywords: Multilingual grammar, Shape grammar, Hybrid grammar

1 Introduction

The International Style dominated the beginning of the XXth century breaking with the mainstream architectural styles in use and proposing a more utilitarian, affordable, modular, industrial perspective to design (Frampton, 2020). Its popularity spread across the world but three main players can be accounted for its success, Mies van der Rohe (1886-69), Gropius (1883-69) and Le Corbusier (1888-65). This study proposes one singular grammar to describe all three languages with the hope to describe one movement "The International Style".

Mies, Gropius and Le Corbusier's design languages are idiosyncratic and distinct. Mies's style was rational, and minimal, with methodical respect for structural and regulating grids. Gropius's style was utilitarian and industrial, while Le Corbusier's language was plastic, volumetric and highly experimental:

'*These shapes are such that they are revealed in the light. The relationships between them have not necessarily had any reference to what is practical or descriptive. They are a mathematical creation of your mind. They are the language of architecture* (Le Corbusier, 2005).

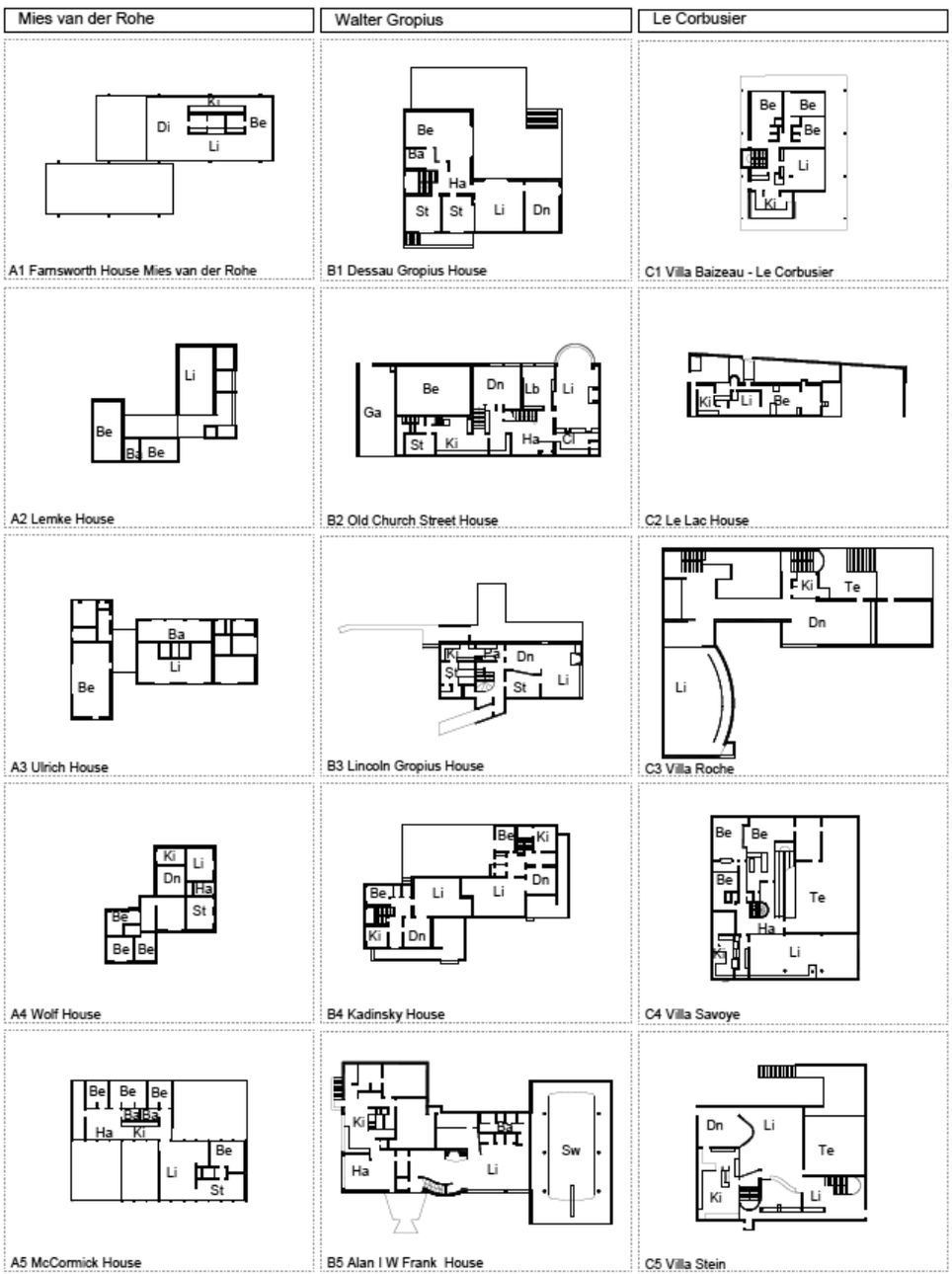

Figure 1. International Style case study of 15 houses from Mies van der Rohe, Walter Gropius and Le Corbusier. **Source**: D. Benros, 2022**.**

‘The International Style’ was a denomination coined by Philip Johnson and Henry-Russell Hitchcock while curating a modern movement exhibition in the newly opened New York’s MOMA in 1932 (Hitchcock & Johnson, 1932). All three architects shared a common ground. At the start of their career, they all worked at Peter Behrens’s office in Berlin (1908-10) where they were exposed to the benefits of industrialization, modularity and rationalization. (Janson et al., 2015). What they did with these principles was unique. Gropius left Dessau and the Bauhaus school to seek asylum first in London and then in Cambridge MA. Mies fled Germany to find exile in Illinois and Le Corbusier left his home country, Switzerland, to settle in France. Their careers developed in parallel in different countries and with little direct contact. All built prolifically in different typologies from commercial to offices, educational, public buildings, and housing. This paper will focus on their experiments in single-family housing and will propose a shape grammar to illustrate it.

A shape grammar is a generative procedure that allows the recreation of several existing design solutions that are part of the same family of designs or styles (Stiny, 1980). It uses a simple graphic formalism which describes rule by rule a set of geometric transformations from the start point to the result. By following these rules recursively the user attains a cohesive design that fits the design criteria described by the shape grammar (Stiny, 2006). The procedure is inspired by the idea of language grammar that uses a set of finite rules to describe numerous combinations of semantically correct sentences. The idea was introduced by George Stiny in the 1970s using a lexicon of shapes and a syntax of geometric operations. The first architectural grammar proposed the language of the Palladian villas illustrating the successful application of grammar using the extensive corpus of existing Palladian designs (Stiny & Mitchell, 1978). In the 80s a three-dimensional grammar is proposed to illustrate the work of Wright’s Prairie houses (Koning & Eizenberg, 1981), the methodology resembled Wright’s design procedure as described in his own words (Wright, 1974). This was followed by the first computer implementation of an architectural grammar by Duarte in the early 2000s using Siza’s Malagueira houses as inspiration and counting with the original architect as grammar ‘evaluator’ (Duarte, 2005, 2005).
The supra-cited grammars established univocal relationships with their corpus and were language exclusive. More recent studies have attempted to propose generic multilingual formalisms. Beirao proposed a generic grammar for urban design that attempted to bridge the gaps in urban planning by mapping generic rules (Beirão et al., 2012). Castro e Costa proposed a generic grammar to design tableware in the product design category. This explored a wide range of designs proposing a parametric grammar (Castro e Costa & Duarte, 2014). Benros also illustrated a generic grammar for housing. This parametric formulation used a case study of distinct languages and proposed a common procedure to design them. The novelty of this formalism was captured in the interval of values allowed for each language which conferred a sense of style.

(Benros, 2018). This study suggested two evaluation methods: a quantitative and a qualitative which allowed for an unbiased appraisal of the system.
The idea of hybrids was raised concerning generative systems and particularly with shape grammars. An unrestricted grammar, as described by Knight (Knight, 1999) will undoubtedly allow for the manipulation of rules and produce hybrid designs. Hybrids can be used for design exploration, design assessment or testing the boundaries of design. Hadighi looked into the presence of hybrids to assess the design evolution of Marcel Breuer-inspired designs to the definition of his signature style practiced on the Penn State campus by William Hajjar (Hadighi & Duarte, 2021). Al-Kazzaz (Al-Kazzaz, 2011) proposed a hybrid grammar for the minarets' designs of religious monuments. Hybrid design rules allowed the solutions to be recreated.
This work used hybrids as a benchmark and delineation of each language parametric space. A parametric space is an abstraction where all design solutions can be encountered within a language. Its boundary is highlighted by the space occupied by its corpus. The boundary line is empirically determined.

2 Methodology

This study is composed of five steps: 1) Definition of case study and rule inference 2) Multilingual grammar and rule system definition 3) Recreation of design examples using derivation 4) Evaluation using quantitative methods 5) Evaluation using qualitative methods:

1) Three precursors of the ‘International style’ were selected, including Mies, Gropius and Le Corbusier. All three men shared the ethos of a new minimal architecture reflecting the effects of industrialization but all with distinct, identifiable languages. Within the extensive corpus of preexisting housing solutions they designed, 15 houses were selected reflecting their independent styles including Mies, Gropius and Le Corbusier as illustrated in Figure 1.

Table 1. Houses by Mies, Gropius and Le Corbusier. **Source:** D. Benros, 2022

Mies van der Rohe		Walter Gropius		Le Corbusier	
House	**Ratio & Area**	**House**	**Ratio & Area**	**House**	**Ratio & Area**
Farnsworth-1951	1/2 (16x8m)	Dessau-1926	3/4 (20x16m)	Baizeau-1928	3/5 (10x16m)
Lemke-1933	4/5 (18x15m)	Old Church-1936	3/8 (31x12m)	Le Lac-1924	1/3 (28x8m)
Ulrich-1935	2/3 (24x15m)	Lincoln-1937	2/5 (18x7.5m)	Roche-1925	3/4 (27x35m)
Wolf-1926	1/1 (15x15m)	Kandinsky-1926	2/3 (25x16m)	Savoye-1931	1/2 (21x19m)
McCormick-1952	2/3 (22x15m)	Alan Frank-1940	3/5 (35x21m)	Stein-1928	5/8 (22x15m)

The case study then inspired several key features from each language from proportions to the area and overall ratios as Table 1 illustrates. Most houses from the corpus showed an orthogonal self-contained layout within an external boundary. Most designs inspired a linear subdivision of internal spaces. Several key internal proportions were captured with a predilection for 1/1, ½, 1/3, 2/3, and 3/5 ratios (in keeping with a more classical tradition). Some geometric complexity was added with processes of space merging of adjacent rooms (particularly evident in Le Corbusier’s work).

2) A subdivision grammar was proposed to represent all three sub-languages within the ‘International style’. This procedure allowed the levelling of the playing field between the three languages. A series of subdivision rules were included to allow for the complex internal compartmentation of each house.

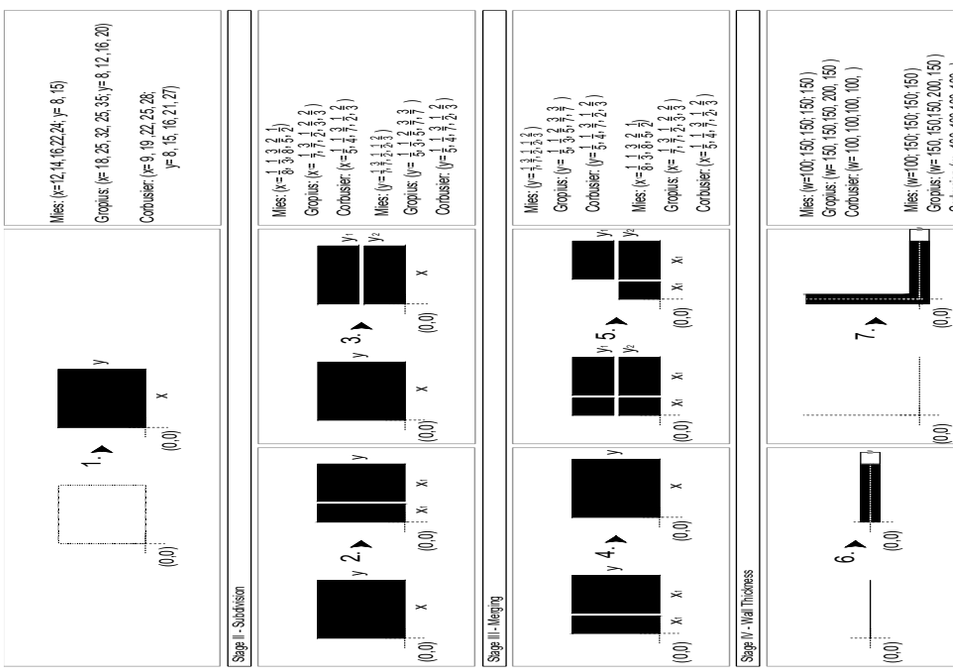

Figure 2. Shape grammar rules 1 to 9. **Source**: D. Benros, 2022**.**

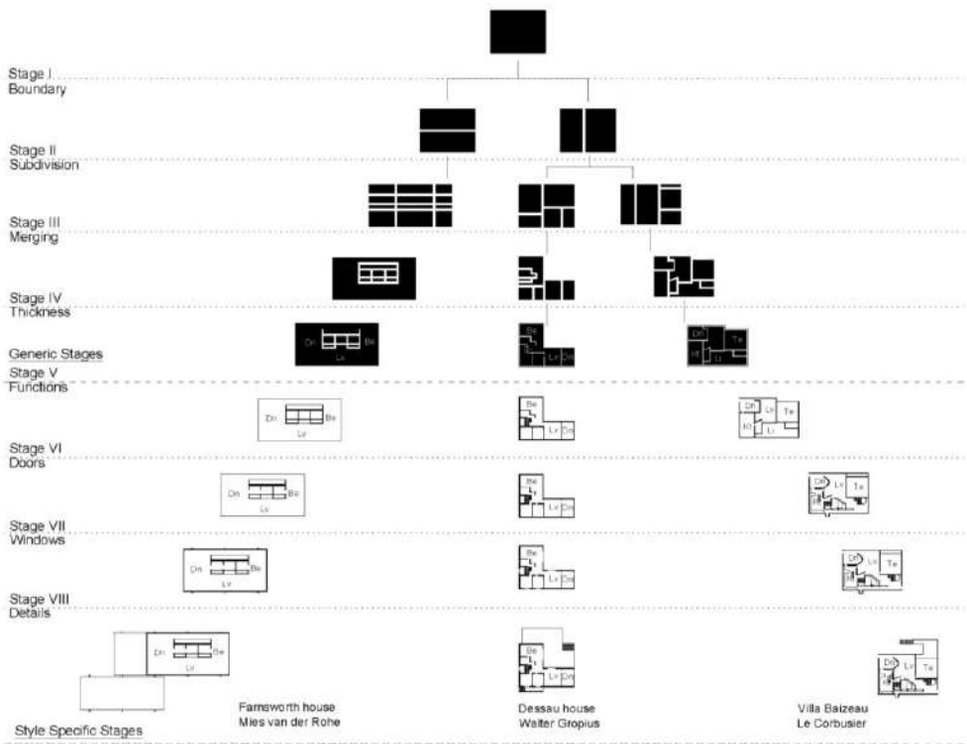

Figure 3. International Style shape grammar tree diagram. **Source**: D. Benros, 2022**.**

3) Within each language, specific parametrization is proposed responding to either Mies, Gropius or Le Corbusier's formulations. Figure 2 illustrates the generic rule system encompassing rules 1 to 9. The proposed rule system is split into generic stages and language-specific stages. The first stage is a typical additive stage and allows the inclusion of the external boundary, it contains one rule with polygonal addition. Stage II allows for subdivision with two rules proposed, a vertical and a horizontal subdivision. Both rules can be applied recursively until the minimal area is attained. Stage III allows spatial merging between adjacent spaces. Stage IV is the last generic stage and the last common branch stage allowing wall thickening. This is composed of four thickening rules that convey the right wall thickness by language and tectonic nature. From Stage IV on the grammar branches out into language-specific shape rules as the tree diagram from Figure 3 illustrates. These stages include Stage IV with functions, Stage V door inclusion, Stage VII with window openings, Stage VIII with the insertion of details (terraces, porches, external stairs, and access points) and the house conclusion. The diagram shows that any of the corpus houses can be recreated using an initial perimeter, their internal spaces recreated using recursive subdivision and further detailed using merging processes. The result is conducive to either the Farnsworth, Dessau House or Villa Baizeau while using the same grammar structure and the same

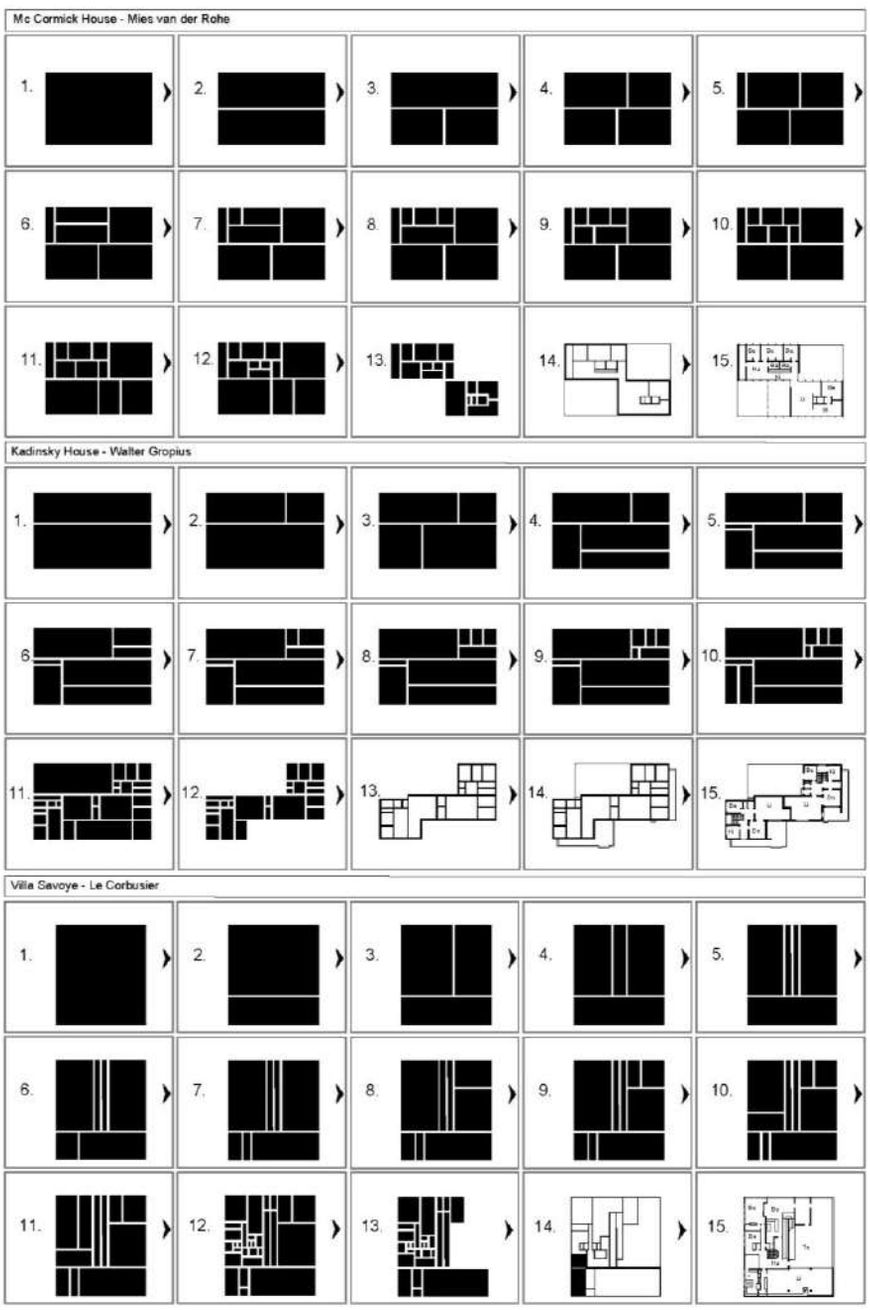

Figure 4-5-6. Derivation of McCormick house by Mies**,** Kandinsky house by Gropius Derivation of Villa Savoye by Le Corbusier. Source: D. Benros, 2022**.**

parametric shape rules. The multilingual parametric nature is also visible in this diagram which describes how different ratios can be generated from the same set of rules branching out from general.

4) In a typical shape grammar methodology, a form of evaluation is the recreation of the existing solutions in a structured and sequential way. This process is called derivation as it describes a graphic solution being derived from start to finish. In this study, all 15 houses' derivations were explored and this paper illustrates 3 examples including the Mc Cormick house designed by Mies and shown in Figure 4, the Kandinsky house designed by Gropius as shown in Figure 5 and Villa Savoye famously designed by Le Corbusier in Figure 6. All these examples represent the rule application system although they do not exhaust all the rules used to generate (for economy o space some subdivision steps and detailing rules were omitted).

5) Most grammars rely on empiric methods of evaluation such as derivation processes, and the recreation of new design solutions. This study proposed an objective form of evaluation. With all the parameters used to recreate the existing houses, the data was used to compare the existing examples. The data set was reduced using statistical methods such as Principal Components Analysis (PCA) and then illustrated in an orthogonal graph. This allowed each house to be represented using a cartesian point and mapped in the orthogonal space. A set of houses of each language would naturally cluster if successfully illustrated and delineate a boundary that contains all examples. That boundary describes what we call the ‘parametric space of a language’ where all existing and new grammar-generated houses would be mapped. This proved to be an unbiased and objective evaluation.

3 Results

The results of this study can be summarized and studied following two evaluation methods used: quantitative and qualitative methods: PCA resulted in a useful tool to illustrate the grammar results using an abstract graphic chart. This chart is illustrated in Figure 7 and maps out all 15 International style grammar-generated houses according to the parameters that originated them. A very strong clustering effect is observed for the Mies houses which naturally group on the top right of the chart. Le Corbusier’s parametric space also showcases clustering, however, a linear spread is visible. In the Gropius case study, the clustering effect is still observed but the spread is wider than in the previous language.
The cause of the wider spread in the former languages can be explained by the variety of the corpus in the original examples both in style, size, and proportion. At the bottom of the chart two houses are shown, Villa la Roche and Alan I W

Frank house. Both examples are paradigmatic and of large proportions. The first was designed for a wealthy Swiss businessman as his Paris home, the latter was designed as a large property for an affluent client which at the time was fitted with a large indoor swimming pool. Both houses might have swayed the range of the language and impacted its parametric space. Similarly, more compact, self-contained regular residences such as Corbusier's Villa Baizeau and Gropius Lincoln's house due to their geometries and compactness are more approximate to the Mies range and occupy a parametric space that overlaps all three styles.

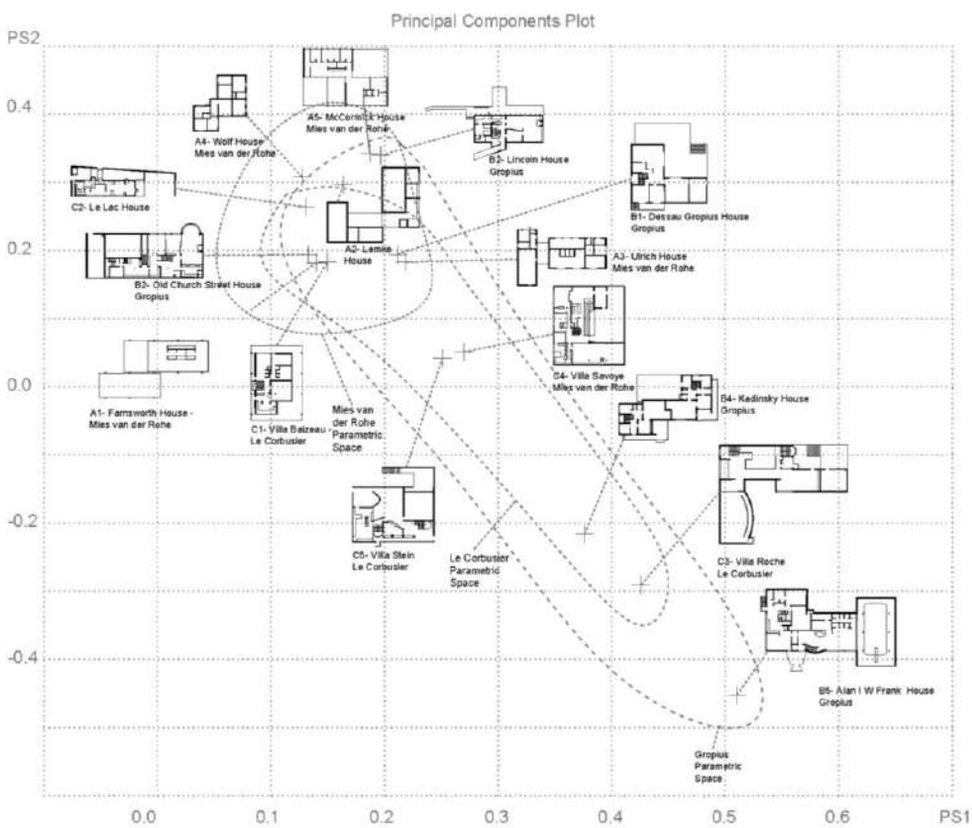

Figure 7. International Style designs from Mies (A), Gropius (B) and Le Corbusier (C) were generated by the multilingual shape grammar and their parametric spaces represented using Principal Components Analysis (PCA). Source: D. Benros, 2022**.**

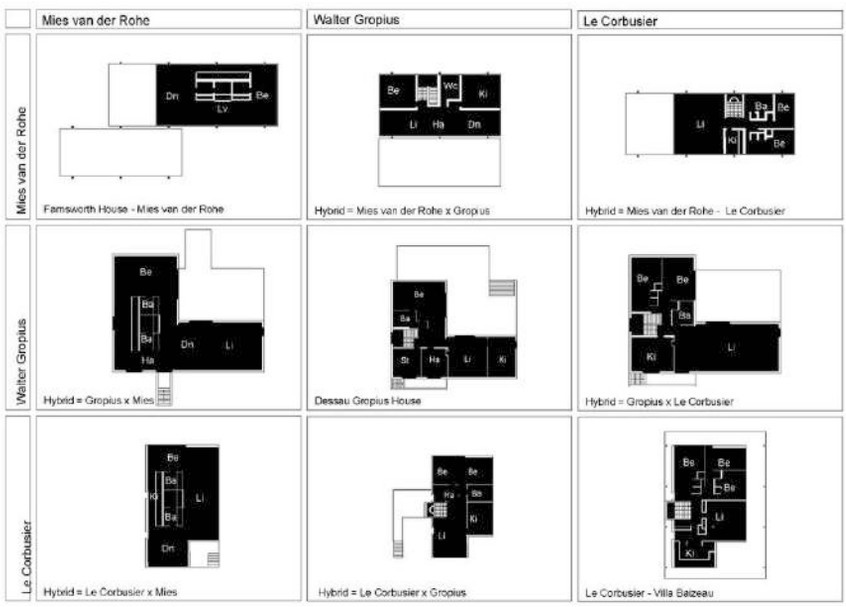

Figure 8. International Style hybrid designs. Source: D. Benros, 2022**.**

The proposal of a new corpus of designs is a good method of empirical evaluation if the new design fits the original features of style and follows the design criteria. Figure 8 shows a set of hybrid designs. These hybrid designs are not attained by morphing or creating new grammar rules as explored before (Al-Kazzaz, 2011), but by manipulating the allowed parametrization for each language. The image shows nine houses of which 6 are new hybrid solutions merged between Mies, Gropius, and Le Corbusier. All hybrids fall within the parametric spaces that are coincident to both parent languages which confirms the parametric space hypothesis.

The qualitative method of evaluation proposed was based on questionnaires posed to third parties both experts and laymen. The idea was that independent users could assess the similarities between a corpus of three houses, two examples from the original corpus and one hybrid. Most users did not distinguish (67% of the participants) the hybrid solutions as significantly different (from the original corpus. Most identified dissimilarities in the hybrid proposals (53% of the enquired). This seems to indicate that the new hybrid designs are identified as part of the ‘original corpus’ and do share perceived commonalities.

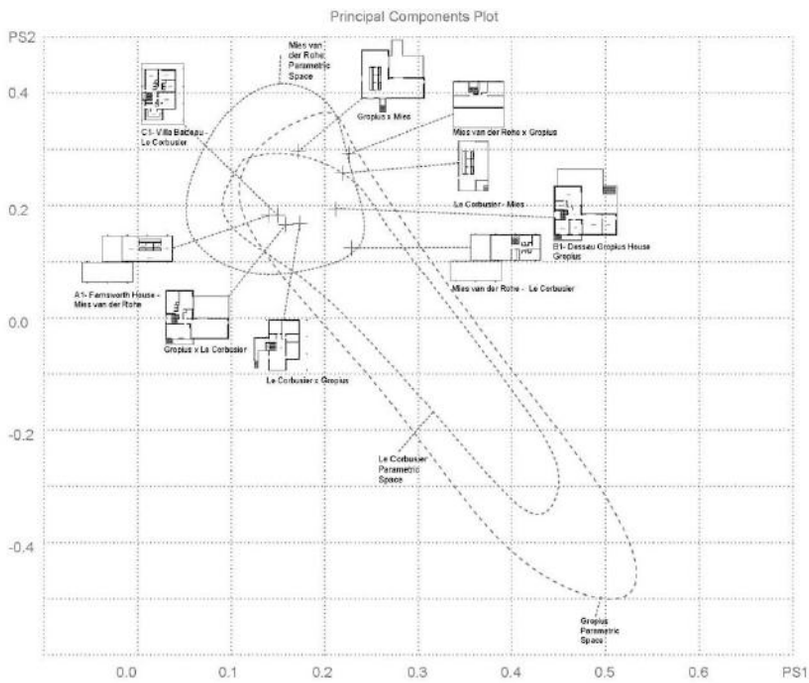

Figure 9. Hybrid designs from Mies van der Rohe, Gropius and Le Corbusier were generated by the multilingual shape grammar using (PCA). Source: D. Benros, 2022**.**

4 Conclusion

The paper exposed a multilingual grammar to reproduce ‘The international style’. A subdivision grammar was presented, with the set of design rules. For each rule, a range of parameters was shown for each sub-language. Hybrid designs were also proposed. The novelty of the methodology used was the dual evaluation using both quantitative and qualitative methods, using PCA provided to map out and show graphically the range and parametric space of each sub-language. The introduction of questionnaires allowed testing the perception of the new corpus of designs using independent observers to highlight similarities and differences between the new designs and the existing families of designs. In most cases, the observers could not differentiate between the new hybrids and original designs. This provided the qualitative method. The introduction of the hybrid design allowed us to test the limits of each parametric space and assess the coincident parametric spaces. The methodology presented could pose a useful analytical tool for architecture historians, it also provides a good design exploration methodology and tool for design students. Future work would consist of a computer implementation tool with three-dimensionality.

References

Al-Kazzaz, D. (2011). Shape grammars for hybrid Component-based design. University of Strathclyde.

Beirão, J. N., Sariyildiz, S., Bekkering, H., Stouffs, R., Duarte, J. P., TU Delft: Architecture: Building Technology / Urbanism, & TU Delft, Delft University of Technology. (2012). CItyMaker: Designing Grammars for Urban Design. abe.tudelft.nl. http://resolver.tudelft.nl/uuid:16322ba7-6c37-4c31-836b-bc42037ea14c

Benros, D. (2018). A generic housing grammar for the generation of different housing languages: A generic housing shape grammar for Palladian villas, Prairie and Malagueira houses. University College London. https://discovery.ucl.ac.uk/id/eprint/10051005/

Castro e Costa, & Duarte, J. (2014). Generic shape grammars for mass customization of ceramic tableware. Springer, 437–454.

Duarte, J. P. (2005). Towards the mass customization of housing: The grammar of Siza's houses at Malagueira. Environment and Planning B: Planning and Design, 32(3), 347–380. https://doi.org/10.1068/b31124

Frampton, K. (2020). Modern Architecture: A Critical History (Fifth edition). Thames and Hudson Ltd;

Hadighi, M., & Duarte, J. P. (2021). Tracing Hybridity in Local Adaptations of Modern Architecture: The Case of A. William Hajjar's Single- Family Architecture. Design Computing and Cognition, DCC'20, 169–188.

Hitchcock, H.-R., & Johnson, P. (1932). Modern Architecture: International Exhibition (1st ed.). MOMA. https://assets.moma.org/documents/moma_catalogue_2044_300061855.pdf?_ga=2.221248861.417687789.1655131576-653882780.1655131576

Janson, H. W., Janson, A., Davies, P., & Denny, W. (2015). Janson's History of Art: The Western Tradition (8th edition). Pearson.

Knight, T. W. (1999). Shape grammars: Six types. Environment and Planning B: Planning and Design, 26(1), 15–31. https://doi.org/10.1068/b260015

Koning, H., & Eizenberg, J. (1981). The language of the prairie: Frank Lloyd Wright's prairie houses. Environment and Planning B: Planning and Design, 8(3), 295–323. https://doi.org/10.1068/b080295

Le Corbusier. (2005). Vers une architecture. Flammarion.

Stiny, G. (1980). Introduction to shape and shape grammars. Environment and Planning B: Planning and Design, 7(3), 343–351. https://doi.org/10.1068/b070343

Stiny, G. (2006). Shape: Talking About Seeing And Doing. MIT Press.

Stiny, G., & Mitchell, W. J. (1978). The Palladian grammar. Environment and Planning B: Planning and Design, 5(1), 5–18. https://doi.org/10.1068/b050005

Wright, F. (1974). The Natural house. Bramhall House.

Programming Complex 3D Meshes. A Generative Approach Based on Shape Grammars

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Abstract: This article summarizes the results of art based research developed thanks to a grant by the PUCP University of Lima in 2021-2022. An open source generative solution will be described, based on generative grammars, to create very complex and programmable 3D meshes. Analyzing hundreds of models generated with these algorithms, a solution was found based on the idea of "intelligent meshes", which change their behavior during the modeling process. This is done using tags, or vertices identifiers, that, like genes, describe the topological characteristics of each vertex and its generative development during the process. Tags can be programmed interactively editing its data with tools provided by the interface or using generative grammars that allow an incredible variety of complex forms and stimulate the user creativity. The research findings also elucidate some important conceptual issues, like the importance of original technology development to defend cultural identity.

Keywords: Shape grammars, complexity, digital fabrication, ethno computation, generative design

1 Introduction

Creativity is a key issue in the arts, science and cultural industries, not to mention that it is of the greatest concern for innovative educational programs. But creativity is a difficult topic to be handled properly. It is enough to mention just three problems: creativity is hard to define, explain and measure (Carnovalini & Rodà, 2020), its aesthetic meaning and aura are jeopardized by postmodern art (Vattimo, 2000), over production and media saturation, and, last but not least, the disruptive effect of digital media. To enter directly into the digital matter, today computational creativity, 3D modeling, animation and image processing technologies research, such as generative algorithms or fractals, is occupied by the AI and Machine Learning discourse. But AI, not so much paradoxically, leaves small room to users' creativity (Colton, 2008) and,

spreading Anglo-Saxon computational thinking, it is one of the most efficient assets of digital colonization (Iranil, 2010).

These are good reasons to develop shape grammars (Stiny & Gips, 1972) and generative algorithms as a valid alternative (McCormack, 2004), for their simplicity, creative power (Prusinkiewicz & Lindenmayer, 1990; Pestana, 2011) and because they offer the possibility to simulate natural phenomena and local artistic traditions, like ethno computation (Varma, 2006; Roncoroni & Crousse, 2016), intuitively and without black boxes (Alfieri, 2005; Colton, 2008). In this paper I will concentrate attention on software development, visual analysis and artistic practice results. Due to these properties, the generative design tools described in the following paragraphs will be valuable to artists, industrial designers and educators to experiment with new design processes, explore computational creativity as a research, or educational tools and to link parametric design with cultural identity. From the production point of view, these algorithms help artists and designers to explore the relationships between forms and new materials also suitable for 3D printers and robotic fabrication.

2 Methodology

This paper is the result of an interdisciplinary artistic research project supported by a grant from the PUCP University of Lima[1]. The research methods expand the art based research framework (O'Donoghue, 2009) and consist of: a) Review of papers in the field of Computer Science, Digital Humanities and Digital Art, especially generative design, shape grammars and ethno computation topics; b) Analysis of software for audiovisual creative production (DAWs and 3D Modeling software Rhino and 3DMax); c) Visual analysis of pre-Columbian art; d) Software development using extreme and incremental programming; e) Artistic practice and digital fabrication with 3D printers and a Kuka robotic arm.

3 Results

3.1 Literature and Software Analysis

Papers about computational creativity, generative art and parametric design show that the potential of shape grammars is not fully developed (Roncoroni, 2022). Besides, there is a lack of friendly and interactive generative

[1] See https://investigacion.pucp.edu.pe/grupos/gries/noticia-evento/concurso-anual-proyectos-investigacion-cap-2021/

applications. On the other hand, plug-ins (like EuroRack), programming languages (like Processing), game design engines or DAWs (like Unity or Reaper) that use AI or generative techniques and can be often installed freely, quite often share the same algorithms and lack proper documentation. This is reflected in repetitive and standardized design artifacts.

3.2 Analysis of Natural Forms, Pre-Columbian Art and Shape Grammars Simulations

The capability and potential of L-Systems to simulate natural phenomena is well known (Prusinkiewicz & Lindenmayer, 1990), so it is not mandatory to enter into this topic here.

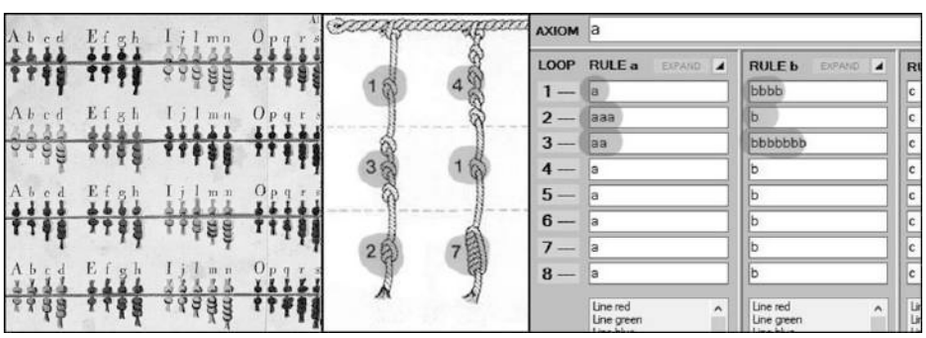

Fig 2. The rule system interface design is similar to *quipus*, with a baseline –the axiom- that opens the sequence of rules. The effect of the rule depends on its vertical hierarchy, like the *quipus*' knots. Source: author (2020).

On the other hand, Pre-Columbian and traditional ethnic art shows (Crousse, 2011) that algorithmic and natural procedures were commonplace. The same could be said about the *chakana* and the *quipus* that will be mentioned in this article, and other ancient artifacts and designs like the *yupana (*Fig. 1). For instance, the generative potential of *quipus* was investigated by the Neapolitan alchemist Raimondo di Sangro (1750). As shown in figure 2, there is obviously a computational thinking in the ropes, knots and colors and a creative hypothesis to use them as a linguistic code or interface design metaphor, to improve usability in shape grammars applications.

3.3 Software Development, Artistic Practice and Improvement of L-Systems Techniques

Even if a huge amount of research about shape grammars already exists, the creative power of symbolic dictionaries, rules and substitution algorithms can be expanded. In existing applications, rules are rigid, they can't share parameters and programming tools like loops or conditional statements. In

previous research (Roncoroni, 2022), improvements were developed to L-Systems dictionary and rule sets, to overcome some of their limitations.

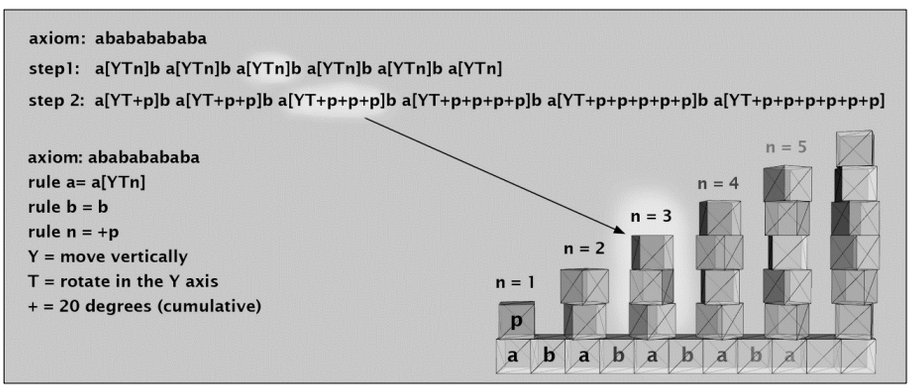

Fig. 3. Example of symbols for nested recursive substitution. Source: Author (2020).

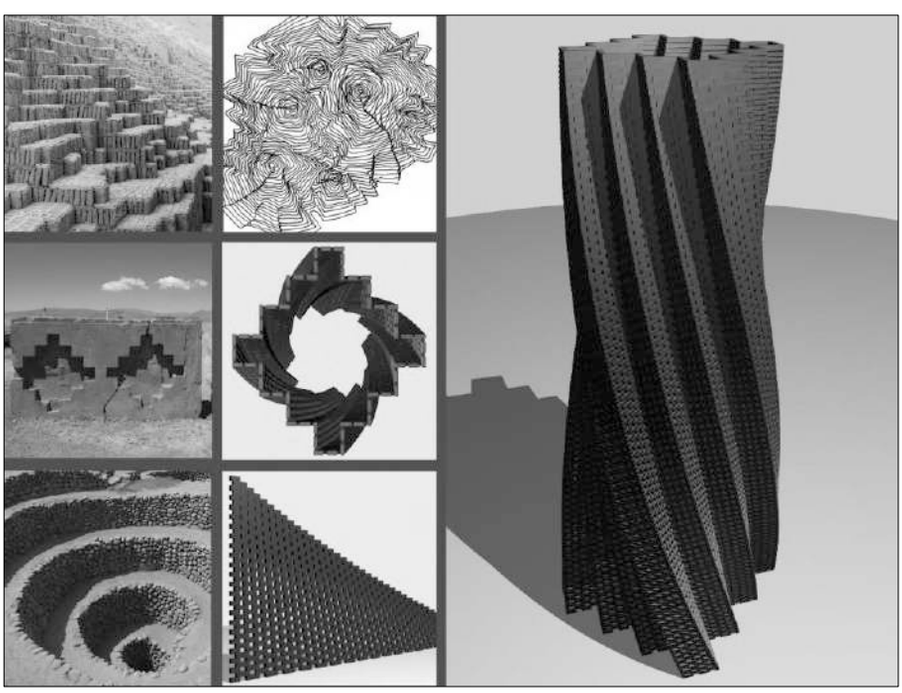

Fig. 4. Left: *huaca*, Andean cross *(chakana)*, and spirals in the Cantalloq aqueduct, near Ica, in Perù. In the middle, Algorithmic drawing, L-Systems' grammar to rotate the *chakana* and to match positions with bricks' numbers. Left: Final L-Systems tower. Source: Author (2018).

I will mention here just one of these extensions: automatic symbols (“n”) with nested recursion and with slave or sub-symbols (“ñ”) controlled by the number of instances, or the master symbol hierarchy in the grammar, or by the level of the substitution process. Figure 3 explains a model that is impossible to build with standard L-Systems vocabulary and rules, since it would be necessary to write a particular rule for every column to match the number of blocks and their rotation degrees. Symbol “n” sets the hierarchy of the columns in the row and “ñ” sets the corresponding number of objects: for example, the first instance of “n” sets 1 block, the third instance 3 blocks, etcetera. In this way L-Systems are converted in a sort of programming language, like side chain functions, to link the number of bricks to the empty space between them, and to match the *chakana’s* grammar to the position and rotation parameters of the growing spiral (fig. 4).

3.4 Software Development and Artistic Production

During the research many generative techniques have been explored, using self-similarity, natural processes, and traditional designs’ ethno computation. After the generation with different functions and parameters of hundreds of models, two solutions were selected that solved the task to create something new. The first is the mesh remix tool set that expands the standard morphing process with additions like masks, side chain modulation, genetic behaviors, shape grammars and cellular automata (fig. 5). The second that will be exposed in the following sections is the programmable mesh technique.

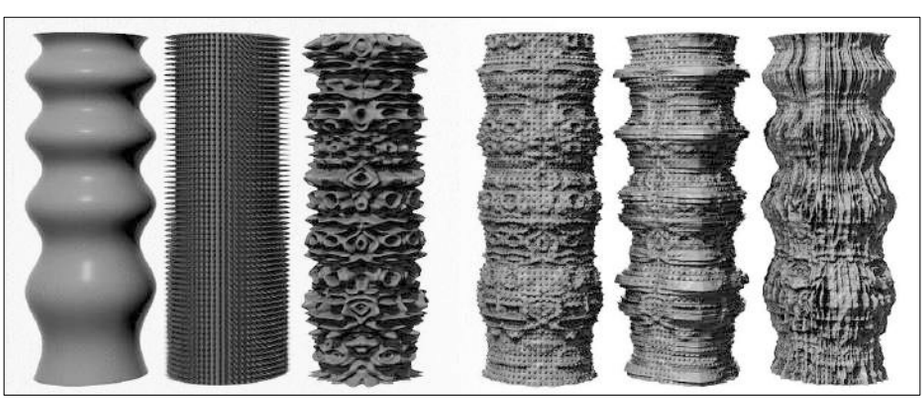

Fig. 5. Left: ancestors meshes. Right: three remix modes. Source: author (2022).

3.5 Generative Programmable Meshes

The algorithm that will be described here is based on the idea of a mesh that changes its geometric properties during the generation process. Like in cellular

automata and finite state machines, the meshes' vertices act like cells whose values describe topological properties, transformation parameters and other behaviors. In this way the mesh grows like an organic natural process.

This is done using "tags", or vertices identifiers, assigned to a pattern of vertices that can be programmed interactively or using L-Systems (McCormack, 2004). This allows for an incredible variety of complex forms, and stimulates the user to experiment freely.

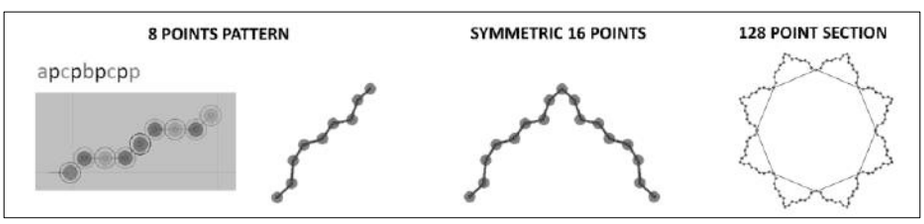

Fig. 6. Left: example of patterns. Left: construction of the mesh sections shape. Source: author (2022).

In the first step, the user creates a pattern of n points (usually a multiple of 8 to match symmetry and bytes) and allocates their alphanumeric identifiers, the tags. This pattern generates a closed shape with 8 or 4 axis symmetry (fig. 6). Here is where shape grammars and L-Systems come into hand, to create interactively the patterns and change the tags during the process.

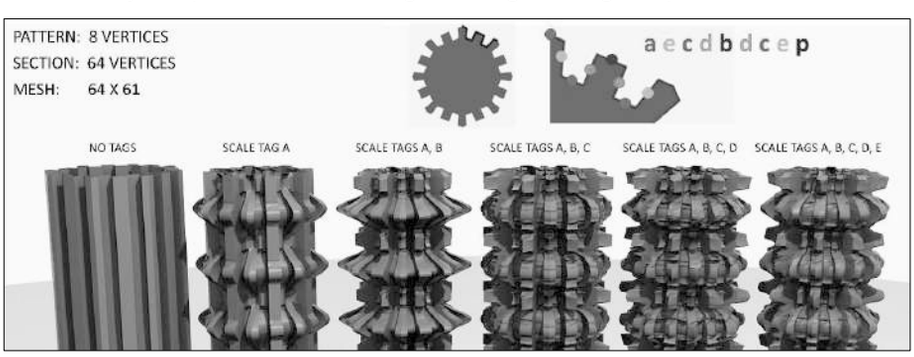

Fig. 7. Top left: L-Systems grammar, tags pattern and the symmetric section shape. Down: adding tags transformations to the linear mesh. Source: author (2022).

Now, during the mesh construction, every point can be translated, scaled or rotated using their TAGs parameters, and behave independently or interacting with other TAGs, considering its XZ position in the section and in its height in the mesh (Fig. 7, 8). In this way, every section or slice of the mesh can smoothly change its form without losing the formal coherence of the mesh as a whole. The interactions between points and TAGs can be done with cellular automata,

interactive functions or reading values from data sets or images. The TAGs rule set can be processed using the usual shape grammars substitution process embedded in the main function (Fig. 8). This data can be saved and combined with the others using the remix tools describe above.

3.6 Technical Issues of Complex Generative Meshes

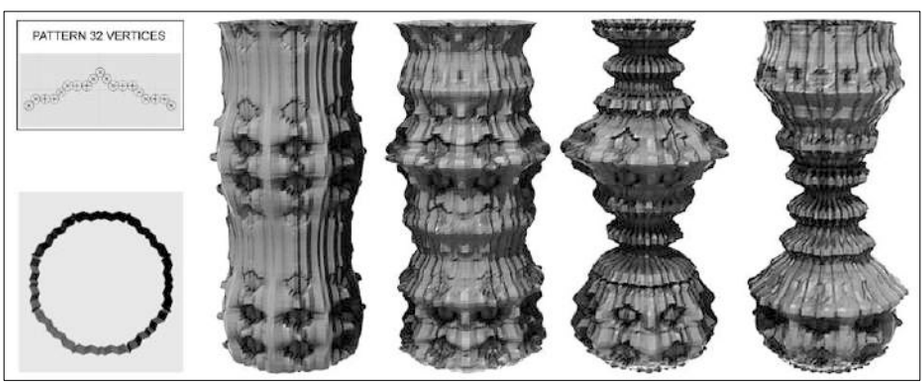

Fig. 8. Left: the pattern, the section and the linear mesh. Right: transforming the mesh with the same pattern and TAGs but different parameters' values. Source: author (2022).

Generative processes like programmable meshes are highly unpredictable (this is the reason why they are so fascinating). But this comes at the cost of geometrical problems that happen when vertices are heavily transformed and vertices' positions are too rough. In this sense, TAGs help to analyze the topological data without performing tests that, when working with more than 1,000,000 polygons, slow down the process excessively. The software additionally takes charge of other issues that could result in geometric inconsistencies, such as face intersections that cause errors, or the need to use support material in the 3D printing process.

3.7 Software Development and Interface Design. The Artist as Computer Scientist

Working with complexity, generative processes and art, it results that software development gets very confusing. It is interesting to stress here the different approach to programming of artists and computer scientists. In the present case, extreme and incremental programming paradigms were used, but when the programmers are artists, the development is a lot less linear than expected. While programming needs careful organization and a precise workflow, the artistic experimentation and software development needs improvisation, serendipity and permanent trial and error processes that quickly lead to bugs, undesired effects and ineffectiveness.

The solution was, in the first place, to experiment freely with the code at the beginning, and rewrite the entire application also improving the user interface design. Through parallel artistic production, it was found that the best software architecture should be modular, to help the user thorough the step-by-step process, with every step enabled by its predecessor and the compatibility of geometric properties. The interface accompanies the workflow with instructions and examples on how to use every function, to make the learning curve as smooth as possible. Finally, considering the open source philosophy of this application, the code was revisited in the literary sense, and considered as a text in its full right.

4 Discussion

Setting apart the artistic and technical benefits, the research findings also elucidate some important conceptual issues about computational creativity and education.

4.1 Original Technology Research

In the first place, software development and artistic results exposed the importance of original technology research. This infers “reinventing the wheel”, in other words, to develop algorithms or functions are already available in internet. The truth of this lies in the fact that real innovation comes from the deep understanding and control of every layer of the process; on the contrary, the use and abuse of libraries and ready to use solutions, that can be helpful to speed up production, generate creative constraints –the proper word should be cages - where creative results are not of the artist. Original technological research is paramount also in the broader cultural domain, to defend cultural identity and correct the ideological biases (Varma, 2009) of the commercial modelling solutions for artists, designers and architects. Every single line of code embeds significant knowledge that will unfold completely when all the pieces are put together, giving to the software and to its users cultural definition and power.

4.2 The Black Box Problem and the Benefits of Generative Grammars Solutions

The computational and artistic research results demonstrate that complexity and creativity forms don’t need complicated technological solutions; L-Systems, in this sense, have many benefits. Firstly, with some improvements, offer control and flexibility almost like a programming language, but are easier to understand (yet certainly difficult to develop properly). In the second place, L-Systems grammars and codes are transparent, and more intelligible, compared, for instance, with AI algorithms (Wyse, 2019) whose deep

computational processes are puzzling even for their creators. I will add that AI can be developed starting from the fundamental idea of meta-medium (Kay, 1980) and can be interpreted as interfaces architecture and design in any application. Furthermore, the difficulties of generative design can be limited with a proper interface design and coding style; both help the users to exploit the parameters' creative properties and the aesthetics properties of algorithms (Fishwick, 2006). It is important to realize that many independent and open source solutions are discarded because of lack of documentation.

4.3 Issues in Educational Technology

These topics are particularly relevant when digital tools are used in learning contexts (Stig Møller, 2017). Generative grammars lingos, like L-Systems, not only can be programmed easily, even without experience, but also, very much like Turing machines, they can be developed by hand (Alfieri, 2005) and can be used as methods in analog processes with traditional materials. Even in digital processes, the need for computers appears only in the last step of the design process; in this way, machines do not interfere with the development of a creative and critical computational thinking. In this sense, cultural identity and ethno computation references and resources, like *quipus* or the *yupana*, are not just visual metaphors for interface layouts or artistic installations. Embedded and coded in algorithms and functions and supported by analogies in design methods, data structures and computations, cultural traditions come to life to shape contemporary culture as concrete methods, solutions and fabrication tools.

4.4 Conclusions

Lastly, I will resume the main concepts and findings of the research, and some ideas about its future developments and improvements.

a) Generative grammars proved, through artistic practice, that they are very creative tools and that there is no need for machines to foster digital literacy and computational thinking. Using traditional techniques and materials overcomes the techno-centric bias that educational technology carry out (Alfieri, 2005).

b) Cultural traditions, native artistic practices and ethno computation are inherently modular and recursive (Khajuraho & Vinayak 2018), thus, can be molded with shape grammars and the tag solution discussed here easily (fig. 9).

c) Generative art and generative grammars are techniques with a great creative and heuristic potential, as software development demonstrated during the project activities. From the aesthetic and epistemological point of view, the artistic research validation can be sustained precisely by this heuristic potential, whose evidence is the artistic production and its diffusion in design communities.

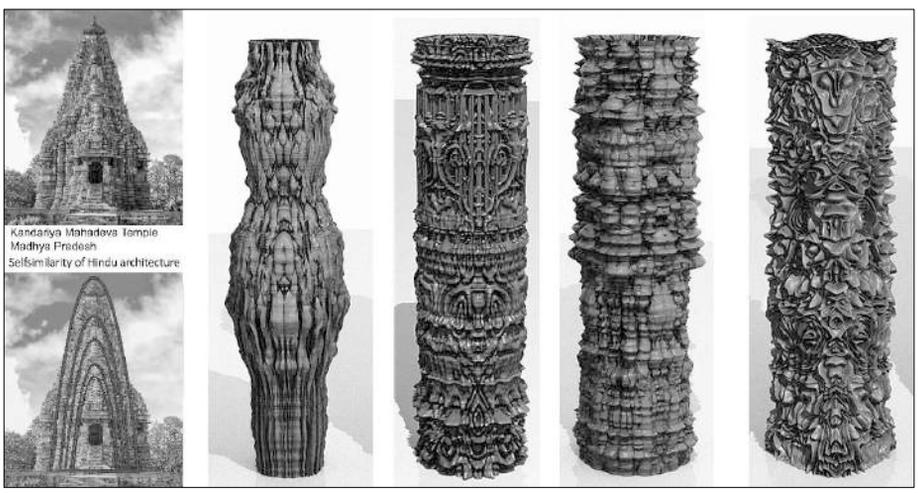

Fig. 9. Generative grammars and programmable meshes can simulate different artistic styles, like medieval Hindu architecture and decorative art, and help to understand their fractal processes. Left: source: Khajuraho & Vinayak (2018). Right: author (2022).

d) Software development and artistic practice also discovered some geometric and topological problems raised by complex generative processes. But the programmable tag mesh solution minimizes these issues and facilitates the compatibility with digital fabrication, and demonstrated that complex forms can improve competences in 3D printing and robotic manufacture, as the *Subdivided Columns* of Michael Handsmeyer (2019) already demonstrated, and the possibilities of recycled organic materials. Technicalities apart, this computer interdisciplinary research also enlighten some interesting concepts about computational creativity and the relationships between computational creativity and education.

e) Writing our own functions and giving up the cut and paste of software libraries may seem excessive, since it requires hard work and a sort of “rediscovering the wheel” process. But this is necessary for true digital literacy, technological innovations and creativity. In fact, through the control over these pieces of knowledge (algorithms, processes and parameters), we eventually miss using libraries lightly, is the key to add aesthetic value and originality to our projects.

f) A lot more attention should be paid to the cultural aspects of software and interface design. Software is a complex cultural object with many layers of meaning that we are still not taking advantage as such. For educational and artistic purposes of computational thinking and creativity, the artistic research enlightened the differences between coding and software. Software is more than writing code, it includes interactivity, the coherence between ends and means, cultural biases, issues about the distribution of information of

knowledge. So far, software as a cultural object needs much more humanities than sciences.

4.5 Further development

Generative design methods like shape grammars and techniques like programmable meshes can be indefinitely developed and improved from the computational, aesthetic and educational point of view. I will mention some lines of research in digital humanities that seem particularly important: to develop interface designs and human-machine interaction strategies for creative purposes; explore software as a text, in the sense defined by Barthes (1997), that gathers technical and creative means, data, concepts and audiovisual resources; and finally, strategies and programs to improve the interdisciplinary formation of artists like inventors and scientists.

References

Alfieri, A. (2005). L-system Fractals: an educational approach by new technologies. *Quaderni di Ricerca in Didattica* (Mathematics), 25:2. Palermo: University of Palermo.

Barthes, R. (1997). The Death of the Author. In S. Heath, trans*. Image, Music, Text*. London: Fontana Books.

Carnovalini, F. y Rodà A. (2020). Computational creativity and music generation systems: An introduction to the state of the art. *Frontiers in artificial intelligence 3*.

Colton, S. (2008). Creativity versus the perception of creativity in computational systems. *AAAI Spring Symposium: Technical Report*, pp. 14-20.

Crousse, V. (2011). *Reencontrando la espacialidad en el arte público del Perú.* Tesis presentada para la defensa del grado de Doctor. Universidad de Barcelona, Barcelona.

di Sangro, R. (1750). *Lettera apologetica dell'Esercitato accademico della Crusca*. Naples: Gennaro Morelli.

O'Donoghue, D. (2009). Are We Asking the Wrong Questions in Arts-Based Research? *Studies in Art Education,* 50: 4, pp. 352-368.

Fishwick, P. (2006). *Aesthetic Computing*. Cambridge, Massachusetts: MIT Press.

Handsmeyer, M. (2019). Tools of Imagination. In Viana, V. (Ed.) *Geometrias' 19. Book of Abstracts*. Porto: Aproged.

Kay, A. (1984). "Computer Software." *Scientific American* 251(3), pp. 52–59.

Khajuraho, T. & Vinayak, S. (2018). Trends in Fractal Dimension in Laxman and Kandariya Mahadev Temples. *International Journal of Applied Engineering Research*, 13, (3) pp. 1728-1741.

Iranil, L., Vertesi, J., Dourish, J., Kavita, P. & Grinter, R. (2010). *Postcolonial Computing: A Lens on Design and Development*. Irvine: University of California.

McCormack, J. (2004). Generative Modelling with Timed L-Systems. In J. S. Gero, ed. *Design Computing and Cognition*. Berlin: Springer, pp. 157–175

Pestana, P. (2011). “Lindenmeyer Systems and the Harmony of Fractals.” *Proceedings of the Chaotic Modeling and Simulation International Conference*, pp. 449–456.

Prusinkiewicz, P. & Lindenmayer, A. (1990). *The Algorithmic Beauty of Plants*. Berlin: Springer.

Roncoroni, U. & Crousse, V. (2016). La virtualidad aumentada: procesos emergentes, arte y medios digitales. *Artnodes*, 17.

Roncoroni, U. (2015). *Manual de diseño generativo*. Lima: Fondo Editorial de la Universidad de Lima.

Roncoroni, U. (2022). Electronic Music and Generative Remixing: Improving L-Systems Aesthetics and Algorithms. *Computer Music Journal*, 45:1, pp. 55–79.

Stig Møller, H. (2017). “Deconstruction/Reconstruction: A Pedagogic Method for Teaching Programming to Graphic Designers”. In Soddu, C. (ed.) 20h *Generative Art Conference GA2017* Proceedings.

Stiny, G., & Gips, J. (1972). “Shape Grammars and the Generative Specification of Painting and Sculpture.” In O. R. Petrocelli, ed. *The Best Computer Papers of 1971*, pp. 125–135.

Varma, R. (2006). Making computer science minority friendly. *Communications of the ACM 49*(2), pp. 129-134.

Vattimo, G. (2000). *La società trasparente*. Milán: Garzanti.

Wyse, L. (2019). Mechanisms of artistic creativity in deep learning neural networks. In *Proceedings of the International Conference on Computational Creativity*.

The Reviver Grammar: transforming the historic center of São Luís through social housing

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Abstract. This work explores the potential of Shape Grammars in generating solutions for the adaptive reuse of historic buildings. It proposes a transformation grammar for the Sobrado building, a typology present in the historic center of São Luís. The methodology proposes a framework for adapting buildings into multi-family apartments, considering spatial and structural requirements. The grammar aims to develop a formalism for repurposing historic buildings into social housing and considers the allocation of three types of apartments in the floor plan: studios, one-bedroom, and two-bedroom apartments. The adopted strategy for the distribution of internal spaces considers opening elements, such as windows and balconies, allowing to benefit from the natural daylighting characteristics of the buildings. This paper describes the grammar rules and its application to a case study building, aiming to demonstrate how the grammar supports different layout solutions for the same design space.

Keywords: Shape grammars, Adaptive reuse, Generative design, Mass customization, Sustainability

1 Introduction

The architectural composition of the historical center of São Luís maintains a rich ensemble of buildings representing the Luso-Brazilian architecture. With similarities to the *Pombalino* style from Portugal, it is an outstanding example of a dense, urban architecture adapted to the unique climatic conditions of equatorial South America. Efforts have arisen from both federal and state organizations to preserve and maintain the historic buildings, contributing to reviving the sense of community in the historic district. Adaptive reuse emerges as a viable solution for reintegrating buildings to new urban requirements, allowing to preserve historic buildings (Mısırlısoy & Günçe, 2016; Yung et al., 2014). However, adaptive reuse is a challenging problem that combines spatial, structural, and architectural requirements, along with current restrictions in

design, enhanced in buildings with heritage value (Bullen, 2007; Shahi et al., 2020).

Since necessary modifications affect the layout configuration of the existing building, one can consider the adaptive reuse problems as a space planning problem. In this scenario, generative design techniques allow exploring different arrangements for a pre-defined problem, assisting professionals during complex design tasks (Agkathidis, 2015). Design is a highly complex task combining creativity, specialist knowledge, experience, and judgment concerning the objective and the aesthetic aspects of a problem domain (Mountstephens & Teo, 2020).

Incorporating the designer's knowledge into the GD process can lead to feasible solutions. In this context, Shape Grammars (SG) are widely applied to understand the formal and syntactic information underlying plan layouts for spatial configuration. SGs comprise a set of transformation rules that can be applied recursively to an initial form to generate new forms (March, 2011; Stiny, 1985a, 1985b). Studies have successfully developed SG to describe and analyze architectural styles or languages of designs by well-known architects (Benrós et al., 2012; Duarte, 2005; Ligler, 2021). However, few attempts have been made to produce reusable grammatical design systems for architectural design tasks, especially regarding the adaptation of buildings (Eloy & Duarte, 2015; Guerritore & Duarte, 2019).

This work utilizes shape grammar concepts to understand and produce a variety of arrangement of elements in the design space. Shape grammar formalism offers a visual, rule-based framework for interpreting architectural languages for over forty years (Ligler, 2021). Thus, this work develops a grammar-based methodology that supports the adaptive reuse process of historic buildings, focusing on the historic center of São Luís as a case study.

2 The architectural typology in the historic center of São Luís

This research explores the architectural typology of buildings in the historic center of São Luís (Figure 1a). This city maintains an important historical center, recognized as a UNESCO World Cultural Heritage Site since 1997. This ensemble preserves a significant architectural, historical and urban collection reminiscent of the XVIII and XIX centuries, a time of economic prosperity through the exportation of rice and cotton. The architectural ensemble shows strong traces of influence from the *Pombalino* buildings (Lopes et al., 2014). This constructive system marked Lisbon’s reconstruction after the 1755 earthquake in the region known as *Baixa Pombalina*.

The design of *Pombalino* buildings included earthquake safety measures and sewerage channeling. Additionally, modular construction methods were implemented as the prevalence of prefabricated architectural elements, such as woodwork and carpentry (cage and roof structure), ironwork, lintels, and jambs in Lioz stone (Figueiredo, 2011). The construction of buildings in São

Luís considered a similar structural arrangement, also benefiting from modular construction. Due to the easy access to São Luís by the sea, most of the construction materials employed in the buildings came from Portugal by ships.

Structurally, *Pombalino's* buildings presented a three-dimensional locking system, also known as *gaiola pombalina,* formed externally by the main walls in stone masonry and internally by the frontal walls. Frontal walls were constituted by a skeleton of wood, formed by vertical, horizontal, and diagonal pieces, known as Santo André cross (Figueiredo et al., 2011). Using this system, it was possible to build lighter and more flexible elements in the event of an earthquake, unlike traditional stone or brick masonry walls (Mascarenhas, 2005). Although there was no risk of earthquake in São Luís, this construction system is found in many buildings in the region (Figure 1b).

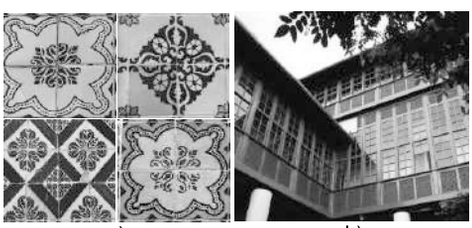
a) b)

Figure 1. The historic center of São Luís: a) Sobrado buildings; b) wall evidencing the Santo André cross structure. Source: a) Source: The Authors, 2022; b) Figueiredo et al., 2011**.**

The main difference between *Pombalino* buildings and the constructive system found in São Luís is found in the distribution of volumes within urban blocks. *Pombalino* buildings followed a strict distribution per block, resulting in a uniform volume, usually a five-story distribution. However, the buildings in São Luís present a variation in the number of floors in the same block distribution (Figure 2). Thus, considering the volume and composition of the façade elements, the buildings in the historic center of São Luís are classified as *Solares*, *Sobrados*, and *Casas Térreas*. The majority of buildings are classified as *Sobrados*, especially in the federal area of protection (Figueiredo, 2014). The term *Sobrado* primitively designates the space left or gained due to the suspended floor enabled by the topography level differences (Ghignatti, 2020).

Figure 2. Schema representing the architectural set of São Luís, featuring blocks of buildings at varying heights. Source: Figueiredo et al. (2011).

São Luís attracts attention for the number of buildings with Portuguese tiles in their facades (Figure 3a). Besides decorative purposes, these tiles provided impermeability during the heavy raining season as well as thermal isolation during summer seasons. In addition, those buildings usually presented internal patios with glazed closure (wood, glass and shutters) of the back balconies, allowing ventilation and light into the buildings (Figure 3b).



a) b)

Figure 3. Façade elements characteristic of Luso-Brazilian typology: a) Portuguese tiles, b) Internal patios. Source: a) Source: The Authors, 2022; b) Figueiredo et al. (2011).

3 Methodology

This work explores the potential of shape grammars in generating floor plan layout solutions for the adaptive reuse of historic buildings in the historic center of São Luís. The proposed grammar is entitled *Reviver*, a word from Portuguese meaning 'to revive'. The name is based on a rehabilitation program created in the late 80s to preserve the city's heritage identity and nowadays, locals refer to the historic center using this term. The methodology proposes a framework for adapting buildings into multi-family apartments, considering spatial and structural elements.

The grammar aims to develop a formalism for repurposing historic buildings into social housing and considers the allocation of three types of apartments in the floor plan: studios, one-bedroom (1B1B), and two-bedroom apartments (2B1B). the design space for producing apartments configurations is the original built-up area (within exterior walls).

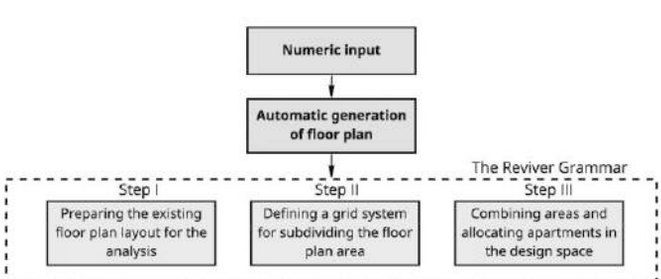


Figure 4. The Reviver Grammar methodology. Source: The Authors, 2022.

Figure 4 summarizes the grammar-based methodology. The grammar considers a numeric input to automatically generate the original floor plan layout. The first step refers to adjustments that may be necessary to perform to the floor plan obtained considering the numeric data input. These adjustments refer to preparing the floor plan for the transformation analysis, such as visually differentiating element types, identifying the landing area for the stair, and identifying the primary and secondary facades. The second focus on defining a grid system for subdividing the floor plan design space. Lastly, third step defines layout solutions for multi-family apartments considering the design space. The implementation of this process is conducted using Python and rhino script syntax, which facilitates the implementation of visual components of this research. However, this paper will not focus on defining the computational implementation, but mainly the grammar strategy.

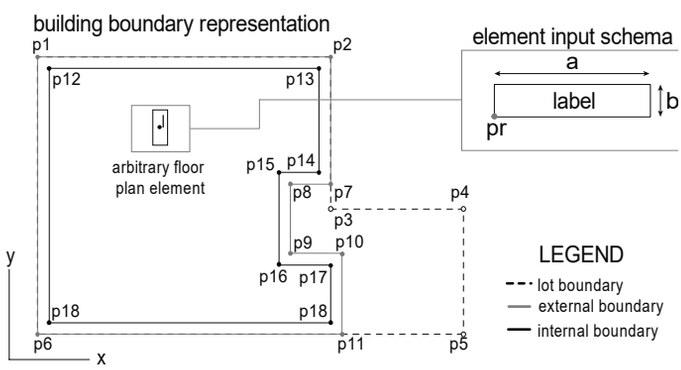


Figure 5. Abstract schema for defining the data input for the floor plan configuration. Source: The Authors, 2022.

The numeric input is designed to be obtained using documentation techniques, such as laser scanning and photogrammetry, and aims to provide an automated strategy for defining the original floor plan layout. Essentially, any floor plan configuration is abstracted as two data sets (Figure 5): a) a list of points defining appropriate boundaries of the building; b) geometric information of existing elements, such as walls, windows, stairs, patios, etc.

Three boundaries are defined as relevant for the adaptive reuse process: the urban lot boundary (*lot*) and the external (*ext*) and internal (*int*) boundaries for the built-up region (inside external walls). The data input for representing these curves are the coordinates (x, y) of the points defining each boundary.

Secondly, information on each element on the floor plan must be provided. Floor plan elements are abstracted as a rectangle, as detailed as the arbitrary internal element in Figure 5. To determine the element configuration, each element is abstracted as the following input variables: reference point defined by coordinates in x and y direction (p_r), dimension of element in x-direction (a), dimension of element in y-direction (b), label for each element ($label$). The labels list will depend on the architectural typology. For the Luso-Brazilian architecture, the list of elements is: external masonry wall (*ew*), gable wall (*gw*),

stone column (*cl*), internal masonry wall (*iw*), frontal wall (*fw*), partition wall (*pw*), entrance door (*en*), balcony (*bc*), secondary windows (*wd*), stairs (*st*) and patios (*pt*).

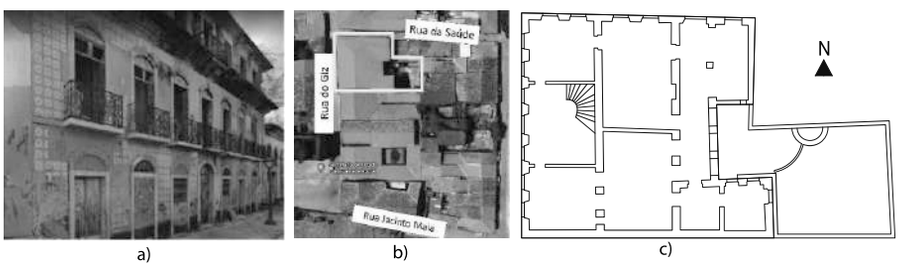


Figure 6. Case study building: a) facade, b) aerial view, c) floor plan configuration. Source: The Authors, 2022.

A case study building is selected to illustrate this research methodology. The building is located at Rua do Giz, 445, São Luís (Figure 6). This *Sobrado* is part of an existing rehabilitation program, coordinated by the city of São Luís, to adapt the structure for mixed-use building, with public offices on the ground floor and multi-family apartments on the first and second floors. Most *Sobrado* buildings were single-family houses originially. However, nowadays most buildings are vacant, which is the current state of the case study building. Figure 7 illustrates the existing floor plan configuration generated considering the input data for the case study building. The total built-up area (within internal boundary) is equal to $481\ m^2$.

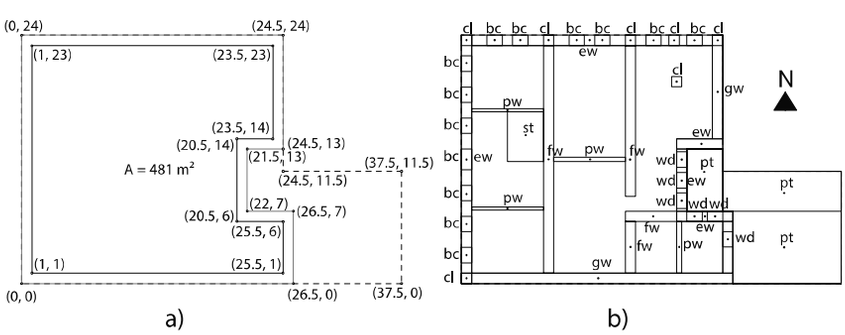


Figure 7. Schema representing the floor plan configuration generated based on the two datasets: a) building's boundaries, b) existing floor plan elements. Source: The Authors, 2022.

4 The Reviver Grammar

The Reviver grammar is composed of 10 stages, as illustrated in Figures 8. Stage 1 focuses on coloring the relevant elements for the analysis, aiming to

define visually distinct shapes (Knight, 1989). For elements where the thickness is important to distinct, like walls and their contained elements (windows, doors, etc), l and t represent the length and thickness, respectively. For other elements (columns, patios, stairs, etc.), dimension representation follows the variables specified in the abstracted schema (Figure 5), where the dimensions

are represented by a (dimension in x direction) and b (dimension in y direction).

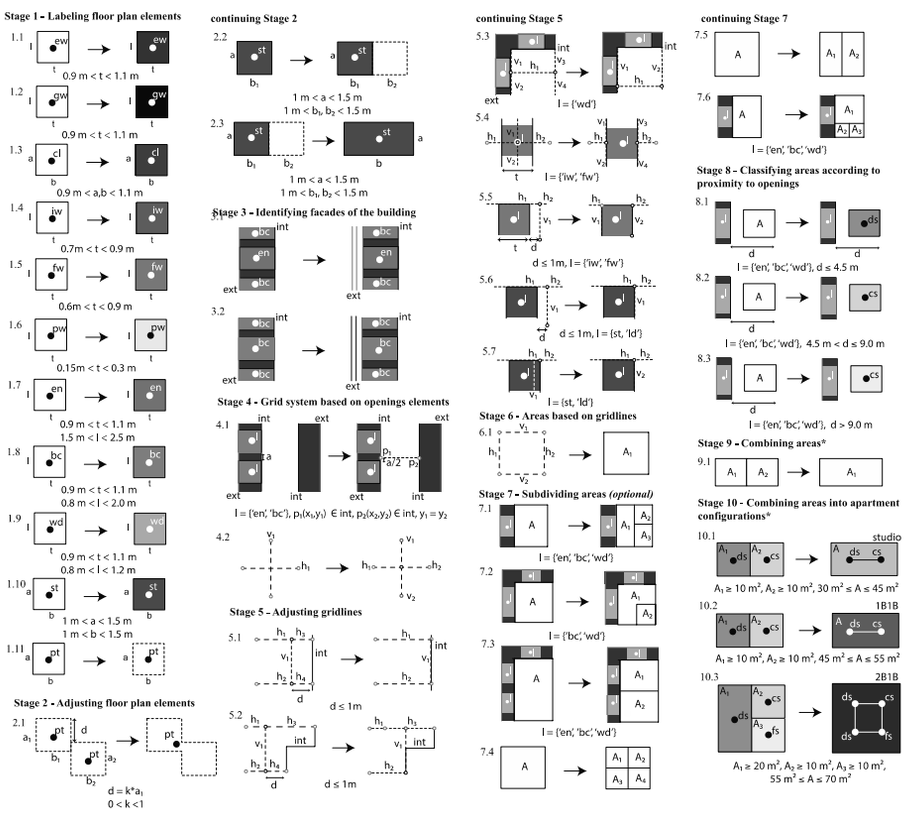


Figure 8. The Reviver Grammar. Source: The Authors, 2022.

Since the data input abstracts elements as rectangles, it may be necessary to perform adjustments on the spatial configurations. Stage 2 focuses on defining adjustments to the existing data input configuration. Since patios may be composed of multiple curves, due their irregularity, they can be grouped as one area (rule 2.1). In addition, it is necessary to define the landing area space for stairs (rules 2.2 and 2.3). For orientation purposes, it is also necessary to encode rules to identify the main facade (rule 3.1) and secondary facades (rule 3.2). This ruleset is used to differentiate if a building is a corner building (both rules are applied) or is a middle building (only rule 3.1 would be applied).

Then, a grid system is defined aiming to facilitate the transformation process for converting the existing space into multi-family apartments. This study focuses on locating the existing opening elements and generating grid lines based on their location. This process is converted into rules during stage 4. In the ruleset, opening elements (main entrance and façade windows/balconies) are used as a reference for defining the grid line.

The grid line is defined considering distance between two façade elements (a). It starts from a point located in the middle distance between two façade elements, and it is extended until a point located in the parallel internal boundary curve (rule 4.1). In sequence, each grid line is subdivided into smaller components considering the points where vertical and horizontal lines connects each other (rule 4.2).

When applying the grid division as defined in stage 4, some undesirable patterns may arise due to the configuration of the existing building, such as grid lines coalescing secondary windows or within a small distance from division elements (such as external walls). Stage 5 presents rules to modify the grid configuration to avoid these patterns. A critical characteristic while preparing the floor plan is adjusting the grid to prevent grid lines from intersecting structural elements. Thus, the design space considers structural elements such as masonry and frontal walls as part of a fixed domain (rules 5.4 and 5.5).

In contrast, since partition walls do not have a structural function, they are not included as a restricted domain when defining grid lines. Other adjustments performed to grid lines are to the ones close to the internal boundary (rules 5.1 and 5.2), intersecting windows (rule 5.3), and crossing or close to stair elements (5.6 and 5.7).

The grid specifies areas for transforming the existing building layout for a multi-family apartment floor plan. Stage 6 presents the rule for generating areas based on the grid lines. Then, the resulting areas can be subdivided to refine the grid size, increasing the combinatory possibilities, following patterns described in stage 7. This stage is optional to allow for design flexibility in the use of the grammar. It is optional since the grammar can produce variations considering the areas defined based on the grid system (as defined in stage 6). Then, each area is labeled according to its proximity to openings (stage 8). These areas are classified as: a) areas exposed to direct sunlight (‘ds’) b) areas without openings but still relatively close to spaces with openings (‘cs’), and c) areas far from sunlight (‘fs’).

For simplicity, areas are illustrated in stages 9 and 10 as squares. However, they can have different configurations as long they respect the prescribed limits in squared meters. In stage 9, areas with the same classification are combined according to limits defined based on the type of apartment (studio, 1B1B and 2B1B), further described in stage 10. Studio apartments must have a total area between $30\ m^2$ and $45\ m^2$, 1B1B must have a total area between $45\ m^2$ and $55\ m^2$, and 2B1B must have a total area between $55\ m^2$and $70\ m^2$.

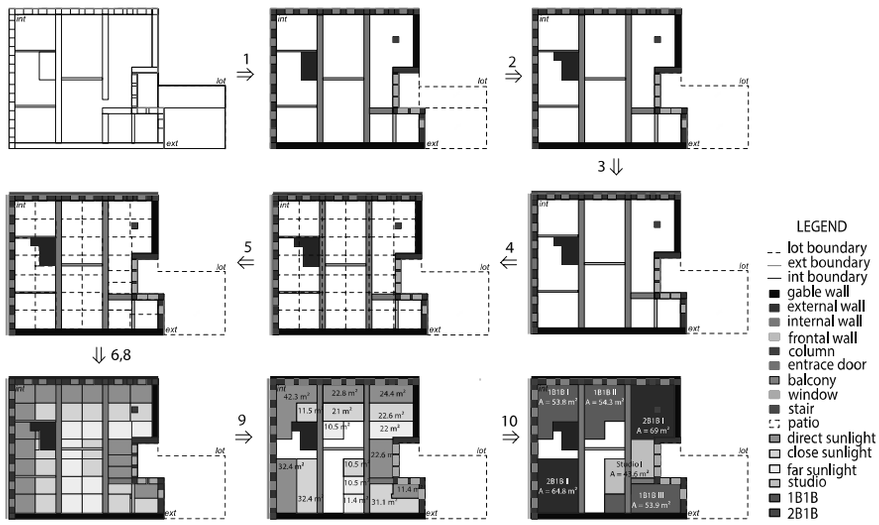


Figure 9. Derivation process using the Reviver Grammar for the case study building. Source: The Authors, 2022.

In stage 10, different area types ('ds', 'cs', 'fs') are combined apartment configurations. Figure 9 illustrates the derivation process for the case study building, showing one possibility of floor plan for multi-family apartments. This derivation did not consider stage 7 (the subdivision of spaces ruleset).

5 Multi-family Apartments Configurations using the Reviver Grammar

Six different floor plan layouts are produced to verify the proposed grammar's applicability in achieving various design solutions. Two different strategies are defined: a) space layout based on the original grid system, which does not apply rules in stage 7 (Figure 10); b) subdividing spaces by applying rules in stage 7 (Figure 11). Rules 7.4 and 7.5 can be recursively applied to refine the subdivision layout. Each variation consists of different layout configurations, with apartment types varying between studios, 1B1B and 2B1B.

The first variation includes one studio, three 1B1B, and two 2B1B; the second contains three studios, three 1B1B and one 2B1B; the third has five studios and three 1B1B. The total area for multi-family apartments compositions is equal to $339.4\ m^2$ for variation one and $342\ m^2$ for variations two and three. In contrast, using strategy 2 the total area of apartments could be increased, since a more refined grid is applied. The first variation has one 1B1B and five 2B1B; the second has two studios, two 1B1B and three 2B1B; the third has three studios, four 1B1B and one 2B1BThe total area for multi-family apartments compositions is equal to $378.1\ m^2$ for variation one and $381.2\ m^2$ for variations

two and three. Table 1 presents the percentage of apartments areas for each solution in comparison to the total floor plan area ($481\ m^2$).

Figure 10. Three different configurations for the case study building produced using strategy 1 (stage 7 is not applied). Source: The Authors, 2022.

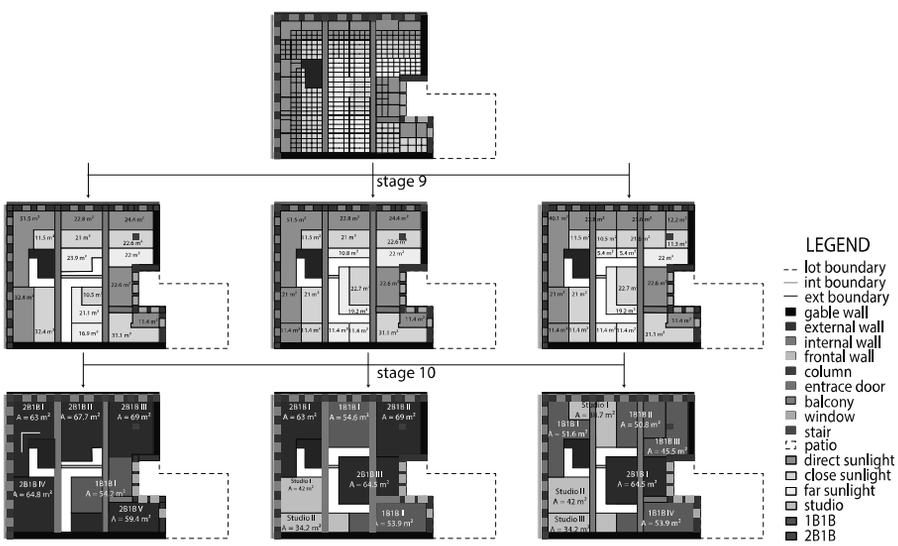


Figure 11. Three different configurations for the case study building produced using strategy 2 (stage 7 is applied). Source: The Authors, 2022.

The transformation grammar can be applied to any floor in the building; however, variations produced in Figures 9, 10 and 11 illustrate possible configurations for the upper floors of the building – since these floors should be adapted into multi-family apartments according to the existing rehabilitation

project. The white internal spaces in these variations represent potential corridors connecting apartments. The best designs should maximize the total area of apartments and minimize the corridor areas.

Table 1. Apartments/floor plan area ratio for solutions using strategy 1 and 2.

Strategy	Variation 1	Variation 2	Variation 3
1	70.56%	71.10%	71.10%
2	78.61%	79.25%	79.25%

6 Conclusions

Adaptive reuse is a challenging task that involves understanding a building's configuration, repurposing it for a new use. Thus, this research investigates how shape grammar formalism can automate the space allocation process for adaptive reuse projects, focusing on historic buildings. The grammar, entitled *Reviver*, presents ten stages that assist transforming an existing floor plan configuration into multi-family apartments. It effectively produces variations of designs considering three different apartment types: studios, 1B1B and 2B1B. This project is part of a broader scope of mixed methods to study how generative design can support adaptive reuse in terms of spatial and structural problems. Future work will integrate the grammar with genetic algorithms and GANs to support the combination of human and machine expertise for the adaptive reuse process.

References

Agkathidis, A. (2015). Generative Design Methods: Implementing Computational Techniques in Undergraduate Architectural Education. *eCAADe 2015*. https://doi.org/10.13140/RG.2.1.3767.1120

Benrós, D., Duarte, J. P., & Hanna, S. (2012). A New Palladian Shape Grammar: A Subdivision Grammar as alternative to the Palladian Grammar. *International Journal of Architectural Computing*, *10*(4), 521–540. https://doi.org/10.1260/1478-0771.10.4.521

Bullen, P. A. (2007). Adaptive reuse and sustainability of commercial buildings. *Facilities*, *25*(1/2), 20–31. https://doi.org/10.1108/02632770710716911

Duarte, J. P. (2005). A discursive grammar for customizing mass housing: The case of Siza's houses at Malagueira. *Automation in Construction*, *14*(2), 265–275. https://doi.org/10.1016/j.autcon.2004.07.013

Eloy, S., & Duarte, J. (2015). A transformation-grammar-based methodology for the adaptation of existing housetypes: The case of the 'rabo-de-bacalhau.' *Environment and Planning B: Planning and Design*, *42*, 775–800. https://doi.org/10.1068/b120018p

Figueiredo, M., Varum, H., & Costa, A. (2011). Caracterização das técnicas construtivas em terra edificadas no século XVIII e XIX no centro histórico de São Luís (MA, Brasil). *Arquitetura Revista*, *7*(1), 81–93. https://doi.org/10.4013/arq.2011.71.08

Ghignatti, L. (2020). The natural landscape as a decisive factor in structuring urban and architectural the historical center of São Luís, Maranhão, Brazil. *Revista Sociedade Científica*, *2*(12), 9–23. Https://Doi.Org/10.5281/Zenodo.3610752

Guerritore, C., & Duarte, J. P. (2019). Rule-Based Systems in Adaptation Processes: A Methodological Framework for the Adaptation of Office Buildings into Housing. In J. S. Gero (Ed.), *Design Computing and Cognition '18* (pp. 499–517). Springer International Publishing. https://doi.org/10.1007/978-3-030-05363-5_27

Knight, T. (1989). Color grammars: Designing with lines and colors. *Environment and Planning B: Planning and Design*, *16*, 417–449. https://doi.org/10.1068/b160417

Ligler, H. (2021). Reconfiguring atrium hotels: Generating hybrid designs with visual computations in Shape Machine. *Automation in Construction*, *132*, 103923. https://doi.org/10.1016/j.autcon.2021.103923

Lopes, M., Meireles, H., Cattari, S., Bento, R., & Lagomarsino, S. (2014). Pombalino Constructions: Description and Seismic Assessment. In A. Costa, J. M. Guedes, & H. Varum (Eds.), *Structural Rehabilitation of Old Buildings* (pp. 187–233). Springer. https://doi.org/10.1007/978-3-642-39686-1_7

March, L. (2011). Forty Years of Shape and Shape Grammars, 1971 – 2011. *Nexus Network Journal*, *13*(1), 5–13. https://doi.org/10.1007/s00004-011-0054-8

Mascarenhas, J. (2005). *Sistemas de construção V: o edifício de rendimento da Baixa Pombalina de Lisboa, processo evolutivo dos edifícios; inovações técnicas; sistema construtivo*. Livros Horizonte.

Mısırlısoy, D., & Günçe, K. (2016). Adaptive reuse strategies for heritage buildings: A holistic approach. *Sustainable Cities and Society*, *26*, 91–98. https://doi.org/10.1016/j.scs.2016.05.017

Mountstephens, J., & Teo, J. (2020). Progress and Challenges in Generative Product Design: A Review of Systems. *Computers*, *9*(4), 80. https://doi.org/10.3390/computers9040080

Shahi, S., Esnaashary Esfahani, M., Bachmann, C., & Haas, C. (2020). A definition framework for building adaptation projects. *Sustainable Cities and Society*, *63*, 102345. https://doi.org/10.1016/j.scs.2020.102345

Stiny, G. N. (1985). Computing with Form and Meaning in Architecture. Journal of Architectural Education, 39(1), 7–19. https://doi.org/10.1080/10464883.1985.10758382

Yung, E. H. K., Chan, E. H. W., & Xu, Y. (2014). Community-Initiated Adaptive Reuse of Historic Buildings and Sustainable Development in the Inner City of Shanghai. *Journal of Urban Planning and Development*, *140*(3), 05014003. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000174

School Grammar: An Exploration on Computational Processes in Architecture

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Abstract. Standard design for schools in underdeveloped countries seems to be the key to lowering the cost of the whole building process, from design to construction. But since it might not be suitable for different situations, the range of each design is limited. This paper presents a parametric algorithm intended to provide mass customized Architectural solutions for school buildings. A Shape Grammar based methodology for customized school designs is proposed. A set of rules is defined based on chosen characteristics in a corpus of analysis and then is implemented in an open-source modeling software. The algorithm proposed is able to provide solutions for different lots and number of students assisted.

Keywords: Shape Grammars, School Architecture, Mass Customized Design, Design Methods, Open-Source Software.

1 Introdução

A padronização nos projetos de arquitetura escolar tem sido a resposta mais comum à grande, e ainda crescente, demanda por escolas nos grandes centros urbanos, levando-se em consideração as vantagens do ponto de vista econômico, logístico e de construção. Porém, segundo Kowaltowski (2011), esse tipo de padronização nem sempre considera as situações locais específicas, o que pode resultar na criação de ambientes desfavoráveis, com problemas de conforto ambiental e de ajustes às condições particulares de implantação.

Uma forma interessante de olhar para este problema pode estar na crescente informatização da arquitetura que, possibilitada por novas tecnologias, ferramentas digitais e subsequentes mudanças nas relações econômicas e sociais, tem trazido à tona questões relacionadas a métodos e processos de projeto arquitetônico para as quais diversas soluções têm sido propostas, tanto no meio acadêmico quanto na indústria, as quais procuram

responder às questões relacionadas à produtividade, eficiência, gestão e colaboração de projeto.

A Gramática da Forma, como demonstrado em trabalhos como de Duarte (2005), Willis et al (2012) de Morais et al (2014), Chokyu (2018) entre outros, tem sido uma teoria utilizada como base para aplicação de metodologias digitais que objetivam permitir a customização em massa de projetos de arquitetura. Tal teoria permite introduzir e explorar as infraestruturas computacionais nos processos de projeto, a partir de análise e crítica de precedentes projetuais consolidados, para fundamentar a inserção das novas ferramentas digitais no campo da concepção arquitetônica.

Considerando estes aspectos, este trabalho busca responder à questão das escolas-padrão ao propor uma metodologia metaprojetual, que permita a criação de projetos customizados, garantindo uma maior flexibilidade e adaptação dos edifícios aos contextos urbanos nos quais serão inseridos. O tema da customização em massa de projetos é amplamente discutido por Kolarevic e Duarte (2019), que apontam o projeto paramétrico e a fabricação digital como seus fundamentos. Entretanto, este trabalho não agrega a fabricação digital nos processos, dada a limitação para o emprego destas tecnologias no contexto local.

2 Uma abordagem computacional para projetos escolares

2.1 Gramática da forma na análise e síntese de arquitetura

A Gramática da Forma é um formalismo criado por George Stiny e James Gips e apresentado pela primeira vez em 1971. Baseia-se no trabalho Syntactic Structures (1954) do linguista Noam Chomsky, usando a mesma estrutura lógica de gramática produzida a partir de regras. Celani et al. (2006), acrescenta o sistema de produção de Émil Post (1943) entre as raízes do conceito de Stiny e Gips, que produz um elemento novo a partir de aplicação recursiva de regras sobre um inicial. A Gramática da Forma emprega formas no lugar de símbolos com uso de operações booleanas na definição das regras.

De acordo com Knight (1999), as Gramáticas da Forma podem ser analíticas ou sintéticas, sendo as primeiras originadas a partir do estudo de um corpus de análise. Segundo Chokyu (2018), busca-se a recorrência de padrões de composição entre os elementos do corpus para a definição das regras. Com relação às sintéticas, Knight (op.cit) comenta que é possível a criação de uma Gramática original em ateliê, mas que na prática o que se observa é a produção de novas a partir de outra existente.

No presente trabalho, a proposta parte da elaboração de uma gramática base a partir de um corpus de análise selecionado. Desta gramática serão

selecionadas regras que possibilitem a conformação de projetos que sejam ao mesmo tempo customizados e padronizados.

Foram selecionados projetos de escolas públicas nas cidades do Rio de Janeiro e de São Paulo para essa Gramática. Desenvolveu-se uma metodologia de análise computacional para extrair regras de composição. Uma gramática da forma inicial foi elaborada com as regras inferidas, buscando-se caracterizar os elementos do corpus. Essa foi alterada de forma a atender as diretrizes.

2.2 Histórico e estado da arte no projeto de escolas-padrão públicas no Brasil

No Brasil, durante o século XX, houve um longo processo de urbanização das cidades que gerou um aumento populacional considerável. A demanda crescente por escolas, existente até os dias atuais, justificou a escolha predominante por projetos padronizados, principalmente a partir da década de 1960, e tiveram seu auge a partir da década de 1980 com os CIEPs e CAICs e os CEUs, projetos escolares de grande porte com processos construtivos racionalizados que visavam a replicabilidade.

Esses projetos padronizados, embora apresentassem vantagens do ponto de vista econômico e construtivo, tiveram também, pela própria natureza, pouca flexibilidade quanto a adaptação aos contextos específicos. Além disso, grande parte desses projetos priorizaram a quantidade e economia de construção em detrimento da qualidade. Seu programa costuma ser reduzido, com poucos ambientes além das salas de aula, espaços livres cobertos ou espaços para prática de esportes, quando há espaço no lote, que em determinados casos são acrescentados posteriormente de forma pouco planejada à medida que a demanda e novos paradigmas educacionais surgem.

No estado de São Paulo, fruto do trabalho implantado em 1976 pela Companhia de Construções de São Paulo (Conesp), foram desenvolvidos catálogos e normas para construção racionalizada de escolas. Tais documentos tinham como objetivo orientar e pautar a concepção de escolas que seriam projetadas por escritórios de arquitetura contratados pelo governo. O sistema foi elaborado pela FDE (Fundação para o desenvolvimento da Educação) que atualmente estabelece critérios e normas para a produção de projetos de escolas públicas no Estado de São Paulo. Os projetos realizados por diferentes escritórios de arquitetura seguem os padrões construtivos definidos pela FDE, com adaptações para cada contexto, o que permite a criação da arquitetura escolar com maior qualidade, se comparado com que a estrutura do projeto padrão 'carimbo', presente na realidade de muitos municípios no Brasil, incluindo o Rio de Janeiro com o projeto mais recente, as Escolas do Amanhã.

2.3 Elaboração da gramática

O objetivo desta pesquisa é explorar como os conceitos da gramática da forma podem ser trabalhados dentro dos emergentes ambientes de programação visual voltados à arquitetura, de forma a reconhecer os potenciais e limitações desses recursos teóricos e tecnológicos na criação de processos de projeto mais abertos. Desse modo, foi escolhido um corpus de análise composto por projetos de escolas públicas de nível fundamental, a partir do qual foram observados padrões relativos à estrutura espacial, setorização, partido e dimensionamento de espaços, considerando inclusive as soluções e técnicas construtivas adotadas.

A partir dos padrões encontrados foram criados paralelamente um conjunto de regras gráficas e um modelo paramétrico utilizando o Sverchok, software de modelagem paramétrica, extensão do software de modelagem Blender, ambas ferramentas livres e de código aberto. Dessa forma, enquanto o conjunto gráfico de regras visuais orienta a organização do algoritmo, o modelo paramétrico permite iterar rapidamente entre os diversos resultados possíveis da gramática através da escolha de certos parâmetros, facilitando a sua utilização como ferramenta de projeto.

2.4 Corpus de análise

As escolas escolhidas para compor o corpus de análise estão divididas em dois tipos que foram analisados com propósitos diferentes: (1) Os últimos três projetos de escola padronizadas realizados no município do Rio de Janeiro, com o objetivo de entender como ocorre o processo de concepção das escolas no município e quais as características específicas e as críticas feitas quanto aos espaços existentes; (2) Os projetos realizados pela FDE (Fundação para o desenvolvimento da Educação) no estado de São Paulo, pela qualidade no processo de produção de projetos de escolas públicas no cenário nacional, que embora não sejam projetos padronizados com a mesma lógica que os encontrados no município do Rio de Janeiro, seguem diversos padrões e um processo de projeto determinado pela FDE.

Tabela 1. Escolas do município do Rio de Janeiro.

Escola	Unidades Construídas	Período de Construção	Autores do Projeto	Gabarito	n° Salas
CIEPs	506	1983 a 87 e 1991 a 94	Oscar Niemeyer	3 a 4	18
Escolas Modulares Padrão	21	2001 a 2008	RioUrbe	3	13
Escolas do Amanhã	16	2009 a 2016	RioUrbe	3	24

Fonte: Acervo dos autores, 2020

Tabela 2. Escolas da FDE do Estado de São Paulo.

Escola	Localização	Ano	Autores do Projeto	Gabarito	n° de Salas de Aula
E.E Ilha da Juventude	Vila Brasilândia, SP	2011	METRÓPOLE Arq.	4	12
E.E. Telemaco Melges	Campinas, SP	2004	UNA Arquitetos	3	13
Várzea Paulista	Várzea Paulista, SP	2008	FGMF Arquitetos	3	10
Nova Cumbica	Guarulhos, SP	2014	H+F Arquitetos	4	15

Fonte: Acervo dos autores, 2020

Os projetos selecionados também estão localizados em zonas urbanas com diversas características semelhantes, predominantemente residenciais com densidade urbana média (edificações que possuem em média 2 a 3 pavimentos). Tal contexto urbano justifica a tipologia escolar de “bloco compacto” verticalizado, muitas vezes com quadra no topo quando não há espaço no terreno.

Com exceção dos CIEPS, todos os projetos foram construídos entre 2001 e 2016. Os CIEPs foram incluídos pois trata-se de uma tipologia que foi largamente replicado por todo o Estado do Rio de Janeiro e por seu caráter icônico que o torna provavelmente um dos projetos mais marcantes quando se trata do tema da arquitetura escolar padronizada no Brasil, que certamente influenciou a adoção desse sistema nos demais projetos que vieram a seguir.

É possível observar que existem similaridades entre os projetos, embora os novos projetos tenham abandonado de certo modo a linearidade funcionalista dos CIEPs em prol de uma organização mais autocentrada, com

espaços dispostos em uma lógica de ferradura, mais adaptada com a teoria pan-óptica descrita por Foucault (1999/1975). Esta organização é comumente observada em edifícios escolares de forma geral, que busca alcançar uma maior vigilância e controle social. Para além disso, os novos pátios centrais cobertos dos projetos mais recentes, além de permitirem que o edifício como um todo seja mais independente do entorno ao negá-lo, também potencializam problemas acústicos (Oliveira Goes et al, 2011).

Contemporâneos aos dois últimos projetos padronizados cariocas, os projetos de São Paulo mediados pela FDE foram projetados especificamente para cada terreno por diferentes escritórios de arquitetura paulistas de grande notabilidade (Palermo, 2021; Gimenez, 2005).

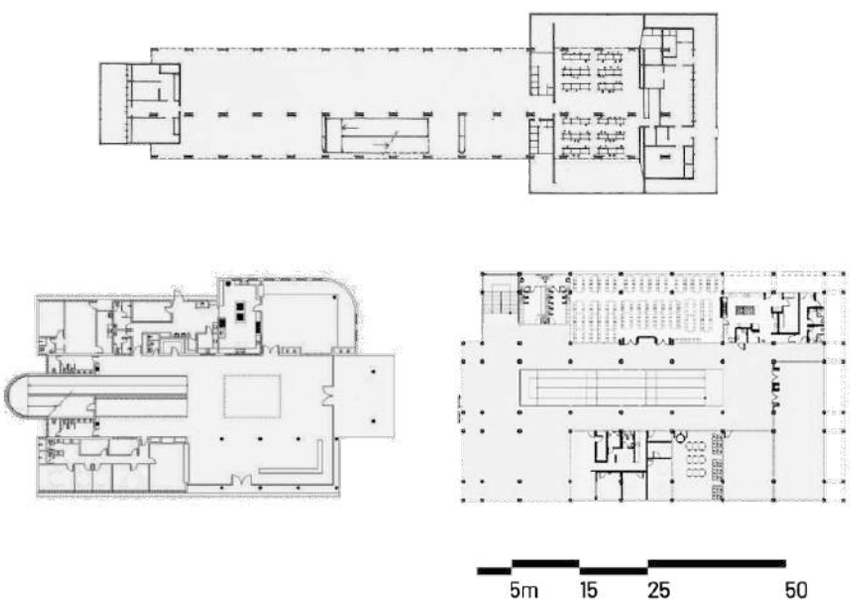

Figura 1. Planta do pavimento térreo do bloco principal das escolas do Rio de Janeiro na mesma escala. Na ordem CIEPs, Modulares Padrão e Escolas do Amanhã. Fonte: Acervo dos autores, 2020

A estética destes edifícios é bastante influenciada pelo brutalismo paulista: volume bem marcado, concreto aparente e a utilização de brises e cobogós. Alguns dos aspectos importantes que foram considerados dizem respeito ao programa do térreo, é possível observar que o pátio coberto tem cerca de metade da área do que pode se considerar bloco principal do edifício, em metade dos casos tem pé direito duplo e está sempre ligada ao refeitório internamente, e à um pátio externo pavimentado.

A circulação vertical localizada nas extremidades do edifício, e não no centro como nas escolas cariocas, permite com maior facilidade a alocação

de quadra esportiva no último pavimento. Um aspecto que certamente tem um papel importante no sucesso desses projetos é a ocupação do terreno que fica entre 25 e 35% considerando a projeção dos edifícios em todos os projetos relacionados, garantindo pátios mais confortáveis e uma melhor relação do edifício com o entorno.

Todos esses projetos foram estruturados espacialmente utilizando uma malha de 90cm onde as salas de aula correspondem 8x8 módulos, ou seja 7,20m que é também a distância entre os pilares longitudinalmente. É importante notar que estes projetos ocupam uma área muito menor que as contrapartes cariocas mesmo quando o número de salas de aula é comparável, isso se dá principalmente porque esses projetos também tem uma área expressivamente menor de circulação e serviços, incluindo refeitórios, que são menores nos projetos paulistas.

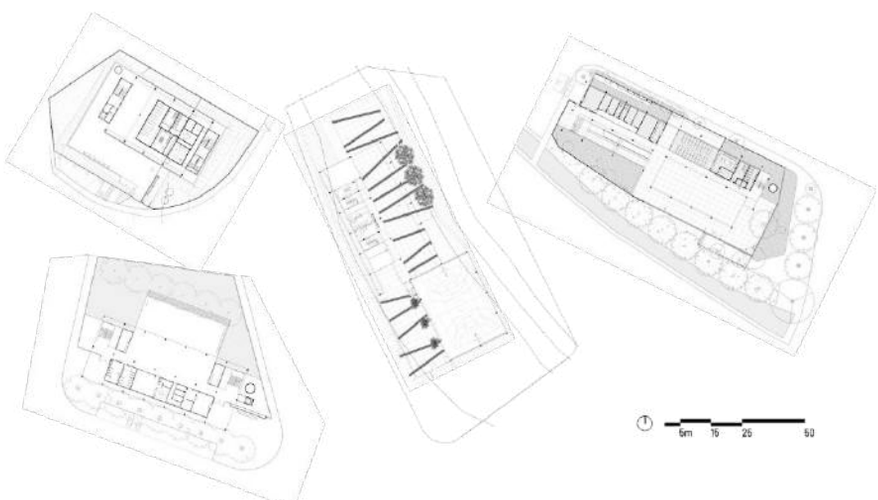

Figura 2. Planta do pavimento térreo das escolas de São Paulo na mesma escala.
fonte: Acervo dos autores, 2020

2.5 Gramática de escolas

A gramática se desenvolve em 5 estágios de forma bastante linear, onde as formas possíveis em cada estágio dependem das formas e parâmetros (principalmente referente ao dimensionamento dos espaços) dos estágios posteriores. O estágio 1 então acaba sendo o mais importante, e é onde é definido a quantidade e tamanho, assim como posição relativa entre os blocos de sala de aula e a posição da circulação vertical, tendo em vista que a circulação vertical é dada por uma rampa, que acaba por ocupar uma área relevante no projeto. O estágio 1 termina com a inserção do pátio externo de acordo com a posição dos blocos e os estágios posteriores do 2 ao 5 tratam de instanciar elementos pertencentes a um vocabulário de formas referentes às estruturas e fechamentos a cada pavimento da edificação

respectivamente, ficando o estágio 6 com a inserção de elementos de cobertura que finalizam.

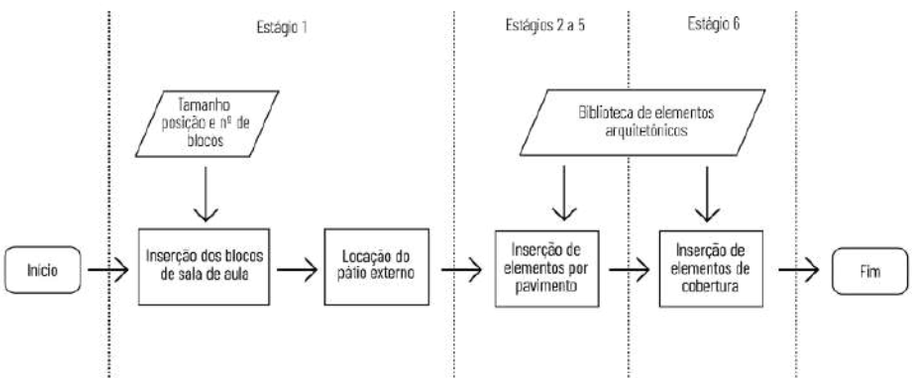

Figura 3. Fluxograma dos estágios de regras. Fonte: Acervo dos autores, 2020

Estágio 1: Definição do arranjo dos blocos. Define o posicionamento geral dos blocos e posição da circulação vertical dada por rampa, bem como a posição do pátio externo com base na posição dos blocos.

Estágio 2: Definição de elementos do pavimento térreo. A partir das formas geradas no primeiro estágio gera as lajes do pavimento térreo com operações de extrusão. Com as lajes formadas então é possível instanciar elementos de fechamento que dizem respeito ao programa arquitetônico do térreo. Neste estágio existe a possibilidade de transformar o bloco secundário em uma quadra térrea, se forem respeitadas as dimensões mínimas.

Estágio 3: Definição de elementos do primeiro pavimento. Neste estágio a maioria das regras são inseridas em consequência dos estágios anteriores, aspecto que diferencia esse estágio é a estrutura que possibilita o mezanino e a inserção dos elementos que constituem a parte administrativa do edifício.

Estágio 4: Definição de elementos do segundo pavimento. Assim como o estágio anterior, este estágio toma como base as dimensões estabelecidas nos estágios anteriores e aloca principalmente as salas de aula.

Estágio 5: Definição de elementos do terceiro pavimento. Neste estágio existe a possibilidade de inserção de quadra esportiva ou conjunto de salas de aula na cobertura.

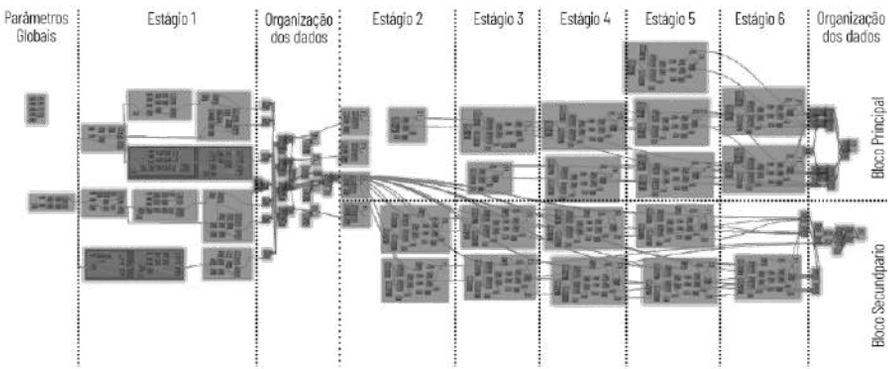

Figura 4. Captura de tela da definição em Sverchok, mostrando sua relação com a estrutura de estágios da gramática. Fonte: Acervo dos autores, 2020

3 Resultados

A gramática gerada possui 119 regras possibilita a geração de 312 modelos diferentes, as quais podem ser filtradas através dos parâmetros: existência de bloco secundário, localização da circulação vertical (que influi na localização do bloco secundário caso este exista), tamanhos dos blocos principal e secundário, existência de quadra térrea ou na cobertura e espelhamento da edificação.

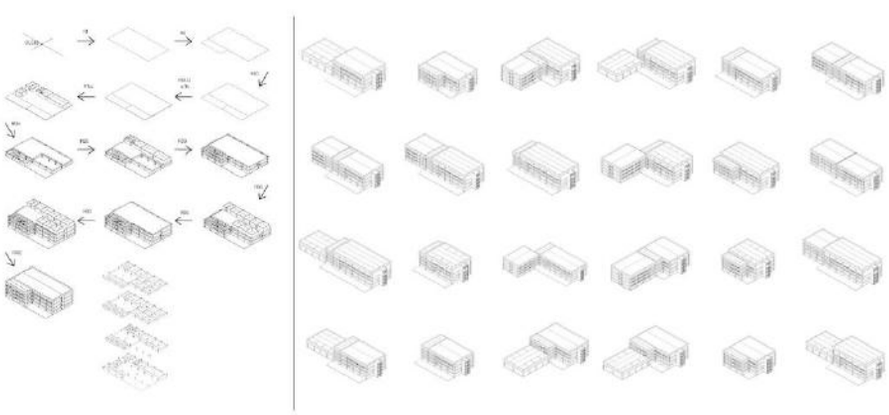

Figura 5. Exemplo de derivação possível (a esquerda) e matriz com algumas possibilidades de projeto geradas (a direita). Fonte: Acervo dos autores, 2020

4 Exemplo de aplicação

Com o fim de testar a aplicação da gramática em uma situação real de projeto, foi escolhido um terreno localizado no Rio de Janeiro, no bairro de Madureira. Terreno este pertencente à prefeitura e no qual estava em construção um modelo de Escola do Amanhã no momento da pesquisa. O script gramatical permitiu testar-se rapidamente várias possibilidades das quais foram escolhidas 3 para se analisar mais a fundo.

Em comparação com a maneira em que os projetos de escolas municipais são propostos no Rio de Janeiro atualmente, só seriam possíveis dois modelos de escola que variam em tamanho, enquanto o modelo proposto permite testar várias possibilidades, e inclusive possibilita que sejam considerados parâmetros, por exemplo, a escolha de uma faixa de ocupação de terreno ótima para cada contexto urbano, que pode ser definida a partir de pesquisas qualitativas, ou mesmo análises numéricas feitas a partir dos modelos gerados.

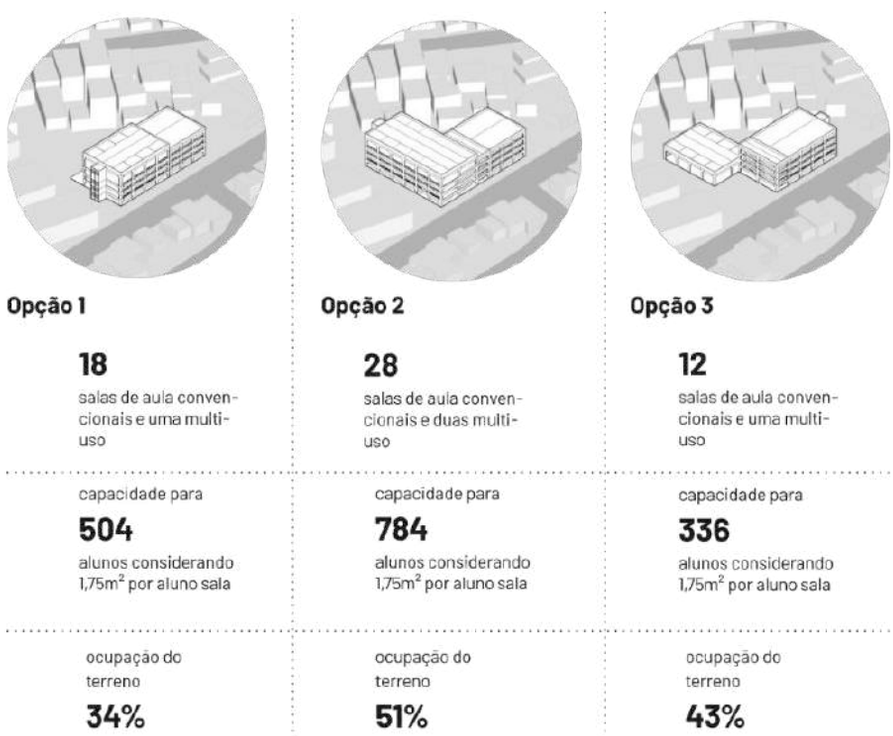

Figura 6. Comparação entre variações de projeto escolhidas. Fonte: Acervo dos autores, 2020

5 Discussão

A possibilidade de geração de diversas soluções utilizando um sistema como a gramática da forma pode ser de grande importância no contexto utilizado, não só pela velocidade na produção das soluções em um ambiente computacional, mas pelas possibilidades que são abertas. Sendo assim, a gramática da forma apresenta-se como um modelo de geração de alternativas de projeto que pode ser utilizado como base para outras metodologias computacionais, como ferramentas de análise ambiental e algoritmos genéticos. Além disso, podem contribuir na fase de concepção de projeto, a partir da comparação entre as soluções geradas. Um fator interessante na metodologia desenvolvida é a possibilidade de criar uma gramática a partir da apropriação crítica de precedentes arquitetônicos. Na fase analógica do trabalho, o desenvolvimento da Gramática buscou, mais do que definir regras que permite antecipar cada passo do processo, um arcabouço que permite delinear a estrutura do algoritmo e as características espaciais do edifício projetado. Dentro da lógica de uma solução que reduza os custos desde a fase projetual, o emprego de software open source aumenta a acessibilidade aos processos, fator importante para projetos de cunho social.

Referências

Blender Development Team. (2020). Blender (Version 2.82.0) [Computer software]. https://www.blender.org

Celani, G., Cypriano, D., de Godoi, G., & Vaz, C. E. V. (2006). A gramática da forma como metodologia de análise e síntese em arquitetura. Conexão-comunicação e cultura, 5(10).

Chokyu, M. L., & Dias, M. A. (2018). Favela’s houses as design reference: using shape grammar. Journal of Civil Engineering and Architecture, 12(7), 483-92.

Chomsky, N. (1957). Syntactic Structures. The Hague: Mouton.

Duarte, J. P. (2005). Towards the mass customization of housing: the grammar of Siza's houses at Malagueira. Environment and planning B: Planning and Design, 32(3), 347-380.

Foucault, M. (1999). Vigiar e punir. Vozes. (Original work published 1975)

Gimenez, L. E. (2005). As quatro escolas do FDE em Campinas. Arquitextos, 6 (064.02).

Knight, T. (1999) Applications in Architectural Design, and Education and Practice. Relatório, Workshop on Shape Computation. Cambridge: Massachusetts Institute of Technology.

Kolarevic, B., DUARTE, J.P. (2019). Mass Customization and Design Democratization. Londres e Nova York: Routledge.

Kowaltowski, D. C. (2011). Arquitetura escolar: o projeto do ambiente de ensino. Oficina de textos.

Mitchell, W. J. (1990). The Logic of Architecture. Cambridge: MIT Press.

Morais, M. de, Santos, L. G. M. dos, Pina, S. A. M. G. (2014). A Leitura Da Gramática Da Forma Do Conjunto Habitacional Campinas-F Da Cdhu Em Campinas. Gestão & Tecnologia de Projetos, 9(2), 23-36.

Oliveira Goes, C. A. F., Martins, V. R., Bueno, L. C., Niemeyer, M. L. A. (2011, August). Escolas-padrão na Cidade do Rio de Janeiro: uma abordagem acústica. In SBQP 2011-Simpósio Brasileiro de Qualidade do Projeto no Ambiente Construído.

Palermo, N. S. (2021) Escolas modernas em São Paulo: passado e presente. Arquitextos, 21(249.08).

Post, E. L. (1943). Formal reductions of the general combinatorial decision problem. American journal of mathematics, 65(2), 197-215.

Stiny, G., & Gips, J. (1971, August). Shape grammars and the generative specification of painting and sculpture. In IFIP congress (2) (Vol. 2, No. 3, pp. 125-135).

Stiny, G. (1980). Kindergarten grammars: designing with Froebel's building gifts. Environment and Planning B: Planning and Design, 7(4), 409-462.

Sverchok Community. (2020). Sverchok (Version vstable4) [Computer software]. https://github.com/nortikin/sverchok

Willis, B. R., Hemsath, T. L., & Hardy, S. (2012). A parametric multi-criterion housing typology.

Manufacturing & Industry 4.0: Robotics

Soft Architecture: Application of Soft Robotics in the Design Responsive-Interactive Architecture

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Abstract. The main objective of this research is to develop a method that can integrate responsive and interactive architecture through the application of soft robotics on a façade. To achieve this objective, a review of the main concepts, adaptive architecture (responsive-interactive) and soft robotics was first carried out. Secondly, recent studies and research that speak of the application of soft robotics in architecture are analyzed. With the knowledge acquired in the analyzes and reference studies, together with the help of programming and computational design tools, a scalable physical prototype was developed that manages to integrate both types of adaptive behaviors (responsive-interactive) in a single hybrid robotic system (soft-rigid), demonstrating the potential of soft robotics in architecture, in this case being applied to be sensitive and act on changes in temperature produced by solar radiation.

Keywords: robotics, generative design, adaptive architecture, sustainable design, soft

1 Introducción

Este trabajo indaga en la intersección de tres áreas generales, la arquitectura de comportamiento adaptativo, los materiales blandos y la robótica. Siendo específicamente el área de investigación la arquitectura responsiva e interactiva mediante la implementación de los *soft robotic*.

En la actualidad, los sistemas adaptativos utilizados, en su mayoría, solo responden a una variable externa, por ejemplo, los cambios climáticos (responsivo), dejando de lado la variable interna (interacción), donde el uso del espacio y el comportamiento humano son relevantes. Como en la mayoría de los casos, la respuesta del sistema adaptativo es unidireccional, es decir solo responde al exterior o interior (no a ambas), la interacción que está asociada al usuario pasa a segundo plano, por lo cual no hay una relación directa entre

responsividad e interacción. La implementación de los *soft robotic* en la arquitectura de comportamiento adaptativo surge como una oportunidad para investigar cómo las propiedades de los materiales blandos pueden aportar a mejorar las posibilidades de involucrar a los habitantes del lugar en un intercambio interactivo directo entre ellos y su entorno construido (Al Faleh, 2017).

En el artículo “Soft Systems: Rethinking Indeterminacy in Architecture as Opportunity Driven Research”, Dickey (2017), mediante una recopilación de investigaciones recientes, utiliza el concepto indeterminable para referirse a los materiales blandos por sus propiedades deformativas, no-lineales y poco predecibles. Asimismo, propone replantear que aquella indeterminación del material visto comúnmente como un elemento de azar por su forma cambiante y de carácter alterable, sea visto, más que como un obstáculo, como una oportunidad de diseño y de estudio respecto a la indeterminación con relación al comportamiento humano (Dickey, 2017) como una posibilidad de interacción.

Entonces, este *artículo buscará* el cruce de la arquitectura y los *soft robots*, con el objetivo de aportar en el desarrollo de arquitectura responsiva e interactiva —que hoy es escasa— a través del estudio de los sistemas robóticos blandos y sus propiedades materiales como medio para llegar a integrar en un solo sistema ambos comportamientos (responsivo e interactivo).

2 Antecedentes

2.1 Arquitectura adaptativa

La arquitectura adaptativa, en palabras de Omar Al Faleh (2017), surge de la intersección entre la arquitectura, el diseño y la tecnología, es decir, es un campo de diseño arquitectónico que se beneficia de la tecnología para crear sistemas autónomos capaces de adaptarse al medio al que se van enfrentando (responsivo o interactivo). En términos prácticos, cuando la arquitectura adaptativa es ambientalmente responsiva, puede ayudar a controlar y reducir el consumo energético de un edificio, aprendiendo y respondiendo a patrones climáticos mediante cambios morfológicos en el edificio, promoviendo una arquitectura más sustentable. El desempeño energético es parte del fin funcional de la arquitectura adaptativa, pero también lo son la protección de agentes medioambientales (lluvia, viento, contaminación, etc.), el confort (térmico, lumínico, calidad de aire, etc.), entre otros elementos.

Si bien es cierto que actualmente el enfoque principal de la arquitectura adaptativa se vincula más a una mirada medioambiental y de eficiencia energética, los sistemas adaptativos hasta fines del siglo XX y principios del XXI se asociaban más a elementos estéticos, temporales e interactivos que buscaban demostrar la potencialidad de estos sistemas, y no tanto con algo funcional y permanente en un edificio.

En general, los sistemas adaptativos pueden ser clasificados según la variable a la que responden (a los medios externo o al interno), al tipo de sistema (fachada, iluminación, acústica, etc.) y a su forma de activación (si es activa o pasiva dependiendo del uso o no uso de energía eléctrica).

2.2 *Soft* robotic

Dentro de la robótica, existen dos categorías en las que se pueden clasificar los robots según la materialidad con la cual están construidos, los de materiales duros y los suaves o blandos. La robótica dura o rígida representa al común de los robots que tenemos en nuestro imaginario al escuchar la palabra, fabricados en su mayoría de metal, con articulaciones y mecanismos complejos de materiales rígidos. Comúnmente, estos funcionan mediante actuadores eléctricos (motores y solenoides) o con fluidos presurizados (neumática o hidráulicamente). La robótica blanda, a diferencia de la rígida y como su nombre lo indica, está constituida por materiales blandos y flexibles que tienen la capacidad de deformarse fácilmente, lo que los hace versátiles, adaptables, eficientes y seguros a la interacción humana.

Según Medina y Vélez (2014), actualmente, podemos identificar dos enfoques con los que se trabaja la idea de “suavidad” en el ámbito robótico. El primer enfoque consiste en el uso de robots convencionales (rígidos) que han sido modificados con partes suaves con el objetivo de tener un comportamiento más seguro, ya que comparten espacio de trabajo con personas. Estos son los casos de los robots manipuladores de alimentos con pinzas suaves presentes en la industria alimentaria. El segundo enfoque, más radical que el anterior, trata de los robots intrínsecamente blandos. Así, tanto su cuerpo como actuadores se componen de materiales suaves cuyo módulo de elasticidad está en el orden de 102-106 Pa, es decir, entre 3 y 10 veces menos rígidos que los robots convencionales (Majidi, 2014).

Este enfoque es posible por los avances en las últimas décadas en tecnologías como impresiones 3D y 4D, materiales inteligentes con memoria de forma, metamateriales y actuadores neumáticos. Actualmente, en la práctica, el primer enfoque es el más usado, debido a que la mayoría del desarrollo de los *soft robotic* está centrado en actuadores y componentes blandos que complementan máquinas complejas rígidas generando una robótica híbrida. El uso de componentes blandos en robots rígidos es una buena idea teniendo en cuenta algunas limitaciones que estos tienen. Según Whitesides (2018), podemos reconocer elementos de los cuales los robots rígidos carecen y que pueden ser complementados o en su defecto abarcados en totalidad con *soft robotic*. Entre ellos, se encuentran la poca colaboración y compatibilidad con los humanos, la poca simplicidad, lo que lleva a altos costos de construcción, y la poca eficiencia termodinámica que, en consecuencia, puede traer alto uso energético.

3 Metodología

Este estudio está comprendido por dos procedimientos metodológicos, el primero de recopilación de antecedentes, estudio de referentes y revisión de investigaciones recientes; y el segundo exploratorio experimental, donde se trabajó bajo dos tipos de exploraciones, un comportamiento interactivo, en el cual se trabajaron varios tipos de interacciones (gestos) y cómo llevarlas del mundo digital al físico, y un comportamiento responsivo, en el cual se buscó aplicar los *soft robotic* mediante el uso de una SMA (nitinol) para que la fachada también sea responsiva al sol.

3.1 Experimentación

Se escogió una fachada como caso de estudio debido a que en esta se encuentran respuestas tanto al exterior como al interior. Esto la convierte en una frontera entre ambos medios, la cual propicia un gran potencial para integrar un comportamiento adaptativo desde el punto de vista responsivo e interactivo. Debido a esto, se diseñó un entramado geométrico (retícula) compuesto de módulos adaptativos que permiten dichas respuestas.

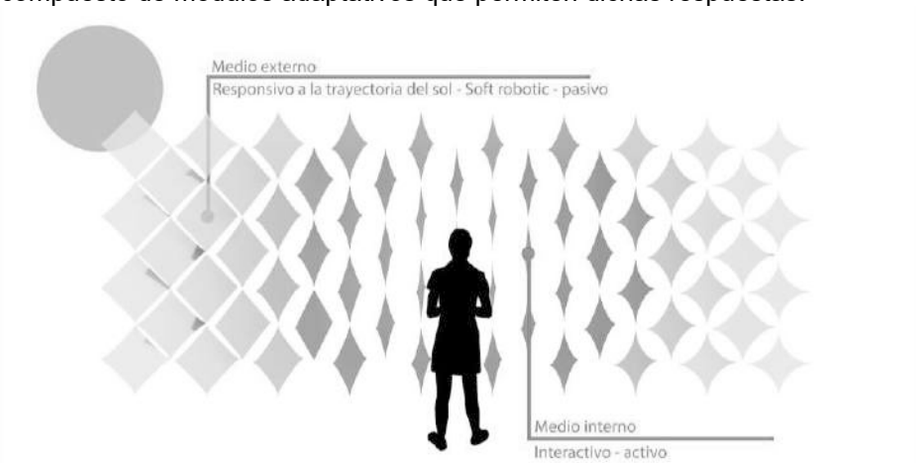


Figura 1. Forma de comportamiento del sistema responsivo e interactivo.

Dada la problemática inicial de que los sistemas adaptativos únicamente responden a una variable, ya sea a un medio externo o interno, en términos de tipos de movimientos realizados se traduce todo el tiempo a uno, abrir o cerrar, arriba o abajo, entre otros. Por lo tanto, para el diseño de esta fachada, era importante integrar dos tipos de movimientos distintos (figura 2), destinados uno a responder a la trayectoria del sol a los cambios de temperatura asociados a este, y otro a las interacciones humanas.

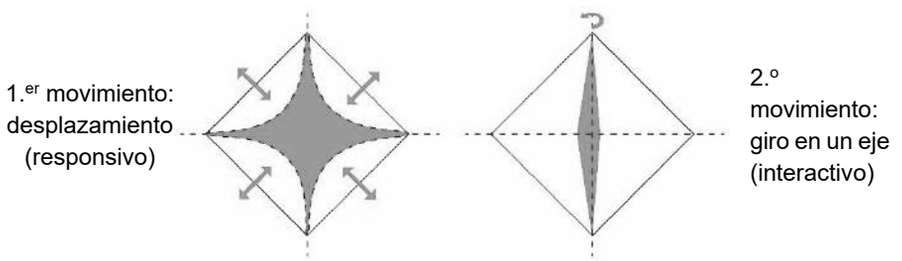


Figura 2. Tipos de movimientos de la fachada adaptativa.

Otro aspecto fundamental del diseño es que se buscó que la acción de responder al medio externo sea pasiva, particularmente por dos razones, disminuir la complejidad del sistema y un ahorro energético. Estas condiciones hacen ideal el uso de *soft robotic* y elementos blandos en la parte responsiva del proyecto.

Las interacciones van ligadas a otro tipo de factores y elementos que requieren un constante suministro de energía eléctrica, como los sensores que capturarán los movimientos de las personas y los controladores que procesarán y ordenarán a la fachada cómo debe actuar en función de una programación. De esta manera, se darán diferentes tipos de integraciones o hibridaciones en una misma fachada, pasivo/activo, *robotic* / *soft robotic* y responsivo/interactivo.

En esta etapa del trabajo, fue imprescindible el uso de herramientas de diseño computacional y de simulación. Para la construcción del modelo digital, se emplearon técnicas de modelado algorítmico y paramétrico a través del *software* Rhinoceros junto al *plug-in* Grasshopper. Además, se utilizaron *plug-ins* de simulación como Ladybug, que extrae datos ambientales reales, y Kangaroo 2, que permite realizar una simulación de elementos blandos. Esto es importante debido a que la parte responsiva del proyecto es la que integra *soft robotic* y materiales blandos. El trabajo en conjunto de ambos *plug-in* permite simular el comportamiento de la fachada (*soft robotic*) ante la posición del sol.

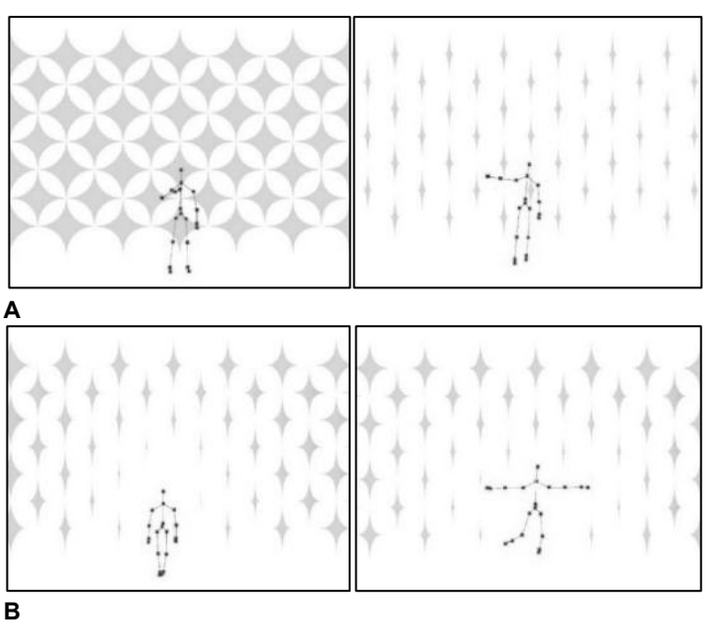
3.2 Comportamiento interactivo

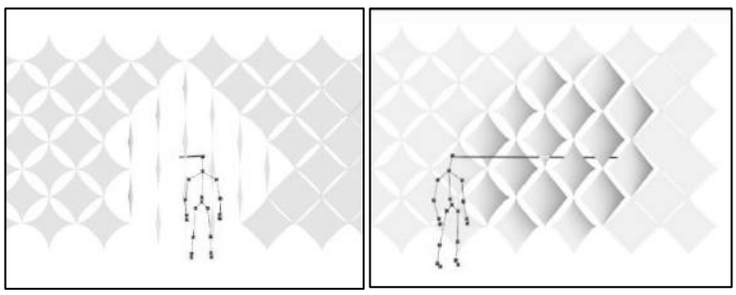
Las interacciones requirieron un flujo de trabajo mediante la hibridación de diferentes dispositivos para asegurar que las interacciones se vean reflejadas tanto en el modelo digital como en el físico (figura 3). De esta manera, el dispositivo a cargo de capturar las interacciones fue una Kinect, originalmente creado para juegos interactivos para la consola Xbox 360. La decisión de optar por este dispositivo y no por otro, como un sensor ultrasónico, fue porque, en primer lugar, Kinect incluye tres sensores, láser IR, cámara RGB y cámara de profundidad, además de incorporar micrófonos. Esto permite una detección precisa tanto del espacio como del movimiento. Lo interesante de la Kinect, aparte de sus sensores, es que es compatible con el *plug-in* Firefly de

Grasshopper, lo que permite detectar la presencia humana a través de un esqueleto representado en Rhinoceros. Firefly, a través de Grasshopper, es esencial en esta etapa del trabajo, debido a que, además de ser compatible con Kinect, posibilita un flujo directo entre el modelo digital y el Arduino. Gracias a informaciones de giros (ángulos) obtenidos desde el modelo digital, se puede dar la orden a un servomotor para que haga exactamente el mismo movimiento, todo esto mediante la conexión Firefly-Arduino.

Figura 3. Hibridación de diferentes elementos electrónicos.

Las interacciones se dividieron en dos tipos, gestual y automática. Las interacciones gestuales son aquellas que requieren un movimiento voluntario para poder abrir o cerrar la fachada, a diferencia de las automáticas, donde la fachada se abre o cierra dependiendo de la presencia de la persona, sin la necesidad de algún gesto en específico.

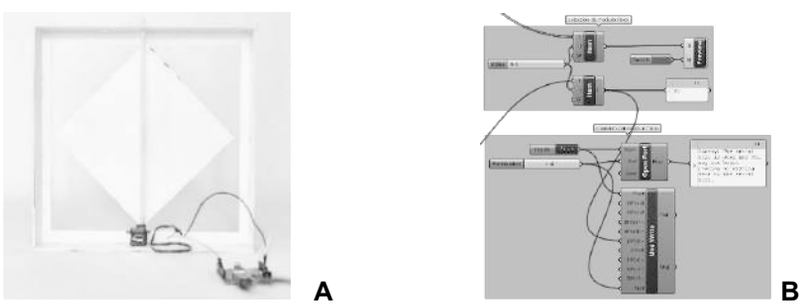




C

Figura 4. (A) interacción gestual, se activa con un gesto de mano; (B) interacción automática, la fachada se activa en donde se encuentre la persona; (D) interacción automática, la fachada se abre en la zona donde la persona está mirando.

Para finalizar la experimentación de la parte interactiva, se construyó un modelo físico de prueba (A), con el objetivo de comprobar que la conexión con Arduino sea exitosa, y que esta sea capaz de reproducir los movimientos de un módulo seleccionado en el modelo digital (B) (figura 5).



A B

Figura 5. (A) Modelo físico de pruebas, (B) *script* de selección de modulo digital

3.3 Comportamiento responsivo

El estudio del comportamiento responsivo de esta investigación está pensado para integrar el *soft robotic* a este sistema de fachada responsiva-interactiva.

Como actuador se decidió usar una aleación metálica con memoria de forma (SMA), en este caso, el nitinol. Este es una aleación de níquel y titanio en proporciones casi iguales (45% y 55%, respectivamente) que se presenta en dos fases estables, una a alta temperatura, austenita, y otra a baja temperatura, martensita. Cuando el nitinol se encuentra en fase martensita es fácilmente deformable, pero al aplicarle una fuente de calor o energía eléctrica este entra en una etapa de transición hasta llegar a la fase austenita, en donde el material vuelve a su forma original con propiedades superelásticas. Luego de enfriarse el nitinol, vuelve a la fase martensita sin deformar.

La experimentación responsiva del trabajo consistió en dos partes. La primera fue lograr reprogramar un nitinol (temperatura 40 °C) de una forma

lineal a una forma de resorte y la segunda fue realizar el ejercicio de fuerza contra fuerza del nitinol con una liga o elástico.

La idea del segundo ejercicio es que el nitinol cuando esté en fase martensita (fase fácilmente deformable) tome una forma estirada por la contracción de un elástico; sin embargo, cuando se aplique el calor de transición, el nitinol vuelva a su forma original (resorte) (figura 6). Esto aplicado a la fachada tiene la lógica de que, cuando el nitinol reciba el calor suficiente por parte del sol, este se contraerá cerrando la fachada. Cuando el nitinol deje de recibir el calor o la radiación necesaria para su transición de la etapa martensita a la austenita, este se volverá a estirar por la tensión del elástico, volviendo a abrir la fachada.

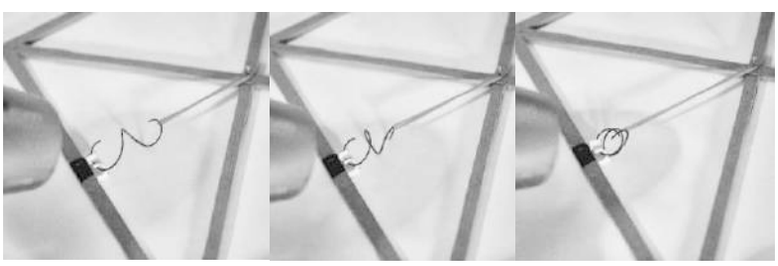


Figura 6. Prueba de tensión y contracción del nitinol y la liga luego de aplicar calor con un secador de pelo.

3.4 Prototipo

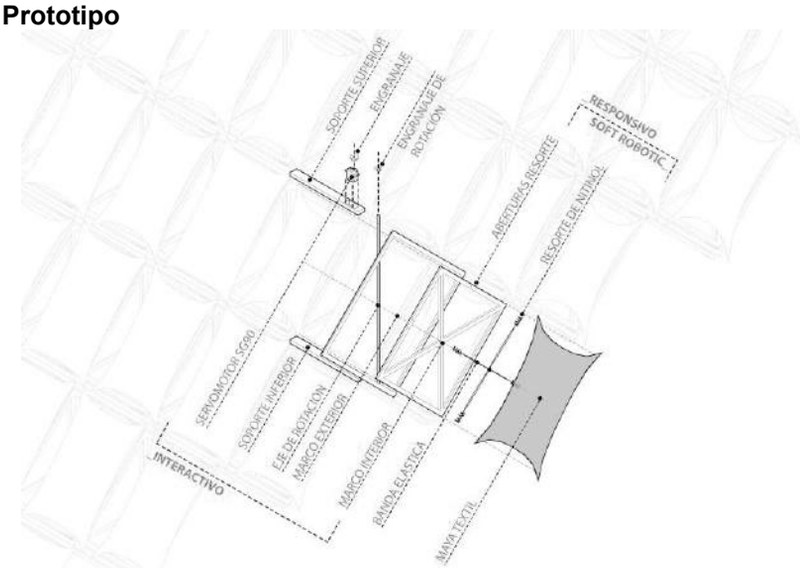


Figura 7. Despiece isométrico de las partes del módulo prototipo físico.

El prototipo final consiste en un módulo de 30 x 30 cm de la retícula de la fachada. Este consta de tres partes importantes. En primer lugar, el marco exterior que tiene el rol de soportar los demás elementos. En segundo lugar, el marco interior, que es donde ocurren ambos movimientos (responsivo-interactivo), además de contener el *soft robotic*. Por último, las barras de soporte en ambos extremos del marco exterior. En las barras, se encuentra el mecanismo de giro (servomotor), que se encarga de la parte interactiva del proyecto (figura 7).

El nitinol usado para este trabajo tiene una temperatura de transición de aproximadamente 40 °C. En funcionamiento en conjunto al elástico, en las pruebas hechas al someter al calor al nitinol con un secador de pelo, este fue capaz de contraerse entre 4 y 5 cm, logrando cerrar casi por completo la fachada (figura 8). También se probó el sistema responsivo en exposición al calor del sol. Con una temperatura de 28 °C el nitinol fue capaz de contraerse 1.5 cm como máximo en los primeros 5 minutos desde la exposición, manteniendo la longitud luego de eso. Este resultado es muy alentador, teniendo en consideración la alta temperatura de transición del nitinol utilizado; por lo que, si en un caso hipotético se decidiera hacer la fachada para algún edificio, un nitinol con temperatura de transición de 20 a 35 °C bastaría para que funcione correctamente.

El *soft robotic* del sistema responsivo lo completa una piel, que consiste en una maya de material blando; en este caso, una tela elástica que permite deformarse, adaptándose a los movimientos del nitinol.

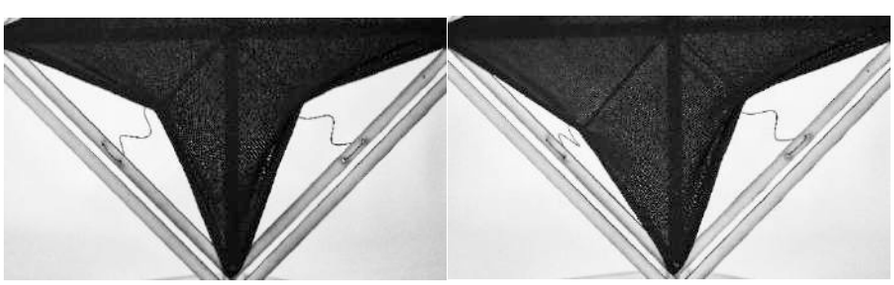


Figura 8. Cerramiento de la fachada a través del nitinol antes y después de la exposición al calor.

El prototipo (figura 9) funciona de tal forma que, al establecer la conexión entre Arduino, la Kinect y Grasshopper, este comienza a responder a las interacciones programadas, pudiendo escoger cuál interacción se desea que esté activa. A la misma vez, mediante el *soft robotic*, es posible modificar la apertura de la piel con una fuente de calor a partir de 35 a 40 °C, aproximadamente.

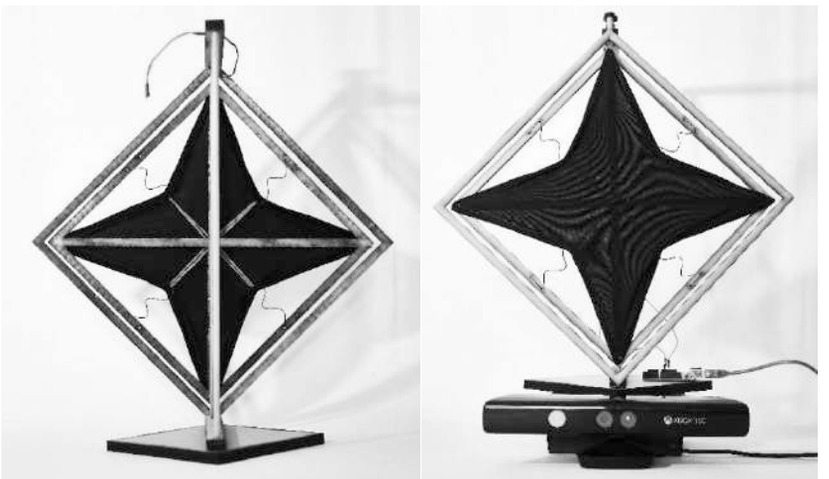


Figura 9. Prototipo del sistema responsivo-interactivo (módulo adaptativo, Kinect, Arduino).

4 Resultados

1. El prototipo tiene el comportamiento esperado, debido a que consigue una respuesta pasiva cuando está expuesto al calor y una activa con las interacciones, todo en un mismo sistema integrado.

2. Las expresiones o gestos de los que está compuesta la parte interactiva del trabajo tiene un gran potencial de personalización. Existe la posibilidad de que, así como se programaron ciertas interacciones propias (por ser el autor), también el sistema pueda ser personalizable desde el punto de vista de quien lo utiliza, entendiendo que cada persona puede tener una forma diferente de hacer los gestos para determinadas acciones. De esta manera, el sistema podría actuar según el usuario y no solo de un modo preestablecido.

3. La programación del nitinol empleado fue relativamente sencilla, puesto que el nitinol del prototipo venía previamente entrenado y con una temperatura de transición específica (40 °C). También se experimentó con un nitinol no entrenado que no tenía temperatura de transición, debiendo asignarla uno mismo, lo que es dificultoso si no se tienen elementos específicos para medir los ciclos de calentado y la temperatura, además de hornos que alcanzan altas temperaturas.

4. Fue posible hacer este sistema integrado a través de la hibridación de distintos elementos previamente diseñados que no necesariamente están hechos para lo que se utilizaron en esta investigación. La manera de integrarlos fue mediante el uso de Grasshopper y sus *plug-ins*, que, en complementación del *soft robotic*, permitió crear un sistema robótico *híbrido* capaz de adoptar ambos comportamientos adaptativos (responsivo-interactivo).

Figura 10. Imagen objetivo de la fachada.

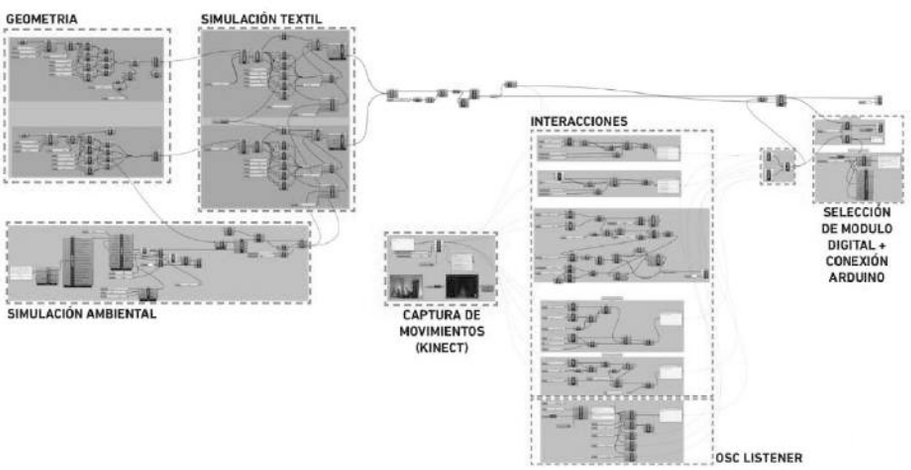


Figura 11. *Script* de la fachada responsiva.

5 Discusión

Una arquitectura que sea capaz de adaptarse a los cambios ambientales, pero que a la vez tenga en cuenta la presencia humana, supone una arquitectura que no es estática y que evoluciona en ambos sentidos, lo cual puede conllevar un sin fin de beneficios. Por un lado, si lo vemos desde un punto de vista responsivo, el poder adaptarse a cambios en el ambiente posibilita la protección de elementos externos, pudiendo aumentar la esperanza de vida de un edificio y también disminuir el consumo energético, entre otros. Desde el punto de vista interactivo, es interesante reflexionar en

una arquitectura expresiva, que sea capaz de reconocer qué actividades se están dando dentro de un espacio, y adapte sus condiciones morfológicas para mejorar la realización o, incluso, posibilitar dichas actividades.

Al iniciar esta investigación, la teoría indicaba que los *soft robotic* podían tener un potencial gigante en las interacciones por sus capacidades blandas y su compatibilidad con los humanos. Es por esto que la aplicación de *soft robotic* a las interacciones en la arquitectura es una oportunidad de investigación relevante, sobre todo, si aquellas interacciones no requieren un suministro constante de energía para funcionar. Un ejemplo de esto es la posibilidad de utilizar nitinol con una baja temperatura de transición (15 o 20 °C) para generar cambios en un edificio únicamente con el calor corporal, sin la necesidad de energía eléctrica, *software* ni mecanismos complejos, solamente la inteligencia del material.

Un camino para avanzar en el estudio de arquitectura adaptativa es mediante la hibridación. Esta permite explorar elementos existentes que están aparentemente separados y juntarlos para obtener un resultado nuevo, distinto al fin para el que fueron hechos. En este caso en particular, permitió integrar dos elementos que por lo visto no suelen relacionarse, responsividad e interacción. Si bien el sistema es una hibridación de varios elementos (Grasshopper, Arduino y Kinect), estos son *open source*. Esto da la posibilidad de que, en caso de querer desarrollar una fachada completa, se adapte la programación a un lenguaje que sea compatible a ordenadores de placa pequeña, como Raspberry Pi. Esto permitiría dejar de emplear una computadora convencional o *laptops* para controlar la fachada, lo que reduciría el tamaño del sistema y la complejidad, y la haría aún más accesible en términos económicos.

Referencias

Al Faleh, O. (2017). Responsive Architecture a Place Making Design Strategy.

De Queiroz, N., Carvalho, J. M., Verzola, C. E. & Nome, C. A. (2018). Pared cinética: una fachada humana y ambientalmente responsiva. Un enfoque de educación en arquitectura. *Arquitecturas del Sur*, *36*(54), 58-69. https://doi.org/10.22320/07196466.2018.36.054.05SAD

Dickey, R. (2017). Soft Systems: Rethinking Indeterminacy in Architecture as Opportunity Driven Research. Protocols, Flows and Glitches, Proceedings of the 22nd International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA), Bhatia 2012, 811-821.

Majidi, C. (2014). Soft Robotics: A Perspective-Current Trends and Prospects for the Future. *Soft Robotics*, *1*, 5-11. 10.1089/soro.2013.0001

Medina H. J. & Vélez N. P. (2015). “Soft Robotic”: una nueva generación de robots. *Maskana*, *0*(0), 109-118.

Whitesides, G. M. (2018). Soft Robotics. *Angewandte Chemie - International Edition*, *57*(16), 4258-4273. https://doi.org/10.1002/anie.201800907

Experimental Study of Prototyping of Autonomous Responsive Cell Panels for Pavilion Design in the Midwest Region of Brazil

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Abstract. There is little research on the possibilities and limitations of digital design, prototyping and manufacturing of architectural components inspired by microscopic plant structures. The hypothesis was that "prototypes of autonomous responsive cell panels can be produced using digital manufacturing by addition and robotics. The objective was to determine the possibilities and limitations of the design, prototyping and manufacture of a responsive cell prototype inspired by the microscopic plant structures of the peel of fruits of Annona Cherimola, Mill and Annona Squamosa, L. (atemoia), Mauritia Flexuosa (buriti), Attalea ssp (babassu coconut), Annona Muricata (soursop) and Annona Squamosa (pine cone or conde fruit). Autonomous responsive cells inspired in plant structures can be produced. But the autonomous responsive cell controlled for sensor-presents itself as an alternative to automatic orientation toward a natural (sun) or artificial lighting source.

Keywords: Robotics, Biomimetic, Responsive Architecture, Arduino, Digital Fabrication.

1 Introdução

This article is about the fifth experiment of seven carried out in the doctoral thesis entitled “Design and Manufacture of a Complex, Cellular and Responsive Biomimetic Pavilion with Digital Technologies and Robotics in Brasília - DF”. Within the research project of “Parametric Modeling, Digital Fabrication and Mass Customization”. Research line of “Production Technology of the Built Environment”. Concentration area of “Technology, Environment and

Sustainability". Graduate Program at the Faculty of Architecture and Urbanism - PPGFAU - University of Brasilia - UnB - Campus Darcy Ribeiro.

The advancement of 3D modeling and digital fabrication by addition technologies has allowed the design and manufacture of prototypes of artifacts with complex shapes in the area of architecture; but there are few experiences that have pointed out the possibilities and limitations of these technologies for the production of components inspired by the structures of nature for the construction sector. In this sense, in this experiment, the possibilities and limitations of digital design and digital fabrication were observed by adding a responsive cell prototype inspired by the natural structures found in the fruit peels of some fruit species present in the Central-West Region of Brazil.

The guiding hypothesis of the research was that prototypes of autonomous responsive cell panels can be produced by mixing digital addition fabrication and robotics.

The general objective was to determine the possibilities and limitations of the design and manufacture of a prototype of a responsive cell inspired by the natural structures found in the fruit peels of the fruit species of atemoia, buriti, babassu coconut, soursop and pine cone or fruit of the count, present in the region. Midwest of Brazil. And the specific objectives were: 1) Determine the possibilities and limitations of retractable surfaces and the type of triggering for responsive cells; 2) Determine the possibilities and limitations of responsive devices by electromechanical actuation; 3) Determine the possibilities and limitations of fabrication of responsive cell panels on double curvature surfaces.

From the specific objectives, the methodological process of the experimental study was organized in 2 stages.

2 Methodology

The study was organized in 2 stages: Rationale and Experimentation.

2.1 Rationale

This step consisted of reviewing the following concepts:

Bionics is seen as the study of the forms of nature to transfer them to technology (Guillen-Salas & Silva & Kallas, 2021a, 2021b) (Guillen Salas & Silva & Kallas, 2020) (Guillen Salas, 2020).

Biomimicry is defined as the science that studies and reproduces the methods, designs and processes of nature (Guillen Salas, 2020) (Badarnah, 2017) Cohen & Reich, 2016) (Chung, 2011) (Santos, 2010). Biomimicry was understood as the conscious imitation of nature in search of making the planet sustainable (Benyus, 1997, citada por Guillen Salas, 2020) (Al-Obaidi, & Ismail & Hussein & Rahman, 2017) (López & Rubio & Martín & Croxford, 2017) (Pawling, 2016).

Responsive architecture is marked as a dynamic architecture that implies physical and autonomous change through computational-electromechanical or natural devices. From the reception of a signal by a sensor, signal processing by a microcontroller and the actuation of motors to regulate the impact of external environmental factors on the internal environment. (Guillen Salas, 2020) (Kolarevic & Parlac, 2015) (Henriques, 2015) (Menges & Reichert & Kieg, 2014).

Generative-algorithmic design is understood as a design method that uses computational rules and algorithms to obtain multiple solutions to resolve a design problem (Guillen Salas & Silva & Kallas, 2020).

Arduino is defined as an open source hardware and software microcontroller (minicomputer) platform for electronic prototyping (Banzi citado por Guillen Salas, 2020).

Digital fabrication is understood as the computer numerically controlled (CNC) manufacturing process of an artifact with customized material. It can also be understood as the preparation of a digital file to be sent to the factory (Guillen-Salas & Silva & Kallas, 2021a, 2021b) (Guillén-Salas & Silva, 2021c) (Guillen Salas & Silva & Kallas, 2020) (Guillen Salas, 2020) (Kolarevic & Klinger, 2008) (Kolarevic, 2003, 2001).

3D printing is defined as a computer-aided additive manufacturing technology by layering three-dimensional artifacts (Guillen-Salas & Silva & Kallas, 2021b).

The prototype is marked as the initial model of a design process (Guillen-Salas & Silva & Kallas, 2021b).

Thus, from the literature review on these concepts, the experimentation stage was structured.

2.2 Experimentation

This stage was organized in 2 phases: Materials and Logistics and Experiment.

The Materials and Logistics phase consisted of 14 categories: 1) Physical space: Residence. 2) Furniture: Tables; Chairs. 3) Equipment: Notebook SONY model VAIO Processor Intel(R) Core (TM) i5-3210M CPU @ 2.50GHz 2.5 GHz RAM 12 GB, Metallizer Belzier SCD 050, Microscope MEV Jeol JSM-7000F, Operacional System 64 bits Windows 8.1, Moonray Printer, RepRap Anet A8 Printer. 4) Softwares: Rhinoceros 5.0, Grasshopper, Autodesk T-Spline for Rhinoceros, Cura 15.04.6, Sprintray Rayware 1.4.6, Arduino software IDE. 5) Office supplies: Pen, White Chamex Paper A4 75gr, Metal Rulers, White Glue, Scissors, Stylus. 6) Sewing material: thread. 7) Cardboard material: Simple wave cardboard 1.40 m x 1.00 m, plastic spatula, wooden sticks. 8) Hospital supplies: Disposable syringes, Silicone hoses. 9) Construction material: Bolts, Wing nuts, Metal washers, Rubber washers. 10) Robotics Material: Arduino Uno Board, USB Cable, Breadboard, Jumpers, Micro Servo 9g SG90 TowerPro, Servo Motor MG996R, Potentiometer 100k, Luminosity Sensors

LDR 5mm, Temperature Sensors LM35DZ, Ultrasonic Sensors HC-SR04, Pan/Tilt Support with 9G Servo Motor, AtMega328P Controller - Standalone Configuration, 12V 3W Solar Panel, 40 cm² Phenolite Board, 9V 240mAh Rechargeable Battery, 1Ω Resistors, 2.2 K Ω Resistors, 10 K Ω Resistor, 150 Ω Resistor, Oscillator Crystal 16 MHz, 2n2222A transistors, reset/push button, 7805 voltage regulator, 220 uF electrolytic capacitor, 100 nF capacitors, 22nF capacitors, 1N4007 diode, LEDs, 9V battery clip. 11) Material for 3D printing: Polylactic acid filament - PLA, Moonray Gray Resin. 12) Material for personal protection: Safety glasses. 13) Electrical tooling: Photovoltaic cell, Nose pliers. 14) Transport: Private car.

The experiment phase consisted of 5 subphases:

1) Characterization of the microscopic structures of fruit peels. The microscopic images were obtained using a scanning electron microscope brand MEV Jeol JSM-7000F from the Laboratory of Microscopy and Microanalysis (LMM) of the Institute of Biological Sciences (IB) of the University of Brasília (UnB) with the support of the laboratory technique.

In the images, the presence of bubbles that are interconnected in layers of different thicknesses was observed. The bubbles appear in smaller sizes when they are located in areas of sharper curvature and closer to the outside of the shell.

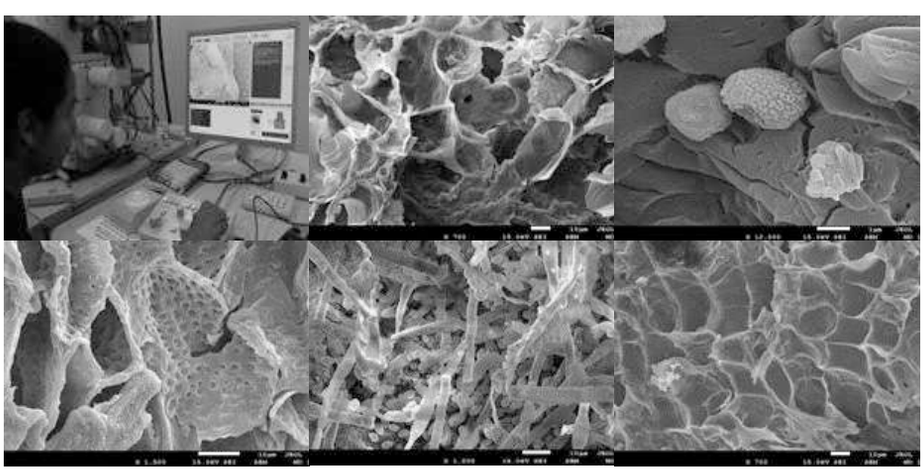

Figure 1. Microscope observation and image capture of atemoya, buriti, babassu coconut, soursop and pine cones. Source: Guillén Salas (2020).

2) 3D Modeling, Simulation and Prototyping of cells. Cells were modeled using rhinoceros 5.0 and the grasshopper and t-spline plugins. The simulation was performed with Autodesk's flow design software. And the fabrication was carried out with PLA on an Anet A8 brand RepRap 3D printer.

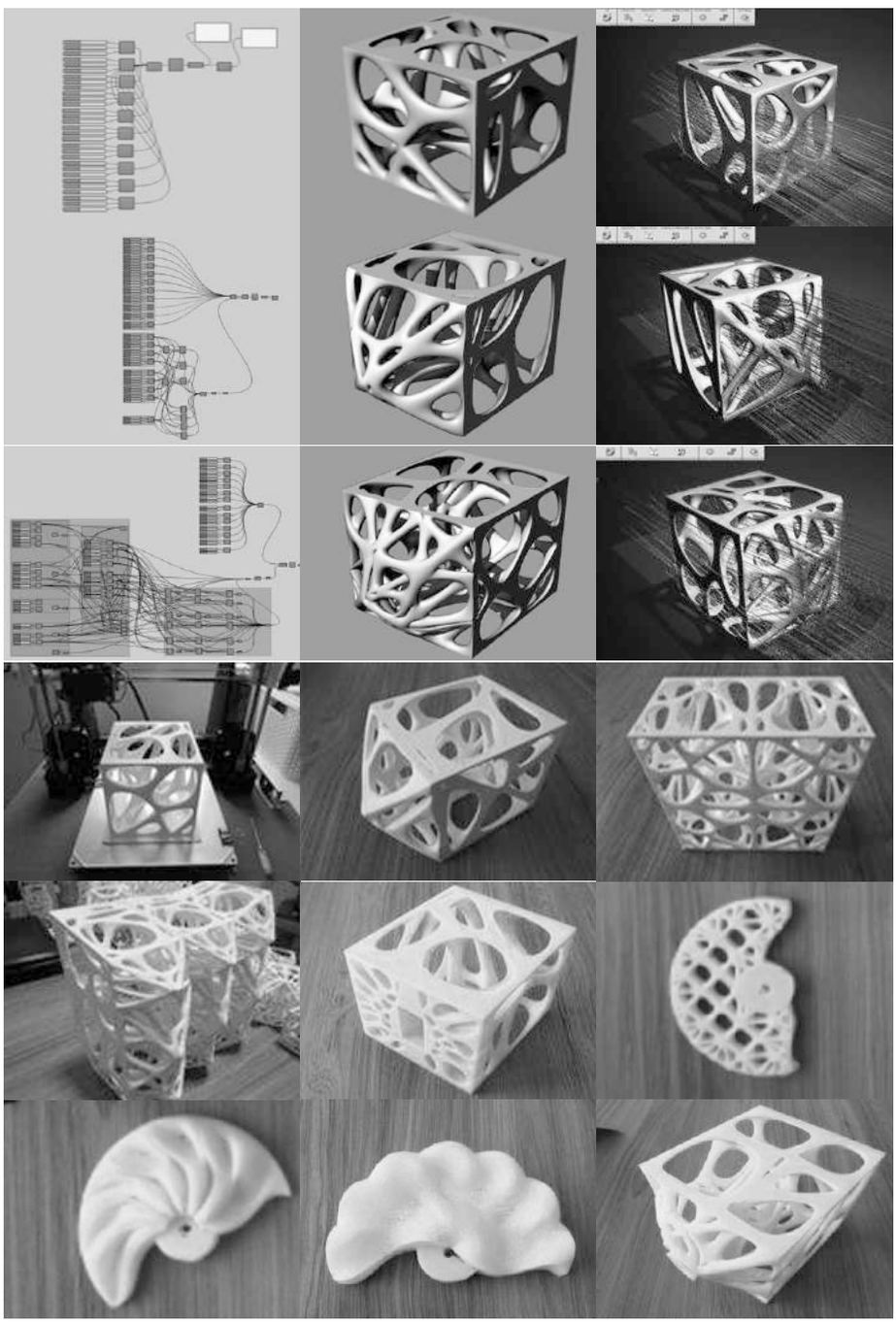

Figure 2. 3D cell modeling and aerodynamic simulation (1st, 2nd 3rd rows). Cell prototypes (3rd, 4th, 5th, 6th Rows). Source: Guillén Salas (2020).

3) Preliminary studies of responsive mechanisms for cells. These studies were carried out in 3 steps:

a) Study of folding surfaces. The mobile part of the cell is intended to be a surface that can be retracted or extended. For this purpose, 4 folds were studied for the device. The folds were made on 75gr paper measuring 21cm x 21cm.

After testing the folding surfaces, a single-direction folding was chosen to facilitate the design of the rail-based system.

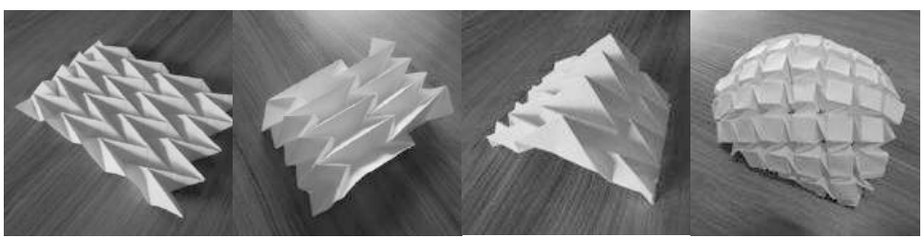

Figure 3. Study of the mobile part of the cell on 75 gr paper. Source: Guillén Salas (2020).

b) Study of unidirectional mechanical drive device. After defining the type of folding of the mobile part of the cell, the drive system was studied. The drive was proposed using guides for the unidirectional sliding of the folding surface when it is retracted or extended.

In the study, it was observed that this type of system demands more space due to the different components necessary for its operation. In view of this observation, the combination of two axes for rotation was chosen, which would occupy less space.

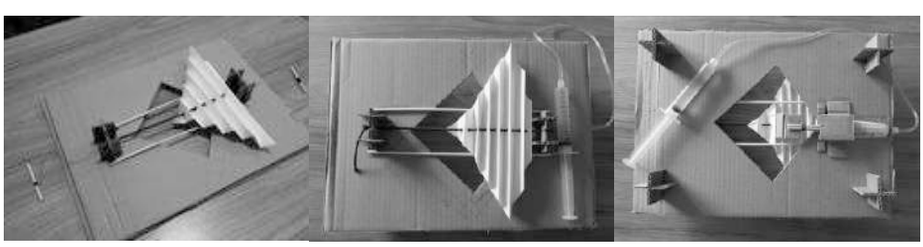

Figure 4. Unidirectional sliding device system of the mobile part of the cell. Source: Guillén Salas (2020).

c) Study of a rotating mechanical drive device. After observing the need that the device should be able to be directed according to a user's requirement. The device was thought to have a horizontal and a vertical axis to allow its direction. The device operation was simulated by manually rotating the axes.

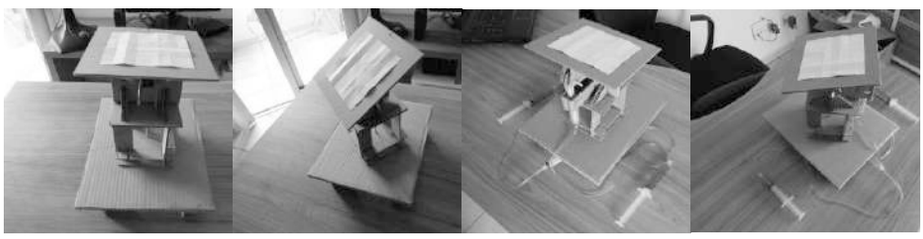

Figure 5. Rotating device of the mobile part of the cell. Source: Guillén Salas (2020).

4) Prototyping of responsive cells. Prototyping was carried out in 4 steps:

a) Prototype driven by potentiometer. The cell was produced with PLA in an Anet A8 3D printer. The fabrication took 28 hours, divided into 24 hours on the fixed part and 4 hours on the mobile part. The dimensions of the fixed part were 12cm x 12cm x 12cm and the mobile part was 11cm x 6cm x 0.5cm.

Figure 6. Cell triggered by potentiometer manually using arduino. Source: Guillén Salas (2020).

b) Prototype driven by ultrasonic sensor. The cell was produced with PLA in an Anet A8 3D printer. The fabrication took 29 hours, divided into 24 hours on the fixed part and 5 hours on the mobile part. The dimensions of the fixed part were 12cm x 12cm x 12cm and the mobile part was 11cm x 6cm x 1cm.

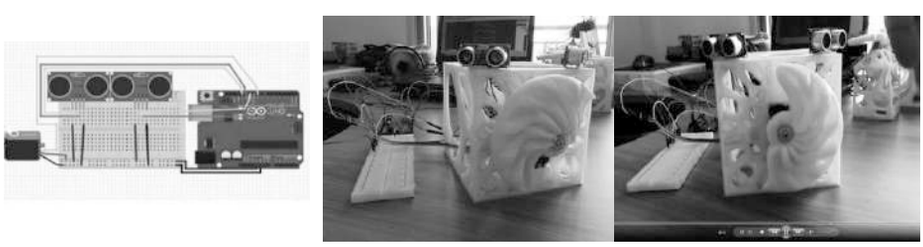

Figure 7. Cell driven by ultrasonic sensors using arduino. Source: Guillén Salas (2020).

c) Prototype driven by temperature sensor. The cell was produced with PLA in an Anet A8 3D printer. The fabrication took 29 hours, divided into 24 hours on the fixed part and 5 hours on the mobile part. The dimensions of the fixed

and mobile parts were 12cm x 12cm x 12cm and 11cm x 6cm x 1cm, respectively.

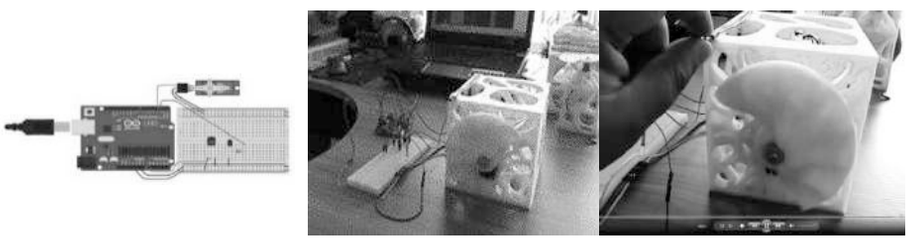

Figure 8. Cell driven by temperature sensor using arduino. Source: Guillén Salas (2020).

d) Prototype activated by light sensor. The cell was produced with PLA in an Anet A8 3D printer. Manufacturing took 36 hours. The cell dimensions were 12cm x 12cm x 12cm.

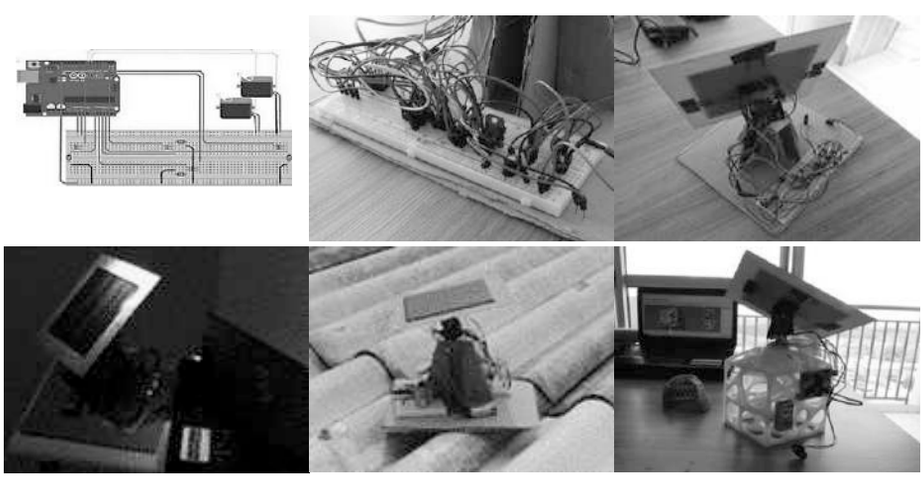

Figure 9. Cell triggered by light sensors using arduino. Source: Guillén Salas (2020).

5) Prototyping panels with responsive cells. Prototyping was performed in 2 steps:

a) Prototype with Type A structural cell driven by an ultrasonic sensor. The panel prototype was produced with 9 cells of different sizes and shapes. The panel was composed of cells organized in 3 rows and 3 columns. Where, in the center, an autonomous responsive cell was implemented. The panel dimensions were 21cm x 21cm x 12cm. And, fabrication by PLA cast filament took 93 hours.

The panel was tested twice with variation in obstacle detection distance and sound wave emission angle. In the first test with a detection distance of 1m and

a sound wave emission angle of 120 degrees, interference between the sensors was observed. In the second test with a detection distance of 25 cm and a sound wave emission angle of 80 degrees, better performance was observed.

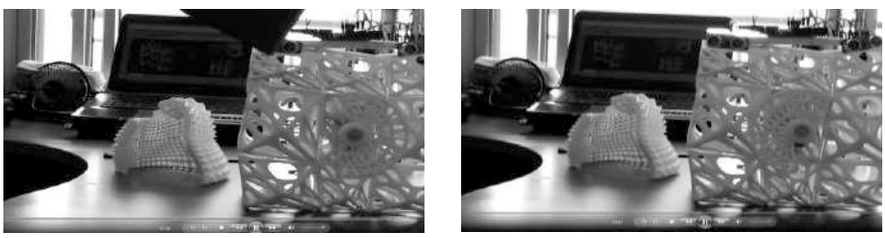

Figure 10. Panel prototype with responsive cell driven with ultrasonic sensors. Source: Guillén Salas (2020).

b) Prototype with Type B structural cell driven by ultrasonic and temperature sensors. The prototype was produced with 32 cells of different sizes and shapes. The panel was composed of cells organized in 4 rows and 8 columns. Where, starting from the left side of the panel, the third cell of column 2 and the second cell of column 7 were implemented with autonomous responsive cells controlled by ultrasonic distance and temperature sensors. The panel dimensions were 60cm x 46cm x 9cm. Manufacturing by cast PLA filament took 384 hours.

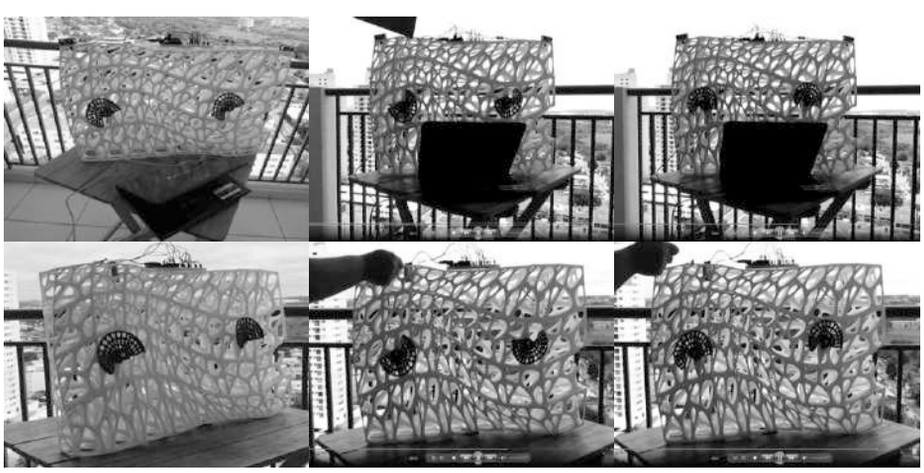

Figure 11. Panel prototype with responsive cell driven with ultrasonic sensors (Top row). Panel prototype with responsive cell driven with temperature sensor (Lower row). Source: Guillén Salas (2020).

The panel was tested with the ultrasonic distance and temperature sensors. In the test with the ultrasonic distance sensors, the obstacle detection distance

and the sound wave emission angle were set to 1m and 80cm, respectively. In the test the two cells were connected to work with the same sensor. In this way, the cells reacted at the same time when an obstacle approached any of the sensors.

In the test with the temperature sensor, one sensor triggered two cells. In the test, it was observed that the activation of the mobile device took a long time because the ambient temperature was stable. But to check the functioning of the system, the sensor was manually touched for 2 seconds and the mobile device of the two cells rotated 180 degrees.

3 Result

The main result of the research was the confirmation of the guiding hypothesis of the study, that “Prototypes of autonomous responsive bioinspired cell panels can be produced by combining digital manufacturing technology by addition (3D printing) and robotics (electronic prototyping with Arduino).

And, that the autonomous responsive cell triggered by light sensors presents itself as an alternative to automatic guidance.

4 Discussão

Four prototypes of responsive bioinspired cells were developed, from the electronic activation by a potentiometer to the activation by light sensors with a solar cell for self-generation of energy.

In the first prototype, the system was manually activated by a potentiometer. In this prototype, the need for the mobile part of the system to react automatically to an external stimulus was observed.

In the second prototype, the system was automatically activated by ultrasonic sensors when an object or person approached. Although the system reacted to an external stimulus, it was still necessary to react to a stimulus from an environmental factor, such as temperature or luminosity.

In the third prototype, the system was automatically activated by a temperature sensor. But the need for the system to reorient itself to the position of the sun and at the same time to feed itself from the sunlight was pointed out.

In the fourth prototype, the system was automatically activated by light sensors that followed the movement of the artificial light source or natural light. And feed itself from the sunlight.

Thus, the first prototype showed the possibility of being electronically controlled, the second prototype was controlled by ultrasonic sensors, the third prototype was controlled by a temperature sensor, and the fourth prototype was controlled by light sensors and powered by a solar cell; In this work, the

possibility of producing autonomous responsive cells was confirmed from the combination of digital fabrication technology by addition and robotics.

Based on this confirmation, the possibility of producing bio-inspired responsive panels controlled by proximity, temperature, luminosity or other sensors was also pointed out. And that these panels can have different applications in external and internal environments. And need further research.

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References

Al-Obaidi, K. M. & Ismail, M. A. & Hussein, H. & Rahman, A. M. A. (2017). Biomimetic building skins: an adaptive approach. Renewable and Sustainable Energy Reviews 79, 1472-1491.

Badarnah, L. (2017). Form follows environment: biomimetic approaches to building envelope design for environmental adaptation. Buildings, 7, 40; DOI:10.3390. http://dx.doi.org/10.3390/buildings7020040.

Benyus, J. M. (1997). Biomimicry. Innovation inspired nature. HarperCollins e-books.

Chung, K. J. (2011). Adaptive biodynamics in architecture: design of a prototype for an immersive sun shading system. 141 f. Tese (Doctor of Architecture) - School of Architecture, University of Hawai`i at Mānoa. Honolulu, Hawaii, United States. 2011.

Cohen, Y. H. & Reich, Y. (2016). Biomimetic design method for innovation and sustainability. Springer International Publishing, Switzerland.

Guillen-Salas, J. C. & Silva, N. F. & Kallas, L. M. E. (2021a). "BIO-FADEN 2.0 Pavilion: Experimental Study of Algorithmic-Generative Design and Digital Fabrication with 3D Printing of a Bionic Pavilion Prototype in the Midwest Region of Brazil", p. 1211-1222. In: XXV International Conference of the Iberoamerican Society of Digital Graphics. São Paulo: Blucher, 2021. ISSN 2318-6968, DOI 10.5151/sigradi2021-12

Guillen-Salas, J. C. & Silva, N. F. & Kallas, L. M. E. (2021b). "Experimental Study of Digital Design and Digital Fabrication with 3D Printing of Bionic Cell Prototype for Pavilion Design in the Midwest Region of Brazil", p. 1385-1396. In: XXV International Conference of the Iberoamerican Society of Digital Graphics. São Paulo: Blucher, 2021. ISSN 2318-6968, DOI 10.5151/sigradi2021-13

Guillén-Salas, J. C. & Silva, N. F. (2021c). Digital Fabrication Experimentations with Complex Form Modular Bionic Building Envelope with 3D Printing and Robotics Technology. In: Rodrigues, H., Gaspar, F., Fernandes, P., Mateus, A. (eds) Sustainability and Automation in Smart Constructions. Advances in Science,

Technology & Innovation. Springer, Cham. https://doi.org/10.1007/978-3-030-35533-3_18.

Guillen-Salas, J. C. & Silva, N. F. & Kallas, L. M. E. (2020). "Pavilion BIO-FADEN 1.0: Experimental study of design and manufacture with digital technologies of bionic prototype inspired by the fruit peels of fruit species present in the Central-Western Region of Brazil", p. 847-854. In: Congreso SIGraDi 2020. São Paulo: Blucher, 2020. ISSN 2318-6968, DOI 10.5151/sigradi2020-115

Guillen Salas, J. C. (2020). Projetação e Fabricação de Pavilhão Biomimético de Forma Complexa, Celular e Responsivo com Tecnologias Digitais e Robótica em Brasília - DF. 377 f. Tese (Doutorado em Arquitetura e Urbanismo) - Programa de Pós-Graduação de Arquitetura e Urbansimo, Universidade de Brasília, Brasília - DF, Brasil.

Henriques, G. C. (2015). Sistemas responsivos: relevância, estado da arte e desenvolvimentos. In: SIGRADI, p. 200-206.

Kolarevic, B. & Parlac, V. (2015). Adaptive, responsive building skin. In: Kolarevic, B. & Parlac, V. (eds.) (2015). Building Dynamics: Exploring Architecture of Change. Routledge Taylor & Francis Group. London and New York.

Kolarevic, B.; Klinger, K. R. (eds.) (2008) Manufacturing material effects: Rethinking design and making in architecture. Routledge is an imprint of the Taylor & Francis Group, an informa business: New York, United States of America. 321 p.

Kolarevic, B. (ed.) (2003) Architecture in the digital age. design and manufacturing. Spon Press is an imprint of the Taylor & Francis Group.

Kolarevic, B. (2001) Digital Fabrication: Manufacturing Architecture in the Information Age. In: ACADIA, 2001, Suny Buffalo, Proceedings… Buffalo, New York, United States of America. Section 4, p. 268-278.

López, M. & Rubio, R. & Martín, S. & Croxford, B. (2017) How plants inspire façades. From plants to architecture: Biomimetic principles for the development of adaptive architectural envelopes. Renewable and Sustainable Energy Reviews, 67, 692–703.

Menges, A. & Reichert, S. & Kieg, O. D. (2014). Meteorosensitive architectures. ResearchGate. p. 39-42.

Pawlyn, M. (2016). Biomimicry in architecture. RIBA Publishing, Newcastle upon Tyne, England, United Kingdom.

Santos, C. dos. (2010). O desenho como processo de aplicação da biomimética na arquitetura e no design. TÓPOS. V. 4, N° 2, p. 144-192.

Zone-sensitive RIZOBots in Action: Examining the Behavior of Mobile Robots in a Heterogeneous Environment

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Abstract. This study proposes a framework for the use of mobile robots namely RIZOBots in form studies in the early phases of design. The proposed framework was tested in two experiments. An agent-based model was utilized for the movement of mobile robots, a drawing task was defined as the task. In particular, rule sets for agent-agent and agent-environment interaction were used. Light-sensitivity rules were utilized to achieve agent-environment interaction, apart from obstacle detection. This study focuses on the effects of two different zone-related states on the behavior of RIZOBot which is a configurable differential-drive wheeled robot developed by authors using off-the-shelf products and 3D printed body parts. Two zone types with very basic features are used to define environmental conditions. The traces left on the canvas, the irregularities in the movement of the robots, and the robot-environment interaction will be evaluated in the study. The results and analysis of the two selected experiments are presented and the potential of the proposed framework is discussed.

Keywords: Robotics, Swarm robotics, Swarm behavior, Mobile agents, Zone-sensitivity

1 Introduction

When Negroponte's (1970) "The Architecture Machine" first published, it was clearly stated that the technology of the machines that were theoritized at that time was not available. Yet, Negroponte (1970) introduced three types of interaction regarding the involvement of machines in architectural design processes. These three types are as follows: Speeding up the already existing procedures through automation, combination and alteration of existing methods, and symbiotic interaction between designer and machine that can evolve and become mutually transformative through time (Negroponte, 1970). With Negroponte's (1970) taxonomy, this study can be considered as an attempt to stretch the second type towards the third through low-cost devices

and existing technologies. In this sense, apart from the experiment scenarios, the rules and relations defined by the authors, can be taken as the original contribution of this stretching attempt. Another issue that Negroponte (1970) emphasizes is the context-awareness. With Negroponte's (1970) words, "*it must have a sophisticated set of sensors, effectors, and processors to view the real worlds directly and indirectly*". Therefore, the architecture machine is expected to recognize the context and process the information before the actualization of an operation. Keeping Negroponte's promises in mind, this work introduces a proof-of-concept study of a design exploration space involving multiple robots.

In this study, we present a framework to produce generative drawings with an autonomous and decentralized multi-robot system. The components of the proposed framework are identical multi-robots namely RIZOBots, a physical environment as an experiment setup, and ongoing interaction between multi-robots and the environment. Firstly, we reconfigured the mobile robots named RIZOBot. RIZOBot is a custom-made wheeled robot developed by the authors to implement diverse studies on the topic of swarm systems. RIZOBot has a core that allows customizing by adding various sensors. In this study, we used light sensors to detect the zones created by different light intensities, and distance sensors to detect obstacles.

The proposed framework is tested within a series of experiments. The experiment setup covers four identical mobile robots equipped with different colored markers, a white canvas as an environment, multiple light sources to create zones and an action camera to record the process. Specifically, we investigate the traces of mobile swarm agents to understand how they interact with other agents and zones with various features.

2 Swarming: From Simulation Towards Actualization

Swarm systems have been studied by many scholars to describe self-organized and complex systems behaviors with bottom-up simple rules and relations (Reynolds, 1987; Theraulaz et al., 1990; Brooks, 1991; Deneubourg et al., 1992; Johnson, 2002). In a broader sense, a system based on swarm behavior is expected to perform more complex and efficient than the arithmetic sum of parts. Basically, this complexity results from the internal dynamics of the system, the interaction of its parts with each other and with the environment. Deneubourg et al. (1992) define swarm as:

"*a set of (mobile) agents which are liable to communicate directly or indirectly (by acting on their local environment) with each other, and which collectively carry out a distributed problem solving*" (Theraulaz et al., 1990; Deneubourg et al., 1992:123).

This conceptualization of swarm by Deneubourg et al., (1992) contributes to the representability of a swarm system through computational models that

cover agents, tasks, functions, and relations. In other words, without a need to direct interaction, a system consisting of agents, the interaction between agent-agent, agent-environment, and agent-action enables models for stigmergic mechanisms (Deneubourg et al., 1992). Reynold (1987) has introduced more specific elements namely ‘collision avoidance’, ‘velocity matching’, and ‘flock centering’. Further to the Reynold’s (1987) assumption, the alignment-cohesion-separation structure has become foundational functions for many algorithms in the swarm literature. Different from a vast body of studies in the literature that focus on representing swarm behavior through digital models, this study aims to provide a better understanding of the behavior of swarm systems in real-world scenarios.

Brooks (1991) puts a special emphasis on real-world scenarios, ‘real sensing’, and ‘real action’ cases regarding the development of intelligent systems. Brooks' proposition, which is nurtured from Heidegger's "being-in the world" discussion, makes it interesting to test models of swarm behavior, which are abstract representations of the real world, in real-world scenarios. Moreover, considering swarm and robotics together, Beni (2005) highlights the potential of key concepts and qualities such as robustness, modularity, scalability, and interchangeability. Discussing the concept of intelligence in the context of swarm robotics, Beni (2005) uses the term "ordered pattern, improbable outcome". While soft components of a robotic system such as programming enable ordered patterns to be achieved, the mechanical parts of robots involved in real-world scenarios trigger improbable outcomes. In this context, Beni (2005) introduces a definition of “intelligent swarm” as follows:

“*a group of non-intelligent robots forming, as a group, an intelligent robot. In other words, a group of “machines” capable of forming “ordered” material patterns “unpredictably*” (Beni, 2005: 4).

There are remarkable studies that utilize multi-robot systems in architectural form explorations (Andreen et al., 2016; Petersen & Nagpal, 2017; Bao et al., 2021). Different from Andreen et al.’s (2016) use of mini robots with a simple movement behavior, this study employs 2 different sensors to inform the mini robots. Secondly, predefined route paths are used in the implementation part of this study. Third, the light quality of the environment in the experiment setup provides a changing feature that influences the complexity of the robot’s behavior. Finally, the mechanical part of the robot body differentiates from the existing studies. Bao et al. (2021) focus on the implementation of swarm logic in the optimization problems simulated in the digital environment. They integrate swarm-based generative design approach and structural topology optimization in their model (Bao et al., 2021) without a need to realize and test in real-world conditions. Petersen, & Nagpal (2017) present a review of real-world implementation of multiple robots in relation to design and construction problems. Besides the aforementioned studies, there are many studies dealing with swarm robotics in relation to the the context of art and design (Valentini et al., 2017; Dorigo et al., 2021).

3 Methodology & Implementation

In the scope of the implementation, two tests lasting 10 minutes were conducted. Each experiment setup consists of a 150*250 cm white canvas as the environment, two light sources with different light intensities and four identical mobile robots equipped with different colored markers. We limited the white canvas with 50 cm height fabric to prevent the mobile robots from leaving the experiment area, and we used black fabric in order to avoid light reflections. As light sources, we used one 100-lumen and one 50-lumen LED lamp hung 120 cm above the white canvas (Fig. 1). Since the light intensity is the main factor in our study, we conducted the experiments between 00.00-02.00 AM in a homogeneously illuminated indoor environment with approximately 20-lumen light intensity.

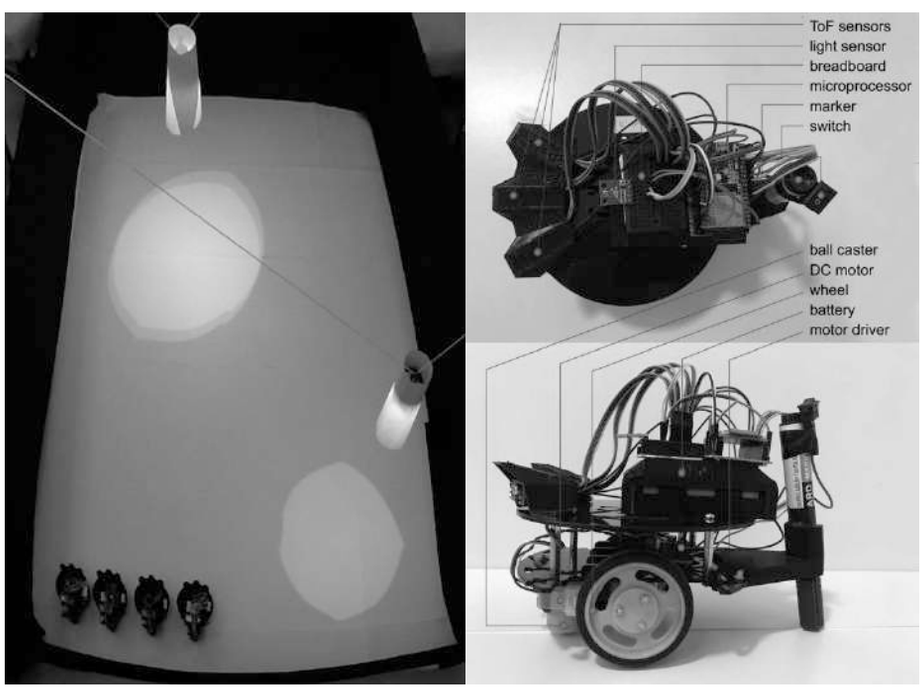

Figure 1. Experiment setup and RIZOBot Mini.

We used four RIZOBot Minis equipped with one of the black, blue, green and red markers as mobile robots to conduct the experiments.

3.1 Body

Each robot consists of 5 main units: chassis, sensors, processor, motor driver and battery unit. As chassis, RIZOBot has a plexiglass platform with 3D

printed body parts, one ball caster, two wheels with 70 mm diameters and two 6V 250 RPM plastic geared DC motors which are connected to the wheels.

Robots are equipped with three VL53L0X time-of-flight (ToF) and one BH1750 light sensor. As is shown in Figure 1, one of the ToF sensors is positioned perpendicular to the direction of movement, other two sensors are positioned at an angle of 30 degrees to increase the range of the field of view. ESP32 Wroom-32D is the microprocessor used in the RIZOBots. The microprocessor runs the tasks according to sensor reads and powers up the DC motors via an L298N dual motor driver to create motion. Three series-connected 3.7V 18650 batteries are used as the power source for the whole system.

3.2 Soft Components

Instead of utilizing a central feedback mechanism for the multi-robot system, we programmed each robot individually with local rules to define behaviors for the agents. Three main behaviors of the robots are listed as follows: movement, obstacle avoidance, and light-sensing behavior. Robots can execute both linear and angular movements. Linear movement is obtained by rotating two motors at the same speed in the same direction, while angular movement is obtained by rotating them in the same direction at different speeds. In addition, robots can turn around themselves by rotating the motors in opposite directions at the same speeds. Obstacle avoidance behavior is utilized to avoid collisions among robots or the environment while robots are on the move. In order to accomplish obstacle avoidance, we used ToF sensors and operated them with Adafruit VL53L0X Library (2022). Obstacle avoidance has three different states: no obstacle ahead, obstacle ahead and obstacle on the sides. RIZOBot constantly reads the distances with middle and side sensors. If there is no obstacle within 300 mm, the robot continues its predefined movement path. Yet, if the robot encounters an obstacle within 300 mm directly in front of it, it avoids the obstacle by turning left or right around itself according to the readings it receives from the side sensors. In the third state if RIZOBot does not detect any objects within 300 mm directly in front of it, however, if it detects an obstacle within 300 mm by one of the side sensors, the robot avoids the obstacle by making an angular movement in the opposite direction. Obstacle avoidance behavior is provided (Fig. 2).

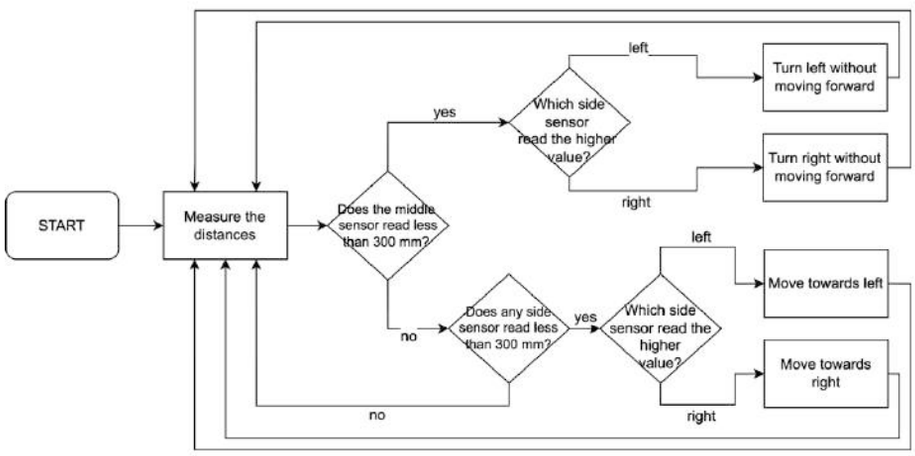

Figure 2. Flowchart of obstacle avoidance behavior.

Light-sensing behavior allows the robot to measure the light intensity at its location via using the light sensor with BH1750 Library (2022). Multiple light sources are utilized to create zones with intangible borders. In other words, the level of illuminance provided to encode a binary zone as dark and light. We developed a movement algorithm based on light intensity and designated it to mobile robots.

3.3 Experiment No.1

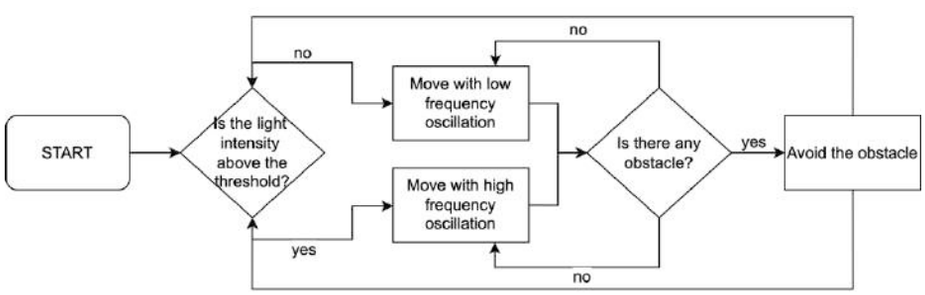

Figure 3. Algorithm schema for Experiment No.1

In the first experiment, we use two fixed position light sources to create two non-intersecting circle-like luminous zones on the white canvas which have light intensity higher than 45 lumens while the rest of the area has an average of 20 lumens. After we programmed the movement behavior of the RIZOBots in the Arduino environment to be a binary state dependent on light intensity. If the light sensor readings are below the predefined threshold, which is 35

lumens, the movement behavior enables the state no.1, and the robot moves forward (as illustrated in Fig. 4).

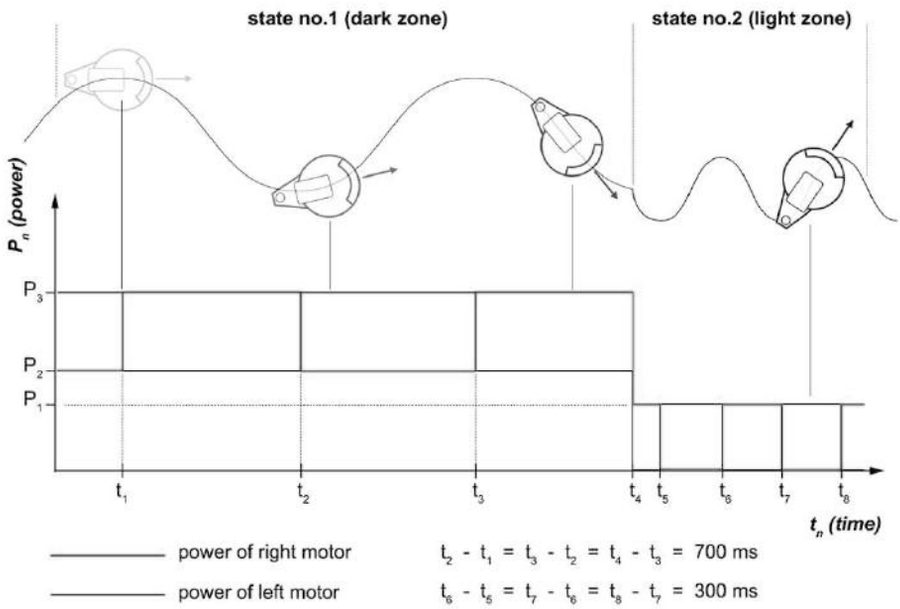

Figure 4. Movement states of RIZOBot.

In order to generate such a movement path, we use a time-integrated switch function to periodically change the power of the two motors every 700 milliseconds. A part of the code for the motion control is shared below:

```
switch = 0
timer = 0
period = 700 ms

function.stateOne()
if (switch = 0 AND (currentTime - timer) >= period)
leftMotor = P2
rightMotor = P3
switch = 1
timer = currentTime
if (switch = 1 AND (currentTime - timer) >= period)
leftMotor = P3
rightMotor = P2
switch = 0
timer = currentTime
End
```

Yet, if the light sensor readings are above the threshold, the mobile robot alters its movement path to state no.2 and increases the frequency of oscillation. The function used to generate the movement path in the first state is used in the second state for the same purpose only with different P1, P2 and period values (Fig. 4).

Marker-equipped four RIZOBots with obstacle avoidance, light-sensing and movement behavior with the aforementioned binary state run for 10 minutes and drew their traces on the white canvas.

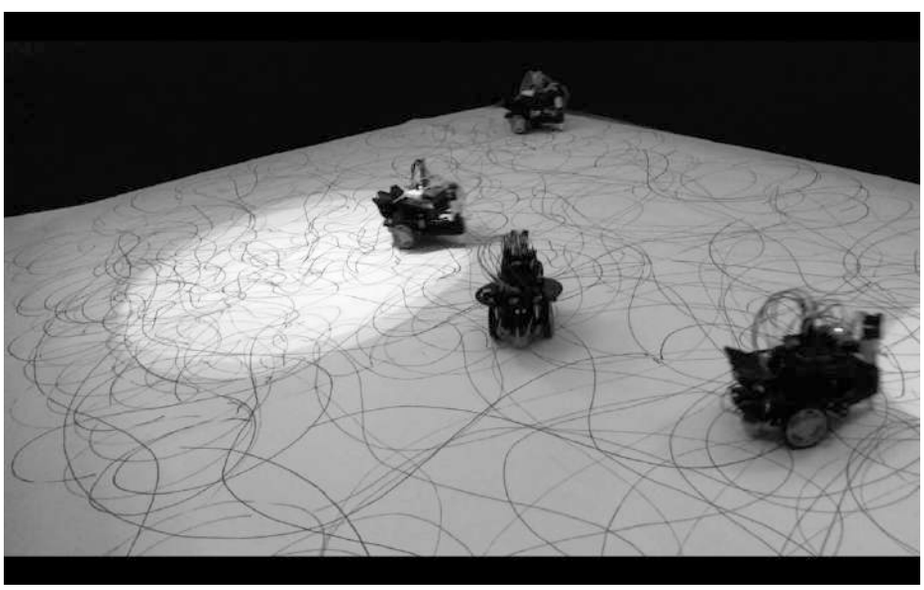

Figure 5. RIZOBots painting on canvas.

3.4 Experiment No.2

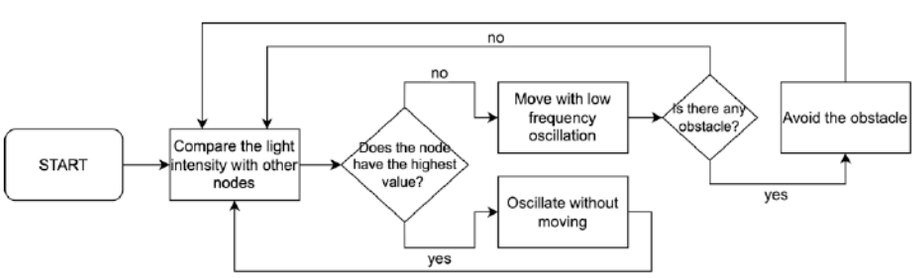

Figure 6. Algorithm schema for experiment no.2

As in the first experiment, we generated two non-intersecting circle-like zones using the same light sources on the white canvas. However, unlike in the first experiment, we manipulated and relocated the light sources

throughout the experiment. Another major difference is that we have designated a communication behavior as well as the three behaviors that the RIZOBots have. RIZOBots use a Wi-Fi mesh network to communicate. Mesh network is a network topology where each agent may act like an access point and create a connection between all the nodes in different forms. We used the Painless Mesh Library (2022) to establish the mesh network in a star topology in which one or more agents become root nodes and the rest of the nodes connect to them. Since there is not any predefined hierarchy between the nodes, any node may become a root node depending on the position of the other nodes. After, we defined a function for RIZOBots to broadcast their light sensor readings, asynchronously, over this mesh network in JSON format by using Arduino JSON Library (2022). Every second, each robot shares the light intensity it measures with the rest of the group and compares it to determine the highest value. The robot with the highest value stops moving forward and draws semicircular shapes by oscillating around itself while other robots continue their movement in seek of a location with higher light intensity. If one of the other robots reads a higher value than the previous point, the robot switches roles with the robot which has the previous highest value and starts to do the oscillation movement while the other robot returns to the seeking state.

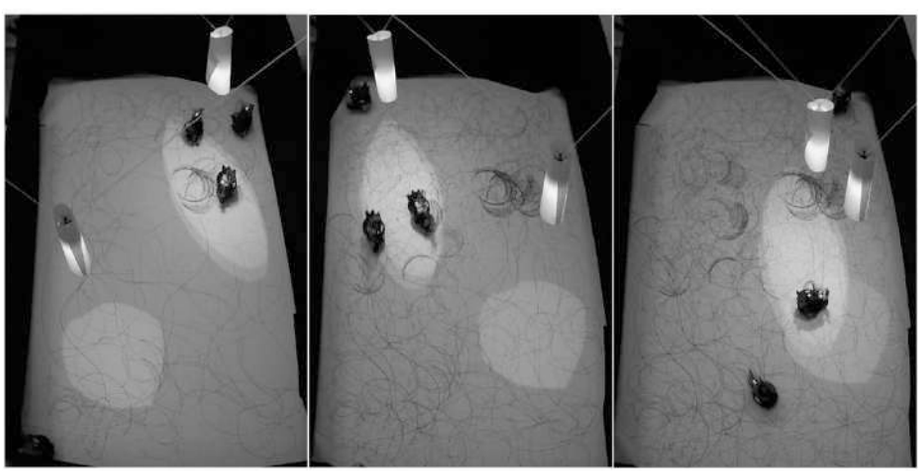

Figure 7. RIZOBots find the brightest point in different zone layouts.

We carried out the experiment with 3 RIZOBots due to the failure of one of the robots after the previous experiment.

3.5 Soft Components

- The proof-of-concept study has been conducted successfully for the proposed RIZOBot framework (Fig. 8).

- All four RIZOBots in both experiments have executed the given drawing task through the utilization of the defined algorithms. In addition, all robots accomplished remaining in the defined boundaries throughout the experiments.
- The interactions among the RIZOBots and between RIZOBots-environmental factors(light) have been monitored through the generated drawing patterns.
- In the first experiment, although the states of luminous and dark have been binary coded, during their movement the RIZOBots performed smooth transitions from one zone to another.
- Another gap that emerged in the intended algorithm and actualized behavior is obstacle avoidance. Some collisions could not be avoided. It is thought to be due to the structure of motors used.
- The movement mechanism of the robots is provided by giving power to the right and left wheels, sequentially. In this case, low precision results were obtained in rotation movements. The precision of movement can be increased if an intermediate layer such as an encoder is used to control the RPM values of the wheels.
- In the second experiment, it is observed that the highest light sensor value could have been detected in approximately 3 minutes time by the RIZOBots. The system as a whole responds to the changing light conditions as real-time feedback.

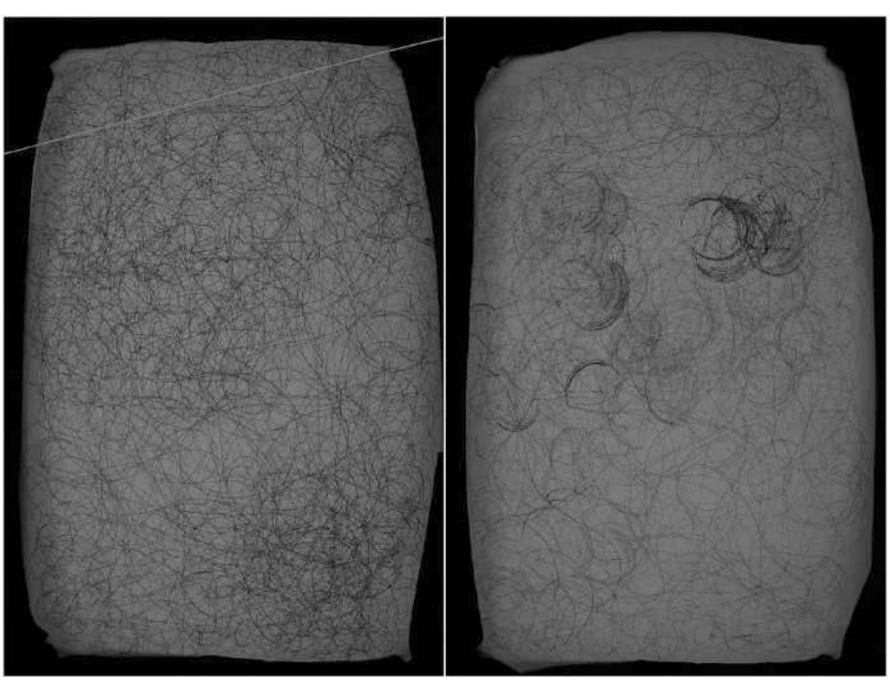

Figure 8. Experiment results (no.1 on left, no.2 on right).

4 Concluding Remarks

In this study, the potentials of swarm behavior are explored through experiments that involve multiple robots, predefined algorithms for movement, and actions defined for the changing light intensity of the environment. Relatedly, the ability to sense and respond to the changing light intensity of an environment by an individual robot, “zone-sensitivity”, has been tested.

During the experiments, we observed several collisions caused by high velocity and short delays in state changes due to latency in sensor readings. These minor errors aside, the framework successfully performed the given tasks in both experiments. When we examined the traces of the robots, we observe consistency in their reactions to different situations such as encountering boundaries, avoiding each other, and change of states due to the light intensity. Besides this consistency in the reactions, the communication behavior used in experiment no.2 provided a stable message transmission over the mesh network between the agents.

The results of the experiments offer that the proposed framework carries the potential to be adapted to different design and representation problems in future studies. More complex tasks can be achieved by defining larger amount and more complex behaviors to RIZOBots.

This study can be considered as an initial attempt to explore the potentials of interaction between a designer and a mechanical system to achieve emergent and unexpected results. Development of the zone-sensitivity behavior might contribute to the context-awareness of the robots.

5 References

Arduino JSON Library. (Version 0.1.0) [Arduino IDE Library]. Retrieved July 12, 2022. https://arduinojson.org/

Adafruit VL53L0X Library. (Version 1.2.0) [Arduino IDE Library]. Retrieved July 12, 2022. https://github.com/adafruit/Adafruit_VL53L0X

Andreen, D., Jenning, P., Napp, N., & Petersen, K. (2016). Emergent structures assembled by large swarms of simple robots. In the Proceedings of the 36th Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA), Posthuman Frontiers: Data, Designers, and Cognitive Machines, Ann Arbor 27-29 October, 2016, pp. 54-6, ISBN: 978-0-692-77095-5. https://doi.org/10.52842/conf.acadia.2016.054

Bao, D. W., Yan, X., Snooks, R., & Xie, Y. M. (2021). SwarmBESO: Multi-agent and evolutionary computational design based on the principles of structural performance.

Beni, G. (2005). From swarm intelligence to swarm robotics. In Swarm Robotics, LNCS 3342, pp. 1–9, 2005. Springer.

Brooks, R.A. (1991). Intelligence without representation. Artificial intelligence, 47(1-3), 139-159.

Deneubourg, J. L., Theraulaz, G., & Beckers, R. (1992). Swarm-Made Architectures. Varela, F. J., & Bourgine, P. (Eds.). Toward a practice of autonomous systems: Proceedings of the First European Conference on Artificial Life. MIT press.

Dorigo, M., Theraulaz, G., & Trianni, V. (2020). Reflections on the future of swarm robotics. Science Robotics, 5(49), eabe4385.

Johnson, S. (2002). Emergence: The connected lives of ants, brains, cities, and software. Simon and Schuster.

Laws, C. BH1750 Library. (Version 1.2.0) [Arduino IDE Library]. Retrieved July 12, 2022. https://github.com/claws/BH1750

Negroponte, N. The Architecture Machine, Cambridge, Mass., USA. The MIT Press, (-1970)

Painless Mesh Library. (Version 1.5.0) [Arduino IDE Library]. Retrieved July 12, 2022. https://gitlab.com/painlessMesh/painlessMesh/-/wikis/home

Petersen, K., & Nagpal, R. (2017). Complex design by simple robots: A collective embodied intelligence approach to construction. Architectural Design, 87(4), 44-49.

Reynolds, C.W. (1987). Flocks, herds and schools: A distributed behavioral model. Proceedings of the 14th annual conference on Computer graphics and interactive techniques. (pp. 25-34).

Theraulaz G., Goss S., Gervet J., and Deneubourg, J.L. (1990) 'Swarm Intelligence in Wasps Colonies: a case for tasks assignment in multi-agents systems', presented at the 1990 IEEE International Symposium on Intelligent Control, Philadelphia, PA.

Valentini, G., Ferrante, E., & Dorigo, M. (2017). The best-of-n problem in robot swarms: Formalization, state of the art, and novel perspectives. Frontiers in Robotics and AI, 4, 9.

Requirements to assemble a digital fabrication robotic unit

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Abstract. This article provides support for Universities dedicated to Architecture and Urbanism to implement a Robotic and Digital Fabrication Unit, based on the experience of laboratories in Chile and Brazil. Public funding agencies often promote "technological innovation" associated with "Industry 4.0" which requires a conceptual understanding of this framework. The authors address the industrial robot as a central element of research projects associated with robotic techniques, and creative processes. In summary, this article discloses a repertoire of technological alternatives and installation considerations, with a detailed review on how to set up a robotic unit for academia, for teaching, research and design development, in the context of Southern Creative Robotics.

Keywords: Digital fabrication, Industrial robot, Industry 4.0, Fab Lab, Maker.

1 Introdução

Neste artigo abordamos os fundamentos para estruturar uma proposta para solicitar apoio de agências de fomento para implementar uma unidade robótica de fabricação digital no contexto da Indústria 4.0, com integração digital, seguindo o conceito de Fab Lab e considerando a robótica de maneira criativa. Iremos também abordar as escolhas de ferramentas e acessórios, que são fundamentais para a implementar e desenvolver o projeto.

1.1 Robótica e Indústria 4.0

Na quarta revolução industrial a informação está omnipresente no processo de fabricação, numa integração sem precedentes (Schwab, 2017). Os

sistemas ciberfísicos fundem informação física, digital e biológica. Assim relativamente às máquinas da terceira revolução industrial operadas individualmente por humanos, os robôs passam a integrar o sistema produtivo como um todo, recolhendo informação, seja através de sensores (força, temperatura, proximidade, umidade), internet das coisas, códigos de barras, e recorrendo crescentemente à utilização de inteligência artificial e big-data, o que expande a capacidade dos robôs, de próteses mecânicas para agentes numa rede integrada de informação.

A aplicação da robótica em Arquitetura tem caraterísticas próprias, que são diferentes de determinados contextos específicos e monofuncionais de engenharia com problemas pré-definidos. A arquitetura utiliza um processo exploratório aberto para descobrir e trabalhar problemas, antes de estes serem definidos. O robô é um objeto de estudo utilizado para repensar toda a cadeia de produtiva de manufatura. O pensamento de projeto suportado pelo design Thinking, utiliza processos empíricos de tentativa e erro, para explorar problemas que ainda não são conhecidos e que podem ser aplicados em diferentes domínios. No entanto, é fundamental uma visão da robótica associada com possíveis aplicações na indústria de construção, e identificando os domínios em que podem ser aplicados os processos robóticos para que se possam traduzir em inovação. Em resumo, é necessária uma visão holística de projeto aplicado na construção, nos materiais, nos processos de transformação, numa visão sustentável, com suporte de uma estrutura do tipo Fab Lab (Diez, 2012).

1.2 Conceito FAB LAB

Caso a universidade não tenha ainda um laboratório de fabricação digital, ou pretenda transformar a sala de maquetes ou a marcenaria em laboratório de fabricação digital é inevitável abordar a cultura maker, e o discurso “Do it Yourself” (DIY) a partir do texto de Gershenfeld (2012). O fundador do primeiro Fab Lab no MIT em 2001, explica quais os fundamentos para superar as barreiras do desconhecimento, já que provavelmente o primeiro questionamento será: “para quê será que a nossa universidade precisa de um robô industrial?”. Pacini (2019) apresenta um resumo sobre as premissas para introduzir uma unidade portátil para a inserir a cultura maker no ensino tradicional. Conceitos similares são também abordados nos textos do laboratório PRONTO Móvel (Pupo, 2020).

1.3 Robótica Criativa do Sul

Como descrito nos levantamentos de fab labs da América Latina no homo Faber 1 e 2 (Sperling, Scheeren e Herrera 2015 e 2018), esta região, tem características próprias diferentes, de outras regiões mais industrializados do Norte da Europa, EUA e Japão. A região tem uma relação com a 4ª revolução industrial enquadrada no conceito de sul global (Santos 2014), que é abordada

na arquitetura por Celani (2020), e em dois números especiais do IJAC sobre a 4ªa revolução na Arquitetura (Henriques et al., 2020 e 2021). As unidades robóticas em Universidade de Arquitetura na América do Sul podem ser contadas numa mão de acordo com o site Robots in Architecture . As primeiras instalações se deram no Chile em Universidades Privadas (UTFSM 2014 e Bio-Bio 2019) e numa empresa no Brasil (2018). Mais recentemente a primeira Universidade Pública nesta região a adquirir um braço robótico foi a UFRJ no Rio de Janeiro (2021). No entanto, esta lista tem crescido e há estudos que apontam novos mais unidades **Robôs na LATAM**.

1.4 Experiências percursoras.

Figura 1. UTFSM, créditos laboratório dos autores.

As experiências percursoras na UFRJ, UTFSM e U. Bio-Bio apontam para a utilização da robótica para a impressão em argamassa e o desenvolvimento de estereotomia para estruturas de madeira. A descrição destas experiências pioneiras pretende contribuir para que os novos laboratórios possam pensar as suas atividades futuras num campo grande ainda por explorar.

As primeiras experiências em Robótica Criativa no Departamento de Arquitetura da Universidade Técnica Federico Santa María, no Chile, ocorreram no verão de 2013 (https://vimeo.com/67483828) no Centro Integrado de Manufatura e Automação CIMA, pertencente aos Departamentos de Engenharia Mecânica, Engenharia Industrial e Engenharia Eletrônica. Testaram o software KUKA PRC + Grasshopper para controlar um robô industrial KUKA KR125/2 com sistema operacional Windows 95 em que os dados foram inseridos no controlador do robô através de disquete de 3,5". Estes testes, pretenderam testar as capacidades da máquina-ferramenta e os 6 graus de liberdade do robô industrial para fabricação subtrativa de geometrias que exigem mais do que 3 graus de liberdade. Foram cortadas treliças deformadas em chapas finas de MDF, testando a geração de percursos

da ferramenta a partir de um ambiente de projeto paramétrico (https://vimeo.com/77546947). Para tal, foram modelados diagramas de Voronoi no Grasshopper com uma ferramenta orientada para usinar com 4º graus de liberdade. Em 2013, foi introduzida a Robótica Criativa em sala de aula por meio de uma oficina de arquitetura conduzida pelo professor visitante Mauro Chiarella (Chiarella et al., 2013). Em 2014, o Departamento de Arquitetura adquiriu o seu próprio robô KUKA KR6 AGILUS em segunda mão, e que por falta de um laboratório próprio ficou alojado no CIMA até 2022.

González, et al. (2014) receberam US $128.578 para pesquisar e desenvolver uma solução para a reprodução robótica de elementos estruturais e ornamentais de geometria complexa, para restaurar e reabilitar patrimônio arquitetônico chileno existente em madeira. As principais conclusões estão descritas em González, et al. (2017). Um dos avaliadores externos do projeto foi Johannes Braumann (https://vimeo.com/201585851), que foi o pesquisador que desenvolveu o KUKA PRC. O projeto de P&D permitiu não apenas expandir a base de conhecimento, mas também o ferramental. Por fim, o projeto levou à criação de uma nova linha de pesquisa no Departamento de Arquitetura designada “carpintaria de montagem robótica” (https://vimeo.com/243491176). Neste novo cenário, a aplicação na construção de estruturas de madeira sem adição de aço nos encaixes, foram expandidas para um protótipo de habitação incremental (https://vimeo.com/284061134) e para um protótipo de uma ponte (https://vimeo.com/232347071). Em 2016, a UTFSM começou a ensinar os alunos de arquitetura do 4º e 5º semestre a programar robôs industriais em aplicações de estereotomia de madeira, somando até hoje mais de 400 alunos, a uma taxa de cerca de 60 alunos por ano. A pesquisa em marcenaria com montagem robótica permite aos arquitetos aprofundar o estudo de juntas de carpintaria, ou seja, as montagens de madeira publicadas em livro (González e Maino, 2019) com uma descrição detalhada da geometria construtiva de 22 classes de montagens e 5 classes de emendas encontradas na estrutura portante de edifícios construídos entre meados do séc. XIX e início do séc. XX na cidade de Valparaíso, no Chile.

Em 2018, graças a uma colaboração com a Universidad do Bío-Bío (García-Alvarado, 2018), foram adicionados ao Departamento de Arquitetura 2 robôs colaborativos UR5/CB3. Em virtude desta nova incorporação, em 2020 foi adquirido um HUSKY A200 UGV com um kit de integração para um UR5/CB3, que devido à pandemia de COVID-19 não pôde ser integrado até 2022. Entre 2020 e 2022 González, et al. (2020) conseguiram USD 217.047 para pesquisar e desenvolver uma solução robótica de carpintaria de montagem para a pré-fabricação in loco de soluções de habitações flexíveis em madeira nos processos de reconstrução do Serviço de Habitação e Desenvolvimento Urbano da Região de Valparaíso. Os UGVs integrados HUSKY A200 e UR5/CB3 permitem usinar madeira no canteiro de obras, mas o principal

objetivo do projeto é permitir a colaboração homem-robô usando visão de máquina, adquirindo a câmara ZIVID TWO 3D. Em 2021 é fundada a área Robots in Architecture (https://arquitectura.usm.cl/robots-arquitectura) e em 2022 é fundado o Robots in Architecture Laboratory em Valparaíso (https://arquitectura.usm.cl/laboratorio-de-robots-en-arquitectura/) e o Laboratório Robotizado de Construção e Manufatura em Santiago do Chile (https://arquitectura.usm.cl/laboratorio-construccion-robotizada-manufactura).

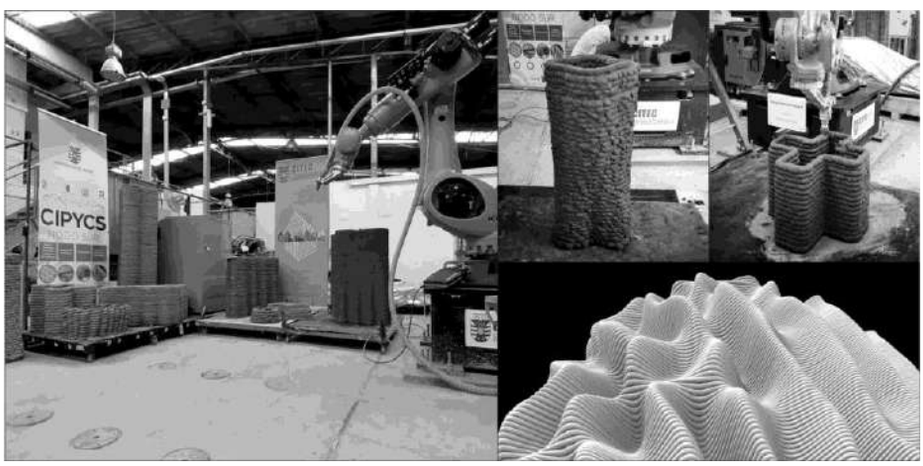

Figura 2. U. Bio-Bio, créditos laboratório dos autores.

A Universidade do Bío-Bío no Chile, instalou em 2019 um robô Kuka 120 R2500 destinado a experimentar a impressão 3D para construção, ligando o robô a uma bomba, e a uma betoneira de 120 litros, com uma mangueira de 8 metros, com grampo no atuador final do robô. https://youtu.be/m5pZdxkvUlg Colocou também na extremidade do robô um tubo de 10 litros com pistão impressão de peças menores de argila e terra. https://youtu.be/LkRa9LcrdeU

Para a impressão em argamassa, desenvolveu uma mistura com o apoio de indústrias locais, desenvolvendo um repertório de mobiliário urbano (Bos et al., 2022), de amostras de recifes artificiais e protótipos de paredes residenciais (Martínez-Rocamora et al., 2020), elaborando desenhos em Revit e Rhinoceros, programando as trajetórias com Kuka PRC. Foi importante considerar a utilização do canteiro para obras úmidas, com plataformas móveis e armazenamento de peças grandes, e a participação de dois ou três operadores para controlar o trabalho do robô e a bomba/misturador. Para aumentar o escopo de trabalho, está planejado instalar o robô num trilho de 7 metros, complementado com um pórtico de impressão grande, permitindo para além deste uso a preparação de maquetes de estudo (mockups) com impressão em argila para desenvolver os detalhes e processos de projeto https://youtu.be/Px75V8lNuPE. Estas atividades foram desenvolvidas num projeto conjunto, em colaboração com o Departamento de Arquitetura da

Universidad Técnica Federico Santa María, que iniciou no Chile o uso de robôs nesta área. Outras tarefas testadas com este Robô foram levantar blocos, tendo sido desenvolvida uma pinça de madeira CNC com design de dupla tesoura para agarrar objetos por aproximação, dispensando a utilização de um motor elétrico. Este dispositivo, foi utilizado para levantar blocos de madeira e concreto e para a montar um sistema construtivo evitando esforços humanos, com execução precisa, mas flexível (García-Alvarado et al., 2020). https://youtu.be/m5pZdxkvUlg

Figura 3. LAMO, créditos laboratório dos autores

No caso do LAMO, o seu o robô industrial Kuka KR 120-270r chegou com apoio da FINEP no início de 2021, e pretende aprofundar uma linha iniciada pelo laboratório em 2013, com a primeira wiki-House da América do Sul (A. Passaro & Rohde, 2016), https://vimeo.com/130312585 pavilhões em escala real (A. M. Passaro et al., 2019) https://vimeo.com/288016937 e experiência com confeção de maquinas para impressão pastosa aditiva (Nóbrega et al., 2021) www.facebook.com/LAMO3D/videos/1284993251645847. O LAMO tem uma parceria com Rodrigo Garcia-Alvarado do U. Bío-Bío, Chile, há alguns anos (Garcia-Alvarado et al., 2022), e tivemos o apoio de alguns consultores entre os quais José Pedro Sousa do DFL, com o seu projeto também no Sul Global (Sousa, 2015) e Eduardo Lopes (Lopes & Fonseca de Campos, 2019) além da equipe do projeto de pesquisa, agradecemos o apoio na preparação e montagem da unidade robótica de William Barbosa (Barbosa et al., 2020).

2 Unidade Robótica de Fabricação

Gramazio, F; Kohler (2014) consideram as unidades robôticas de acordo com diferentes configurações de uso de acordo com a pesquisa e aplicação,

entre as quais estão: Unidade Robótica de Fabricação; Unidade Robótica Container; Unidade Robótica de Prototipagem; Unidade Robótica de Fabricação in Situ; Unidade Robótica de Modelagem; Unidade Robótica de Produção. A descrição de cada uma requer mais espaço, pelo que optamos por aprofundar a instalação de uma Unidade Robótica de Fabricação, dando subsídios para a escolher o equipamento e acessórios. Para aprofundar o assunto consultar “Towards a Robot Architecture" de Daas & Wit (2018).

Compra

Os vendedores de robôs industriais da América Latina não parecem preparados a 100% para atender a complexidade que implica um laboratório de pesquisa de uma universidade. Os vendedores estão familiarizados com a indústria, mas menos com o conceito indústria 4.0, desta forma há o risco de se focarem o tempo todo em dimensionar “uma” necessidade para uma unidade, por exemplo algo como soldar uma mesma peça infinitas vezes, e toda a unidade gravita em torno da solda dessa peça. Na Europa, nos Estados Unidos e em outros países as faculdades de arquitetura estão desbravando possibilidades, atualmente há 107 instituições cadastradas somente na Association for Robots in Architecture, que abordamos atrás. Claro que há algumas outras que não estão cadastradas. Mas em todo caso não há nenhuma unidade na África, e de acordo com esta associação atualmente há apenas 5 unidades na América do Sul.

Valores

Uma outra situação perversa na hora da compra é relativa ao entendimento do que é um robô minimamente funcional. O Robô Industrial é somente parte de uma engrenagem das “Unidades”, pelo que é necessário um check-list aprofundado com alguém que tenha conhecimento do assunto. Se faltar alguma peça vai atrasar o funcionamento da unidade.

Editais manutenção

Uma outra questão importante na compra, que nem sempre é tida em conta, são os editais de manutenção de equipamentos de grande porte. No Brasil saiu recentemente um da FINEP, e para entrar neste edital o valor do equipamento deveria ser de no mínimo U$100.000,00. Então na hora de comprar Braço e mesa posicionadora ou trilho e acessórios, procurem saber qual o valor desses editais nas vossas agências estaduais/federais, e verifiquem que o valor total da nota fiscal ultrapassa com alguma folga esse valor.

Software

O software embarcado além de caro geralmente é desnecessário, atualmente a Association for Robots in Architecture desenvolveu um plugin para Grasshopper específico para os robôs da Kuka chamado de PRC (Parametric Robots Control), e há mais laboratórios construindo estes plugins geralmente gratuitos, ou com anuidades acessíveis para os laboratórios. Estes plugins permitem gerar, operar e simular o G-Code a partir do próprio Grasshopper agora embarcado dentro do Rhinoceros, algo em torno a U $200,00 em comparação com valores entre US $7.000,00 a US $10.000,00 que os vendedores oferecem para tarefas específicas.

Acessórios

As empresas fabricantes de robôs oferecem alguns acessórios, para automatizar a produção a partir das especificidades da produção (indústria 3.0) e os labs de fabricação geralmente desenham e executam os seus acessórios, ou compram peças separadas para os montar. No caso vale a pena estudo aprofundado sobre os acessórios necessários para o robô e solicitar um valor de aproximadamente metade do valor do braço robótico para este fim: Spindle, Finger elétrico e Finger pneumático, ventosa, solda, extrusor para impressão 3D de médio e grande porte, projetora de argamassa, etc.

Instalação

Vale a pena também reservar uma outra verba igual a metade do custo do braço para a instalação. A instalação de maior custo é a elétrica, mas temos água, esgoto (se for executar impressão 3D em argamassa é importante ter uma caixa de areia), instalação pneumática, extrator de pó, ar comprimido, e base apropriada, geralmente para fixar o braço é necessário cravar estacas no solo para aguentar os diferentes momentos fletores.

Gaiola segurança

É necessário garantir a segurança do local, geralmente uma gaiola ou sensores que parem a operação do braço quando alguém se aproximar. Há diversas normas, e os vendedores fazem questão em indicar todas as possibilidades. Mas para quem fez qualquer workshop abordando questões responsivas, via arduíno, com sensores pode a partir de um DIY reduzir estes valores. O ideal é ter espaço, em local térreo para que o robô opere solto, com giro ampliado de 370° e com folga de passagem de 1m no mínimo, espaço para movimentar diferentes mesas de trabalho, para estocar a produção imediata, e eventualmente um equipamento de troca de ferramentas. A construção do local é uma atividade complexa e deve ser projetada com ajuda de alguém experiente.

Tabela 1. Unidade Fabricação Robótica

item	Custo em dólares
robô industrial	70.000,00 a 100.000,00
software	1.000,00 a 5.000,00
acessórios	2.000,00 a 10.000,00
instalações	15.000,00 a 35.000,00
gaiola de segurança	3.000,00
inicialização do robô	5.000,00
total	**124.000,00 a 154.000,00**

Robô industrial e unidade fabricação digital

Basicamente um laboratório de fabricação digital gira em torno de várias questões, sendo que os laboratórios aqui descritos, de acordo com a pesquisa Homo Faber (2015) são labs voltados para construção de pavilhões 1/1, e partilhamos a nossa perspetiva de acordo com essa experiência.

Como referido, há preferência pela marca KUKA relativamente a outras marcas porque os plug-ins de fonte aberta e o PRC foram originariamente desenvolvidos para esta marca. Hoje é possível encontrar plug-ins para outras marcas, mas há ainda um deserto em novidades. Para as tarefas de fabricação, visando escala 1/1 de pavilhões, o ideal é adquirir um robô parrudo dentro da linha Quantec. A nomenclatura é do tipo KR 120 R2700, onde:

KR = Kuka Roboter

120 = chamado pay load ou carga de trabalho, isto significa no senso comum que pode ser colocada uma ferramenta de trabalho com 120 quilos, ainda que no cálculo há que considerar atritos, etc.

R2700 significa um raio de trabalho do equipamento de 2,7m. Como referimos, a gaiola perfaz um quadrado de 5,40m de lado colocamos uma ferramenta numa área de uso de 6m, com a área de segurança de trânsito, dá no total um quadrado de 8m x 8m.

3 Discussão

Este artigo expõe um repertório de alternativas tecnológicas e considerações práticas para a implementação de uma unidade robótica para o ensino e pesquisa em arquitetura, promovendo mais do que uma visão técnica estrita, uma visão abrangente que inclui diferentes critérios que abaixo resumimos.

Os principais fabricantes de robôs industriais KUKA, ABB, UR, FANUC, produzem robôs semelhantes em termos de hardware, pensados como manipuladores para tarefas industriais repetitivas, em células de trabalho e ambientes estruturados, como na indústria automóvel. De acordo com a nossa experiência e de parceiros de outros países, o principal fator de diferenciação na escolha do robô é a possibilidade de utilizar programação visual, o que é dado pelo Kuka PRC ou HAL, que o torna mais amigável para a prática de arquitetos, designers e artistas.

Os robôs industriais não foram originalmente concebidos para funcionar como máquinas-ferramentas ou para servir um modelo de fabrico digital ágil baseado em CAD-CAM como o dos Fab Labs. O aprendizado com outras máquinas como cnc, cortadoras a laser e impressoras 3D, embora vinculados à cultura maker, não prepararam diretamente para a utilização de um robô industrial, dado o aumento de complexidade e dadas as suas especificidades. A implementação de equipamentos robóticos para o ensino de arquitetura enfrenta o dilema entre instalar um robô industrial maior, e mais dispendioso, para atividades de construção na escala real, mas em menor número, e a alternativa de vários robôs colaborativos menores, que permitem desenvolver mais atividades, envolvendo mais estudantes e pesquisadores. Independentemente da escolha, a melhor preparação para o uso criativo de robôs é ensinar design paramétrico, e programação visual e textual. Aprender a programar é considerado vital em diversas áreas e pode alterar o paradigma de projeto (Henriques et al, 2022).

Para organizar um laboratório de robótica criativa, como vimos, o robô industrial requer além de espaço, infraestruturas, formação e o desenvolvimento de ferramentas próprias. No fundo, a ideia recursiva de desenvolver máquinas (e códigos), que desenvolvem novas máquinas ou ferramentas. O robô industrial terá certamente um papel central na organização de novos espaços e das tarefas a realizar, sendo que no caso da expansão de laboratórios existentes é necessário integrar, não só no aspeto físico, mas de acordo com as capacidades e demandas existentes. Definir as ferramentas implica experimentar diferentes materiais, tarefas e acessórios, que devem estar associadas com ideias de desenvolvimento de projeto. O robô além de tarefas mecânicas pode também desenvolver atividades inteligentes, que requerem conhecimentos especializados, que também necessitam estar enquadrados no contexto de projeto. Para implementar uma unidade robótica são relevantes os conceitos da indústria 4.0 e estimular capacidades computacionais, para fomentar o desenvolvimento das nossas próprias capacidades robóticas, na arquitetura do Sul.

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Referências

Barbosa, W. S., Gioia, M. M., Natividade, V. G., Wanderley, R. F. F., Chaves, M. R., Gouvea, F. C., & Gonçalves, F. M. (2020). Industry 4.0: examples of the use of the robotic arm for digital manufacturing processes. *International Journal on Interactive Design and Manufacturing (IJIDeM)*, *14*(4), 1569–1575. https://doi.org/10.1007/s12008-020-00714-4

Bos, F. P., Menna, C., Pradena, M., Kreiger, E., da Silva, W. R. L., Rehman, A. U., Weger, D., Wolfs, R. J. M., Zhang, Y., Ferrara, L., & Mechtcherine, V. (2022). The realities of additively manufactured concrete structures in practice. *Cement and Concrete Research*, *156*, 106746. https://doi.org/10.1016/j.cemconres.2022.106746

Celani, G. (2020). Shortcut to the Fourth Industrial Revolution: The case of Latin America. In G. C. Henriques, J. P. Sousa, P. Gomez, & H. Achten (Eds.), *International Journal of Architectural Computing* (Vol. 18, Issue 4, p. 1478077120942193). SAGE. https://doi.org/10.1177/1478077120942193

Chiarella, M., González, L. F., & Calvo, C. (2014). Robots: Automatización en Diseño y Construcción para la Enseñanza de Arquitectura. *XVII Congress Osf the Iberoamerican Society of Digital Graphics SIGraDi 2013*, 439–443. https://doi.org/10.5151/despro-sigradi2013-0084

Diez, T. (2012). Personal Fabrication: Fab Labs as Platforms for Citizen-Based Innovation, from Microcontrollers to Cities. *Nexus Network Journal*, *14*(3). https://doi.org/10.1007/s00004-012-0131-7

Garcia-Alvarado, Rodrigo Garcia, Henriques, G. C., & Chiarella, M. (2022). Co-creating together: Ibero-American emergent collaborations in architecture and digital manufacture /Cocreación: colaboraciones iberoamericanas emergentes en arquitectura y en fabricación digital. *Arquitecturas Del Sur*, *40*(61), 118–133. https://doi.org/10.22320/07196466.2022.40.061.08

García-Alvarado, Rodrigo, Perez, A., Pulido, J. A., Ulloa, P., & Forcael, E. (2020). Assembly of Stay-In-Place Concrete Blocks Using a Robot. *IOP Conference Series: Earth and Environmental Science*, *503*(1), 012077. https://doi.org/10.1088/1755-1315/503/1/012077

Gershenfeld, N. (2012). How to Make Almost Anything: The Digital Fabrication Revolution. *Foreign Affairs*, *91*(6), 90.

González, L. F., & Maino, S. (2019). *Uniones carpinteras de Valparaíso: la geometría de ensambles y empalmes*. RIL editores.

González Böhme, L. F., Quitral Zapata, F., & Maino Ansaldo, S. (2017). Roboticus tignarius: robotic reproduction of traditional timber joints for the reconstruction of the architectural heritage of Valparaíso. *Construction Robotics*, *1*(1–4), 61–68. https://doi.org/10.1007/s41693-017-0002-6

Gramazio, F., & Kohler, M. (2014). *The Robotic Touch: How Robots Change Architecture*. Park Books AG.

Henriques, G. C., Sousa, J. P., Gomez-Zamora, P., & Achten, H. (2020). Architecture in the age of the 4th industrial revolution I. *International Journal of Architectural Computing*, *18*(4), 317–319. https://doi.org/10.1177/1478077120950939

Henriques, G. C., Xavier, P. M., Silva, V. de L., Bispo, L. R., & Fraga, J. V. (2022). Computation for Architecture, hybrid visual and textual language: Research developments and considerations about the implementation of structural imperative and object-oriented paradigms. International Journal of Architectural Computing, 20(23), 200–250. https://doi.org/10.1177/14780771221121829

Lopes, E., & Fonseca de Campos, P. (2019). Robotic Digital Fabrication of Lightweight Laminar Prefabricated Structures: The Dragados case study in 1990's. *12th International Symposium on Ferrocement and Thin Cement Composites: The Technology on a Human Scale – FERRO12At*, 1–10.

Martínez-Rocamora, A., García-Alvarado, R., Casanova-Medina, E., González-Böhme, L. F., & Auat-Cheein, F. (2020). Parametric Programming of 3D Printed Curved Walls for Cost-Efficient Building Design. *Journal of Construction Engineering and Management*, *146*(5). https://doi.org/10.1061/(asce)co.1943-7862.0001811

Pacini, G. D., Passaro, A. M., & Henriques, G. C. (2019). Pavilhão FAB!t: proposta portátil para inserção da cultura maker no ensino tradicional. *Gestão & Tecnologia de Projetos*, *14*(1), 76–89. https://doi.org/10.11606/gtp.v14i1.148143

Passaro, A. M., Henriques, G. C., Sansão, A. S., & Tebaldi, I. (2019). Tornado Pavilion-Simplexity, almost nothing, but human expanded abilities. In José Pedro; Sousa, G. C. Henriques, & J. P. Xavier (Eds.), *Architecture in the Age of the 4th Industrial Revolution - 37th eCAADe and 23rd SIGraDi Conference* (pp. 305–314). eCAADe SIGraDi. https://doi.org/10.5151/proceedings-ecaadesigradi2019_102

Passaro, A., & Rohde, C. (2016). Casa Revista: arquitetura de fonte aberta. *Gestão & Tecnologia de Projetos*, *11*(2), 25. https://doi.org/10.11606/gtp.v11i2.114437

Pupo, R. T. (2020). PRONTO Móvel – A Way of Transporting Creativity and Technology. In K. H. (Ed.), *Lecture Notes in Computer Science: Vol. 12213 LNCS* (pp. 308–317). Springer. https://doi.org/10.1007/978-3-030-50537-0_23

Santos, B. de S. (2014). Epistemologies of the South: Justice Against Epistemicide. In *Epistemologies of the South*. Routledge. https://doi.org/10.4324/9781315634876

Scheeren, R., Sperling, D., Herrera, P., Pacheco, P., & Vasconselos, T. (2018). *Homo Faber 2.0: Politics of Digital in Latin America* (1st ed.). IAU/USP. http://www.sigradi2018.iau.usp.br/wp-content/uploads/2018/11/HomoFaber2.pdf

Schwab, K. (2017). *The Fourth Industrial Revolution*. Penguin Random House.

Sousa, José Pedro. (2015). *RobTech - Robotic Technologies for a Non-Standard Design and Construction in Architecture* (DFL-Digital Fabrication Lab).Faculdade Arquitectura do Porto. https://issuu.com/jpsousa76/docs/robtech_pre-print_lr/1

Sperling, D., & Herrera, P. (2015). *Homo Faber: Digital Fabrication in Latin America*. Instituto de Arquitetura e Urbanismo.

Wit, A., & Daas, M. (2018). Towards a Robotic Architecture. ORO Editions.

Planning & Design Platform of Buildings by Robotic Additive Manufacturing for Construction

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Abstract. The following paper describes and comments a construction planning platform for the Additive Manufacturing of wall modules, as a set of design and planning actions that interwove robotic, material capacities and spatial characteristics. Goal here is to take semi-conventional strategy and augment the algorithmic process for design and knowledge acquisition regarding design oriented to 3D Printing Construction.

Keywords: additive manufacturing for construction, 3D printing, digital fabrication, parametric design.

1 Introducción

La aplicación Manufactura Aditiva para la Construcción (AMC) con extrusión de material semifluído o *contour crafting* (Khoshnevis, 2004; Khoshnevis & Rosanne, 1998) ha sido utilizado ampliamente en el mundo en la impresión de edificios con mezclas cementicias, en su mayoría casas de un piso. Se observan formas que varían desde lo ortogonal, al redondeo de esquinas y muros levemente curvos (García-Alvarado *et al.*, 2021).
Este artículo presenta una plataforma para preparación de la impresión de un edificio de dos pisos, desde la descomposición hasta el diseño a escala media y de detalles, así como la planificación de la rutina de impresión. Estos detalles, en parte, incrementan el diseño de la solución a nivel de muros (meso) hasta nivel de detalles (ruta de impresión y ediciones *in situ*). El objetivo de esta realización es observar en las distintas etapas el conocimiento de diseño y de manufactura aplicada.

1.1 Diseño digital asociado a manufactura aditiva

En diversos actores actuales de la AMC, se observa la implementación de modelado paramétrico como Rhinoceros con Grasshopper sin esclarecer propiamente la metodología de diseño como tal. Algunas excepciones han sido revisadas, como una propuesta de viviendas individuales (Banda et *al.*, 2021; Cascone *et al.*, 2020) y reconstrucción de edificios no-estándar poniendo el énfasis en la solución de componentes estructurales optimizados (Alabbasi *et al.*, 2021; Kontovourkis & Tryfonos, 2020).
Por otro lado, la AMC ha tenido un mayor desarrollo en su implementación desde plataformas Building Information Modeling (BIM), limitando su vinculación con la manufactura aditiva al proceso de *slicing* o laminado (ver figura 1), el que ocurre procesando un modelo de malla poligonal .STL del edificio completo (Allouzi *et al.*, 2020; Davtalab *et al.*, 2018; Ding *et al.*, 2014) o de un grupo de muros individuales previamente segregados (Forcael *et al.*, 2021; Khajavi *et al.*, 2021). La generalidad de este tipo de experiencias BIM, el trabajo sobre diseños arquitectónicos convencionales sin ahondar de forma intensiva en la repercusión misma que la AMC puede realizar sobre el lenguaje arquitectónico.

2 Metodología

La metodología toma como base el flujo genérico observado (figura 1), incorporando la tarea de subdivisión. Entendiendo la escasez y disparidad de procesos documentados a la fecha, dentro de estas etapas se produce un desarrollo exploratorio e interpretativo para incluir requerimientos en el desarrollo algorítmico y tectónico que ofrece la plataforma.
La tarea de diseño principal se realiza a través de Rhinoceros-Grasshopper, en cuanto a módulos de especificación geométrica, detallado de volúmenes y *slicing* personalizado, e implementación y corroboración con actuales *plug-ins* de simulación robotizada.

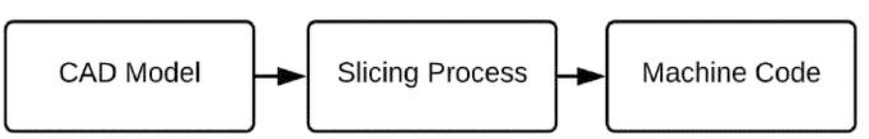

Figura 1. Proceso genérico de preparación para imprimir un objeto digital

2.1 Diseño

La plataforma lograda se basa en la recepción de un diseño existente a través de un modelo BIM, el que en este caso corresponde a un edificio consistente de dos pisos y tres unidades residenciales. Basado en una estructura de losas y pilares, libera a los muros impresos de transmisión de esfuerzos; es decir, su solicitud estructural solamente es de autosoportantes. Como características generales de este proyecto, está la curvatura simple (2.5D) de los muros exteriores.

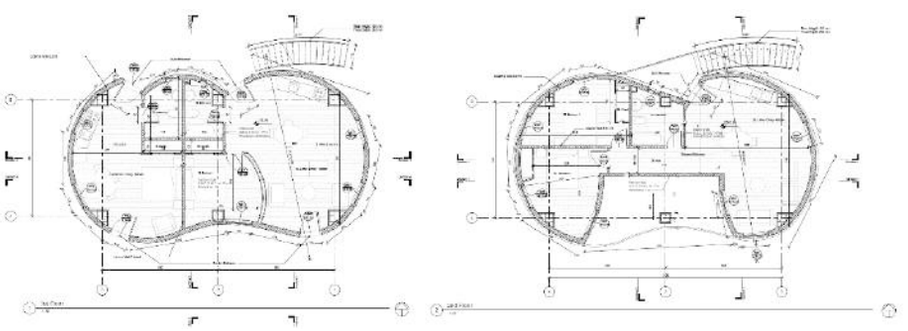

Figura 2. Proyecto arquitectónico a procesar por el algoritmo

3 Resultados

3.1 Diseño del proceso

Este proceso transcurre luego y escindido del diseño arquitectónico, ampliando el proceso de laminado o *slicing*, generación y ejecución del código de impresión para sumar niveles de detalle al proyecto en la etapa de particularidades del muro. A través de este proceso, además, se establece un enfoque y énfasis en el diseño del muro y la ruta de impresión.

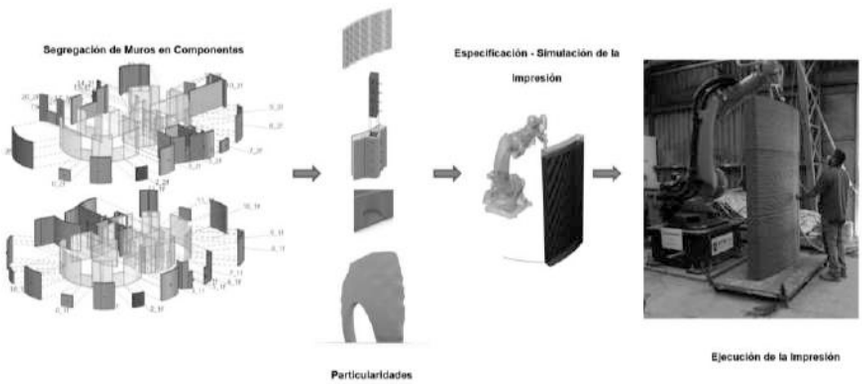

Figura 3. Principales subtareas de la plataforma

Tabla 1. Subtareas de diseño de la plataforma

Nombre de subtarea	Definición breve	Producto
Segregación de muros	Satisface distintas restricciones, tales como peso resultante del elemento, volumen máximo del robot, relación del muro con el vano.	Geometría de muros segregados
Particularidades de muro	Incrementación de detalle del muro: uniones con piso, cielo, columnas y vanos, así como la inclusión de patrones texturados.	Rutas de muro con particularidades
Código de impresión	Se obtiene integrando distintos parámetros: brazo robótico, materiales y extrusión, espacio de trabajo, etc.	Código de impresión
Ejecución de la impresión	Proceso de manufactura aditiva del elemento muro	Muro impreso en 3D

3.2 Resultados de la subdivisión

Las variables de la subdivisión establecen de manera directa distintas formas para los muros resultantes en cascada o sublocación volumétrica:

- Volumen máximo está establecido de forma singular por la capacidad del manipulador robótico y su cinemática.
- Capacidades técnicas como la sofisticación de la bomba o la capacidad material para hacer buenos amarres estructurales en los *cold joints* cuando un muro consista en más de una rutina de impresión.
- Capacidad de levante, el que limita directamente la dimensión de los muros.

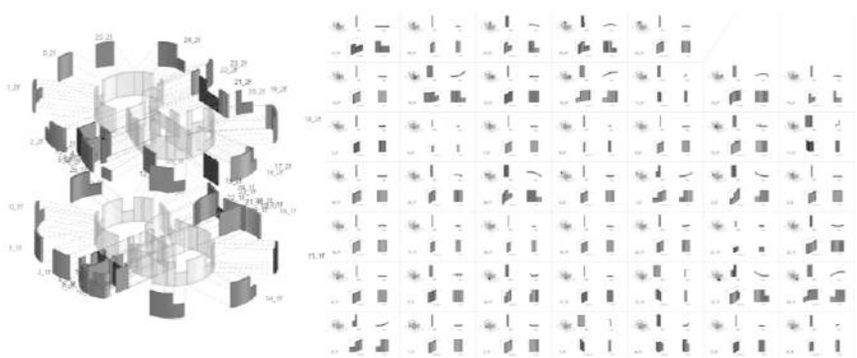

Figura 4. Despliegue de muros a imprimir bajo la premisa de montacarga liviano

La intersección de estas restricciones va secuencialmente generando muros más pequeños; no obstante, estas piezas de muros pueden ser fusionadas y contrastadas por el volumen máximo, de modo de ser cortados los muros.

3.3 Características del muro

En esta etapa se empiezan a definir las características del muro, desde el volumen principal hasta los trazos que finalmente configurarán la ruta del robot manipulado, ya que algunos detalles están en el volumen, y otros deben ser trazados directamente o modificando *paramétricamente* los trazos de la ruta de impresión.

El muro principalmente es caracterizado por su perímetro u *outline*, el cual es la frontera física de su volumen. Otro trazo característico de la impresión es la trama estructural de relleno o *infill*, la cual consiste en un vaivén modulado con cierta frecuencia y que une ambos perímetros. En la instancia de trabajo, debido a la situación de otoños e inviernos sumamente helados, el *infill* es problemático, pues produce puentes térmicos con posibilidad de congelamientos en el interior de los recintos. Por ello, la conexión estructural entre caras exterior e interior del perímetro del muro se realiza por pequeñas barras estriadas (ver figura 6 a la derecha). Estas actúan anclando ambas

caras del perímetro también en su estado fresco colaborando con la estabilidad y el aplomo.

3.4 Texturado de muros y cualidades

Cualidades prestacionales necesarias de adherir a los muros, en cuanto a su capacidad de instalación y recepción de instalaciones. Las siguientes adiciones han sido exploradas:

- Adición de vacíos a nivel de contacto con el suelo y superior
- Diseño y relación lateral con los demás muros
- Relación con objetos que han de portarse: ventanas y puertas
- Otros

El texturado corresponde a la adición de una dimensión extra de diseño, una ampliación del diseño original. Como tal, establece en un margen limitado pero notable un aprovechamiento a nivel plástico de la tecnología de AMC. A nivel geométrico, se determina en un rango acotado con centro en el volumen original, el cual debe delimitarse con respecto al grosor del cordón impreso, el alto de capa, las características del material y el número de la capa en cuestión, entre otros parámetros, ya que localmente estos aspectos podrán establecer localmente situaciones de excentricidad del centro de masa y desplomes. La relación cóncavo-convexa de la forma constituye una granularidad del patrón, el cual posiblemente posea una gran expresividad plástica (ver figura 5).

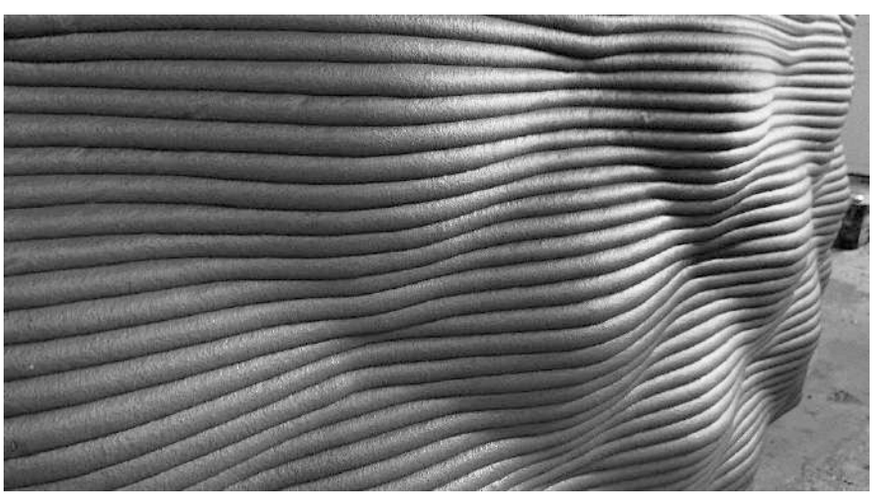

Figura 5. Detalle de textura de muro impreso.

3.5 Generación de ruta y ejecución de manufactura aditiva

En esta etapa, se toman los trazos modificados con texturas y demás singularidades incluidas en el muro para establecer la ruta del robot. Es deseable para esta etapa terminal coordinar todos los trazos y planos que conformarán los movimientos lineales del robot en una secuencia de espiralización o *vase mode* (términos de impresión 3D FDM) para asegurar zonas sin costuras.

En un proceso singular de manufactura, es importante verificar alturas con respecto a la superficie de impresión, geometría de la herramienta de impresión y la relación entre espacio de trabajo robótico y la pieza a imprimir. Como en esta plataforma dichos aspectos están incluidos dentro del algoritmo de segregación, es importante la corroboración final mediante una simulación digital del proceso de impresión, que consiste en correr el código ruta del robot y verificar la existencia de singularidades. La ejecución de la AMC como tal puede realizarse desde ese entonces, donde la ocurrencia de otros fenómenos físicos provenientes de los múltiples parámetros de la deposición del material podría hacer fallar la impresión. Estas vicisitudes son importantes y deberán ser analizadas y devueltas como conocimiento de manufactura a la plataforma.

Figura 6. Impresión de muro prototipo según alcance robot Kuka

4 Discusión

4.1 Segmentación y su visualización como espacios de diseño

La segmentación realizada en la instancia estudiada se produjo a través de la intersección de rangos paramétricos materiales (peso propio, capacidad del robot, relación con vanos), donde será necesario realizar mayor exploración en trabajos futuros para pasar de la elección manual de restricciones de segmentación a una opción que deduzca mejores opciones y las fundamente comparativamente con resultados comparados. Independientemente de lo anterior, la visualización del espacio de diseño se posicionó como una herramienta valiosa para el análisis de viabilidad de la AMC por medios robotizados, para conocer un panorama de las características del muro impreso en 3D mediante la variación de distintas premisas de subdivisión.

Programar la etapa de segmentación con un diseño ya establecido acusa el nivel de implementación del conocimiento de fabricación con el robot en la etapa de diseño; es así como radios de curvatura, puntos de inflexión, de concomitancia entre muros, etc., podrían acoplarse de buena manera con el espacio de trabajo del robot. En desarrollos futuros, este acople podría ser abstraído e invertido para producir herramientas y posiblemente sistemas generativos basados en regímenes de portes, trazos de arcos y su relación, y gestión con respecto a la geometría global.

4.2 Nivel muro como objeto de diseño

En manufactura aditiva para la construcción, es tendencia general el enfoque en el muro para solucionar la impresión del edificio. Siendo esta una unidad de análisis e intervención, ha sido probada desde la especificación y evaluación de desempeños, pudiendo levantar el diseño de patrones interiores del muro para desempeño térmico (Alkhalidi & Hatuqay, 2020; Giraud, 2019). Esto es aún acrecentado en cuanto a que otras tipologías como techumbres todavía son raramente exploradas (Craveiro *et al.*, 2019; García-Alvarado *et al.*, 2021). A nivel global, esto es coherente con una aproximación *top-down* (Bernal & Eastman, 2011; Carrara & Novembri, 2000; Sacks *et al.*, 2004), en la cual la abstracción de una parte para la solución del todo ha sido planteada como una situación favorable.

Conclusiones y trabajo futuro

El presente trabajo estableció una rutina de obtención de código de impresión para manipuladores robóticos desde un diseño dado. Su principal diferencia con las experiencias BIM antes mencionadas radica en la inclusión de diversos criterios para obtención de módulos de muro y el aumento del diseño de este

en mayores niveles de detalle y de funcionalidad. Como una experiencia en desarrollo para producir una construcción completa (2023), las situaciones en terreno derivarán en adquisición de conocimiento de fabricación valioso para introducir a la plataforma.

Entendiendo el contexto actual en el que se produce la construcción y su cadena productiva caracterizada por una abrumante intervención de elementos de especialidades fabricados convencionalmente, embebidos y que modifican el muro como tal, es necesario el relevamiento a nivel sistémico del muro de forma abstraída de la programación misma de las tareas de la plataforma. De esta forma, se podrían integrar de mejor manera distintos procesos constructivos y salvaguardar la distinción de diseño de la manufactura aditiva. La implementación de ingeniería de sistemas basada en modelos (MBSE) ha sido implementada para estos propósitos (Valdes *et al.*, 2016), además de como una alternativa a espacios de diseño diversos (Bernal, 2016).

Referencias

Alabbasi, M., Chen, H. & Agkathidis, A. (2021). Developing a Design Framework for the 3D Printing Production of Concrete Building Components. 713-726.

Alkhalidi, A. & Hatuqay, D. (2020). Energy efficient 3D printed buildings: Material and techniques selection worldwide study. *Journal of Building Engineering*, *30*, 101286. https://doi.org/10.1016/j.jobe.2020.101286

Allouzi, R., Al-Azhari, W. & Allouzi, R. (2020). Conventional Construction and 3D Printing: A Comparison Study on Material Cost in Jordan. *Journal of Engineering*, *2020*(Cc). https://doi.org/10.1155/2020/1424682

Banda, P., García-Alvarado, R. & Muñoz-Sanguinetti, C. (2021). Architectural Digital Design for 3D Printing Housing : Search for 3D Printing in Construction Trends for a Design Methodology. En SIGraDi (Ed.), *SIGraDi 2021, Designing Possibilities* (pp. 1409-1422).

Bernal, M. (2016). From Parametric to Meta Modeling in Design. En SIGraDi (Ed.), *XX Congreso de la Sociedad Ibero-americana de Gráfica Digital* (pp. 579-583). https://doi.org/10.5151/despro-sigradi2016-815

Cascone, P., Laddaga, M. & Forestiero, F. (2020). Digital Construction: 3D Printing for Performative Houses. *Digital Concrete 2020*, *28*, 804-813. https://doi.org/10.1007/978-3-030-49916-7_79

Craveiro, F., Duarte, J. P., Bartolo, H. & Bartolo, P. J. (2019). Additive Manufacturing as an Enabling Technology for Digital Construction: A Perspective on Construction 4.0. *Automation in Construction*, *103*, 251-267. https://doi.org/10.1016/j.autcon.2019.03.011

Davtalab, O., Kazemian, A. & Khoshnevis, B. (2018). Perspectives on a BIM Integrated Software Platform for Robotic Construction Through Contour

Crafting. Automation in Construction, *89*, 13-23. https://doi.org/10.1016/j.autcon.2018.01.006

Ding, L., Wei, R. & Che, H. (2014). Development of a BIM-based automated construction system. *Procedia Engineering*, *85*, 123-131. https://doi.org/10.1016/j.proeng.2014.10.536

Forcael, E., Pérez, J., Vásquez, Á., García-Alvarado, R., Orozco, F. & Sepúlveda, J. (2021). Development of Communication Protocols between BIM Elements and 3D Concrete Printing. *Applied Sciences (Switzerland)*, *11*(16). https://doi.org/10.3390/app11167226

García-Alvarado, R., Moroni-Orellana, G. & Banda, P. (2021). Architectural Evaluation of 3D-Printed Buildings. *Buildings*, *11*(6), 254. https://doi.org/10.3390/buildings11060254

Giraud, I. (2019). Incorporating Thermal Performance in Clay 3D Printing (pp. 1-10).

Khajavi, S. H., Tetik, M., Mohite, A., Peltokorpi, A., Li, M., Weng, Y. & Holmström, J. (2021). Additive Manufacturing in the Construction Industry: The Comparative Competitiveness of 3D Concrete Printing. *Applied Sciences (Switzerland)*, *11*(9). https://doi.org/10.3390/app11093865

Khoshnevis, B. (2004). Automated Construction by Contour Crafting - Related Robotics and Information Technologies. *Automation in Construction*, *13*(1), 5-19. https://doi.org/10.1016/j.autcon.2003.08.012

Khoshnevis, B. & Rosanne, D. (1998). Innovative Rapid Prototyping Process Makes Large Sized, Smooth Surfaced Complex Shapes in a Wide Variety of Materials. *Materials Technology*, *13*(2), 53-56. https://doi.org/10.1080/10667857.1998.11752766

Kontovourkis, O. & Tryfonos, G. (2020). Robotic 3D Clay Printing of Prefabricated Non-conventional Wall Components based on a Parametric-integrated Design. *Automation in Construction*, *110*, 103005. https://doi.org/10.1016/j.autcon.2019.103005

Valdes, F., Gentry, R. & Eastman, C. (2016). Applying Systems Modeling Approaches to Building Construction. *33rd International Symposium on Automation and Robotics in Construction (ISARC 2016)*. https://doi.org/10.22260/ISARC2016/0102

Manufacturing & Industry 4.0: Digital Fabrication

Digital Fabrication and Mass Customization in Temporary Structures: a Systematic Review of Literature

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Abstract. This article presents a Systematic Literature Review (SLR) intending to answer the research question: how Digital Fabrication (DF) and Mass Customization (MC) are being used for the development of temporary or ephemeral architectural structures? The goal was to identify current literature on temporary structures guided by DF and MC. Notably, there is a lack of research in this field. The literature reviewed present variations in the proposition of MC in two aspects: process and product; the main discussions found focused on establishing parametric and / or adequate workflows, and on the production of the complex form. The emphasis of the SRL is on the importance of expanding the discussions of DF and MC to ephemeral structures in architecture, not necessarily associated with complex form and contribute to local cultural productions. It is part of a research that seeks to develop co-participatory models of stalls guided by the DF and MC.

Keywords: Digital Fabrication, Mass Customization, Ephemeral Architecture, Ephemeral Structure, "*Festa de Largo*" Stalls**.**

1 Introduction

De acordo com Galvão e Pereira (2014, p. 183), a Revisão Sistemática da Literatura (RSL) é *um tipo de investigação focada em questão bem definida, que visa identificar, selecionar, avaliar e sintetizar as evidências relevantes disponíveis*. Neves et al. (2017),

RSLs são estudos secundários com vistas a mapear, encontrar, avaliar criticamente, consolidar e agregar os resultados de estudos primários relevantes sobre um tópico específico de pesquisa, bem como identificar lacunas a serem preenchidas (Neves et al., 2017, p. 141).

A RSL desenvolvida foi conduzida com o objetivo de encontrar modelos, processos, estudos de objetos similares ou próximos a estruturas efêmeras com área não superior a 12m^2 e que tivessem a função de servir bebidas e

comidas em espaços públicos e que fossem orientadas pela Fabricação Digital (FD) e Customização em Massa (CM), em um recorte temporal de 20 anos (2.000 a 2.020). O objetivo principal desta revisão foi encontrar trabalhos científicos completos disponíveis por meio eletrônico que tenham passado por um processo de revisão respondendo à questão principal de pesquisa: como a FD e a CM estão sendo usadas para o desenvolvimento de estruturas arquitetônicas provisórias ou efêmeras?

Questões secundárias foram estabelecidas para auxiliar a coleta de dados dos trabalhos selecionados: (1) quais os conceitos e as definições para a CM?; (2) qual é a produção atual de estruturas arquitetônicas provisórias ou efêmeras desenvolvida por meio da FD na escala 1:1?; e, (3) quais são os métodos atuais de geração e criação de sistemas provisórios construídos por meio da FD?

Este trabalho faz parte de pesquisa doutoral que trata da adoção da FD e da CM para desenvolvimento de modelos alternativos para estruturas efêmeras de comidas e bebidas em festas populares de rua, popularmente chamadas de “Barracas”. Tais estruturas são elementos constituintes de Festas Populares tradicionais da cidade de Salvador, Bahia, e hoje encontram-se descaracterizadas e sem valor artístico-cultural, sendo construídas através de um sistema de produção em série de modelo único, como um suporte utilitário.

2 Metodologia da revisão

Para o desenvolvimento da Revisão Sistemática da Literatura (RSL), estabelecemos descritores associados aos temas da questão principal de pesquisa e posteriormente construímos expressões lógicas (interseção entre os descritores por meio de OR e AND).

Os descritores consistem em classificadores de um domínio ou uma lista de termos definidos. *Esses métodos se baseiam, principalmente, na freqüência* (sic) *de ocorrência de palavras em documentos* (Campos, 2010, p. 221). Campos (2010) aponta para a importância de uma classificação robusta para os descritores, dentro do domínio de interesse, pois caso contrário eles podem ser pouco efetivos como elementos de recuperação de informação.

Os descritores foram testados em pesquisa exploratória, servindo para conhecer os termos utilizados nos artigos, identificar os mais próximos ao tema da pesquisa e refinar a RSL.

Esta pesquisa parte de uma abordagem quantitativa para identificar métodos e processos desenvolvidos na produção contemporânea do objeto de pesquisa, e qualitativa para compreender os resultados e aplicações do objeto, aproximando-o da questão de pesquisa. Interpretação dos dados realizada de modo interpretativista e a hermenêutica como modo de análise.

De acordo com Groat e Wang (2002, p. 136, tradução nossa), a pesquisa interpretativa é definida especificamente como investigações em fenômeno físico-social dentro de um contexto complexo, com vista a explicar esse fenômeno em uma forma narrativa e de um modo holístico.

A Hermenêutica como modo de análise sugere uma maneira de compreender os dados textuais, preocupando-se com o significado do texto, dando sentido a um objeto de estudo, tornando-o claro (Myers, 2020). Neste modo de análise, há uma expectativa de significado que parte do todo para as partes e das partes para o todo, onde as partes são determinadas pelo todo, mas também determinam esse todo (Gadamer, 1976, p. 117 apud Myers, 2020).

3 Materiais e método

Com base no modelo de Galvão e Pereira (2014, p. 183), porém modificado e ampliado pelas autoras, o percurso metodológico realizado para esta RSL foi: (1) elaboração da pergunta de pesquisa; (2) definição dos descritores; (2) construção das *strings* de busca a partir de descritores; (3) construção do protocolo da RSL; (4) recuperação automática de trabalhos nas bases de dados pelas *strings*; (5) aplicação dos critérios de inclusão e exclusão; (6) busca e armazenamento dos trabalhos completos; (7) extração dos dados; (8) síntese dos dados; (9) análise dos resultados; (10) publicação dos resultados.

Buscamos com as expressões lógicas interpretar a interseção entre as quatro dimensões da pesquisa: **elemento** (estrutura provisória ou efêmera) x **técnica** (Fabricação Digital) x **produção** (Customização em Massa) x **contexto** (Festa popular).

Em pesquisa prévia, identificamos que o descritor “barraca” não retornava trabalhos relativos ao tema de pesquisa. Com o intuito de ampliar este descritor e encontrar referências que trouxesse possíveis resultados ao tema, utilizamos os termos “estruturas provisórias” e “arquitetura efêmera”.

O protocolo e a condução da RSL foram auxiliados pelo aplicativo *start* v.3.3 Beta 03. Usamos como bases de dados: Scopus; Web of Science; Science Direct; e Scielo Brasil. Realizamos dois ciclos de buscas contendo em cada um deles quatro variações das expressões lógicas. No primeiro ciclo, utilizamos as quatro dimensões da pesquisa que queríamos investigar, partindo da *string* completa até a geração de três decomposições derivadas da primeira *string*. Neste primeiro ciclo não tivemos resultados para a questão problema.

Excluímos assim a dimensão contexto no segundo ciclo (festa popular), tornando as expressões lógicas mais genéricas. Iniciamos o segundo ciclo partindo da mesma lógica anterior. Esta ampliação das expressões lógicas visou diminuir a especificidade da busca e obter resultados com vistas a encontrar discussões e aplicações acerca de estruturas temporárias e / ou

arquitetura efêmera orientadas a FD e CM. Neste segundo ciclo encontramos os resultados que amparam esta RSL.

Das oito expressões lógicas desenvolvidas para esta RSL, apenas duas retornaram com trabalhos relativos a questão de pesquisa (strings seis e sete), conforme pode ser visto no Quadro 1. Apesar desse resultado, dois artigos apresentaram as três dimensões de pesquisa (Schimek; Stavric; Wiltsche, 2013; Crolla *et al.* 2019).

Quadro 1. Ciclos e expressões lógicas da RSL

	Dim	**Elemento**	**Técnica**	**Produção**	**Contexto**
	Strings	***Stall*** *or* ***tent*** *or* *“**temporary structures**” or “**ephemeral architecture**”*	***“Digital fabrication”*** *or* *“**digital manufacturing**”*	***“Mass customization”***	***“Cultural festivities”*** *or* *“**popular events**”*
1 ciclo	1	✓	✓	✓	✓
	2	✓			✓
	3		✓		✓
	4			✓	✓
2 ciclo	5	✓	✓	✓	
	6		✓	✓	
	7	✓	✓		
	8	✓		✓	

Fonte: Autoras, 2022.

3.1 Critérios de inclusão e exclusão

Estabelecemos os critérios de inclusão e exclusão para direcionar a coleta e seleção dos trabalhos objetivando os interesses da pesquisa, uma vez que o tema abordado trata de um campo amplo, com questões recentes que estão em andamento e possui muitas áreas de aplicação. Apresentamos no Quadro 2 os critérios que definiram a etapa da extração.

Aplicamos os critérios no processo de seleção e extração de dados. Contudo eles sofreram ajustes. Ao iniciar a revisão, pretendíamos encontrar modelos desmontáveis e remontáveis de pequenas estruturas sendo critério de inclusão toda arquitetura desmontável desenvolvida por FD ou MD com área até 50m^2. Não encontramos trabalhos com essas características, independentemente da dimensão do objeto. Com os resultados das buscas da sexta *string*, não aplicamos mais restrições às dimensões do objeto efêmero. Percebemos essa modificação com os trabalhos desta string, quando começaram a retornar nas buscas. Nenhuma string anterior retornou com trabalhos que tratassem de objeto arquitetônico efêmero.

Quadro 2. Critérios de inclusão e exclusão etapa extração

Critérios de inclusão
Toda arquitetura desmontável desenvolvida por FD (i.e., arquitetura efêmera, estrutura efêmera e estrutura temporária).
Critérios de exclusão
Qualquer referência que traga a FD e não trate de arquitetura efêmera.
Qualquer referência que traga a FD fora da área de engenharia, arquitetura e design.
Qualquer referência que trate apenas de objetos de uso cotidiano, exclusivamente por fabricação aditiva.
Qualquer referência que traga exclusivamente modelagem numérica generativa e performativa.
Qualquer referência que traga a FD dentro dos conceitos e aspectos de *small and medium sized enterprises* (SMEs), *Life-cycle, Data-driven, Smart object,* uso das nuvens, *digital Twin, Cyber-Physical Systems,* realidade aumentada, internet das coisas, esforços físicos de materiais, mecânica de materiais, cálculos matemáticos etc.
Toda referência que tratar exclusivamente de prototipação digital, prototipagem rápida, realidade aumentada, geração de modelo numérico por escaneamento físico etc.
Referências que tratem exclusivamente de robótica / automatização de robôs.
Referências cujo acesso ao documento ou ao conteúdo não estava disponível.

Fonte: Autoras, 2022.

O retorno das buscas indicava que o campo da estrutura / arquitetura efêmera orientada a FD e CM é um campo aberto. Conforme afirma Campos (2010), a RSL se baseia na frequência de ocorrência de palavras em documentos, havendo trabalhos com abordagens diferenciadas dentro do campo da FD e da CM.

Ao tratar a Customização em Massa como um sistema de produção (E não apenas como uma diferenciação em série de elementos arquitetônicos para atender a complexidade da forma. Detalharemos este tópico na seção 4.1.), levamos em consideração trabalhos que discutiam modelos customizáveis de estrutura (e.g. MORK *et al.*, 2019). Abordaremos melhor esta questão na quarta seção, onde discutiremos os trabalhos selecionados.

Com respeito aos conceitos, conceituamos a arquitetura efêmera nesta pesquisa considerando duas características principais intrínsecas a ela: a efemeridade e a materialidade. A primeira refere-se ao tempo transitório que a estrutura / arquitetura efêmera ocupa em um determinado lugar. A segunda, à materialidade de sua construção, refere-se as suas possibilidades e facilidades de montagem e desmontagem. Levy (1998, p. 53) reforça que *a questão da efemeridade liga-se intimamente à questão da técnica*. A arquitetura ou estrutura foi denominada efêmera quando apresentou os aspectos de itinerante e / ou transitório.

4 Resultados

Dos 132 trabalhos recuperados automaticamente nas bases de dados pelas expressões lógicas, selecionamos 124 pela sexta e sete trabalhos pela sétima string. Desse total, ficamos com 40 trabalhos após a aplicação dos critérios de inclusão e exclusão no título, resumo e palavras-chave, assim como a exclusão de duplicados.

Destes 40 trabalhos, após buscas das disponibilizações dos artigos completos, sobraram em uma primeira seleção 14 artigos, dos quais seis mostraram-se relevantes para a questão de pesquisa. Alguns títulos recuperados nas bases de dados não estavam disponíveis para leitura na Comunidade Acadêmica Federada (CAFe) na plataforma Periódicos da CAPES. Detalhamos esses resultados na próxima seção.

4.1 Customização em Massa: conceitos e definições

De acordo com Crolla *et al.* (2017) e Mork *et al.* (2019) o termo "Customização em Massa" foi cunhado por Stan Davis em seu livro Future Perfect em 1987. Segundo os autores, a CM definida por Davis (1987) estaria localizada entre as exigências do cliente, com as possibilidades do produtor e a preços como os desenvolvidos na produção em massa. De acordo com Mork *et al.* (2019), o termo foi refinado por Andreas M. Kaplan e Michael Haenlein em 2006, tendo sido definido como *uma estratégia que cria valor de alguma forma pela interação empresa-cliente no estágio de projeto no nível de operação para criar produtos customizados, seguindo uma estratégia híbrida combinando liderança de custo e diferenciação* (Kaplan; Haenlein, 2006 *apud* Mork *et al.*, 2019, p. 222).

Para Mork et al. (2019, p. 223), com a abordagem computacional e o pensamento paramétrico pode-se alcançar a CM: o objetivo deve ser criar um fluxo de trabalho paramétrico contínuo, do esboço à fabricação, aplicável a uma ampla variedade de projetos. A CM pode ser oferecida por meio da variabilidade do produto ou da variabilidade do processo.

Esses pesquisadores trazem um relevante questionamento sobre a CM na arquitetura: se cada projeto é único e não estândar, como então trabalhar a concepção de CM para a arquitetura? Mork *et al.* (2019) defendem que um modelo digital para ser customizável em massa deve levar em consideração um sistema estrutural que pode ser replicável em diferentes objetos. Este modelo deve contemplar informações na linguagem dos atores envolvidos no processo e na produção do objeto (arquiteto, engenheiro e manufaturador). Esta ação se torna uma ação *especialmente complexa* para o campo, uma vez que oferecer uma ampla variabilidade de processos e de produtos é o que torna o arquiteto, arquiteto.

Apesar das ressalvas apresentadas por Mork *et al.* (2019) em relação a utilização da CM para arquitetura, os autores acreditam que a associação dos sistemas digitais de concepção e produção com o pensamento paramétrico é

o caminho natural para a produção da arquitetura e da indústria construtiva (Mork *et al.*, 2019, p. 223).

Para Kolaveric (2003 *apud* Adrita; Widyowijatnoko, 2016, p. 777) muitas abordagens de Fabricação Digital (FD) têm vantagens em sua capacidade de CM, ou seja, a capacidade de criar tipos diferentes de componentes de forma relativamente eficiente, permitindo uma melhor exploração da forma do que o processo de fabricação convencional (variabilidade do produto).

Para Adrita e Widyowijatnoko (2016, p. 780), na construção convencional os projetistas trabalham com componentes construtivos disponíveis no mercado. Com a utilização da CM, os projetistas trabalham com componente a ser fabricado, desenvolvido a partir de uma geometria preliminar, aprofundado no detalhe para a sua produção e montagem. Sendo assim, os projetistas criam elementos que podem ser desenvolvidos facilmente em projetos, com um custo razoável, assumindo a função de conceber, desenvolver e executar o produto pensado, mudando a maneira de desenvolver e produzir projetos do séc. XX. Ao criar o modelo para ser executável em massa por variedades, é preciso considerar todos os aspectos do objeto, i.e. firmeza, execução e montagem. O modelo deve conter essa compreensão do todo.

4.2 Quais técnicas e materiais estão sendo utilizadas para a produção das estruturas efêmeras?

No Quadro 3 estão elencados os programas, as técnicas e os materiais utilizados nas pesquisas selecionadas.

Quadro 3. Síntese dos programas, técnicas e materiais utilizados

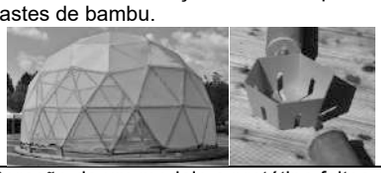
Autor	Programa	Técnica	Material
Mork *et al.* (2019)	Rhinoceros *e* Grasshopper. Woodpecker exporta 3D CAD / CAM.	Fresadoras CNC	Madeira.
Aditra; Widyowijatnoko (2016)	Programação visual	Fresadoras CNC	Hastes de bambu padronizadas e conectores metálicos customizados.
Schimek; Stavric; Wiltsche (2013)	Rhinoceros e Grasshopper. ABAQUS software de simulação.	Fresadoras CNC	Madeira laminada cruzada padronizada.
Crola *et al.* (2017)	Rhinoceros e Grasshopper.	Impressão 3D	Metal customizado, tubos de alumínio e membrana em tecido padronizados.
Martín-Pastor *et al.* (2017a)	Não informado	Fresadoras CNC	Laminado de madeira.
Martín-Pastor *et al.* (2017b)	Não informado	Fresadoras CNC	Laminado de madeira.

Fonte: Autoras, 2022.

4.3 Qual a produção atual das estruturas efêmeras por FD em escala real?

As pesquisas recuperadas apresentaram três abordagens para a produção das estruturas provisórias / efêmeras: (a) conector customizado por variação seriada adaptando-se a materiais construtivos padronizados (hastes e nós) (Adrita; Widyowijatnoko, 2016; Crolla *et al.*, 2017); (b) produção de forma complexa a partir de elemento construtivo padronizado (Schimek; Stavric; Wiltsche, 2013); e (c) construção do volume a partir da revolução de superfície plana (Martín-Pastor *et al.*, 2017; Martín-Pastor *et al.*, 2020). As imagens dos trabalhos podem ser vistas na Quadro 4.

Quadro 4. Achados da RSL

Autores	Objeto de estudo	Objetivo do trabalho
Mork *et al.* (2019)	Modelo computacional customizado de sist. construtivo em madeira para aplicações diversas direcionado para locais específicos, com a participação do cliente e sob medida.	Apresentar um conjunto de ferramentas paramétricas para o desenvolvimento de estruturas em madeira customizável em massa.
Aditra; Widyowijatnoko (2016)	Construção de domos geodésico em bambu com aplicação da CM nos nós estruturais e construção tradicional para as hastes de bambu. 	Explorar um fluxo de trabalho de construção e método alternativos com a combinação de CM e métodos de construção convencional.
Schimek; Stavric; Wiltsche (2013)	Geração de um modelo e protótipo feitos a partir da CM com materiais disponíveis em mercado e de forma não estândar.	Explorar arquitetura não-estândar construída com elementos padrão usando processos de construção contemporâneos e recursos de materiais de forma eficiente.
Crolla *et al.* (2017)	Nó estrutural topologicamente restrito para atender aos desafios da impressão 3D.	Investigar o potencial de combinação de materiais de construção padrão com nós personalizados otimizados individualmente em resposta às condições de carga local em estruturas não padronizadas, irregulares ou de dupla curvatura.

Quadro 4. Achados da RSL (continuação)

Autores	Objeto de estudo	Objetivo do trabalho
Martín-pastor *et al.* (2017a)	Pavilhão desenvolvido no Trabalho final de graduação.	Discutir a incorporação de competências específicas relacionadas com projeto digital e FD em trabalhos finais de graduação.
Martín-Pastor *et al.* (2017b)	Papel do arquiteto frente as novas tecnologias de projeto e construção a partir da experiência de quatro pavilhões efêmeros em quatro universidades e países diferentes.	Propor um modelo de arquitetura efêmera de fácil montagem, baixo custo e reutilizável, cujos destinatários são os cidadãos, em espaços públicos geridos por eles.

Fonte: Autoras, 2022.

Em dois artigos as pesquisas foram desenvolvidas usando um conector de peças estruturais para estruturas de forma não-estândar (Crolla et al. 2019; Adrita; Widyowijatnoko, 2016); um trabalho apresentou um modelo computacional para CM de estruturas em madeira (Mork et al., 2019); em duas pesquisas foram desenvolvidos o objeto arquitetônico a partir de superfícies planas (Martín-Pastor et al. 2017a; 2017b); um trabalho trouxe um modelo que utilizou elementos construtivos padrão para desenvolver uma estrutura não estândar (Schimek; Stavric; Wiltsche 2013).

5 FD e CM em estruturas provisórias: processo em experimentação

A partir dos resultados desta RSL, identificamos uma lacuna de trabalhos no campo da arquitetura efêmera e em objetos similares às barracas de feiras e / ou festas populares, tão comuns em festas de rua em todo o Brasil e no mundo.

Pelo que foi depreendido da pesquisa, os métodos atuais de geração e criação para sistemas provisórios / efêmeros construídos orientados por meio da FD e CM estão sendo desenvolvido pela parametrização e pelos processos de FD subtrativo e aditivo.

A produção atual de estruturas arquitetônicas provisórias ou efêmeras desenvolvida por meio da FD na escala 1:1 apresenta-se de maneira experimental, testando e aprofundando os conceitos de CM, com a utilização de elementos construtivos padronizados associados com elementos customizados e com a produção da forma complexa.

Contudo, aspectos como um objeto pensado para ser montado e desmontado, podendo ser remontado eventualmente, ainda não apareceram sob essa vertente da FD e CM, que seria nosso objetivo de pesquisa.

Os artigos analisados convergem na interpretação e entendimento acerca dos conceitos e definições da FD e CM. Os trabalhos recuperados apresentam abordagens diferenciadas de como desenvolver a CM, seja ela a partir do processo de produção ou a partir das variações seriadas de componentes do produto, apontando para uma flexibilidade na utilização desses sistemas.

Alguns aspectos resultantes desta RSL podem ser listados para a arquitetura: a coparticipação na criação de objetos / produtos; a interdisciplinaridade; a mudança do pensamento focado no objeto para o pensamento voltado para o fluxo de informações (aproximação ao entendimento de sistemas); a antecipação na fase de concepção do processo de fabricação e montagem (característica inerente à arquitetura efêmera e à FD).

A nomenclatura para arquitetura efêmera mostrou-se pouco utilizada no campo da FD e CM, ficando dispersa ou absorvida pela nomenclatura das estruturas provisórias. O que não caracteriza que os termos utilizados tenham partido de uma classificação fraca, como poderia suscitar as colocações apresentadas por Campos (2010). O que nos parece demonstrar é que as discussões sobre a produção de FD e CM para a arquitetura efêmera ainda estão se desenvolvendo e que as discussões centrais sobre esses sistemas estão versadas sobre o estabelecimento de parâmetros ou fluxos adequados para a aplicação na produção arquitetônica.

O termo pavilhão apresenta-se como um objeto de arquitetura efêmera, é transitório, não perene. Não possui funcionalidade específica, não se diferenciando por exemplo das obras de cunho escultórico, como algumas recuperadas nesta RSL. Porém o termo pavilhão tem uma forte associação com uma configuração de base complexa quando associado à FD e CM.

Neste sentido, como apresentado por Neves *et al.* (2017), a RSL nos permitiu agregar resultados para a utilização de estruturas arquitetônicas provisórias com métodos digitais atuais de produção e identificar lacunas a serem preenchidas em trabalhos futuros.

6 Considerações finais

Os resultados desta investigação apresentaram, além da escassez de trabalhos que tratem dos temas pesquisados, aplicações

de elementos provisórios que testam e desenvolvem o ferramental digital disponível atualmente para arquitetura e construção. A efemeridade ou o aspecto provisório destes trabalhos não estão ligados diretamente ao desenvolvimento de um objeto efêmero em si, mas às tentativas de viabilidade da FD e da CM para soluções em escala real.

O argumento resultante desta RSL para a produção de estruturas arquitetônicas provisórias ou efêmeras desenvolvida por meio da FD e CM na escala 1:1 é que estas estão sendo usadas experimentalmente, testando seus aspectos e alcances no campo da arquitetura sob duas vertentes: processo e produto.

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Referências

Aditra, R., & Widyowijatnoko, A. (2016). Combination of mass customisation and conventional construction. A case study of geodesic bamboo dome. In Chien, S. Choo, S. Schnabel, M. A. Nakapan, W. Kim, M. J. Roudavski, S. (Eds.), Living Systems and Micro-Utopias: Towards Continuous Designing, Proceedings of the 21st International Conference of the Association for Computer-Aided Architectural Design Research in Asia, CAADRIA (pp. 777–786). Hong Kong.

Campos, M. (2010). O Papel Das Definições Na Pesquisa Em Ontologia. Perspectivas em Ciências da Informação, 15(1), 220-238. https://doi.org/10.1590/S1413-99362010000100013.

Crolla, K., Williams, N., Muehlbauer, M., & Burry, J. (2017) Smartnodes Pavilion. Towards Custom-optimized Nodes Applications in Construction. In P. Janssen, P. Loh, A. Raonic, M., & A. Schnabel (Eds.), Protocols, Flows and Glitches, Proceedings of the 22nd International Conference of the Association for Computer-Aided Architectural Design Research in Asia, CAADRIA (pp. 467 - 477). Xi'an Jiaotong - Liverpool University. https://doi.org/10.52842/conf.caadria.2017.467.

Galvao, T., & Pereira, M. (2014). Revisões sistemáticas da literatura: passos para sua elaboração. Epidemiologia e Serviços de Saúde, 23(1), 183-184. http://dx.doi.org/10.5123/S1679-49742014000100018.

Groat, L., & Wang, D. (2002) Architectural research methods. John Wiley & sons inc.

Levy, R. (1998) Entre Palácios e Pavilhões: a arquitetura efêmera da Exposição Nacional de 1908. [Unpublished master's thesis] Universidade Federal do Rio de Janeiro.

Martín-Pastor, A., López-Martínez, A. & Santos-Calvo, H. (2017a). Digital fabrication and ephemeral architecture: teaching Innovation in the final degree project for the creation of new Professional opportunities. Proceedings of the 9th International Conference on Education and New Learning Technologies, EDULEARN (pp. 3830-3835). IATED. DOI: 10.21125/edulearn.2017.1830. Barcelona.

Martín Pastor, A., Martín-Mariscal, A., & López Martínez, A. (2017b). Rethinking Ephemeral Architecture. Advanced Geometry for Citizen-Managed Spaces. In P. Mercader-Moyano (Ed.), Sustainable Development and Renovation in Architecture, Urbanism and Engineering (pp. 301-310). Springer. DOI: 10.1007/978-3-319-51442-0_25.

Mork J. H., Luczkowski M., Manum B., & Rønnquist A. (2019) Toward Mass Customized Architecture. Applying Principles of Mass Customization While Designing Site-Specific, Customer-Inclusive and Bespoke Timber Structures. In F. Bianconi & M. Filippucci (Eds.), Digital Wood Design. (pp. 221-249). Springer. DOI: 10.1007/978-3-030-03676-8_7. Suíça.

Myers, M., (2020, July 2022) Qualitative Research in Business & Management. Sage Publications. Third edition. https://www.qual.auckland.ac.nz/.

Neves, L., Bernardini, S., Ruschel, R. & Moreira, D. (2017). Revisões sistemáticas da literatura: parte I. PARC Pesquisa em Arquitetura e Construção, 8(3), 141–143. https://doi.org/10.20396/parc.v8i3.8651561.

Schimek, H., Wiltsche, A., Manahl, M. & Pfaller, C. (2013). Full scale prototyping. In R. Stouffs, P. Janssen, S. Roudavski, & B. Tunçer, (Eds.), Open Systems, Proceedings of the 18th International Conference on Computer-Aided Architectural Design Research in Asia, CAADRIA (pp. 653–662). Research Publishing Services. Singapura.

Shell Structure of Bamboo Composite

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Abstract. This research is aimed at proposing a lightweight shell structure made from a bamboo composite. The research explores the addition of glass fiber to bamboo veneer for adhesion to produce a bamboo composite. Adding glass fiber improves the material's elasticity and ductility and strengthens the bond between units of laminated bamboo veneer. Moreover, we utilized a simulation tool to analyze the structural performance and compare the shell structure's mechanical differences before and after adding the glass fiber. In terms of fabrication, this paper presents a computational workflow for mesh segmentation and unrolling as well as a design for unique snap- fit joints for the connection between mesh strips. Finally, this paper outlines the fabrication of one part of the overall form as a demonstration case to verify the proposed method.

Keywords: Digital Fabrication, Bamboo composite

1 Introduction

Because of bamboo culm's growth characteristics (joints, diameter, hollowness, etc.), its material characteristics and dimensions are inconsistent. Therefore, the current research on and uses for construction of bamboo are mainly based on bamboo culm or simple processing for subsequent application (Huang, 2017). Among bamboo materials, laminated bamboo has the most representative development and utilization. Laminated bamboo originates from natural materials and has excellent mechanical properties in addition to being environmentally friendly (Sharma et al., 2015). Relevant studies have pointed out that laminated bamboo's properties are similar to those of wood, and laminated bamboo has been compared with traditional wood in the construction of tructural beams (Echavarria et al., 2012). Hence, laminated bamboo is widely used to make various composite engineering

material products, such as strand board, laminated lumber flooring, and construction beam material. However, aside from the traditional beam column structure application, laminated bamboo's mechanical performance in shell structures and its natural fiber material characteristics' effects on structures have rarely been discussed.

2 Objective

In this study, we developed a bamboo composite snap-fit joint method suitable for shell structures. To improve the shell structure's overall mechanical strength, we supplemented bamboo veneer with glass fiber, which is laminated in different fiber directions, to form a bamboo composite. The bamboo composite material completes the lightweight construction by improving the original natural fiber's poor splitting tensile strength and bending strength. This paper presents this material's properties. In terms of the joint design, we consider and discuss the fiber's texture and the snap-fit size and design appropriate joints and patterns to facilitate the joint test. In the second part of this paper, we develop a computational workflow for production and manufacturing and demonstrate the bamboo composite's bending strength on complex curved surfaces. We aimed to build a large-scale pavilion by designing a free-form thin shell structure. In this paper, we take a part of the structure (ratio 1:3 and 1:1) as a demonstration case to verify feasibility.

The current process is as follows: (1) Generate the desired form based on the parametric 3D modeling software Rhino and Grasshopper, and analyze the structure using Karamba3D. (2) After determining the shape, split the mesh, cut it into strips, and unroll them into 2D curves. (3) Automatically generate snap-fit joints on the strips. (4) Laser cut the strips, and then assemble them (Figure 1).

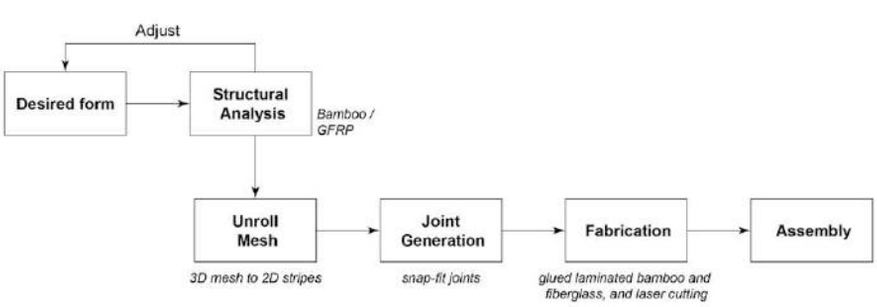

Figure 1. Shell structure made from bamboo composite.

3 Material

Bamboo is slightly similar to wood in structure, and it has strong directionality. Basic material tests show that bamboo has a high tensile strength in the parallel fiber direction, but its splitting strength (i.e., the shear force perpendicular to the fiber direction) is much lower than its tensile strength (i.e., the stretching stress in the fiber direction; You, 2009). Generally, in bamboo structures, damage is rarely caused by axial tension and is mostly due to bending (namely, flexural damage) or buckling caused by an excessive axial load (Lin et al., 2011). Therefore, in our preliminary study, we conducted an experiment with bamboo laminated in the fiber direction to improve its splitting strength and bending strength. After the experiment, we determined that if a construction with a higher bending degree is needed, it may be unable to bear high-strength structural force, depending on the glued bamboo-laminated material's properties. Thus, the laminated material may be easy to break. Previous studies have shown that material structure can be optimized by controlling the fibers' arrangement in different directions of bamboo sheets (30、60 and 90 degrees) (Chieh et al., 2022; Figure 2) and adding glass fiber material to become bamboo composite material (Thwe & Liao, 2003) to improve the shell structure's overall mechanical strength and make it more difficult to crack. In this study, we added bamboo veneer vertically and horizontally arranged and GFRP at a ratio of approximately 2:1 for gluing lamination to improve the material's elasticity and ductility, strengthen the joint strength between parts, and, thus, meet the fabrication requirements.

The bamboo composite used in this study comprised 7 layers, including 4 layers of bamboo veneer and 3 layers of fiberglass material. Based on the bamboo material's fiber direction, we mainly used bamboo veneer cross-laminated with GFRP material and epoxy resin as the adhesive for gluing. Finally, we used a heavy weight to press the materials together to bond more closely while the adhesive dried, thus completing the bamboo composite. The detailed steps are as follows: (1) First, spread a layer of release paper and polyester wadding on the predefined production platform to absorb excess adhesive and prevent it from spilling out of the platform. (2) Place the material in a specific order (Figure 3), and evenly apply the epoxy resin between each two layers. (3) After bonding, place a layer of release paper and polyester wadding on materials, and place a heavy weight on the top of them until the epoxy dries. (4) Repeat the above steps until sufficient material has been produced (Figure 3).

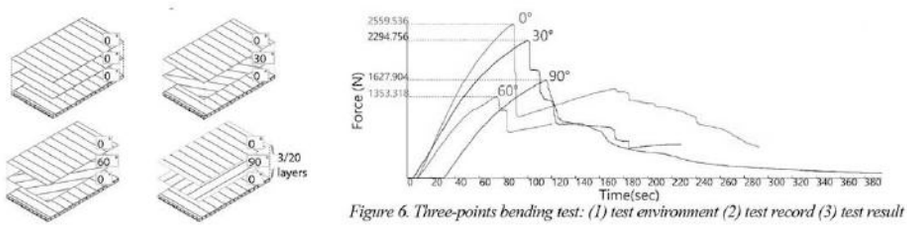

Figure 2. Robotic fabrication process of glued laminated bamboo for material-efficient construction (Cheng et al. 2022).

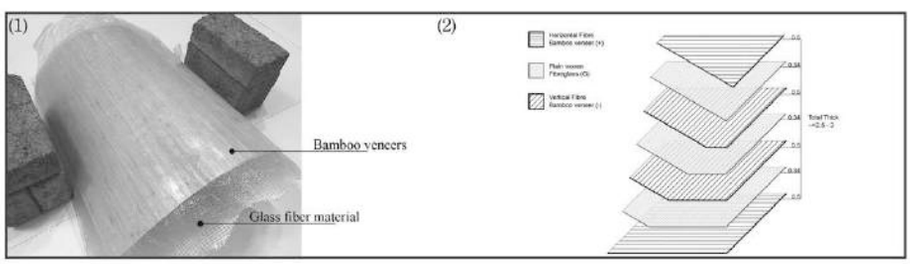

Figure 3. (1) Bamboo composite. (2) Gluing schematic diagram.

4 Design Experiment

In this study, we aimed to build a large-scale pavilion by designing a thin shell structure with a complex curvature. In this paper, we take a part of the structure (ratio 1:3 and 1:1) as a demonstration case (Figure 4) to verify the proposed snap-fit method and demonstrate the bamboo composite's bending strength on complex surfaces. When generating the form at the design end, the surface's curvature is excessively large, making it impossible to bend the material. Therefore, it is necessary to use structural analysis software to optimize the form and eliminate the problem of excessively large bending curvature.

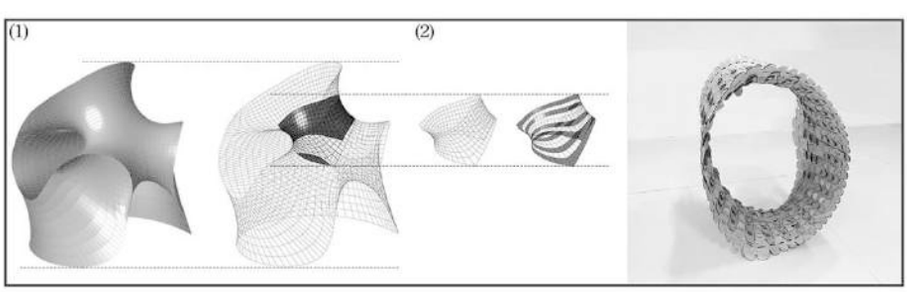

Figure 4. (1) Shell structure design. (2) Part selected for the demonstration (ratio 1:3).

4.1 Structural analysis

After we generated the desired form using Rhino and Grasshopper, we conducted structural analysis using Karamba3D (Figure 7), which analyzes the distribution and value of a model's stress and deformation before optimizing the model to mitigate any excessive curvature of its shape. In terms of parameters the external force adopts self weight and 18 km/hr air speed. Because we did not obtain the material parameters of the bamboo composite used in this study, we used those of bamboo and GFRP to calculate the approximate values. We compared the overall structure difference before and after form optimization and evaluated different materials' influences on the shell structure (Figure 5). The analysis's results are as follows:

(1) Based on the bamboo material's parameters, the structural strength increased by 1.5–1.8 times after form optimization, which shows that the form adjustment improved the material's structural stability (Table 1).

(2) Before the shape adjustment, building a large-scale shell structure with the required structural strength using only bamboo material, the material's thickness should be at least 5 mm. When using bamboo material with GFRP, the material's thickness can be 2 mm to achieve the same structural performance (Table 2).

(3) After the adjustment of shape, the bamboo material and the glass fiber material are mixed in proportion to estimate the displacement, and the material parameter setting is tried to be closer to the bamboo composite material properties, so that the estimation result can be predicted more accurately. The results show that when the glass fiber material content is 33% and the thickness is 3mm, the displacement is 9.39 cm. When the content is increased to 50%, the displacement is reduced to 7.47 cm (Table 3).

(4) When the thickness exceeds 3mm, the overall displacement tends to be gentle. Continuing to increase the thickness of the material cannot effectively improve the structural strength. Considering the production cost of bamboo composite materials, a thickness of 3mm is selected for subsequent development (Figure 6).

After discussions with structural engineers, the displacement needs to be controlled within 15 cm, and the overall structure is relatively safe. Therefore, after adding the safety factor (the intended load-bearing capacity of the structure), the bamboo composite material proposed in this research chooses the thickness of about 3mm and the glass fiber material content of 33% for subsequent manufacture.

Table 1. Comparison of structure performance before and after geometric modification.

	Material	Thickness				
		1 mm	2 mm	3 mm	4 mm	5 mm
Stress	Bamboo	256.00%	67.00%	30.10%	18.00%	12.20%
Stress	Bamboo	141.10%	41.80%	19.80%	12.00%	8.60%

Table 2. Strength and displacement comparison of bamboo and GFRP.

	Material	Thickness				
		1 mm	**2 mm**	**3 mm**	**4 mm**	**5 mm**
Stress	Bamboo	141.10%	41.80%	19.80%	12.00%	8.60%
Stress	GFRP	4.80%	1.50%	0.70%	0.50%	0.30%
Displacement	Bamboo	277 cm	43.5 cm	14.7 cm	6.82 cm	3.8 cm
Displacement	GFRP	31.7 cm	5.12 cm	1.83 cm	0.89 cm	0.52 cm

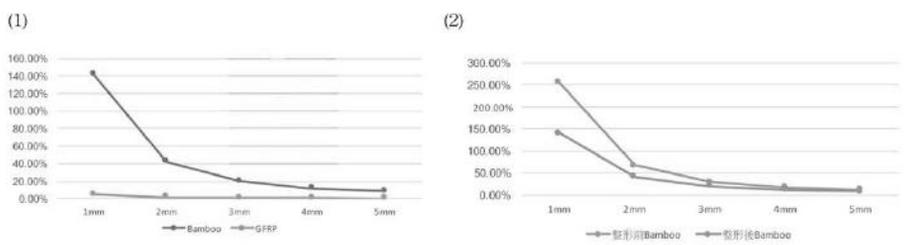

Figure 5. (1) Strength comparison before and after geometric modification. (2) Comparison of thickness and strength of bamboo and GFRP.

Table 3. Displacement comparison chart.

	Material	Thickness				
		1 mm	**2 mm**	**3 mm**	**4 mm**	**5 mm**
Displacement	Bamboo	286.52 cm	41.28 cm	13.49cm	6.14 cm	3.35 cm
Displacement	GFRP	29.44 cm	4.35 cm	1.46 cm	0.69 cm	0.40 cm
Displacement	B+G Composite(33%)	199.11 cm	28.72 cm	9.39 cm	4.28 cm	2.34 cm
Displacement	B+G	157.98	22.81	7.47 cm	3.41	1.87 cm

	Material	Thickness				
		1 mm	2 mm	3 mm	4 mm	5 mm
	Composite(50%)	cm	cm		cm	

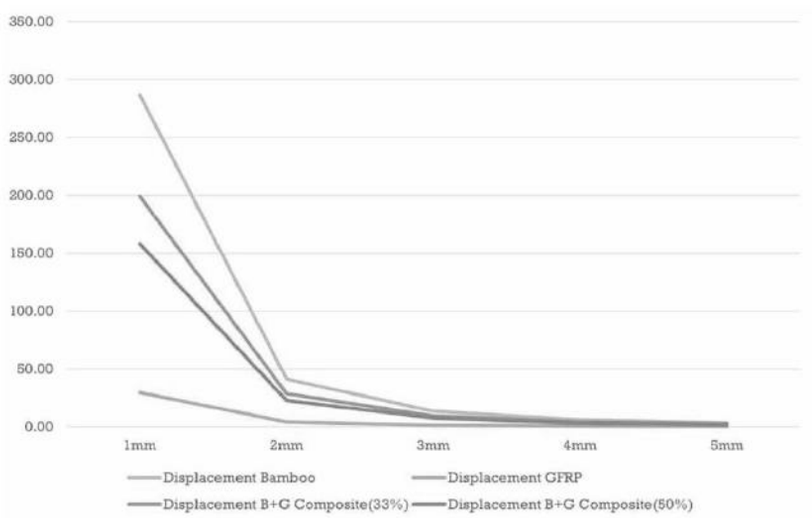

Figure 6. Displacement comparison chart.

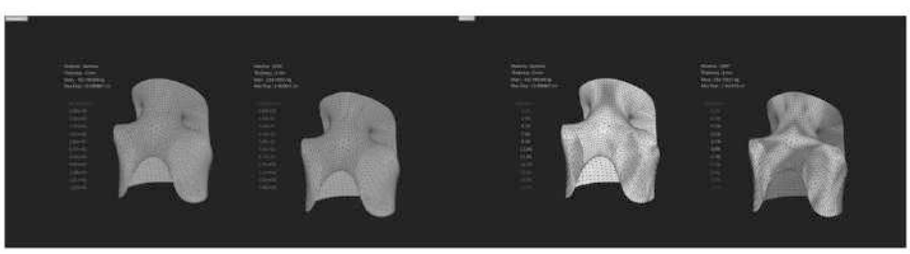

Figure 7. Structural analysis using Karamba3D.

4.2 Mesh segmentation and unrolling

We used Ivy, a plug-in for Grasshopper, to generate clusters of 2D strips and joints from 3D mesh. The arithmetic logic is as follows: (1) Find the mesh's outer edges. (2) Find the shortest distance between the mesh's vertices and its outer edges. (3) Compare the distance with 0 to obtain the Boolean value. (4) Use this Boolean value to split and cut pieces of mesh to generate a cluster of strips. (5) Continue cutting strips according to the above

steps until the mesh is completely split. (6) Unroll strips into 2D planar curves for the subsequent joint design (Figure 8).

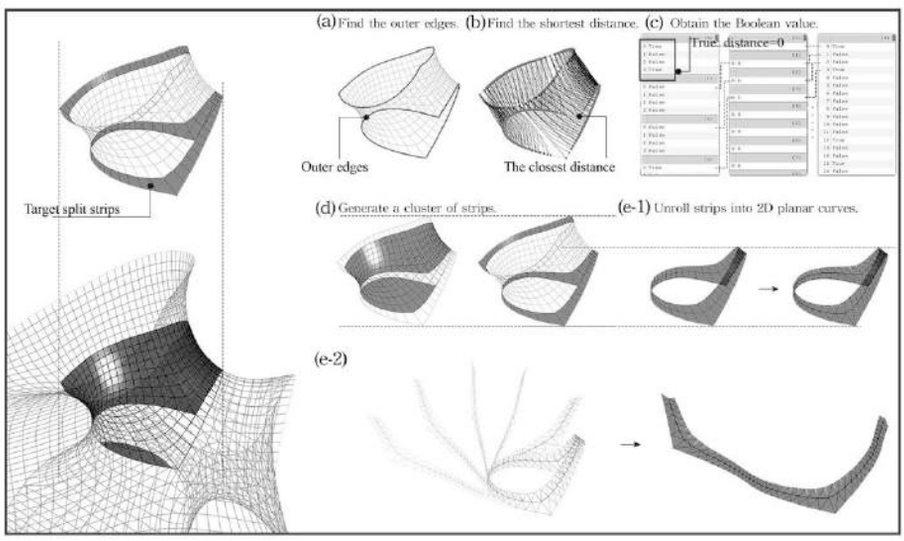

Figure 8. The mesh segmentation and unrolling process. (a) Step 1. (b) Step 2. (c) Step 3. (d) Step 4. (e-1; e-2) Step 6.

4.3 Joint design

After the previous step, we designed snap-fit joints for the connections between the strips. In the preliminary study, we used the friction force generated by the overlapping of the materials and the contact surface for our design and experiment. However, we found that when the material bends, its contact area tends to decrease, resulting in insufficient friction force, which becomes a structural weakness. Therefore, we adopted the snap-fit method instead and used the front and back folding buckle for fixation to increase the contact area and improve the structural strength. In this way, a part of model with a ratio of 1:3 was carried out. The test results are as follows:

(1) Because of the thickness of the material, the junction cannot be folded and buckled smoothly. The surrounding material fibers are often damaged due to the excessively large angle required for fastening, lead to the structural strength lost.

(2) Bamboo composite material with a ratio of 1:1 has a thickness of about 3mm, and has a certain hardness. It cannot be buckled by manual force, and needs to rely on other tools to assist. It is difficult to construct.

To sum up, the method of judging the fastening is not suitable for the actual construction situation, and when the bamboo composite material is folded and overlapped at the ratio of 1:1, it has a high degree of friction. Therefore, due to the required thickness, this fastening method is not

applicable, and the upper and lower layers are kept folded back and forth (Figure 10), and fixed directly with wooden tenons at the breakpoint (Figure 11).

In this study, the snap-fit joints were automatically generated based on 2D planar strips. To prevent the joints from being the weak points of the overall structure, we doubled the number of layers of mesh strips. The high number of overlapping layers increased the structure's overall strength (Figure 9).

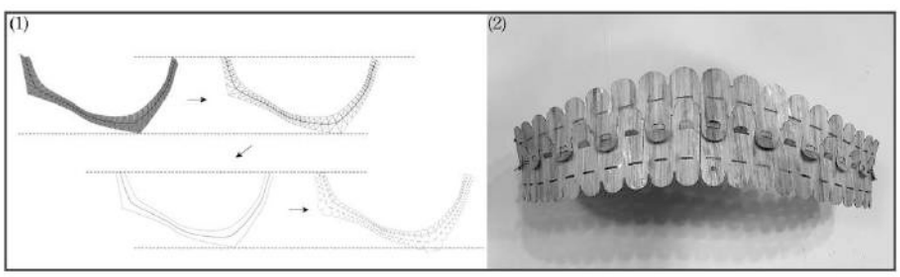

Figure 9. (1) Generation of snap-fit joints based on 2D planar strips. (2) Physical model of joints. (ratio 1:3)

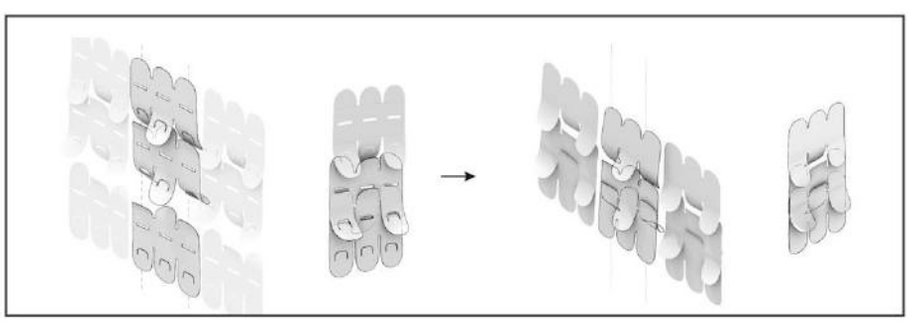

Figure 10. Joint design.

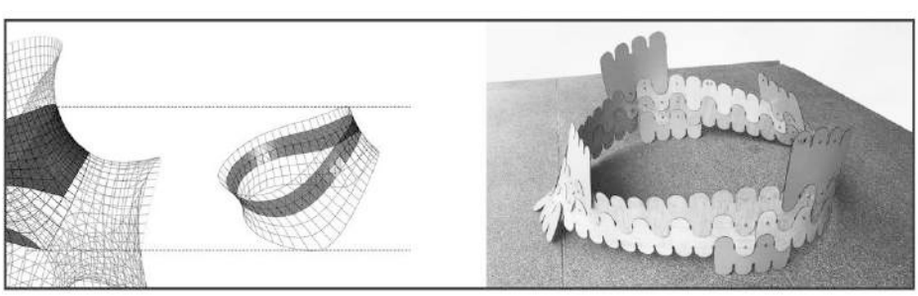

Figure 11. 1:1 a part of model test result.

5 Conclusion and Future Steps

In this paper, we first presented the material properties of laminated bamboo and its current development achievements. The goal of this research was to put forward the ideas of adding GFRP to improve bamboo's structural performance and of designing snap-fit joints for the fabrication of a lightweight shell structure. In this paper, we also proposed a method for optimizing the complex form with structural analysis software to realize the possibility of large-scale fabrication. This study's main contributions are (1) proposing the addition of GFRP to improve bamboo veneer materials' poor bending strength. and (2) demonstrating the bamboo composite's mechanical structure on free-form surfaces; (3) designing a snap-fit method for the joints' connection; and (4) using bamboo composite to fabricate a piece of a shell structure that can be used for further research and applications.

References

Huang, J. M. (2017). Integrating Computational Design and Traditional Crafts-A Reinvention of Bamboo Structures.

Sharma, B., Gatóo, A., Bock, M., & Ramage, M. (2015). Engineered bamboo for structural applications. *Construction and building materials, 81*, 66-73.

Echavarria, C., Jimenez, L., & Ochoa, J. C. (2012). Bamboo-reinforced glulam beams: an alternative to fiberglass-reinforced glulam beams. *Dyna, 79*(174), 24-30.

Yu-Chun Lin, Ja-Shian Chang, & Jia-Cheng You. (2011). Experimental Study on Structural Behavior of Taiwan Moso Bamboo Members. *Journal of Architecture* (75), 1-22.

Jia-Cheng You. Bamboo Shed System Planning and Applicationof Historic Buildings. Master's Thesis, National Cheng Kung University, Master's degree program in Architecture, 2009. https://hdl.handle.net/11296/ytj8j2.

Cheng, C.-C., Sheng, Y.-T., & Wang, S.-Y. (2022). Robotic Fabrication Process of Glued Laminated Bamboo for Material Efficient Construction.

Thwe, M. M., & Liao, K. (2003). Durability of bamboo-glass fiber reinforced polymer matrix hybrid composites. *Composites science and technology, 63*(3-4), 375-387.

The Maker Movement and its relationship with contexts of socioeconomic inequality: a Fab Lab Livre SP Network case study

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Abstract. The aim of this article is to analyze and discuss the implementation of the Fab Lab Livre SP Network, a public network of digital fabrication laboratories located in the city of São Paulo, in a context of large popularization of the Maker Movement and its premises of technological democratization. Based on quantitative user data and on-site experience acquired through a practical workshop, results show different processes of digital fabrication technology appropriation according to the territorial distribution of these public Fab Labs - which include extremely vulnerable places, such as slums. Considering the heterogeneity of urban and social conditions found in São Paulo, the proposed discussion here situates digital fabrication technologies and the Maker Movement from a socioeconomic inequality perspective, typical of Latin American countries.

Keywords: Digital Fabrication, Fab Lab, Public Policy, Social Inclusion, Maker Movement.

1 Introdução

A popularização das ferramentas de fabricação digital e a disseminação dos ideais do chamado Movimento *Maker* têm despertado uma série de debates acerca de alternativas produtivas, onde se propõe uma nova visão sobre os padrões de consumo, empreendedorismo, educação e a democratização do acesso às novas tecnologias. Oriundo da lógica “faça-você-mesmo” (ou DIY, *Do It Yourself* em inglês), o Movimento *Maker* se apoia em ferramentas digitais para o desenvolvimento e prototipação de novos produtos, além de utilizar o potencial de compartilhamento da Internet para fomentar a colaboração em rede e a disseminação de projetos abertos, segundo uma visão análoga aos softwares *opensource* (Anderson, 2012).

A materialização e difusão desses conceitos acontecem, sobretudo, a partir de laboratórios de fabricação digital como os *makerspaces*, *hackerspaces* e

Fab Labs, que têm se proliferado rapidamente no cenário mundial. De acordo com Kohtala (2016), esses espaços são variações de oficinas comunitárias, onde pessoas podem utilizar equipamentos de fabricação digital para produzir seus próprios artefatos. Nesse tipo de ambiente, o "fazer" é muitas vezes uma experiência social e colaborativa, com a publicação de projetos em plataformas digitais de livre acesso, equivalentes a *public libraries*, com grande incentivo à cooperação ativa entre seus membros/usuários e ao compartilhamento de ferramentas e espaços de trabalho.

Dentre as tipologias citadas, o formato Fab Lab pode ser considerado o mais organizado devido à sua operação em rede, protagonizada pelo CBA (*Center for Bits and Atoms*) do MIT (*Massachusetts Institute of Technology*), a partir do qual foi definido um padrão de funcionamento para os laboratórios, em nível internacional. Para Neil Gershenfeld, diretor do CBA e idealizador da Rede Fab Lab, a democratização das ferramentas de fabricação digital pode levar ao empoderamento tecnológico dos usuários, provendo *liberação intelectual, econômica e, de certa forma, espiritual* (Gershenfeld, 2005).

O impacto dos Fab Labs e outros laboratórios de fabricação digital no espaço urbano também é objeto de discussão no ecossistema *Maker*, a partir do qual se propõe um novo modelo de cidade sustentável, apoiado pela produção local e fabricação digital em pequenas células: a Fab City. O conceito de Fab City, inicialmente proposto por Antoni Vives, Neil Gershenfeld e Vicente Guallart para a cidade de Barcelona, consiste em uma rede de unidades produtivas localizadas em centros urbanos, conectadas entre si, que servem como plataformas de conhecimento e empreendedorismo para os cidadãos (Diez, 2012). De acordo com Gershenfeld (2012), o objetivo é que a cidade [Fab City] esteja conectada em nível global para o compartilhamento de ideias, mas seja autossuficiente para o que consome.

1.1 Colocação do problema

Apesar do grande entusiasmo acerca do potencial disruptivo dessas novas tecnologias, vozes dissonantes do Movimento *Maker* têm questionado até que ponto os laboratórios de fabricação digital associados a essa tendência têm sido fiéis à sua missão social autoproclamada de empoderamento tecnológico. Grande parte das observações gira em torno de uma relativa falta de clareza ao se reproduzir um discurso de pretensa neutralidade da tecnologia (Nascimento, 2014; Fonseca de Campos & Dias, 2018; Söderberg, 2013). Contesta-se, a princípio, a crença de que as máquinas em si — ou o simples acesso a delas— irão liderar uma revolução na cadeia produtiva e de consumo.

Por sua vez, ainda que as origens do Movimento *Maker* possam estar apoiadas sobre algumas referências históricas antissistema, como é o caso do conceito de *Do It Yourself*, um grande número de *makers* parece mais abraçar as concepções hegemônicas de corte neoliberal, juntando-se ao que Smith (2017) define como:

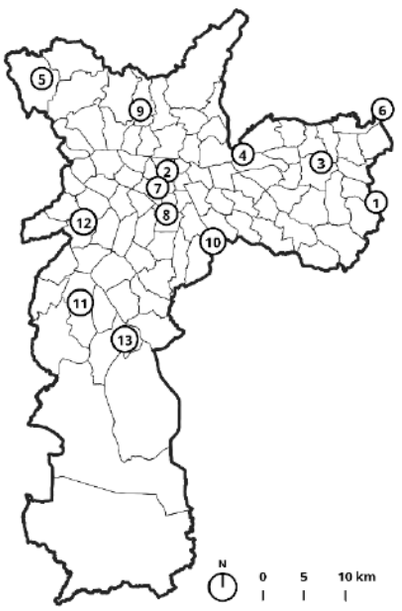
[...] onda impulsionada pela celebração do empreendedorismo fundamentado na iniciativa individual, muitas vezes desconsiderando as desvantagens a ele associadas, tais como as novas formas de exploração e precarização do trabalho (Smith, 2017, p. 60).

Por sua vez, em uma leitura mais otimista sobre o tema, Dias & Smith (2018) admitem que não é incomum que previsões de revoluções tecnológicas sejam frustradas, mas isso não significa que não estejamos vivenciando *valiosos cenários de experimentação*, onde potencialidades podem ser exploradas e, algumas vezes, concretizadas. Ao estudar o cenário brasileiro, os mesmos autores apontam para a incompatibilidade entre os *scripts* de tecnologias importadas e o contexto socioeconômico local, o que levou à adoção de políticas de desenvolvimento focalizadas e à criação de enclaves de tecnologia avançada em uma sociedade altamente desigual. Desse modo, defende-se a construção de um novo *script tecnológico* (Akrich, 1992, apud Dias & Smith, 2018) para o Brasil, baseado no conceito de tecnologia social — promoção da inclusão através da tecnologia — e no potencial das ferramentas de fabricação digital com uma abordagem mais apropriada ao contexto local (Dias & Smith, 2018).

Os pesquisadores citados que estudam o caso do Brasil (Dias & Smith, 2018; Fonseca de Campos & Dias, 2018), apostam no exemplo da Rede Fab Lab Livre SP, implantada a partir de 2015 na cidade de São Paulo, como modelo alternativo de difusão das ferramentas tecnológicas associadas ao Movimento *Maker* e, por se tratar de um equipamento público, integrado a outras áreas de interesse social como saúde, educação, cultura e sustentabilidade ambiental. O potencial empoderador, muito presente no discurso *Maker* sustentado por Gershenfeld, pode ser entendido nesse contexto como uma emancipação social coletiva (Fonseca de Campos & Dias, 2018), onde as ferramentas de fabricação digital assumem um papel de articulação entre sociedade civil e Estado. Frente a isso, coloca-se aqui a Rede Fab Lab Livre SP como um estudo de caso relevante, de modo a se refletir e poder validar os ideais do Movimento *Maker* conforme os interesses e necessidades das comunidades residentes em São Paulo, dentro de uma perspectiva inclusiva e territorializada.

1.2 A Rede Fab Lab Livre SP

A Rede Fab Lab Livre SP pode ser considerada na atualidade a maior rede pública de laboratórios de fabricação digital do mundo (PMSP, 2020), com 13 unidades distribuídas de forma descentralizada no município de São Paulo. Além de disponibilizar ferramentas e suporte técnico aos seus usuários, os Fab Labs da rede pública contam também com cursos regulares, oficinas e eventos relacionados à produção de conhecimento na área de tecnologia, ciência, arte e inovação, sem custos para os participantes. Devido à relevância da Rede Fab Lab Livre SP para o município e como exemplo de política pública, São Paulo aderiu à rede Fab City em 2019.



UNIDADE FAB LAB LIVRE SP	INAUGURAÇÃO	PORTE
1 CFC Cidade Tiradentes	17/12/2015	Lab. Grande
2 Galeria Olido	08/03/2016	Lab. Grande
3 Itaquera	10/03/2016	Lab. Pequeno
4 C. Cultural da Penha	10/03/2016	Lab. Pequeno
5 CEU Pq. Anhanguera	18/03/2016	Lab. Pequeno
6 CEU Três Pontes	21/03/2016	Lab. Pequeno
7 Vila Itororó - Bela Vista	22/03/2016	Lab. Pequeno
8 C. Cultural São Paulo	22/03/2016	Lab. Pequeno
9 C. Cult. da Juventude	23/03/2016	Lab. Pequeno
10 CEU Heliópolis	29/03/2016	Lab. Grande
11 São Joaquim	15/04/2016	Lab. Pequeno
12 Chácara do Jóckey	30/04/2016	Lab. Grande
13 CEU Vila Rubi	15/12/2020	Lab. Pequeno

Figura 1. Mapa com a localização das 13 unidades da Rede Fab Lab Livre SP no município de São Paulo. Fonte: Elaboração própria.

A iniciativa é financiada pela Prefeitura Municipal de São Paulo (PMSP), porém a gestão dos serviços é realizada em colaboração com um parceiro privado (Scheeren & Sperling, 2020), o ITS Brasil (Instituto de Tecnologia Social). O ITS Brasil, instituto que vem trabalhando no campo da tecnologia social e assistiva desde 2001, foi escolhido em 2015 por Edital de Chamamento Público para a criação e manutenção das 12 primeiras unidades da Rede Fab Lab Livre SP e se manteve na gestão dos laboratórios desde então.

A Figura 1 apresenta a localização das unidades, bem como suas respectivas datas de inauguração. Adicionalmente, os laboratórios são classificados pela Rede como “pequenos” ou “grandes”, dependendo de suas dimensões e do maquinário disponível em cada um.

2 Metodologia

O presente artigo faz parte de uma pesquisa de mestrado em andamento que possui o objetivo principal de analisar como a implantação da Rede Fab Lab Livre SP tem impactado as comunidades residentes em São Paulo, considerando as diferentes localidades e contextos urbanos onde as 13 unidades foram estabelecidas. Além de investigar a abrangência desta política pública em relação ao perfil de usuário atendido em cada unidade, a pesquisa principal visa entender como as diferentes populações estão se apropriando

das ferramentas de fabricação digital e das práticas associadas ao Movimento *Maker*. Ressalta-se que, por ser uma pesquisa desenvolvida na grande área das ciências sociais aplicadas, considera-se como 'indutivo' o método principal sobre o qual a mesma se apoia.

Como metodologia de trabalho, o primeiro passo da pesquisa foi a revisão bibliográfica dos principais autores que se debruçam sobre a temática abordada com um olhar crítico, procurando apresentar distintos pontos de vista, alguns deles antagônicos entre si, para consolidação da base teórica e sintetização do estado da arte.

Por sua vez, a abordagem empírica do artigo consiste em um recorte da pesquisa principal, baseada principalmente em dados primários fornecidos pela gestão atual da Rede Fab Lab Livre SP, sob a responsabilidade do ITS Brasil. Os dados referentes aos usuários cadastrados, cursos ministrados e projetos submetidos entre dezembro/2015 e março/2019 foram tratados e sistematizados com o auxílio de planilhas eletrônicas e softwares de geoprocessamento, já permitindo algumas conclusões parciais e iniciais relevantes para o direcionamento da pesquisa como um todo.

Levando-se em conta a proposta do presente artigo, foram selecionados quatro laboratórios da rede pública para análise e caracterização de seus entornos geográficos e socioeconômicos, quais sejam: Fab Lab Galeria Olido, no centro; Fab Lab CEU Heliópolis, na região sul; Fab Lab Chácara do Jockey, na região oeste; e Fab Lab Centro de Formação Cultural (CFC) Cidade Tiradentes, na região leste do município. A escolha das unidades foi baseada em critérios de localização geográfica e socioeconômicos, procurando-se contemplar distintas comunidades e grupos sociais no município; além da diversidade de perfis de usuários, validada por meio de visitas a campo e de vivências realizadas nos ambientes estudados. Ademais, para que a base de comparação tomada fosse a mesma, os quatro laboratórios escolhidos são do mesmo porte e possuem maquinário similar.

Por fim, ainda segundo a abordagem empírica adotada, pesquisas e experimentos de campo, tais como visitas e oficinas realizadas nos laboratórios da Rede Fab Lab Livre SP, respectivamente, foram incorporados no artigo com o objetivo de validar algumas das hipóteses e premissas assumidas no início da pesquisa.

3 Resultados

A partir do tratamento e sistematização dos dados primários brutos fornecidos pelo ITS Brasil, entidade responsável pela gestão da Rede Fab Lab Livre SP, foi possível se chegar a algumas conclusões parciais sobre o alcance da rede enquanto parte essencial de uma política pública. Inicialmente, pode-se afirmar que a maioria dos usuários cadastrados entre 2015 e 2019 são

homens (58%), com idade entre 18 e 35 anos (56%) e possuem ensino superior incompleto/completo (69%).

Entretanto, apesar dos números gerais indicarem um perfil bem determinado de usuário/frequentador, a vivência pessoal dos autores, que possuem reconhecida trajetória no tema da pesquisa, revela que este não é um perfil predominante em todos os laboratórios da rede pública. Em visita realizada na unidade Fab Lab Livre SP - CFC Cidade Tiradentes — localizada no extremo leste de São Paulo — foi observada a presença de crianças e adolescentes, em sua maioria moradores do entorno ao laboratório. O técnico presente no laboratório à época da visita confirmou que aquele era o cenário típico da unidade, uma vez que as unidades ficam abertas apenas durante o horário comercial, período de trabalho para a maioria dos adultos moradores da região, que se deslocam até as áreas centrais da cidade, nas quais se concentram as oportunidades de emprego. Assim, as crianças, que inicialmente foram atraídas pelos computadores conectados à Internet disponíveis, começaram a se apropriar do espaço, utilizando o laboratório como um equipamento público alternativo de lazer e aprendizagem.

Sendo assim, entendendo ser o exemplo comentado representativo de uma questão mais abrangente sobre a diversidade de inserções urbanas e de público frequentador de cada laboratório, a pesquisa evoluiu para uma leitura de dados georreferenciados do entorno, para que os números da Rede Fab Lab Livre SP fossem articulados com questões associadas às desigualdades socioespaciais presentes em uma cidade heterogênea e complexa como São Paulo.

Figura 2. Crianças e adolescentes trabalhando em projetos pessoais na unidade CFC Cidade Tiradentes. Fonte: Acervo pessoal.

3.1 A implantação dos laboratórios na cidade de São Paulo

De modo a contextualizar territorialmente os laboratórios da Rede Fab Lab Livre SP, foi realizada a caracterização do entorno imediato de cada uma das unidades selecionadas, a partir de indicadores demográficos e urbanos na área de influência do laboratório (raio de 1,5 km). Como resultado, uma leitura comparativa dos indicares apresentados na Tabela 1 constata a variedade de condições socioespaciais de implantação dos laboratórios da Rede pública.

A unidade Fab Lab Livre SP - Galeria Olido está inserida no centro de São Paulo, local com ampla oferta de empregos, transporte público de massa, e concentração de comércio e serviços. Além disso, é o entorno que apresenta a maior densidade demográfica e de renda per capita entre os laboratórios analisados, bem como o maior número de usuários residentes na área de influência.

Por sua vez, a unidade Fab Lab Livre SP - Chácara do Jockey, localizada em uma área residencial na região oeste do município e próxima à Universidade de São Paulo, entre outras instituições de ensino superior, apresenta uma alta concentração de usuários em relação aos moradores da região. Comparativamente, a renda per capita da população residente no entorno está bem próxima da região central (Fab Lab Livre SP - Galeria Olido), embora a taxa de emprego formal esteja abaixo da média municipal (6,7).

Na sequência, apesar do seu entorno ser predominantemente residencial de médio e alto padrão, tem-se a unidade Fab Lab Livre SP - CEU Heliópolis, que foi implantada para atender à maior favela de São Paulo, Heliópolis, localizada a 8 km do centro da cidade. Entretanto, dentre os quatro laboratórios estudados, a unidade Fab Lab Livre SP - CFC Cidade Tiradentes é a que está inserida em um contexto de maior desigualdade socioeconômica.

Distante 25 km do centro de São Paulo, a unidade Fab Lab Livre SP - CFC Cidade Tiradentes possui o menor número de usuários cadastrados em seu entorno imediato. Na região onde foi implantado o laboratório, a população residente apresenta baixíssima renda e são escassas as oportunidades locais de emprego formal, além de se tratar de uma população constituída majoritariamente por pessoas negras. Ademais, a falta de informações cadastrais relacionadas ao uso do solo no local demonstra a negligência do Poder Público ao caracterizar a área, onde predominam tipologias habitacionais de autoconstrução e loteamentos irregulares.

A caracterização socioespacial dos locais de implantação dos laboratórios apresentada denuncia as condições de segregação que marcam o espaço urbano de São Paulo, onde a distribuição desigual de infraestrutura, recursos e oportunidades de emprego são fatores que podem influenciar os impactos da Rede Fab Lab Livre SP e as formas de apropriação da população sobre estes equipamentos sociais.

Tabela 1. Indicadores de caracterização do entorno imediato dos laboratórios (raio=1,5 km)

Indicadores	**Galeria Olido**	**CEU Heliópolis**	**Chácara do Jockey**	**CFC Cidade Tiradentes**
Uso predominante do solo	Comércio e serviços	Uso residencial horizontal médio/alto padrão	Uso residencial horizontal médio/alto padrão	Sem informação
Estações de Metrô ou trem urbano (CPTM)	9	0	1	0
Densidade demográfica (hab/ha)	183,68	168,60	107,53	116,07
População preta e parda	29%	32%	30%	58%
Renda per capita	R$ 1.632,58	R$ 1.043,41	R$ 1.629,76	R$ 483,81
Taxa de emprego	25,12	1,59	3,25	0,44
Total de usuários	630	448	429	237
Usuários a cada 10mil habitantes	48,54	43,11	61,67	31,23

Fonte: Elaboração própria com base em dados do Censo 2010 (IBGE), do Geosampa (PMSP), do Mapa da Desigualdade 2019 (Rede Nossa São Paulo) e do ITS Brasil.

3.2 A Rede Fab Lab Livre SP em números

Atendo-se aos laboratórios selecionados para a presente pesquisa, são apresentados a seguir os números globais de projetos submetidos e de participantes em cursos ministrados em cada unidade — valores adotados pelos gestores da rede como indicadores de desempenho.

Como mencionado na seção 2 (Metodologia) do presente artigo, atividades realizadas pelos pesquisadores nos laboratórios da Rede Fab Lab Livre SP foram consideradas neste artigo como fontes de informação qualitativa que complementam os resultados obtidos a partir das bases de dados primários. Dentre as atividades realizadas, destaca-se a oficina de corte a laser realizada na unidade Fab Lab Livre SP - Galeria Olido com moradoras do Jardim Colombo, bairro localizado na região oeste de São Paulo.

Um dos objetivos da oficina proposta era aferir os procedimentos usualmente adotados para se utilizar o maquinário dos Fab Labs públicos. Em linhas gerais, antes de usar um dos laboratórios é necessário se cadastrar na plataforma online da Rede e inscrever um projeto em uma das unidades. Após a aprovação pelos técnicos, o usuário prossegue com o agendamento das

máquinas/ferramentas necessárias para a elaboração do projeto, conforme o calendário disponível.

Por sua vez, os cursos abordando os diferentes processos de fabricação digital são ministrados presencialmente pelos técnicos de cada unidade, desde a concepção do projeto até a execução do modelo final. Para participar dos cursos é necessário ser maior de dez anos e se inscrever em um calendário mensal. Todos os cursos possuem certificado de participação.

O gráfico da Figura 3 mostra a quantidade de projetos submetidos em comparação com o número de participantes em cursos para cada unidade da Rede Fab Lab Livre SP estudada neste artigo.

A partir dos dados apresentados, pode-se inferir que existe uma dinâmica diferente na submissão de projetos e na participação em cursos em cada laboratório, provavelmente relacionada com a inserção urbana e perfil de frequentadores de cada espaço.

Como exemplo, observa-se que a unidade localizada na região central (Fab Lab Livre SP - Galeria Olido) possui o maior número de projetos e participantes em cursos comparativamente, demonstrando que a localização privilegiada e a facilidade de acesso (confluência de fluxos e oferta de transporte coletivo) podem influenciar a apropriação do espaço pelos usuários e seu engajamento nas atividades.

Ao mesmo tempo, as unidades inseridas em favelas (Fab Lab Livre SP - CEU Heliópolis) e em situações de extrema desigualdade socioeconômica (Fab Lab Livre SP - CFC Cidade Tiradentes) apresentam um baixo número de projetos submetidos, porém, uma quantidade notavelmente alta de participantes em cursos, o que indica que existe uma frequência de usuários equivalente à unidade Fab Lab Livre SP - Galeria Olido. Entendendo que a oferta de maquinário e infraestrutura é a mesma nos quatro laboratórios estudados, a questão levantada aqui é: *por que existe uma diferença tão grande na proposição de projetos por unidade?*

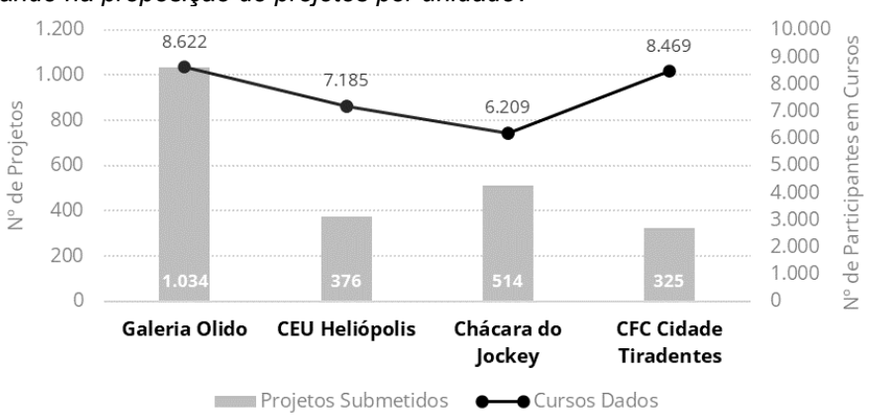


Figura 3. Número de projetos submetidos e participantes em cursos dados na Rede Fab Lab Livre SP. Fonte: Elaboração própria com base em dados do ITS Brasil.

4 Discussão

Assim como aponta Smith & Dias (2018), muitos dos que estudaram as implicações e possibilidades do “fazer” o fizeram de um ponto de vista norte-americano ou europeu, assumindo determinadas suposições sobre manufatura, design, tecnologia e sociedade que negligenciam como esses recursos são percebidos em diferentes lugares ao redor do mundo, a exemplo da América Latina.

No cenário latino-americano, a complexidade social, econômica e política característica de países em desenvolvimento exige uma visão qualificada do que pode vir a ser a introdução de novas tecnologias, segundo a qual seja possível perceber os valores, as normas sociais e as relações de poder a ela vinculadas e, assim, evitar uma apropriação ingênua destes novos meios de produção. Desse modo, os conceitos e premissas do Movimento *Maker* — produção colaborativa, democratização das tecnologias digitais e o acesso às máquinas de fabricação digital, que podem fazer “quase” tudo — podem ser reavaliados sob a ótica local, a partir das especificidades e dos desafios que dela derivam.

Em São Paulo um grande passo já foi dado nesse sentido com a criação da Rede Fab Lab Livre SP, iniciativa totalmente pública, gratuita e acessível a uma maioria da população que habitualmente se vê excluída dos modelos hegemônicos de desenvolvimento econômico. A distribuição descentralizada dos 13 laboratórios na cidade releva o propósito da rede que, como política pública, visa ampliar o horizonte de inovação e trabalhar como um mecanismo de emancipação da comunidade (Cordeiro, Barroso & Magli, 2016).

Partindo de uma leitura aproximada da Rede Fab Lab Livre SP, a hipótese levantada no início da pesquisa e evidenciada na apresentação dos resultados é de que existe uma variável socioeconômica, intrínseca ao local de implantação dos laboratórios na cidade de São Paulo, que impacta na forma como os Fab Labs públicos são apropriados pelos usuários — seja por meio da frequência aos cursos ministrados pelo corpo técnico ou da realização de projetos pessoais e/ou coletivos.

Figura 4. Workshop de corte a laser realizado com moradoras do Jardim Colombo na Rede Fab Lab Livre SP.

Tomando como exemplo a experiência obtida com a oficina de corte a laser realizada com moradoras do Jardim Colombo — bairro localizado no complexo de Paraisópolis, a segunda maior favela de São Paulo —, foi constatado no início das conversas que as participantes não tinham conhecimento algum sobre a Rede Fab Lab Livre SP ou sobre fabricação digital, mesmo morando a menos de 2 km da unidade Fab Lab Livre SP - Chácara do Jockey. A falta de intimidade com as máquinas e o processo de projeto também foi uma barreira inicial a ser superada, apesar da surpresa e interesse demonstrados pelas participantes na visita ao laboratório público.

Além disso, a própria organização da oficina evidenciou obstáculos enfrentados pelos usuários da Rede Fab Lab Livre SP que, em outra situação, seriam difíceis de diagnosticar, tais como: deslocamento até o laboratório (como chegar no Fab Lab se não possui veículo particular ou se existe pouca disponibilidade de transporte público?), custo do material para realizar o projeto, disponibilidade de tempo (mulheres como chefes de família e que trabalham fora), falta de rede de apoio (com quem deixar os filhos pequenos?), entre outros pontos relacionados à segregação socioeconômica e espacial.

Outro apontamento relevante é que, apesar de ser a unidade mais próxima do Jardim Colombo, o Fab Lab Livre SP - Chácara do Jockey estava fechado durante a mobilização das participantes, o que levou à escolha do Fab Lab Livre SP - Galeria Olido para a realização da oficina. A escolha se deu, em grande parte, pela facilidade de acesso por transporte coletivo e a localização central — o que diz muito sobre a influência da inserção urbana dos laboratórios públicos.

5 Considerações finais

A partir dos indícios apresentados nos resultados e na experiência prática, espera-se avançar com a investigação do porquê laboratórios com o mesmo conjunto de equipamentos, mas com localizações geográficas diferentes, apresentam níveis de resposta discrepantes em termos de projeto — ou seja, indicadores apontam distintos níveis de engajamento e autonomia dos usuários, dependendo da localidade. Considerando-se o fato de que esta pesquisa segue em desenvolvimento, acredita-se que nas próximas etapas técnicas provenientes das ciências sociais, como é o caso da etnografia, podem levar a um maior aprofundamento das questões aqui levantadas, levando o pesquisador à condição de observador-participante, para verificação e validação de fatores qualitativos que apoiem a investigação.

Espera-se que os desenvolvimentos futuros da pesquisa sirvam de insumo para reflexões acerca do Movimento *Maker* e a sua relação com contextos (e problemas) locais, a partir de uma perspectiva latino-americana. Nesse cenário, observa-se que as alternativas tecnológicas apresentadas pelo Movimento *Maker* não podem ser colocadas como uma solução universal para

todos os problemas, mas sim como instrumentos de mediação entre diferentes atores sociais, com o objetivo de fortalecer a cultura e potencialidades locais, respeitando as diferenças e especificidades de cada lugar.

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Referências

Anderson, C. (2012). Makers: *The New Industrial Revolution*. Crown Business.

Cordeiro, A. V., Barroso, C. H., Magli, L. (2016). Fab Lab Livre SP: laboratories of digital fabrication as public policy from São Paulo City. *Fab12*, Shenzhen.

Dias, R., & Smith, A. (2018). Making in Brazil: can we make it work for social inclusion? *Journal of Peer Production*, (12), 43-59. http://peerproduction.net/issues/issue-12-makerspaces-and-institutions/peer-reviewed-papers/making-in-brazil/

Diez, T. (2012). Personal Fabrication: Fab Labs as Platforms for Citizen-Based Innovation, from Microcontrollers to Cities. *Nexus Network Journal*, *14*(3), 457-468. https://doi.org/10.1007/s00004-012-0131-7

Fonseca, F. S. (2014). Redelabs: Laboratórios experimentais em rede [Master's thesis, Universidade Estadual de Campinas]. Repositório da Produção Científica e Intelectual da Unicamp. https://doi.org/10.47749/T/UNICAMP.2014.930569

Fonseca de Campos, P. E., & Dias, H. J. S. (2018). A insustentável neutralidade da tecnologia: o dilema do Movimento Maker e dos Fab Labs. *Liinc em Revista*, *14*(1), 33-46. http://revista.ibict.br/liinc/article/view/4152/3691

Gershenfeld, N. (2005). *FAB: The Coming Revolution on Your Desktop – From Personal Computers to Personal Fabrication*. Basic Books.

Gershenfeld, N. (2012). How to Make Almost Anything. *Foreign Affairs*, *91*(6), 43-57. http://cba.mit.edu/docs/papers/12.09.FA.pdf

Kohtala, C. (2016). Making "Making" Critical: How Sustainability is Constituted in Fab Lab Ideology. *The Design Journal*, *20*(3), 375-394.

Nascimento, S. (2014). Critical Notions of Technology and the Promises of Empowerment in Shared Machine Shops. *The Journal of Peer Production*, (5). http://peerproduction.net/issues/issue-5-shared-machine-shops/

PMSP - Prefeitura Municipal de São Paulo. (2020, 29 de dezembro). *Fab Lab Livre SP*. https://www.prefeitura.sp.gov.br/cidade/secretarias/inovacao/inclusao_digital/index.php?p=194463.

Smith, A. (2017). Innovación social, democracia y makerspaces. *Revista Española del Tercer Sector*, (36), 49-74. https://grassrootsinnovations.files.wordpress.com/2017/06/smith-2017-revista_rets_n36.pdf

Söderberg, J. (2013). A ilusória emancipação por meio da tecnologia. *Le Monde Diplomatique Brasil*, (7 de janeiro de 2013). https://diplomatique.org.br/a-ilusoria-emancipacao-por-meio-da-tecnologia/

Towards Robotic Fabrication in Landscape Architecture

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Abstract. With the fourth industrial revolution advancements, digital fabrication and automation have been widely adopted in design and manufacturing domains and deliver exceptional architectural design and fabrication potential. Specifically, robotic fabrication, as cutting-edge technology, pushes the boundaries of architecture to reach structural improvements. However, the potential for robotic fabrication of landscape architecture, which goes beyond the automation and maintenance of existing techniques, remains relatively untouched. This research explores the potential of robotic fabrication in landscape architecture by evaluating its applications in architecture. Therefore, a systematic review was conducted on pioneering architectural research groups involved in robotic fabrication projects. The collected projects were classified and analyzed based on their main parameters, including material, the implemented task, final products, and goals. This evaluation system helps to identify new areas of activity that will enhance landscape architecture, and it will help to change the historical link between a landscape architect and his production techniques.

Keywords: Digital Fabrication, Automation, Industry 4.0, Landscape Architecture, Robotic Fabrication.

1 Introduction

Since the turn of the 20th century, the field of robotics has attracted the public's attention. Electro-mechanical equipment controlled by a computer program or electronic circuitry is commonly thought of as a robot. Robots are frequently created to adopt human-like behaviors to provide the user with helpful labor. They are programmed to perform certain behaviors and respond to commands (Westort & Shen, 2017). Although robots are widely utilized in industry, the technologies and solutions used in robotics and automation nowadays are mostly not generic but rather domain-specific. The industries that rely on manufacturing processes in which the work pieces can be moved around a manufacturing plant have benefited most from this technology (Buchli et al.,

2018). Recently, numerous design and construction disciplines have been transformed by the possibility of fabricating components directly from design information. Therefore, robotic fabrication has become a hot issue of study in architecture.

2 Literature Review

The relevant literature is addressed in two main areas. The first section presents existing research on robotic fabrication in architecture, where we provide an overview of merging robotic tools into architectural projects. Then, we emphasize the current research on various robotic applications in landscape architecture.

2.1 Robotic Fabrication in Architecture

“We become what we behold, we shape our tools, and then our tools shape us (Culkin 1967).”

The above quote by John Culkin conceptualizes the function of new digital design and robotic technologies in the architectural and building sector. Robotic fabrication is an interdisciplinary discipline focusing on the creative use and forward-thinking advancement of robots in architecture (Gramazio & Kohler, 2014). Architects use different capabilities of these tools to prototype and create complex designs that are challenging to manufacture using traditional methods. This approach opens up some new opportunities for innovative design explorations. Today, Architects with little to no scripting experience may program devices like industrial robots using specialized plug-ins for Grasshopper, such as KUKA|prc or HAL. Processes are advancing quickly, making it possible to modify and individualize architectural design and its materialization with minimal time and effort. This advancement in digital fabrication fundamentally alters how architects interact with technological devices and offers fresh insight into the interplay between the digital and physical worlds. Thanks to the development of new, robotically assisted manufacturing techniques, designing new materials and geometries with novel functionalities is now possible. This promotes a new way of thinking about architecture's process, application, and aesthetics of architecture (Weissenböck, 2015).

Furthermore, architects benefit from these robotic manufacturing technologies for construction. The construction sector has struggled with low productivity, a lack of skilled workers, and high accident rates on job sites during the previous few decades. Therefore, there is an unmatched need for automation and its possibilities as a viable solution to enhance worker safety, boost environmental sustainability, and address labor shortages and efficiency (Yu, Zhang, & Zhang,

2021). The sustainability of architectural construction is mainly improved by using naturally occurring and recycled materials.

2.2 Robotic Fabrication in Landscape Architecture

The term "landscape" describes the essential collection of components, such as landform, water, and vegetation, or a complicated interaction of dynamic forces operating across periods, from seconds to centuries (Ervin, 2003). As a result of the 19th-century development of hydraulic machinery, landscape architecture has evolved. Recent trends in landscape architecture require the discipline to embrace more expansive territorial systems, such as naturally occurring processes or performance-oriented physical events (Duque Estrada et al., 2020).

Due to the irregularity of natural terrains, they provide a high level of difficulty for digital fabrication. This circumstance is known as uncertainty in the world of robotics (Shaked & Dubin, 2019). The uncertainty is caused by differences between the virtual model and the real world, unexpected material behavior in their interaction, and problems with motion planning and control that result from these differences. An iterative robotic fabrication process can overcome these issues (Bar-Sinai et al., 2019). However, due to the intrinsic complexity of the reality on-site, robotic fabrication in landscape architecture has lagged behind other fields like architecture and infrastructure engineering (Hurkxkens, 2020). Although the current on-site robotic construction techniques in landscape architecture aim at planning and horizontal grading through the optimization of material flow (Bock & Linner 1995) with the use of GIS guidance systems (Petschek 2014), a more sensitive approach to the local topological and material circumstances is required for landscape architecture (Hurkxkens et al., 2017).

Besides, the on-site construction techniques and materials are tied closely to environmental factors such as ground stability, severe winds, and other factors (Keating et al., 2017). Therefore, robotic landscape modeling on location needs to be flexible enough to adjust to these shifting environmental factors. For instance, in a recent study, robotic landscapes were suited to local conditions by utilizing only on-site materials, balancing cut and fill, and adapting the design to the found material (Jud et al., 2019). Alternatively, another study introduces a revolutionary coastal design strategy for autonomous construction in dynamic environments, merging several technologies to create new possibilities for design exploration and research. Instead of using conventional engineering methods to address the problem of extreme erosion in coastal environments caused by storm surges, the paper integrates robotic and natural processes into continuous maintenance strategies for dynamic coastal defense structures that concentrate on local material changes and bathymetry modification. This procedure uses erosion and sedimentation's potential for forming landforms while minimizing the mechanical intervention necessary to accomplish coastal remediation goals (Hurkxkens, Pigram, & Melsom, 2021).

Although the existing research on landscape robotics provides noteworthy developments, they are limited in quantity. We need more design research, tools, and procedures for landscape robotic fabrication today.

3 Methodology

This paper aims to find the potential of robotic fabrication for landscape architecture by focusing on the robotic applications and tools currently used in architecture. To do so, we conducted an extensive systematic review of the existing research and projects of the most renowned institutions in the field of robotic fabrication and computational design that have established digital construction laboratories for extensive research and experimentation. Namely, ICD/ITKE (URL-1), Gramazio Kohler Research group (URL-2), Kokkugia (URL-3), Neri Oxman's Mediated Matter (URL-4), DFAB (URL-5), and ZHA Code (URL-6). First, we excluded the irrelevant projects with no relation to robotic machines and restricted the projects to the recent 15 years, extending from 2008 to 2022. However, as we observed that the sampled research before 2012 stood as outliers, the time frame was limited further, and a total number of 65 research projects were identified from 2012 to 2022. They were transmitted into an Excel database. We classified all the data based on their main aspects and analyzed them under the themes of use of material, the implemented task, the final product, and the project's goal, which were subcategorized into the four main themes of productivity and efficiency, sustainability, safety, and new possibilities. First, we sorted all category data chronologically to find the most and minor focus within years. Afterward, we also matched the final products with their goal and material in a separate excel sheet to detect the existing gap in robotic projects more in detail. Figure 1 shows the research workflow, and Table 1 demonstrates the list of reviewed cases.

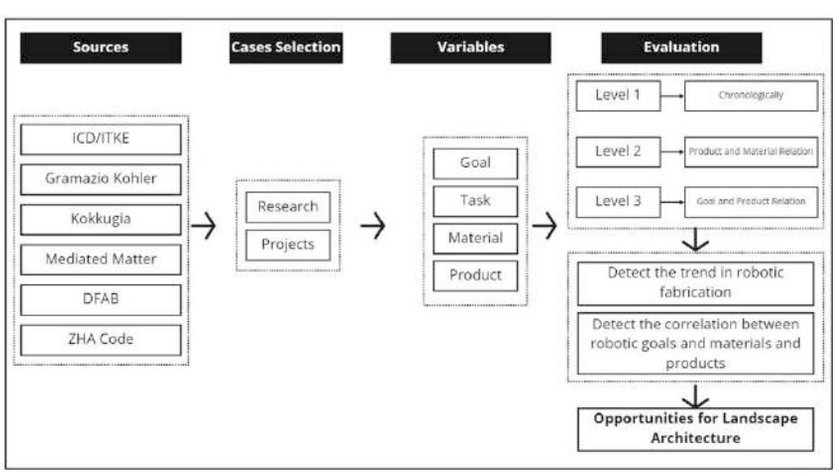

Figure 1- Workflow of the research

Table 1. The List of Reviewed Cases (URL 1,2,3,4,5,6)

Source	Project titles and years
DFAB	Mesh Mould and In situ Fabricator (2017), Lightweight Flexible Formwork (2018), Large-Span Self-Supporting Assemblies (2019), Spatial Timber Assemblies (2020), Performance-Integrated 3D Printing (2021), Moldless Shaping of Concrete Elements (2022)
Gramazio Kohler	Flight Assembled Architecture (2012), Echord (2012), BrickDesign (2012), TailorCrete (2013),Acoustic Bricks (2014), Mesh Mold (2014), Topology Optimization of Spatial Timber Structure (2015), Smart Dynamic Casting (2015), Aerial Construction (2015), YOUR Robot Programming (2015), Mobile Robotic Tiling (2016), Robotic Integral Attachment (2016), Spatial Wire Cutting (2016), Robotic Cosmogony (2017), Sisyphus (2017), Spatial Timber Assemblies (2018), Prefabrication with Smart Dynamic Casting (2018), Mesh Mold Metal (2018), DFAB House (2019), Digital Ceramics (2019), RobotSculptor (2020), Jammed Architectural Structures (2020), Robotic Fabrication Simulation for Spatial Structures(2020), Deep Timber (2020), Adaptive Detailing (2020), FrameForm (2020), The Folded Concrete Structures (2020),Data Science Enabled Acoustic Design (2021), RIBB3D (2022), (Heap)Autonomous Dry Stone(2022), Eggshell (2022), Timber Assembly with Distributed Architectural Robotics (2022), Robotic Plaster Spraying (2022), Human-Machine Collaboration (2022)
ICD/ITKE	Landesgartenschau Exhibition Hall (2014), Hive: A Human and Robot Collaborative Building Process (2015), Elytra Filament Pavilion (2016), ICD Sewn Timber Shell (2017), Cyber Physical Macro Material (2017), MoRFES_01: Mobile Robotic Fabrication Eco-System (2017), ICD Aggregate Pavilion (2018), BUGA Wood Pavilion (2019), ITECH Research Demonstrator (2019), BUGA Fiber Pavilion (2019), Fiber Façade (2020), Maison Fiber (2021), livMatS Pavilion (2021), Bio-composite Façade Panel (2022)
Kokkugia	Extruded Inlay (2012), Fibrous Concrete (2013), AADRL Arial Robot Thread Construction (2015), AADRL Swarm Printing (2015)
Mediated Matter	Spider bot(2014), Digital Construction platform (2017), Fiberbot (2019), Aguahoja III (2022)
ZHA Code	Thallus Installation (2017), Striatus 3D Printed Concrete Bridge (2021)

4 Results

4.1 Goals

Extracted from the literature, architectural robotic fabrication goals were classified and analyzed into four main themes: productivity and efficiency, sustainability, safety, and new possibilities to construct things we were unable to previously. As demonstrated in Figure 2, the proportion of studies with efficiency goals surpasses the others. Additionally, new possibilities and then. sustainability covers a large area in robotic applications. However, safety has been the mainly ignored goal.

As shown in the chart, productivity and efficiency had a slightly fluctuating trend which experienced a sharp fall in 2021, followed by another fall in 2022. As the second most popular goal among research projects, the number of new possibilities has gradually declined after 2016. Whereas it bucked the trend in 2022 and started growing again. Furthermore, although low initially, sustainability goals have increased enormously after 2017. Safety, the most ignored goal, has recently received little attention.

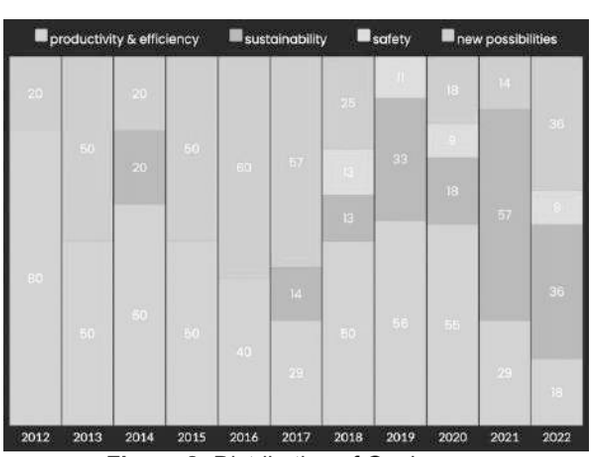

Figure 2- Distribution of Goals

4.2 Implemented Tasks

As a result of the analysis, the authors have identified numerous tasks implemented in architectural robotics research and projects. These tasks include assembly, 3Dprinting, moldless fabrication, sculpting, formwork development, casting, structure reinforcement, slip forming, in-site fabrication, hot-wire cutting, bricklaying, welding, simulation, milling, spraying, winding, jamming, tool or process development, sand suction, and creating suspension spaces. As shown in Figure 3, the most popular robotic task among architects is assembly. Considering that robotic assembly is a critical phase in the workflow from design to construction and the ultimate expression of a robotic fabrication system is in the assembly of the structure, the obtained outcome is not a surprise. 3Dprinting and in-site fabrication are also among the most utilized tasks. A detailed look at the chart also discloses the chronological trends of these tasks. Though the fluctuations in the number of assembly projects, the trend rose in 2019 and remained almost constant after a slight decrease in 2020.

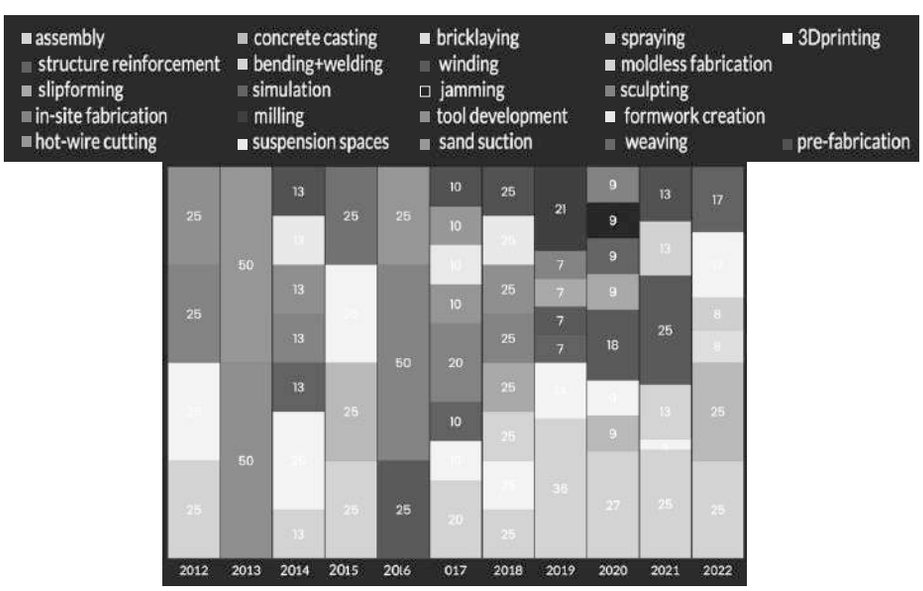

Figure 3- Distribution of Tasks

4.3 Utilized Materials

The analyzed projects have shown great diversity in terms of utilized materials. These materials contain concrete, timber, brick, metal, fiber composite, and plastic as the most popular ones. However, stone, plaster, sand, ceramic, clay,

bio-materials, and much more are among the materials used in these projects. Though covering a considerable proportion of materials in robotic applications, the timber had been mostly ignored until 2014, when it experienced a significant shift. Followed by an increasing oscillation and reaching the peak in 2019, a gradual decrease was observed afterward. Despite this reduction, timber remains the most in-demand material in recent years (Figure 4). Likewise, concrete has been highlighted after 2013. It was on the rise with slightly varying patterns. Notwithstanding the concrete and timber, brick has received the proper attention from the beginning of the period. However, it has lost its initial popularity in recent years.

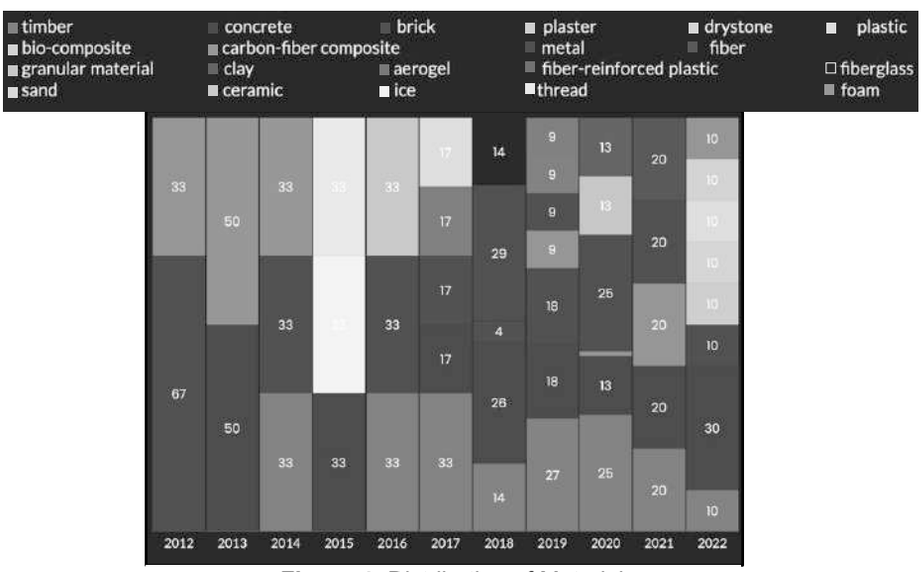

Figure 4- Distribution of Materials

4.4 Final Products

The review of the implemented projects provides various products in structures, pavilions, façades, mesh mold, construction objects, floating objects, sculptures, robots, and tools and frameworks. To clarify, structures include footbridges, slabs, frames, and walls. At the same time, tools and frameworks cover novel fabrication processes, construction platforms, and design software. Since 2013, many products have been devoted to structures. On the other hand, pavilions and tools are the second most popular robotic products, covering almost one-third of all. While tool/framework quantity maintained an almost constant pattern, the number of pavilions disregarded the trend with its highest rate in 2019.

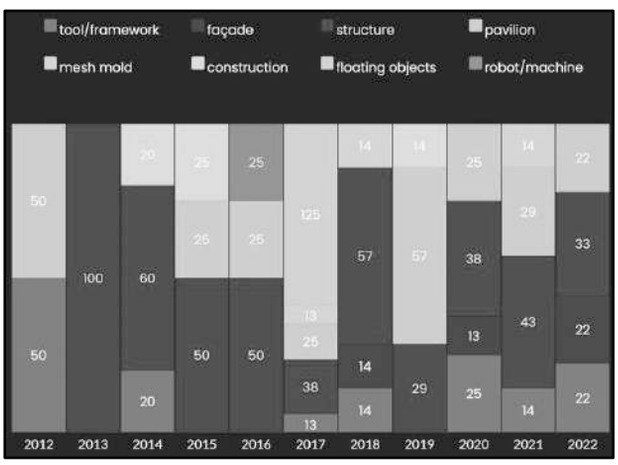

Figure 5- Distribution of Products

4.5 Correlation between Goals, Products, and Materials

As an additional step, a separate Excel sheet was created to match the most popular products with their extensively used materials and goals. The popular products were extracted in the previous step as structures and pavilions. Tools and frameworks were excluded from the product category because they mostly do not contain any materials. As illustrated in Figure 6, structures mainly utilized concrete and timber for productivity, efficiency, and safety purposes. Moreover, pavilions involved a wider variety of objectives: sustainability, new possibilities, and safety. Fiber-reinforced composites are the most significant materials used in pavilions.

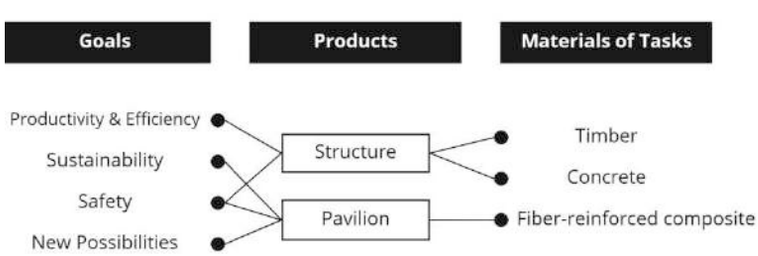

Figure 6- Correlation between the Most Popular Products, Goals, and Materials

5 Gaps and Opportunities

Finally, we summarized all the variables based on their most frequent attributes from 2012 to 2022 (Table 2). Gathering all the data together would help us better detect bottlenecks or potentials. The first potential in applying robotic fabrication in landscape architecture is related to the goals of reviewed projects (Figure 2). Sustainability, as an essential element in landscape architecture, played a significant role in some of the recent projects. The ever-rising focus on sustainability, especially after 2017, shows the attempt to prioritize this goal. Considering architectural robotics' most prevalent materials, sustainable and unsustainable resources were discerned. Even the allocation amount of sustainable materials varies. While more conventional types of sustainable materials like timber have been widely used, materials like fiber composites and bio-composites are less employed.

On the other hand, the most common tasks in architectural robotic fabrication include assembly, 3Dprinting, and in-site fabrication. While assembly and 3D printing maintain an increasing use, in-site fabrication tasks have seen a dramatic fall in 2020 (Figure 3). This gap highlights the previously mentioned intrinsic complexity of the reality of on-site robotic fabrication in landscape architecture. That is why the on-site robotic fabrication of landscape architecture cannot go beyond the automation of the existing techniques.

Additionally, 3Dprinting, as an essential task in architectural robotics, faces boundaries in the realm of landscape architecture. Often used for large-scale areas, landscape architecture planning and design combine natural elements like vegetation. Due to financial and physical limitations, current 3D printing technology cannot support such situations. According to the literature review, one of 3D printing's constraints is speed, which makes it challenging to use the technology in most sectors because it takes a long time to produce a large-scale model (Easley et al., 2017).

Table 2. Most Popular Variables based on Years

	Goal	Task	Material	Product
2012	Efficiency	3Dprinting	brick	pavilion+tool
2013	Efficiency+ New possibilities	tool development+hot-wire cutting	concrete	structure
2014	Efficiency	3Dprinting	timber + brick	structure
2015	Efficiency+ New possibilities	3Dprinting	concrete	structure
2016	New possibilities	in-site fabrication	timber+metal	structure
2017	New possibilities	assembly+in-site fabrication	timber	structure
2018	Efficiency	3D printing	concrete+metal	structure
2019	Efficiency	assembly	timber	pavilion
2020	Efficiency	assembly	timber+metal	structure
2021	Sustainability	assembly+winding	concrete+timber+metal	structure
2022	Sustainability+New possibilities	assembly+concrete casting	concrete	structure

6 Conclusion & Future Work

This paper addressed the robotic applications in the field of architecture to examine the possibilities it can offer to landscape architecture. For that purpose, existing research projects of the most renowned architectural research labs were overviewed in four main categories: goals, materials, tasks, and products. Figure 7 shows some of the reviewed projects. As a result of this research, we spotted both the gradual and sharp chronological changes in each theme. Additionally, we were able to discover the correlation between the subjects. This approach helped us to highlight the gaps and opportunities in the realm of robotic landscapes. We believe this research will be essential in bridging the gap between landscape architecture and robotic fabrication and provide a roadmap for landscape architects.
However, the scope of the research is constrained in terms of the comprehensiveness of the research labs. As a future step, we plan to collect more projects from different research groups and increase our dataset.

Figure 7- Heap (URL-7), Thallus Installation (URL-8), DFAB House (URL-9), Maison Fiber (URL-10), BUGA Fiber Pavilion (URL-11), Jammed Architectural Structure (URL-12), livMatS Pavilion (URL-13), Fiberbots (URL-14)

References

Bar-Sinai, K., Shaked, T., & Sprecher, A. (2019). Informing Grounds: A Theoretical Framework and Iterative Process for Robotic Groundscaping of Remote Sites. 10.52842/conf.Acadia.2019.258.

Bock, T., & Thomas, L.(1995). Robot-Oriented Design. Design and Management Tools for the Deployment of Automation and Robotics in Construction, New York, Cambridge University Press.

Buchli, J., Giftthaler, M., Kumar, N., Lussi, M., Sandy, T., Dör, K., & Hack, N. (2018). Cement and Concrete Research Digital in situ fabrication - Challenges and opportunities for robotic in situ fabrication in architecture, construction, and beyond, 112(January), 66–75.

Culkin, John Macaulay. (1967). A schoolman's guide to Marshall McLuhan. New York: Saturday Review, Inc. Bottom of Form.

Duque Estrada, R., Kannenberg, F., Wagner, H., Yablonina, M., & Menges, A. (2020). Spatial winding: cooperative heterogeneous multi-robot system for fibrous structures. Construction Robotics. 4. 1-11. 10.1007/s41693-020-00036-7.

Easley, W., Buehler, E., Salib, G., & Hurst, A. (2017). Fabricating Engagement: Benefits and Challenges of Using 3D Printing to Engage Underrepresented Students in STEM Learning. 10.18260/1-2--28347.

Ervin, S. M. (2003). Trends in landscape modeling. In Conference Proceedings at Anhalt University of Applied Sciences.

Gramazio, F., & Kohler, M. (2014). Made by Robots: Challenging Architecture at the Large Scale AD Wiley.

Hurkxkens, I. (2020). Robotic Landscapes Topological Approaches to Terrain, Design, and Fabrication.

Hurkxkens, I., Girot, C., & Hutter, M. (2017). Robotic Landscapes: Developing Computational Design Tools Towards Autonomous Terrain Modeling. 10.52842/conf.Acadia.2017.292.

Hurkxkens, I., Pigram, D., & Melsom, J. (2021). Shifting Sands : Experimental Robotic Earth-Moving Strategies in Dynamic Coastal Environments, 66–74. https://doi.org/10.14627/537705003.

Jud, D., Leemann, P., Kerscher, S., & Hutter, M. (2019). Autonomous free-form trenching using a walking excavator. *IEEE Robotics and Automation Letters*, *4*(4), 3208–3215. https://doi.org/10.1109/LRA.2019.2925758

Keating, S., Leland, J., Cai, L., & Oxman. (2017). Toward site-specific and self-sufficient robotic fabrication on architectural scales. Science Robotics. 2. eaam8986. 10.1126/scirobotics.aam8986.

Petschek, P. (2014). Grading: Landscaping Smart Machine Control Systems Stormwater Management. Basel, Switzerland, Birkhausser.

Shaked, Tom, and Uri Dubin. (2019). Exercises in Style: A Transdisciplinary Discussion." In Instabilities and Potentialities: Notes on the Nature of Knowledge in

Digital Architecture, edited by A. Sprecher and C. Ahrens. New York; London: Routledge.

Westort, C., & Shen, Z. (2017). Robot in the Garden: Preliminary Experiments Programming an On-site Robot Ball Assistant to the Landscape Architect Prior Work: Robots in the Garden, 223–234. https://doi.org/10.14627/537629023.

Weissenböck, Renate. (2015). Robotic Design-Fabrication - Exploring Robotic Fabrication as a Dynamic Design Process. 10.52842/conf.eCAADe.2015.2.309.

Yu, B., Zhang, L., & Zhang, H. (2021). Towards “Autonomous”: A review of the “stereotypical” behaviors in Robotic construction, 04035, 4–7.

URL-1 https://www.icd.uni-stuttgart.de/

URL-2 https://gramaziokohler.arch.ethz.ch/

URL-3 https://www.kokkugia.com/

URL-4 https://www.media.mit.edu/groups/mediated-matter/overview/

URL-5 https://dfab.ch/streams

URL-6 https://www.zaha-hadid.com/archive

URL-7 https://gramaziokohler.arch.ethz.ch/web/e/forschung/382.html

URL-8 https://www.zaha-hadid.com/design/thallus-installation/

URL-9 https://dfabhouse.ch/DFAB%20HOUSE/

URL-10 https://www.itke.uni-stuttgart.de/research/built-projects/maison-fibre-2021/

URL-11 https://www.itke.uni-stuttgart.de/research/built-projects/buga-fibre-pavilion-2019/

URL-12 https://gramaziokohler.arch.ethz.ch/web/e/forschung/275.html

URL-13 https://www.itke.uni-stuttgart.de/research/icd-itke-research-pavilions/livMatS-pavilion-2020-21/

URL-14 https://www.media.mit.edu/projects/fiberbots/overview/

Notes for a general interpretation of the application of digital fabrication in the global south context

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Abstract. Over time, digital fabrication technologies were assimilated, based on project references, techniques and machinery from the global north, determining dependency relationships. Recently, architecture and design schools, fab labs, and design offices in South America have expanded their infrastructure in order to create laboratories using these technologies. The objective is to present framings about production plus a framework for the application of technologies. Originated from a thesis research, the methods that support the theoretical elaboration consisted of a bibliographic and systematic review of topics related to digital fabrication, information mapping, surveys, interviews and case studies carried out in South America. The contribution of the article is to provide a background for thinking, interpreting and executing procedures and artifacts with the support of digital fabrication, oriented to the development of our context. In addition, it deepens a critical view of this condition, which involves advances in socio-technical adequacy and innovation policies.

Keywords: Digital Fabrication, Digital Theory, Design Innovation, Technological Appropriation, Hybrid Practices.

1 Introdução

Há cerca de 20 anos as tecnologias digitais para prototipagem e manufatura têm sido integradas aos sistemas técnicos no design, na arquitetura, e na construção, por meio de estratégias e princípios como o faça você mesmo, a materialização de dados, o controle do processo de manufatura, a automação de tarefas, a digitalização da cadeia produtiva, a otimização de resultados, a inovação de produtos, entre outros (Yuan et al., 2018). A conformação de tal cenário decorre de discursos e da condição tecnológica oferecida, configurando situações hegemônicas, mas também alternativas, determinando relações e regimes simbólicos, éticos e estéticos, influenciando a organização social e do trabalho (Feenberg, 2001). Assim,

teorias, códigos e significados de uso das tecnologias, além de exemplos de sua aplicação em projetos, figuram no escopo epistemológico e do sistema de práticas que se reconhece como a fabricação digital (FD). Em consequência, delimita-se um arcabouço conceitual e imaginário de propostas projetuais que influenciam modos de fazer. Logo, toda e qualquer forma aplicada de conhecimento e técnica vinculada às máquinas de fabricação digital carregam em si mesmas a concretização histórica de uma racionalidade que direciona decisões, por vezes circunscritas, por vezes expandidas.

Com a influência da globalização desigual, as tecnologias de fabricação digital foram assimiladas, ao longo do tempo, a partir de matrizes do norte global na universalização de epistemologias particulares (Hui, 2020, p. 23), determinando relações de dependência e limitações produtivas no sul global. O insuficiente desenvolvimento em geral, ou subdesenvolvimento, foi encarado por muitos como resultado de um atraso histórico ou uma mera defasagem temporal, e não como resultado da própria estrutura e ordem (ou desordem) econômica mundial (Bonsiepe, 2012, p. 65). Não somente a base econômica, mas também a base epistêmica vinculada à aplicação da FD, têm suas ideologias e valores advindos dessas matrizes. Essas relações tendem a acontecer devido ao precedente temporal da existência de ferramentas e maquinário, e de projetos originários que servem como orientação para o desdobramento de outros projetos. Em período recente, escolas de arquitetura e de design da América do Sul adquiriram equipamentos, expandiram a infraestrutura e contrataram profissionais a fim de criarem laboratórios utilizando essas tecnologias, além do surgimento de fab labs e a incorporação de estratégias similares em escritórios e fornecedores de serviços. Nesse cenário, foram desenvolvidas propostas que, em conjunto com análises críticas, aprimoraram a experiência local.

Este artigo objetiva apresentar enquadramentos teóricos a partir de dados e informações relevantes da cultura material, do contexto tecnológico sul-americano e seus determinantes socioculturais, frente às crescentes demandas pela digitalização, transformação do aprendizado e das cadeias de produção baseadas na absorção das tecnologias habilitadoras da “indústria 4.0”. Além disso, indica uma estrutura de trabalho com diretrizes situadas de implementação de estratégias para a composição de projetos e práticas com o uso das tecnologias de FD, a partir de condições e produções emergentes do contexto sul global, indicando contribuições para o desenvolvimento de processos locais. A elaboração desses elementos surge de pesquisa prévia (Scheeren, 2021), fundamentada na revisão bibliográfica e sistemática de temas vinculados à fabricação digital, mapeamento de informações, entrevistas, visitas técnicas e estudos de caso, realizados na América do Sul e na Europa.

Partimos da premissa de que o uso de tecnologias digitais, técnicas e produtos concebidos ser configurados de maneira distinta às suas predeterminações ou utilizações mais usuais conformadas no campo da prática, promovendo aberturas disciplinares, despertando caminhos alternativos e tensionando uma reflexão acerca dos seus resultados. Os procedimentos e interesses, nesse sentido, tendem a se deslocar do abstrato ao concreto: da geração de geometrias complexas aos elementos construtivos adaptados a problemáticas bem definidas, promovendo o aperfeiçoamento técnico e estratégias em escala de modo experimental, direcionados ao desenvolvimento social local. Essa mudança de horizonte denota a reflexão e realização criativa inevitavelmente ligados às cosmologias, éticas e sistemas de conhecimento locais (Tlostanova, 2017).

2 Indicadores para a elaboração de uma estrutura de trabalho e configuração de projetos

Ao longo da investigação, percebemos a capilarização das mais diversas formas de apropriação tecnológica e variedade de propostas desenvolvidas, recentemente, na América do Sul (Sperling et al., 2020; Scheeren et al., 2019). Contudo, um panorama inicial obtido por meio de uma revisão sistematizada de artigos sobre o tema da fabricação digital (Scheeren, 2021) – com as palavras-chave digital fabrication, digital manufacturing, fabricação digital, fabricación digital, rapid prototyping, CAD/CAM, robot* e 3d print* –, publicados por autores sul-americanos entre o período de 2000 a 2018 no SiGraDi, disponíveis no repositório Cumincad, mostrou algumas peculiaridades. Disso, emergiram algumas categorias de aplicação da FD, como análise teórica, educação, efeito cultural, processo construtivo, desenvolvimento técnico, método de design digital, objeto de design, modelo arquitetônico, projeto em escala arquitetônica, instalação artística, e outros. Dos 191 artigos avaliados (Scheeren, 2021, p. 121-2), diagnosticamos que grande parte dos trabalhos se enquadram nas categorias de análise teórica (41), design de objeto (67), e modelo arquitetônico (35), principalmente baseados em atividades educacionais em que poucos envolvem certo tipo de desenvolvimento técnico. Isso reforça a questão de que as experimentações acontecem com demandas de pequena escala e com experiências curtas (Felipe & Nome, 2020).

As diversas entrevistas, visitas técnicas e estudos de caso realizados no contexto da América do Sul, ampliaram a compreensão do cenário inicialmente analisado. A partir dessa percepção extensiva, obtivemos um conjunto de elementos que nos permite sugerir desdobramentos e avanços em nossa condição, no intuito de intensificar os vínculos, processos de produção e ampliar a escala dos produtos. De um modo geral, os elementos

indicadores levam em conta: a) políticas: proposições teórico-ideológicas e encaminhamentos do projeto, relações institucionais e ecossistemas, público-alvo e participação, diretrizes sócio-técnicas e transferência de conhecimento; b) fluxos: atores e procedimentos, saberes e técnicas, projetos e planejamento, meios e recursos; c) tecnologias: dispositivos e ferramentas, diversidade e complexidade da aplicação, potencialidades e limitações de uso, abertura e capacidade de intervenção, accessibilidade e integração; d) experiências: conhecimento aplicado e práticas, impacto e divulgação dos resultados, formação profissional e de interdisciplinaridade.

Figura 1. Esquema representando os elementos indicadores em um quadro que apresenta as relações de abertura, formalização e determinação em nosso contexto de aplicação das tecnologias de FD. Fonte: Autores, 2022.

Os elementos indicadores permitem constituir um primeiro enquadramento, em um processo de atribuir sentido à produção e organizar conhecimentos que, para mobilizar experimentos, deve ser traduzido em modelos, que formalizam variáveis e princípios para estabelecer lógicas de desenvolvimento efetivo (Fressoli et al., 2014, p. 280). Com isso em mente, indicamos diretrizes que possam embasar processos de projeto utilizando tecnologias de FD como suporte parcial ou total, esquematizadas na figura 2. A aplicação dessas tecnologias não acontece de maneira isolada, mas envolve o uso criativo de estratégias de design computacional, simulação, modelagem da informação, técnicas CAD e CAM, abordagens híbridas com preparação manual, etc. Logo, o aprendizado dessas habilidades permite um maior domínio na exploração e desenvolvimento das propostas de cada projeto.

Para o desenho de uma estrutura de trabalho, adaptamos algumas diretrizes do modelo “nível de maturidade tecnológica” (Straub, 2015), sua compreensão das etapas e atores envolvidos no desenvolvimento do projeto. Elas envolvem elementos de pesquisa básica, iniciando pela proposição de princípios básicos e conceitos para a aplicação, passando pelo

desenvolvimento experimental que envolve aplicação, validação e demonstração, por meio de prova de conceito, verificação funcional em laboratório, verificação funcional crítica em ambiente relevante e demonstração do modelo em protótipo acabado. Todas essas etapas têm o potencial de incorporar as tecnologias de FD, além da participação do público não-especialista, para aperfeiçoamento e análise dos elementos criados, concretizando uma racionalidade informal. Na sequência das etapas, avança-se para a manufatura em nível industrial e em larga escala, em que há a demonstração do protótipo em ambiente operacional e o seu desdobramento em um sistema real, assim, apto a avaliações qualitativas e ser disponibilizado para a produção.

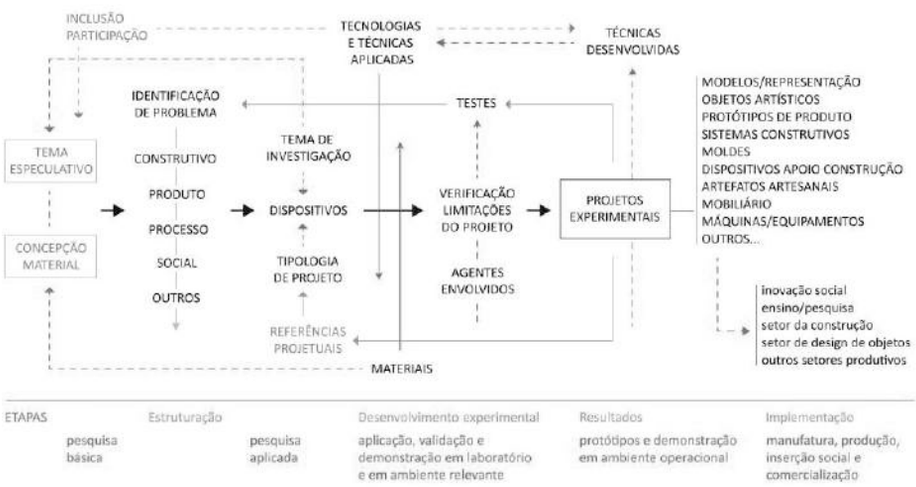

Figura 2. Esquema proposto da estrutura de trabalho com as tecnologias de FD.
Fonte: Autores, 2022.

No momento da estruturação da prática, inicia-se a investigação em que se evita determinar previamente o objeto em si, acontecendo de modo aberto e experimental, com a escolha de um tema especulativo abstrato – derivando de conceitos, geometrias ou algum tipo de elemento pré-configurado – ou de materiais – trabalhando as suas propriedades e combinações. Também, pode-se iniciar diretamente pela identificação de alguma problemática que se pretenda solucionar, oriunda de questões que emergem dos setores de produção, da adequação ou melhoria de processos estabelecidos em distintas cadeias, das necessidades de grupos ou indivíduos em situação de vulnerabilidade, dentre outros. A esse primeiro momento, é válido adequar temas de investigação que atribuam uma forma ao problema, especular sobre dispositivos que se pretenda adaptar ou criar, das predisposições de grupos e

sua inclusão no processo, ou utilizar tipologias de projeto como base para guiar estudos, todos podendo se servir de referências já produzidas.

A seguir, são elegidas tecnologias, técnicas e materiais capazes de serem adequados ao desenvolvimento da proposta, variando a partir do reconhecimento das opções ao alcance do laboratório, que podem ser assimilados ou desenvolvidos de acordo com as necessidades que surgirem. Após a verificação das limitações acerca do que foi proposto até então, há a opção de integrar agentes para colaborarem na sua continuidade – que podem, também, estar inseridos em etapas anteriores –, sendo especialistas ou não-especialistas e, assim, realizar protótipos e testes necessários. Logo, são alcançados resultados em fase experimental, dos quais é possível também extrair aprendizados técnicos que podem ser refinados e aplicados em outros artefatos. Cada um deles liga-se a determinadas operações: modelos arquitetônicos e de representação, protótipos especulativos, objetos de escala média, instalações artístico-conceituais, moldes para construção, componentes construtivos, objetos de demonstração e sistemas de construção em escala real, entre outros. Estes resultados passam por análise de suas restrições e adequação às especificações localmente determinadas, demonstração de suas características e efetivação como um produto final. Finalizado, é um elemento de avaliação, utilizado como referência para ajustes e novos projetos, além de poder ser produzido industrialmente e em ambiente controlado.

Nesse sentido, podem ser concebidos dispositivos utilitários para a sociedade, elementos leves para estruturas e fechamentos, novas técnicas para a construção, customização de objetos de design e mobiliário, moldes para elementos complexos, infraestrutura adaptável para o canteiro, máquinas com propostas originais de funcionamento, entre outras opções. Muito além de finalizar nessa etapa, é crucial compreender que a obtenção de um resultado não é apenas um fim em si mesmo, mas relevante numa cadeia de desenvolvimentos técnicos cumulativos e continuados, estruturados em um processo de investigação que se desenrola a longo prazo. Desse modo, são alicerçados conhecimentos e implicações mais robustas no meio, que podem ser difundidas de maneira dinâmica nos setores da sociedade e nas cadeias de produção. O estabelecimento de redes de colaboração auxilia nessa tarefa, que podem surgir pelo reconhecimento dos pares em busca de interesses similares e potenciais contribuições em construções coletivas, além de colaborações diretas das universidades, comunidades e instituições de C&T com setores industriais identificados nas proximidades da região, como moveleira, metalmecânico, de transformação, entre outros.

Os resultados dependerão da motivação dos atores, da infraestrutura e dos espaços físicos, das estratégias de trabalho, das relações entre

laboratórios acadêmicos, laboratórios independentes, escritórios profissionais e outras configurações, que colaborem com instituições, sociedade civil, indústria e serviços, instituindo práticas situadas e observando necessidades emergentes. Na medida do possível, que os projetos e processos sejam mantidos na modalidade de código aberto em repositórios, e divulgados para tornar a informação pública, motivando não-profissionais a aprender e intervir (Feenberg, 2001, p. 120) e, assim, que o conhecimento seja estruturado e desdobrado em outros contextos, gerando variações e certa inteligência coletiva de projeto.

A aplicação de fato das estratégias indicadas acima não pode se resumir aos meros objetos resultantes ou à automação de certas tarefas, mas promover uma abertura no escopo de decisão que privilegie a participação ativa dos agentes na construção do conhecimento. Desse modo, o dispositivo tecnológico é apropriado e adaptado aos interesses políticos de grupos sociais relevantes e, em vez de replicarmos saberes e técnicas, o conhecimento e a tecnologia existentes são ajustados às particularidades dos problemas de cada contexto (Dagnino, 2009). Essa visão construtivista promove a abertura das tecnologias, que necessitam ser utilizadas de maneira transformadora e na construção de arranjos socioeconômicos alternativos (Fressoli et al., 2014). Assim, as estratégias de projeto são moldadas na forma de pesquisas, pois os problemas tendem a crescer em complexidade, e a finalidade é a de produzir um conhecimento explícito, discutível, transferível e acumulável (Manzini, 2015, p. 38-39). A principal motivação nessa tarefa é a de melhorar propriamente o bem-estar humano, sem contá-lo como uma consequência secundária, determinando o que se entende por inovação social.

Quando indicamos a importância de procedimentos a longo prazo, remetemos a proposta de políticas “orientadas para missões”, compreendendo que, não restritos a objetivos específicos, eles estejam direcionados a idealizar situações que promovam uma mudança ampla de um paradigma corrente, já que visam abordar desafios que requerem compromisso de futuro, sendo tanto sociais quanto tecnológicos (Mazzucato, 2018, p. 804). Essa perspectiva pode ser compreendida como uma proposta guarda-chuva de ambição relevante, da qual projetos serão desenvolvidos, formando uma base de conhecimentos que permita alcançar objetivos superiores. Os pontos-chave de uma proposta orientada a missões envolvem a escolha de projetos estratégicos que devem ser bem definidos, resultando no investimento em setores diversos e envolvendo diferentes tipos de atores, criando “uma agenda pública de longo prazo para políticas de inovação, atendendo a uma demanda ou necessidade da sociedade e aproveitando o alto potencial do sistema de ciência e tecnologia do país para desenvolver inovações” (Mazzucato, 2018, p. 805).

Figura 3. Esquema de um enquadramento relativo a uma proposta orientada à missão em nosso contexto de aplicação das tecnologias de FD, capaz de gerar um ecossistema de inovação. Fonte: Autores, 2022.

Essa não é uma tarefa trivial quando lidamos com os desafios e obstáculos de implementação dessas matrizes no setor da construção, já que este envolve empreendimentos complexos, por serem baseados no local e na grande quantidade de processos e participantes inter-relacionados, devido às incertezas em relação a falta de especificações dos processos, a cadeia de fornecimento fragmentada e constituída por pequenas e médias empresas, ao pensamento de curto prazo, e a cultura resistente a mudanças (Oesterreich & Teuteberg, 2016). Assim, trabalhar com outras escalas e setores de produção contribui para que o potencial dos processos de inovação resultantes possam ser aplicados com menos limitações e resultar em amplos ganhos para a comunidade em geral, integrando profissionais e dinâmicas de projetos em diversas áreas e atividades.

3 Discussão

As diferentes conformações dos laboratórios que utilizam tecnologias de FD podem tornar-se espaços privilegiados para o desenvolvimento de projetos robustos para a comunidade, a indústria e outros setores produtivos, que exijam interação, colaboração e prototipagem. Um dos maiores desafios desses espaços de fazer, que foram identificados na pesquisa, é manter um modelo economicamente sustentável de funcionamento, sem tornar-se um mero fornecedor de serviços. A questão relevante a ser abordada sempre será a proposição de projetos que abarquem o maior número de estratégias e ações significativas e que sejam centralizadores de processos experimentais,

geração de saberes e de técnicas produtivas, ao mesmo tempo que descentralizadores ao efetivar parcerias que ampliem o escopo através dos diversos tópicos trazidos por diferentes atores e a consolidação de uma abordagem interdisciplinar. Conjuntamente, as atividades de ensino, aprendizagem e de investigação necessitam de uma mudança radical, em que a dedicação às práticas aconteça de maneira mais intensiva e extensiva.

Diante de um cenário de escassez comumente encontrado na América do Sul, o uso das tecnologias de FD surge com potencial enorme para o contexto, porque são capazes de contribuir na solução de problemas da ordem material e ampliar a variedade de soluções nas áreas de design, arquitetura e construção. No decorrer das práticas, tornamo-nos capazes de refletir sobre os encaminhamentos, questionar as tarefas assumidas nos projetos e para quem servem as tecnologias, priorizando atividades que ampliem o impacto social. Assim, evita-se recair em meras especulações formais e materiais que mantenham lacunas em relação às demandas imediatas de aplicação tecnológica, focando em incertas realizações futuras ou práticas voltadas a geração de objetos para consumo.

Alguns caminhos da aplicação da estrutura de trabalho no cenário local podem ser ilustradas por alguns temas e exemplos já identificados no mapeamento da pesquisa. A conformação de elementos de representação pode ser expandido das tradicionais maquetes para artefatos instrucionais, articulando-se modos de facilitar o aprendizado e amplificar as práticas pedagógicas com modelos tridimensionais de sistemas construtivos e de peças das edificações, contribuindo para a visualização da linguagem compositiva, a apreensão da relação entre técnicas, materialidade e historiografia. A concepção de sistemas e elementos construtivos em escala real é potencializado por desdobramentos técnicos, novas propostas de construtibilidade e racionalização, em que não se materializam apenas formas complexas de maneira facilitada, mas são desenvolvidos experimentos que geram avanços em estratégias de criação e execução, originando novas técnicas e produtos de baixo custo, como peças moduladas em composições complexas, sistemas leves de encaixe e de pré-fabricados. Além disso, há a produção de dispositivos de apoio para o canteiro, criação e a aplicação de maquinário específico e flexível para a realização das tarefas, como tecnologias customizadas e robóticas.

A reflexão acerca das estratégias de design, considerando sua dinâmica distribuída, permite gerar artefatos de pequena e média escala que possam influenciar mudanças nos modos operacionais de setores e impactar cadeias produtivas, além de resultados conceituais e artísticos. Essa ideia se manifesta por meio da noção de "porosidades tecnológicas", em que consideram-se as limitações dos dispositivos tecnológicos digitais como um potencial criativo a ser explorado, assim como a incorporação de

conhecimentos e elementos cotidianos que adentram campos já constituídos, a fim de conduzir processos especulativos, na confluência entre alta e baixa tecnologia. O seu papel está em ampliar o escopo de aplicação das estratégias digitais, inseridas em distintas áreas disciplinares, questionando o modelo produtivo convencional, ao mesmo tempo que considera o processo e seu resultado como geradores de impacto social, reduzindo a intermediação e aproximando criadores e usuários. A concepção de "produção situada" engloba essa situação, indicando a capacidade de integrar a racionalidade de uso do sistema ao meio, promovendo a abertura e adequação das tecnologias de maneira concreta aos valores e técnicas resistentes às hegemonias, considerando demandas e mediações éticas, estéticas e sociais, e reconhecendo os códigos de utilidade e eficácia constituindo sentido a longo prazo.

Ademais, a contribuição já instalada do artesanato é fortalecida pelas tecnologias de FD, quando não se busca gerar elementos exóticos ou para mero consumo, mas desvelar técnicas esquecidas ou pouco valorizadas, integrando saberes de profissionais e artesãos como colaboradores na criação de artefatos. Essa disposição define certa "diversidade tecnopoética", que vincula múltiplas ontologias, culturas e interpretações tecnológicas, fomentando a realização de experimentos que alteram o funcionamento corrente das máquinas e seus materiais, explorando o hackeamento, a instabilidade e incerteza dos resultados, que reverberam diferentes intencionalidades, conhecimentos e imaginários coletivos. Soma-se a isso a noção de "modelos híbridos", que convergem iniciativas, enquadramentos e propostas oriundos tanto de modo emergente quanto institucionalizado. Tal dinâmica motiva uma sinergia entre atores através da amálgama de distintos panoramas culturais, expandindo as possibilidades de projeto, além da rearticulação com antigos e novos instrumentos, processos e produtos, denotando fatores de identidade e identificação com os usuários.

A fim de estender a capacidade técnica e tecnológica da fabricação digital, um aporte importante envolve o desenvolvimento de novos materiais e biofabricação, com potencial de nos apropriarmos da notável diversidade natural existente em nosso continente. Além disso, a reutilização e reciclagem de materiais, principalmente devido à quantidade de resíduos gerados em contextos de escassez, permite a inovação por meio da economia circular. Esse tema considera que outras cadeias de produção são criadas em paralelo, envolvendo atores distintos e não especialistas, incluindo a sustentabilidade das ações. Com o intuito de expandir as tecnologias ofertadas e das quais nos apropriamos, com seu efeito centralizador e de sistemas fechados, propostas de remodelagem de máquinas e adaptação às necessidades correntes de manufatura e do canteiro é cada vez mais essencial. Por meio desses procedimentos práticos, há um reconhecimento das possibilidades e limitações das tecnologias,

capacidade de ajustes de funcionamento ao que se pretende empregar, além da acessibilidade e adequação dos sistemas com o propósito de diminuir custos.

4 Considerações

Compreendendo que se trata de uma cadeia complexa de processos, a expansão da dimensão teórica a respeito das tecnologias de FD permite qualificar um panorama que indique estratégias e atividades práticas a partir de conceitos e enquadramentos específicos, resultando em novas experiências situadas de trabalho. Assim, configuram uma práxis alternativa com seus graus de abertura, que desnaturalize os pressupostos de racionalidade formal, objetividade e eficácia das práticas dominantes, incorporados pelo sentido de opacidade e fetichismo tecnológico. De maneira geral, sintetizamos estratégias emergentes a partir de situações locais, complementadas por temas de trabalho dos quais podem ser abstraídas táticas com potencial absorção em práticas.

Muitos dos casos pesquisados ainda limitam-se a uma visão de soluções particulares e imediatas, ao contrário de focar esforços em propostas de impacto fundamentais, amplas e duradouras para que os benefícios possam estar voltados para mudanças na sociedade. Inevitavelmente, são procedimentos experimentais que envolvem tentativas, erros e acertos. Reconhece-se a dificuldade de integrar efetivamente o público na apropriação da fabricação digital e realizar mudanças sistêmicas. Além disso, dá-se atenção demasiada às aplicações e pouca reflexão crítica sobre os sentidos de uso da tecnologia: o “porque” que não é apenas explicação dos resultados, mas deve englobar os processos e direcionamentos. Futuramente, com base no plano de trabalho proposto, podem ser desenvolvidas métricas para análise e maturidade dos modelos subsidiárias da estrutura de trabalho. Além disso, cabe pensar em modelos localmente plausíveis para a geração de cadeias de digitalização e ecossistemas de construção 4.0.

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Referências

Bonsiepe, G. (2012). *Design como prática de projeto*. Edgard Blücher.

Dagnino, R. (Org.). (2009). *Tecnologia social: ferramenta para construir outra sociedade*. IG/UNICAMP.

Feenberg, A. (1999). *Questioning Technology*. Routledge.

Felipe, B. L., & Nome, C. (2020). Digital Fabrication Techniques: A systematic literature review. In *Proceedings of the XXIV International Conference of the Iberoamerican Society of Digital Graphics,* (pp. 9–16). Editora Edgard Blucher. https://doi.org/10.5151/sigradi2020-2

Fressoli, M., Arond, E., Abrol, D., Smith, A., Ely, A. & Dias, R. (2014) Whe.n grassroots innovation movements encounter mainstream institutions: implications for models of inclusive innovation. *Innovation and Development, 4*(2), 277-292. https://doi.org/10.1080/2157930X.2014.921354

Hui, Y. (2020). *Tecnodiversidade*. Ubu Editora.

Manzini, E. (2015). *Design when everybody designs: an introduction to design for social innovation*. MIT Press.

Mazzucato, M. (2018). Mission-oriented innovation policies: Challenges and opportunities. *Industrial and Corporate Change, 27*(5), 803–815. https://doi.org/10.1093/icc/dty034

Oesterreich, T. D., & Teuteberg, F. (2016). Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry. *Computers in Industry, 83*, 121–139. Elsevier B.V. https://doi.org/10.1016/j.compind.2016.09.006

Scheeren, R. (2021) *Digital fabrication in South America: laboratories, strategies, processes and artifacts for design, architecture and construction*. Tese (Doutorado em Teoria e História da Arquitetura e do Urbanismo – Instituto de Arquitetura e Urbanismo, Universidade de São Paulo), São Carlos, 2021.

Scheeren, R., Herrera, P. C., Sperling, D. (2019). Evolving stages of digital fabrication in Latin America Outlines of a research and extension project. In *Proceedings of 37 eCAADe and XXIII SIGraDi Joint Conference*, (pp. 797-808). Editora Edgard Blucher, 2019. https://doi.org/10.5151/proceedings-ecaadesigradi2019_519

Sperling, D. M., Herrera, P. C., & Scheeren, R. (2020) Fabricating (Other) Computations: Digital Fabrication and Technological Appropriation in Latin America. *Dearq, 27*, 76-87. https://doi.org/10.18389/ dearq27.2020.06

Straub, J. (2015). In search of technology readiness level (TRL) 10. *Aerospace Science and Technology, 46*, 312–320. https://doi.org/10.1016/j.ast.2015.07.007

Tlostanova, M. (2017). On decolonizing design. *Design Philosophy Papers, 15*(1), 51–61. https://doi.org/10.1080/14487136.2017.1301017

Yuan, P. F., Menges, A., & Leach, N. (Eds.). (2018). *Digital Fabrication*. Tongji University Press.

Digital fabrication of facial prostheses from photogrammetry, three-dimensional modeling and 3D printing on filament (FDM) and resin (SLA).

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Abstract. This paper aims to describe the process of digital manufacturing of facial prostheses for patients injured by cancer. For this the proposed innovation is the use of low-cost digital tools, such as photogrammetry, 3D modeling and 3D printing. The main software used are Blender for modeling the prostheses and the add-on OrtogOnBlender for generating photogrammetry. As a result of the process, the following can be observed: 1 - Less invasive approach to the patient; 2 - Low production cost; 3 - Optimization in production time; 4 - Greater anatomy accuracy and prosthesis details; 5 - Documentation through digital recording of the entire process.

Keywords: Digital fabrication, Prostheses, Photogrammetry, 3D Modeling, 3D Printing.

1 Introdução

A confecção de próteses faciais é um trabalho que exige do profissional protético, método, técnica e habilidade manual. Para que uma prótese fique com a aparência realística é preciso reproduzir os detalhes e imperfeições da pele humana, além de acertar nas proporções e formas naturais da anatomia específica para cada paciente, um trabalho bastante meticuloso, com várias etapas e especificidades.

Com o avanço das tecnologias CAD/CAM (Computer-Aided Design/ Computer-Aided Manufacturing), foi possível agregar inovações relevantes ao processo de confecção das próteses faciais nas várias etapas de sua produção. Todo o potencial inovador está atrelado à interdisciplinaridade entre

áreas do conhecimento distintas, como: o design, a fabricação digital e a medicina. Possibilitando maior praticidade e demais benefícios descritos ao longo deste artigo, através da utilização de ferramentas de digitais, como: fotogrametria, modelagem 3D e impressão 3D, que dão o suporte necessário para este fim.

Este modelo de fabricação digital já é desenvolvido por alguns poucos profissionais, dentre os quais, é imprescindível enfatizar o pioneirismo e qualidade técnica dos trabalhos do Dr. Rodrigo Ernesto Salazar Gamarra (2016), cirurgião dentista, com diversas publicações na área de próteses utilizando recursos digitais de baixo custo, como smartphones e *softwares* de fotogrametria e também é imprescindível destacar o trabalho do designer 3D Cícero Moraes (2019), desenvolvedor do *add-on* (extensão) *OrtogOnBlender,* script facilitador com diversos recursos gráficos tridimensionais voltados para o planejamento cirúrgico baseado no software de modelagem tridimensional Blender, desse conjunto utilizaremos os recursos de fotogrametria e modelagem 3D.

Diante desse cenário, é justificável a relevância desta pesquisa/método de trabalho para difusão e fomento do conhecimento de uma técnica acessível à comunidade científica e criativa, que proporcione melhor qualidade de vida aos pacientes, maior praticidade aos médicos protéticos e que possa expandir o campo de atuação dos profissionais de design.

Sendo assim, este artigo pretende descrever o processo de fabricação digital da prótese facial do paciente RBT (sigla fictícia criada para preservar a identidade real do paciente), colaborador desta pesquisa, autorizando uso de sua imagem para fins didáticos. Como o foco deste artigo é demonstrar a etapa de design no processo, será necessário a utilização demasiada de figuras para uma melhor compreensão do método, além disso aspectos de métodos tradicionais de confecção de próteses só serão abordados para efeito comparativo. Outro ponto relevante que precisa ser mencionado é o baixo custo dos equipamentos utilizados:

Tabla 1. Equipamentos Utilizados

HARDWARES

Equipamento	Especificação	Função no projeto
Smartphone	MI A2 Xiaomi	Fotografar as diversas fotos necessárias para geração da fotogrametria.
Computador 1	Processador Ryzen 5 3600 Placa de vídeo Nvidia RTX 2060 16GB de memória RAM	Gerar fotogrametria e fazer a modelagem tridimensional das próteses para impressão.
Computador 2	Processador Ryzen 5 1600 Placa de vídeo AMD RX 550 16GB de memória RAM	Preparar os arquivos para impressão 3D (Fatiamento).
Impressora em Resina (MSLA)	Creality LD 002 H	Imprimir prótese.
Impressora em Filamento (FDM)	Creality Ender 3	Imprimir face (referência).

SOFTWARES

Software	Especificação	Função no projeto
Blender	Modelagem 3D	Fotografar as diversas fotos necessárias para
OrtogOnBlender	Add-on (extensão) do Blender voltado para o planejamento cirúrgico de ortognáticas.	Gerar fotogrametria da face do paciente.
MeshMixer	Modelagem 3D	Recortar e solidificar o modelo tridimensional da fotogrametria.
Chitubox	Fatiador de impressão em Resina	Fatiar o arquivo 3D
CURA	Fatiador de impressão em FDM	Fatiar o arquivo 3D

Fonte: Autores, 2022.

1.1 Baixo custo

Como pode-se observar todos equipamentos são modelos comuns do dia-a-dia, computadores com processadores intermediários, smartphone intermediário e impressoras 3D de entrada, além disso todos os softwares utilizados são gratuitos.

2 Processo de Fabricação Digital de Próteses Faciais

O processo de produção de próteses faciais descrito neste artigo possui 4 etapas sequenciais: **Etapa 1 - Fotogrametria da Face do Paciente**: é gerado um modelo 3D da face do paciente a partir de diversas fotos tiradas por smartphone; **Etapa 2 - Modelagem 3D da Prótese**: é criado o modelo tridimensional a partir de modelagem 3D utilizando o software Blender; **Etapa 3 - Impressão 3D**: são impressas a referência da face do paciente em FDM e a prótese em resina; **Etapa 4 - Moldagem e Finalização:** é criada a prótese final de silicone a partir das impressões anteriores.

2.1 Etapa 1 - Fotogrametria da Face

A fotogrametria é a tecnologia que permite a digitalização 3D a partir de fotografias. A grosso modo, seria similar a um escaneamento digital, mas ao invés da utilização de scanners específicos, utiliza-se equipamentos mais acessíveis, como as câmeras de smartphones. O protocolo adotado é o mesmo "Protocolo de Fotogrametria de Face" sistematizado por Cícero Moraes (2016). Esta etapa é subdividida em outras 2 fases: a realização das fotografias e a geração do modelo 3D no *software* específico.

2.1.1 Instruções Fotográficas

Ao todo são feitas 26 fotos divididas em 2 tomadas de 13 fotos. A primeira tomada de fotos, descrita na imagem como *Level 1*, é realizada na altura central da face, alinhada entre os olhos e o nariz, a uma distância em que englobe a face por completo, a um ângulo perpendicular à linha da parede. A segunda tomada de fotos, descrita na imagem como *Level 2*, é realizada com uma inclinação de 35º graus abaixo, para otimização do tempo é sugerido que seja tirado no sentido inverso em relação ao *Level 1* para que o fluxo fotográfico seja contínuo, de acordo com as imagens abaixo:

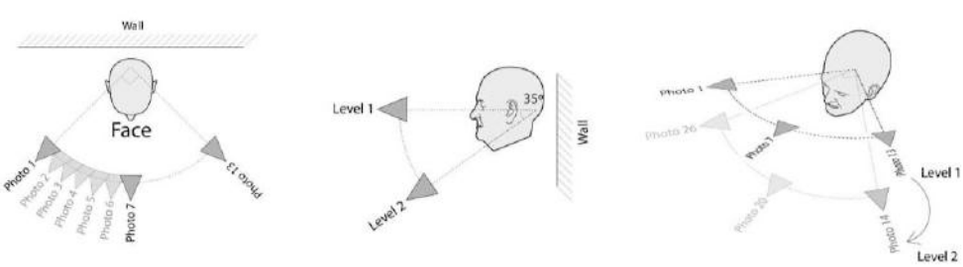

Figura 1. Tomadas Fotográficas. Fonte: Cícero Moraes, 2021.
http://www.ciceromoraes.com.br/doc/pt_br/OrtogOnBlender/Fotogrametria_Face.html

2.1.2 Geração do modelo 3D

Ao realizar as 26 fotos, seguindo as instruções descritas anteriormente, é preciso transformar todas essas imagens em um modelo tridimensional, para isso utilizamos a ferramenta digital: — *OrtogOnBlender — add-on (extensão, complemento ou plugin),* composto por uma série de scripts que utiliza ferramentas nativas e externas ao próprio *Blender*, com o intuito de adicionar funcionalidades e simplificar o uso de ferramentas complexas, como definem os próprios autores: "trata-se de um conjunto de comandos sequenciais que foram organizados e programados de modo a facilitar o planejamento de cirurgia ortognática" (MORAES et. al, 2016).

Sendo assim, o procedimento de fotogrametria no *OrtogOnBlender* é bastante simples, ao abrir a aba "*Photogrammetry Start*" e definir a pasta na qual as fotos estarão presentes, basta o usuário clicar no botão "*Start Photogrammetry!*". Os únicos parâmetros a serem ajustados são a escolha do sistema de fotogrametria (biblioteca) que será utilizado, por padrão a opção sugerida é o "OpenMVG+OpenMVS" (MORAES, 2020), o mais indicado para as fotogrametrias de face; e os demais parâmetros são os valores: "*D Factor:* 6" e "*Smooth Factor*: 16", que também não precisam ser alterados. Ao final dos cálculos de processamento, o modelo 3D é gerado.

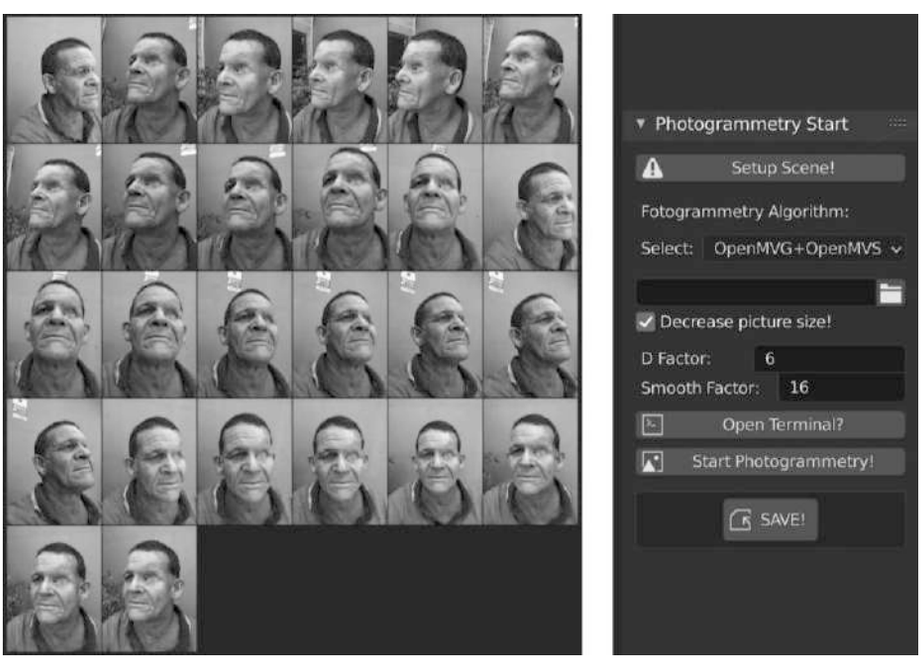

Figura 2. Fotos do Paciente e aba "Photogrammetry Start". Fonte: Autores, 2022.

2.2 Etapa 2 - Modelagem da Prótese

Após a geração do modelo tridimensional é possível iniciar a Etapa 2 - Modelagem da Prótese, que consiste na confecção do modelo digital da prótese. Para isso, utilizaremos ferramentas nativas do próprio Blender, como os modificadores *boolean* e *mirror*, para recortes e espelhamentos, e mais três modificadores pré-configurados: *smooth, multiresolution e displace,* para detalhamento da textura da pele. Como o paciente exemplificado apresenta a lesão na região ocular esquerda, usamos o lado íntegro como referência, sendo assim replicamos o lado direito espelhado utilizando os modificadores:

2.2.1 Espelhamento do lado íntegro

Criamos uma esfera na região do olho íntegro e aplicamos o modificador *boolean* de interseção, assim o volume onde face e a esfera estão em contato foi preservado e o restante da face foi excluído. Após o recorte da região de interesse, espelhamos o olho direito utilizando o modificador *mirror.*

2.2.2 Recorte do encaixe da prótese

Para que a prótese se encaixe perfeitamente na lesão da face é preciso fazer uma outra operação booleana, dessa vez uma operação booleana de diferença, para que a esfera ocular já espelhada seja recortada de acordo com a topologia da malha da face.

2.2.3 Detalhamento

Para aumentar os níveis de detalhes da prótese, os desenvolvedores do *OrtogOnBlender* pré-configuraram três modificadores no fluxo da modelagem: 1 - *smooth* - suaviza a malha; 2 - *multiresolution* - subdivide a malha sem alterar sua topologia (alto processamento); 3 - *displace* - cria relevo a partir da textura, ideal para enfatizar marcas de expressão da pele.

2.2.4 Escala

Para atribuir a escala real da face e da prótese é medido dois pontos na face do paciente na sessão fotográfica, esses pontos podem ser de um canto a outro dos olhos (na horizontal) ou do queixo para outro ponto entre as sobrancelhas (na vertical), a depender de qual seja a lesão do paciente. Após a geração do arquivo 3D da fotogrametria criamos um plano ligando esses dois pontos e atribuímos as medidas reais, após esse procedimento encontramos o fator de escala pretendido.

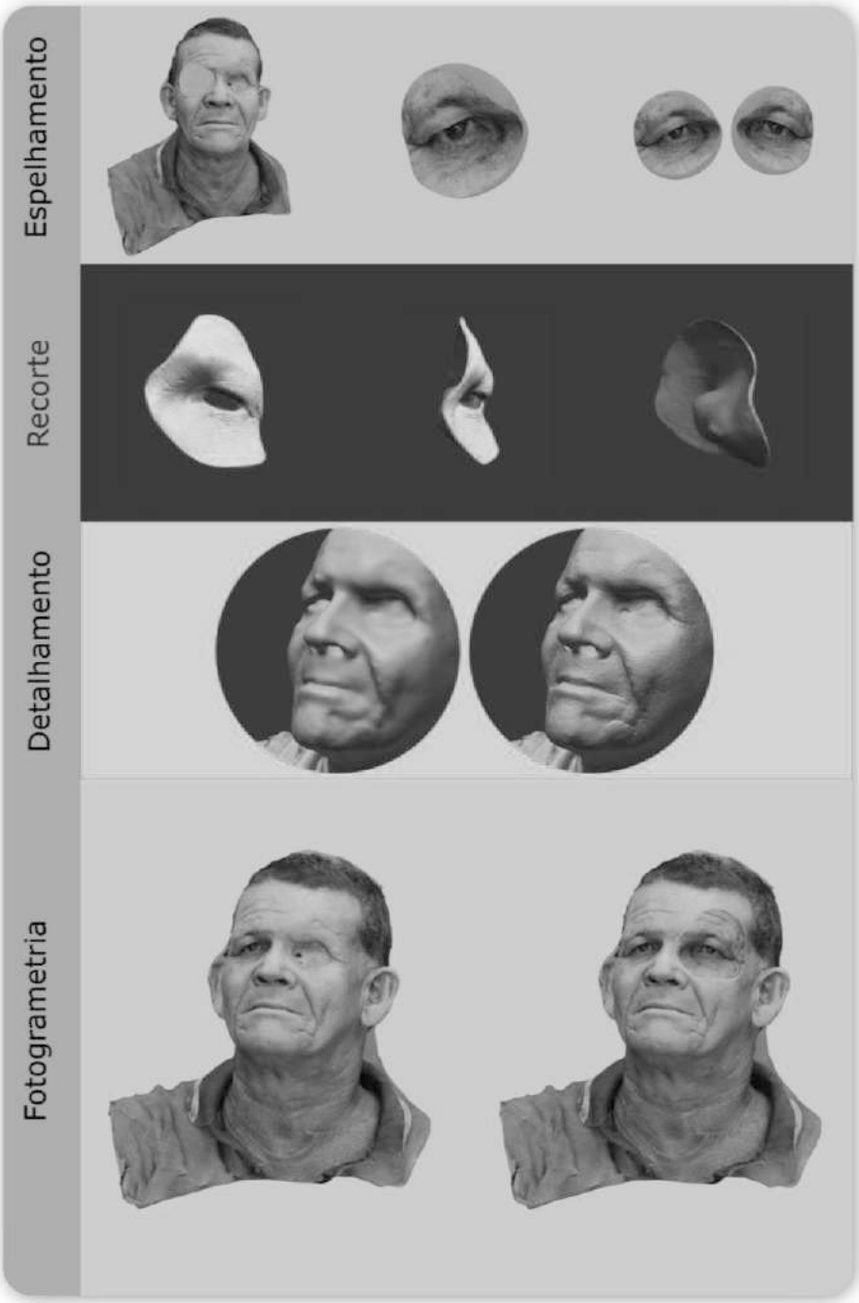

Figura 3. Espelhamento, Recorte, Detalhamento e Fotogrametria + Planejamento da Prótese. Fonte: Autores, 2022.

2.3 Etapa 3 - Impressão 3D

A etapa de impressão 3D da prótese e da referência de face é um processo bastante simples, não diverge de uma impressão comum de algum outro objeto qualquer, desta forma as tecnologias utilizadas foram: 1 — FDM — *Fused Deposition Modeling,* popularmente conhecida como impressão em filamento, na qual os objetos são impressos por uma extrusora de termoplástico**;** 2 — MSLA — *Masked Stereolithography Apparatus*, são as impressoras em resina mais acessíveis, neste tipo de tecnologia a resina é fotopolimerizada através da radiação UV expelida por um display LCD semelhante à tela de smartphone.

Após o salvamento dos arquivos tridimensionais no formato STL na Etapa 2 - Modelagem da Prótese, os modelos são fatiados em camadas nos softwares de fatiamento — CURA para impressão de filamento; CHITUBOX para impressão em resina — após o fatiamento em camadas de impressão os arquivos são salvos em formatos específicos para cada impressora para serem impressos de fato.

É importante ressaltar que as referências de face são impressas em filamento (FDM), pelo fato das impressoras FDM possuírem maiores áreas de impressão e por não haver a necessidade dos modelos em apresentar grandes detalhes como rugas e texturas de pele. No caso das próteses, são impressas em resina, pois a impressão em resina consegue ter uma maior resolução na impressão devido à altura de camada de 0.05 mm por padrão.

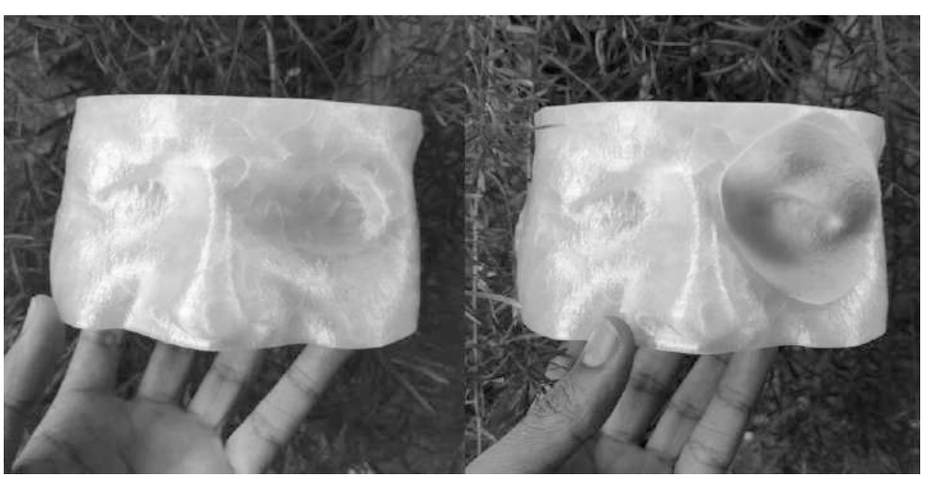

Figura 4. O modelo branco é a referência de face do paciente impressa em filamento (FDM) e a parte bege é a prótese impressa em resina (MSLA). Fonte: Autores, 2022.

2.4 Etapa 4 - Moldagem e Finalização

Esta etapa é o fluxo mais tradicional da confecção. A partir do modelo impresso é criado um molde em gesso para criar um novo modelo, dessa vez em silicone biocompatível, adequado ao uso do paciente. Também é nesta fase que são reforçados os detalhes de expressão, rugas e manchas de pele através da pintura.

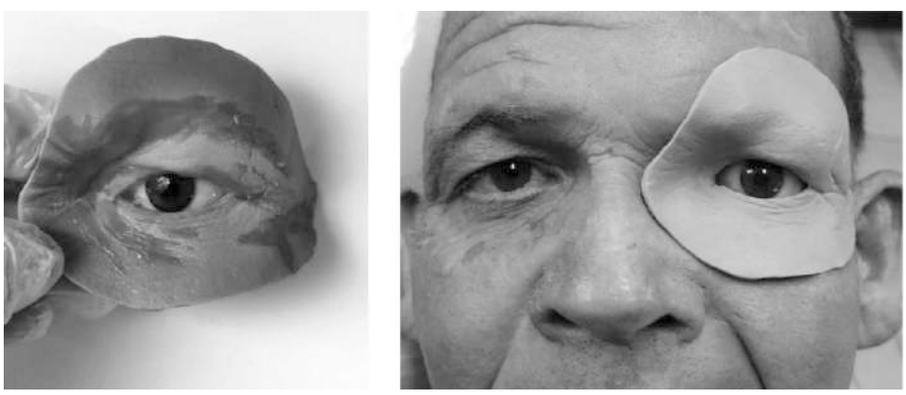

Figura 5. Processo de moldagem da peça. Fonte: Autores, 2022.

Por ora vale mencionar que alguns melhoramentos podem aperfeiçoar ainda mais o processo, como a utilização de outros softwares com recursos mais avançados, maior processamento gráfico permitindo uma maior subdivisão na malha de alta resolução e consequentemente mais detalhes na prótese e a impressão direta em material biocompatível que eliminaria a fase de moldagem do processo, seja em algum tipo de resina siliconada ou até mesmo em impressões de tecidos humanos, tecnologia que já está sendo aprimorada.

3 Resultados

Como resultado deste processo foi observado alguns aspectos positivos em utilizar ferramentas digitais no processo de fabricação das próteses, entre esses benefícios podemos destacar:

1 - **Abordagem menos invasiva:** a etapa da fotogrametria permite que seja capturada a referência da face somente a partir de fotos, sem que haja contato físico com o paciente, pois se esta etapa fosse feita a partir do método tradicional seria necessário tirar um molde de gesso da área lesionada.

2 - **Baixo custo de produção:** por utilizar computadores e smartphones comuns, impressoras 3D de entrada e softwares gratuitos.

3 - **Otimização no tempo de produção:** Por utilizar ferramentas de modelagem 3D digital como operações booleanas que permitem recortar partes já existentes na face como referência e *mirror* que permite espelhar o lado íntegro do paciente, o que possibilita uma maior praticidade e otimização do tempo de trabalho.

4 - **Maior definição de detalhes e proporções:** Por fazer cópias idênticas ao que já é existe é possível extrair marcas de expressões e proporções anatômicas com boa qualidade.

5 - **Documentação digital:** o fato das próteses serem arquivos digitais (formato STL) facilita a sua replicabilidade e logística substituindo os espaços em armários por memória computacional.

4 Discussão

Sobre os impactos sociais do trabalho, é notória a relevante contribuição que o campo do design e da fabricação digital podem oferecer à medicina, assim como o impacto positivo que esta junção, entre áreas de conhecimentos completamente distintas, pode oferecer em prol da sociedade.

Tais benefícios são percebidos a partir da melhora da qualidade de vida dos mais variados grupos de pessoas, seja através de produtos ou de serviços aprimorados. Entretanto, analisando sob a ótica inversa, esta interdisciplinaridade, contribui na área do design primordialmente na expansão da área de atuação do designer, e traz a esse profissional criativo uma compreensão maior sobre a demanda real de um grupo de pessoas com necessidades bem específicas — os pacientes — que talvez, se não houvesse essa imersão, o profissional de design não perceberia.

4.1 Comparação com trabalhos similares

Em relação aos trabalhos similares, propostos pelo Dr. Rodrigo Salazar Gamarra e pelo Designer Cícero Moraes, podemos notar muita similaridade no processo, com sutis diferenças, seja no software de fotogrametria utilizado, por ora o software 123D Catch (descontinuado) ou Recap 360, ambos da mesma empresa a Autodesk®, o que proporciona maior praticidade da etapa de fotogrametria por precisar de menos fotos, 3 tomadas de 5 fotos em ângulos distintos, para gerar o modelo tridimensional; ou por outros aspectos técnicos, como a atribuição de escala na fotogrametria de face, pois Cícero Moraes

desenvolveu um método de posicionamento e escalonamento automáticos, que utiliza uma *TAG* com um *QR Code* fixado em cima da face do paciente numa espécie de diadema, no qual o próprio *software* a partir da leitura deste *QR Code* consegue atribuir a escala e o posicionamento automaticamente.

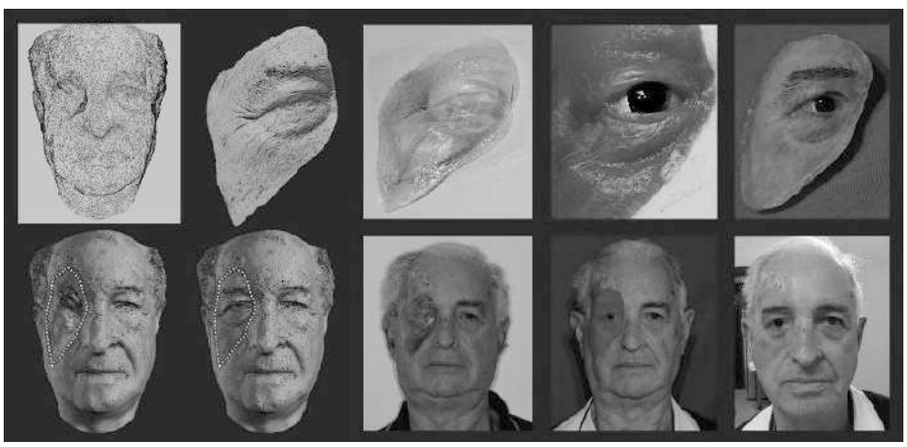

Figura 6. Prótese desenvolvida pela Equipe composta pelo Dr. Rodrigo Salazar e pelo Designer Cícero Moraes. Fonte: http://www.ciceromoraes.com.br/blog/?p=2613

Figura 7. Tiara com QR Code. Fonte: Cícero Moraes (2022)

Referências

Moraes, Cícero. (2016). OrtogOnBlender - O que é e Aspectos Técnicos. In OrtogOnBlender Documentação Oficial (primeira edição, pp 1-20) SINOP-MT. URL:https://www.researchgate.net/publication/337290937_OrtogOnBlender_-_Documentacao_Oficial

Moraes, Cícero; Salazar-Gamarra Rodrigo; Rosa, Everton L. S.; Seelaus, Rosemary; Silva, Jorge V. L.; Dib, Luciano Dib. (2020). Multiresolution and Displacement: Modifier Attribution to Enhance Realistic 3D Photogrammetry for Models of the Face. Biomedical Journal of Scientific & Technical Research. (V. 29, 5, pp 22812 - 22817). DOI: http://dx.doi.org/10.26717/BJSTR.2020.29.004864.

Moraes, Cicero; Kimura, Ricardo Nisioka; Bezzi, Luca; Bezzi, Alessandro. (2022). Fotogrametria com Limpeza de Pontos, Alinhamento e Redimensionamento Automáticos no OrtogOnBlender. In OrtogOnlineMag (v4, pp. 33 - 71). Figshare. DOI: https://doi.org/10.6084/m9.figshare.19450283

Salazar-Gamarra, Rodrigo; Seelaus, R.; da Silva, J.V.L; et al. (2016) Monoscopic photogrammetry to obtain 3D models by a mobile device: a method for making facial prostheses. Journal of Otolaryngol - Head & Neck Surg. (V. 45, 33, pp 1-13) DOI: https://doi.org/10.1186/s40463-016-0145-3

Salazar-Gamarra, Rodrigo. (2019). Introdução à Metodologia “Mais Identidade”: Próteses Faciais 3D com a utilização de tecnologias acessíveis para pacientes sobreviventes de câncer no rosto. In: E-book Comunicação Científica e Técnica em Odontologia. Ponta Grossa (pp. 251 - 272). Atena Editora. DOI:http://dx.doi.org/10.22533/at.ed.265192903

Salazar-Gamarra Rodrigo; Moraes, Cícero; Rosa, Everton L. S.; Seelaus, Rosemary; Silva, Jorge V. L.; Seignemartin; Crystianne, Oliveira, Joaquim P; Dib, Luciano Dib. (2016). Prótese facial humana de baixo custo com o auxílio de impressão 3D. URL: http://www.ciceromoraes.com.br/blog/?p=2613

Ludo/Faber Alumni: Playful Experiences of Digital Manufacturing for the Appropriation of Educational Spaces

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Abstract. The present study is inserted in the learning context of the Architecture career of 40 students in a course of Applied Digital Fabrication. It seeks to explore the design possibilities that are produced by permeating game design features with digital architectural design and digital fabrication with each other. What spatial design potentials appear when introducing and intermingling the notions of Homo Ludens and Homo Faber in architectural generative design systems?

Keywords: play, generative design, Shape Grammar, augmented reality, 3D printing

1 Introducción

El presente estudio se inserta en el contexto de aprendizaje de la carrera de Arquitectura de cuarenta estudiantes de segundo año, en un curso de Fabricación Digital Aplicada. Se busca explorar las posibilidades de diseño que se producen al hacer permear características del diseño de juegos con el diseño arquitectónico digital y fabricación digital entre sí. El puente entre campos surge al evidenciar los puntos en común que posee el diseño generativo, con el diseño de juegos como sistemas que se sustentan a partir de reglas y condiciones de interacción entre elementos. En este sentido, entendemos juego como sistema complejo (Zimmerman & Salen, 2004), que tanto en su concepción como en su uso promueve la aparición de dinámicas emergentes difíciles de predecir, pero con mecánicas subyacentes declaradas desde un inicio.

El objetivo de este artículo es indagar en resultados del trabajo con el concepto de juego como proceso y también como uso. Por un lado, se trata de introducir mecánicas y dinámicas de juegos en el proceso en sí de diseño generativo; y, por otro lado, como elementos a fabricar, se apunta a la creación de sistemas de piezas físicas —juego constructivo— que, al posicionarse en una zona común del campus de la casa de estudios, promueva la colaboración entre estudiantes y la sensación de apropiación del espacio.

1.1 *Homo ludens* y *Homo faber*

Es común que nos refiramos a nuestra especie con el término *homo sapiens*, donde el adjetivo *sapiens* se deriva del latín *sapientia*, que significa 'sabiduría'. Entonces, la principal característica del *Homo sapiens* es la habilidad de pensar y actuar usando como base la razón y el conocimiento. No obstante, en su libro *Creative evolution*, Bergson (1998) argumenta que deberíamos autodenominarnos *Homo faber* en lugar de *Homo sapiens*, pues nuestra propiedad fundamental es la capacidad de “fabricar objetos artificiales”. Por otro lado, en su libro *Homo ludens*, 'hombre que juega', Huizinga (1954) posiciona el juego en un aspecto relevante y como digno contendiente ante los otros dos conceptos predecesores. En el presente artículo, no se busca relevar una de aquellas ideas por encima de las otras, sino más bien establecer algunos nexos entre ellas que puedan ser de utilidad en el quehacer del estudiante de Arquitectura.

¿Qué potenciales de aprendizaje aparecen al introducir y entremezclar las nociones de *Homo ludens* y *Homo faber* en el contexto de estudios de Arquitectura? El concepto de *Homo faber* o humano fabricante hace alusión a nuestra habilidad de crear. Aprendemos haciendo, construyendo y creando formas rígidas y dinámicas. Esto entendido no solo desde una dimensión material, sino también psicosocial (imaginarios, crear historias, realidades) y el potencial de expresión creativa que el nexo entre la creación de lo tangible y lo intangible supone. A través de lo que creamos, llegamos a entender y modelar nuestro entorno no como un mero conjunto de objetos, sino como entidades en las que cohabitamos y en las que damos un sentido a la interconexión de las partes que lo componen, constituyendo un todo a nivel de artefactos y a nivel de las relaciones socioespaciales que los rodean y atraviesan.

Las conexiones entre arquitectura y tecnologías digitales, que inicialmente se remitieron al campo de la representación, y luego se ampliaron hacia los procesos de diseño (surgiendo campos como el diseño computacional, diseño paramétrico, diseño generativo, etc.), hoy en día presentan un amplio potencial de desarrollo para los procesos de fabricación (impresión 3D, CNC, Robots, Laser cut, etc.). De esta manera, los estudiantes de arquitectura se enfrentan a la opción-necesidad real de prototipar de manera rápida las ideas de forma, espacio y objeto que pueden especular.

El *Homo ludens* sitúa al juego como una función esencial que antecede a la cultura; más aún, señala que la cultura humana brota del juego y en él se desarrolla. Si bien desde el juego es posible desarrollar muchos tipos de aprendizaje (físico, social, cognitivo, emocional), es una acción que traspasa los límites de la ocupación biológica o física. Es una función con sentido en sí misma, que se desarrolla dentro de límites temporales y espaciales determinados, según reglas obligatorias, aunque libremente aceptadas (Huizinga, 1954).

Las prácticas lúdicas son algo que usualmente se ve en oposición al trabajo o a lo serio, producto de lo cual se puede malentender el juego como algo que se contrapone al aprendizaje. Sin embargo, existen varios puntos que nos pueden ayudar a posicionar al juego como un catalizador de aprendizaje. En el juego se aliviana el miedo al error o a la equivocación. Estamos jugando; por ende, lo podemos volver a intentar cuantas veces queramos. Y, considerando esto último, todo juego es un sistema de aprendizaje en sí mismo, ya que, en cada iteración, en cada reintento, llevamos consigo las habilidades adquiridas de las instancias de juego anteriores. Tomando en consideración lo anterior, en el contexto específico del curso implementado por los autores de este artículo, los estudiantes se encargan de designar reglas de diseño y también reglas de juego para el uso de piezas a fabricar, manteniendo un constante nexo entre diseño generativo y juego.

1.2 Diseño generativo

El diseño generativo se caracteriza por el uso de medios algorítmicos discretos para la exploración rápida de vastos espacios de diseño (Emdanat *et al.*, 1999) desplazando al diseñador desde un rol de dibujante hasta el de un ganadero, o criador de especies digitales (De Landa, 2002). Contando con varias décadas de desarrollo y los más diversos métodos, poseen como aspectos fundamentales la capacidad de embeber comportamientos en sus soluciones (Stiny & Gips, 1972) y ofrecer cierto espesor o integridad, de modo que el todo sea más que la suma de sus partes (Alexander, 2009). Para introducir a este modo de diseñar de forma temprana, se revisaron distintos sistemas generativos clásicos en el aula, como Shape Grammar (Stiny & Gips, 1972), agentes tipo Boids (Reynolds, 1987) y autómatas celulares (Conway, 1970; Wolfram, 2002).

1.3 Gamificación en arquitectura

Gamificación es el uso de estrategias, mecánicas y elementos propios de los juegos en contextos ajenos a estos, con el propósito de transmitir mensajes, cambiar comportamientos, propiciar la motivación o activar el aprendizaje. Algunos autores (Ekim, 2020; Savov, 2016; Schnabel, Lo & Aydin, 2014; Redondo *et al.*, 2020), en investigaciones recientes, han logrado aplicar gamificación en el contexto académico de arquitectura con resultados interesantes en cuanto a la evaluación de la motivación a la participación en la resolución de problemas de diseño complejos.

2 Metodología

La metodología empleada utiliza una investigación básica que comprende un análisis bibliográfico del juego como concepto y una posterior investigación aplicada en el marco del curso teórico universitario dictado por los autores. Esto último implica el desarrollo iterativo de diseño y testeo de prototipos.

2.1 Conceptualización del juego

Se utilizan dos bases conceptuales para operar en el diseño con foco en la realización de juegos: el *framework* MDA y las categorías de juegos. MDA significa mecánicas, dinámicas y estéticas, en idioma inglés. Estos tres conceptos se sitúan como un puente que comunica al autor o autores del juego con los eventuales jugadores. Las mecánicas describen las reglas de juego, entendidas como componentes que contienen algoritmos y procesan *inputs*. Las dinámicas son el conjunto de interacciones que aparecen cuando los jugadores actúan según las mecánicas, y las estéticas definen las respuestas conductuales y emocionales que se espera despertar en los jugadores (Hunicke *et al*., 2004).

En estudios sobre el tema se han descrito en un comienzo cuatro categorías para los juegos: *agon*, *alea*, *ilinx* y *mimicry* (Caillois, 1961). A estas luego se les une recientemente una quinta llamada *peripatos* (Mandoki, 2008).

- *Agon* (competencia). Juegos que representan una lucha de dos o más participantes, enfrentados en condiciones ideales. Este tipo de juegos requiere entrenamiento, disciplina y perseverancia.
- *Alea* (suerte). En esta categoría se busca ser favorecido por el destino o el azar.
- *Mimicry* (simulacro). Jugar al “como si”, creer o hacer creer a los demás de ser algo distinto.
- *Ilinx* (vértigo). Acciones en que se apunta a remecer por un momento la percepción y de infligir a la conciencia lúcida un estado de alerta.
- *Peripatos* (explorar). Juegos de explorar, descubrir, recorrer un entorno.

Entendiendo el MDA como herramienta y las tipologías de juego, los estudiantes plantean un objetivo de actividad a diseñar. Luego, en el proceso de diseño enfocado en la fabricación, se revisan diferentes referentes desde la naturaleza como inspiración. Se apunta a un diseño *bottom-up*, desde la concepción de una pieza que se pueda propagar, que contenga un sistema de uniones. A través de diferentes iteraciones de diseño análogo y digital, basadas en Shape Grammar, los estudiantes definen reglas que interrelacionan secciones de la geometría de la pieza base para lograr una propagación de la misma en diferentes direcciones del espacio.

2.2 Aspectos de desarrollo del diseño

Para concretar los diseños se recurrió a procesos de modelado paramétrico con *software* de diseño 3D. Posteriormente, se realizaron prototipos con impresión 3D. Para visualizar en el espacio físico las propagaciones propuestas por los estudiantes se utilizó realidad aumentada.

Tabla 1. Aspectos metodológicos del diseño digital

Aspecto	Definición	Instrumento específico
Modelado	Secuencia congruente de insumos y productos numéricos, la que en su conjunto establece distintos estados de concreción de un modelo geométrico.	Se expresa a través de programación en Grasshopper, de Rhinoceros.
Impresión 3D FDM	Modelación por disposición de material fluido, en forma de capas apiladas de forma sucesiva para crear un volumen.	Se expresa a través de generación de ruta de impresión (Cura slicer) y físicamente en impresora FDM Ender 3 V2.0
Realidad	Montaje a tiempo y escala real de modelos geométricos digitales en una escena de contexto físico real.	Se expresa a través de la herramienta Spark AR e Instagram.

2.3 Roles y retroalimentación del trabajo

El carácter complejo del juego constructivo fue abordado a través de la especialización de los miembros del grupo, haciéndolos responsables de los diversos flancos de desarrollo (tabla 2). Es de espacial relevancia resaltar el carácter iterativo del proceso de diseño, realizando varias versiones de sus proyectos, avanzando siempre desde la retroalimentación entre prototipos digitales (RA) y prototipos físicos (3D). Esta escisión del desarrollo establece una secuencia, y demanda retroalimentaciones de diverso tipo: cercanas en esta secuencia y a través de todo el quehacer del proyecto (figura 1). En cuanto a proceso de diseño aplicando gamificación, la asignación de roles considera una visión no competitiva, sino de juego colaborativo. Es decir, un grupo de estudiantes con un objetivo común general, con roles complementarios entre sí, que a su vez cuentan con metas específicas que requieren una constante sinergia (Rocha *et al*., 2008).

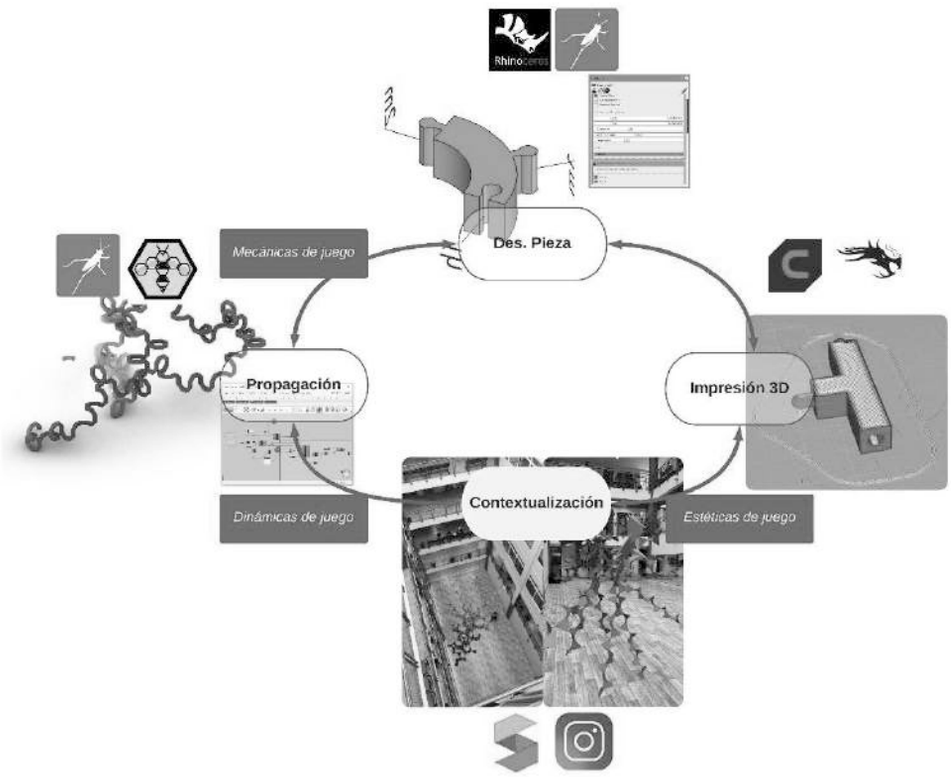

Figura 1. Comunicación entre roles del proyecto

Tabla 2. Roles por estudiante para el desarrollo de los proyectos

Rol de estudiante	Descripción	Técnicas empleadas	Aspectos a considerar
Diseño de pieza base	Desarrollo de modelación 3D de pieza del sistema.	Modelado 3D usando Rhinoceros y Grasshopper.	Escala y morfología de la pieza. Mecánicas de juego.
Desarrollo de propagación	Implementación de reglas de propagación.	Definición de programación visual de propagación usando Grasshopper y WASP. Aplicación de Shape Grammar.	Direcciones de propagación según reglas de vinculación geométrica. Espacialidad generada. Mecánicas y dinámicas de juego.
Encargado de impresión 3D	Impresión de piezas a escala. Evaluación y monitoreo de resultados. Levantamiento de errores para mejora de siguientes prototipos.	Fabricación digital aditiva. Prototipos a escala.	Definición de impresión. Control de proceso. Patrón de *infill*, peso, soportes de impresión. Estética de juego.

Visualización de contextualización	Evaluación y testeo de prototipos digitales en realidad aumentada a través del campus de estudio.	Fotomontajes. Testeos de visualización utilizando realidad aumentada. SparkAR.	Relación con el entorno. Elementos relevantes de contexto. Dinámica y estética de juego.

2.4 Desarrollo de piezas

Componente que posee las relaciones y la geometría que define lugar y tipo de acoplamiento. Se relaciona directamente con la propagación, en cuanto establecer el espacio de diseño de las posibles propagaciones. Además, se relaciona directamente con impresión, en cuanto a establecer tiempos y calidades al introducir o no conocimiento de fabricación con FDM.

2.5 Propagación

La propagación es el proceso de agregar piezas dados ciertos planos en cada pieza e instrucciones o reglas que establecen la posibilidad de acople. Para llevar a cabo este proceso se utilizó el plugin WASP (Rossi, 2021). Estas reglas fueron heredadas de observaciones y la creación de un Shape Grammar primitivo; no obstante, el diálogo entre la herramienta de propagación, las capacidades de la pieza y las propagaciones resultantes establecieron modificaciones. Se relaciona directamente con la pieza, en cuanto a que están en ella embebidas las reglas de propagación.

2.6 Contextualización

La contextualización es el proceso de emplazamiento de la propagación. Como tal, el encargado posee una relación ubicua con el grupo, proponiendo desde el carácter del proyecto formas de emplazamiento (posicionamiento, anclaje, etc.), velando por aspectos de escalamiento material, relación con técnicas de fabricación terminales, etc.

3 Resultados

Se concretaron siete proyectos grupales de estudiantes, explorando diferentes mecánicas y dinámicas de juego, de los cuales se seleccionan tres para analizar.

3.1 Proyecto A: cubiformaciones gamificadas

Mobiliario de juego armable, concebido de plástico reciclado.

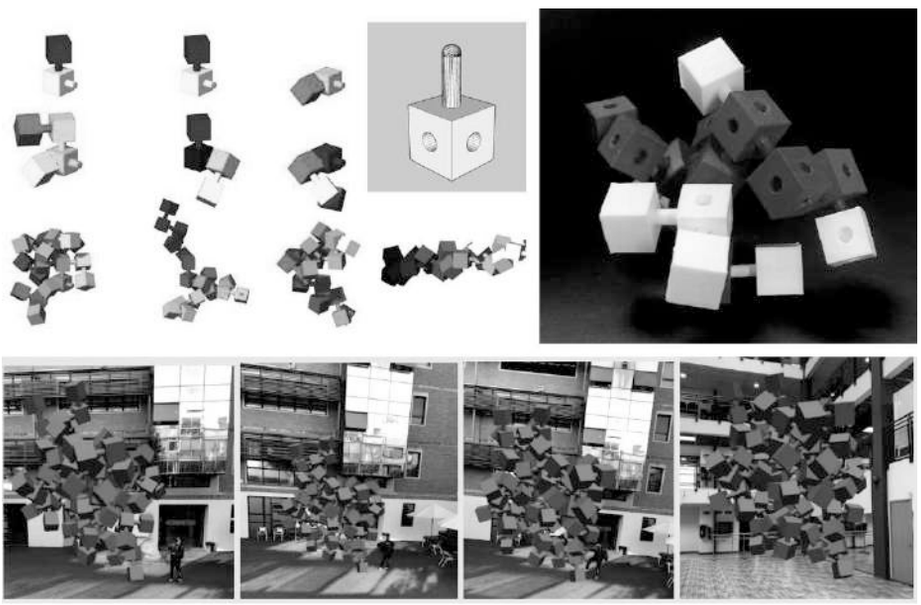

Figura 2. Cubiformaciones gamificadas

Tabla 3. Procesos del proyecto cubiformaciones gamificadas

Proceso/rol	Resultados	MDA	Categorías de juego
Pieza base	Componente único consistente de un cubo con tres cavidades o juntas hembras y un vástago o junta macho, el cual posee un largo mayor que la profundidad de las cavidades, de modo de poder mantener una distancia y así variar la densidad volumétrica de las formaciones a producir. La junta macho es lisa y cilíndrica, permitiendo una rotación modulada.	Mecánicas: conexión, construcción de patrones, cooperación, destreza. Dinámicas: juego libre. Representación de formas y figuras. Emergencia. Estética: expresión.	*Ilinix*, *peripatos*
Propagación	La propagación se basa tanto en la existencia de tres hembras perpendiculares a una junta macho con capacidad de rotación discreta. La conjugación de ambas características dotó de tendencia al giro de 90° y 45° de forma alterna. La extensión del macho logra patrones de densidad media y heterogénea.		
Impresión 3D	Se optó por producir grupos impresos con la junta macho apuntando hacia arriba, teniendo la base ciega de cada pieza directamente contra la superficie de impresión.		

Contexto	Espacios intermedios o públicos. Escala manipulable con relación al cuerpo humano.

3.2 Proyecto B: propagación natural-recreativa

Juego urbano ensamblable con escala de piezas de 50 cm de diámetro.

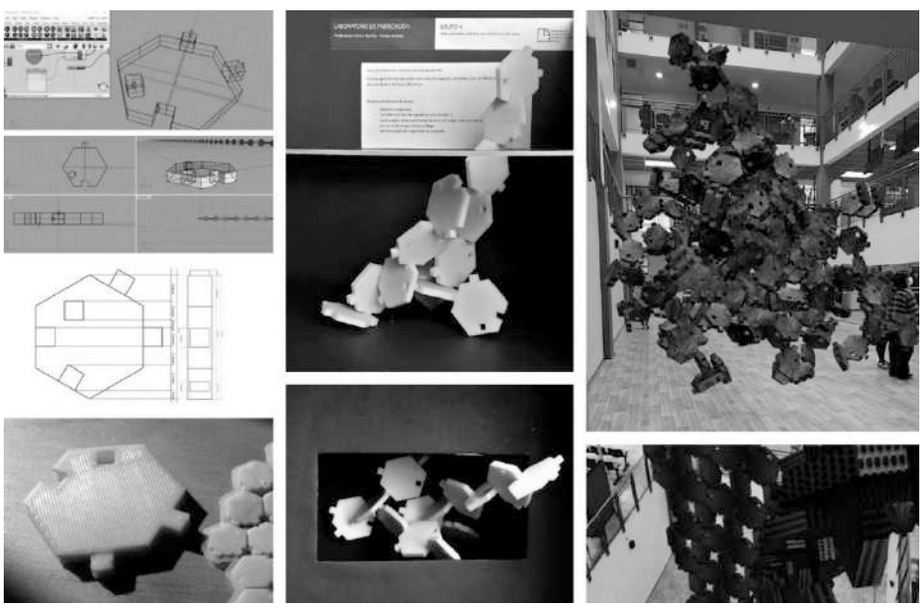

Figura 3. Propagación natural-recreativa

Tabla 4. Procesos del proyecto Propagación natural-recreativa

Proceso/Rol	Resultados	MDA	Categorías de juego
Pieza base	Componentes hexagonales planos, los que poseen limitadas locaciones de juntas macho (dos adyacentes) y hembra: una opuesta y otra forzando el giro de la pieza, procurando a la vez simplicidad y variaciones diversas.	Mecánicas: trepar, juego físico, carreras. Dinámicas: competencia. Estética: desafío.	*Ilinx*, *agon*
Propagación	Las juntas establecen tanto regularidad de la propagación como un componente reorientador y caótico, en donde las sucesiones de componentes hexagonales son redirigidas por interrupciones tipo meseta.		
Impresión 3D	La impresión 3D de estos prototipos fue simple, ya que no presentaron zonas tipo voladizo. Fabricación ideal de estas piezas pudo ser corte láser de acrílico.		

Contexto	Zona *indoor* o *outdoor* con suficiente altura libre. Requiere apoyos a muro y refuerzos a suelo.

3.3 Proyecto C: deja tu rastro

Juego *indoor* y *outdoor* capaz de rellenar el espacio cartesiano y conectar múltiples niveles con piezas que establecen una trama permeable.

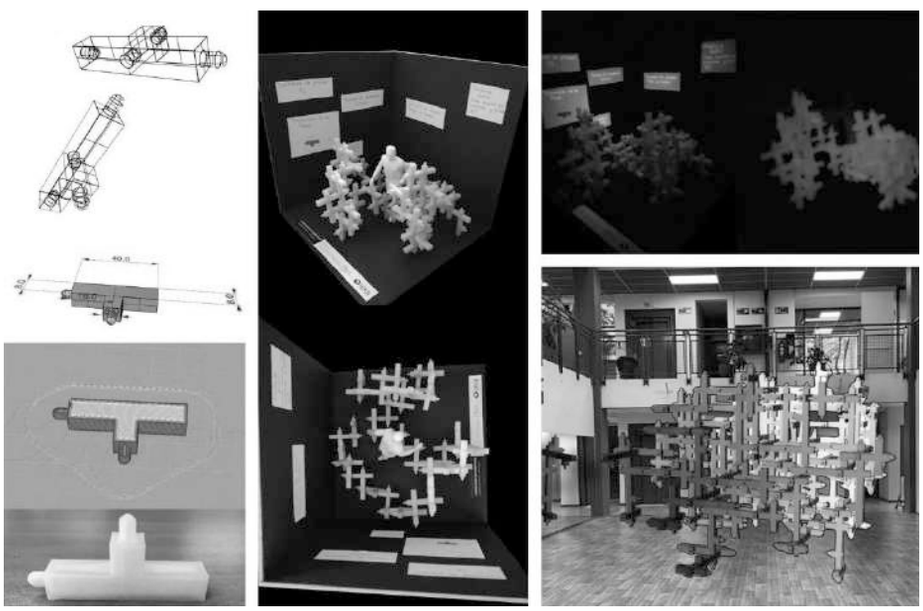

Figura 4. Deja tu rastro

Tabla 5. Procesos del proyecto Deja tu rastro

Proceso/rol	Resultados	MDA	Categorías de juego
Pieza base	Piezas conformadas por un tramo largo de 1 m y otro perpendicular y centrado al mismo de 0.5 m, formando un componente con la silueta de una letra “T”, con dos hembras y dos machos localizados de forma alternada, con un macho en el extremo corto y en la base conformada por el extremo largo.	Mecánicas: conectar, reconocimiento de patrones, límite de tiempo, destreza, *storytelling*. Esconderse. Construir.	*Peripatos*, *agon, mimicry*.
Propagación	Las juntas tienden a crear relaciones de tramas tipo *lattice* genéricas, las cuales, debido a procesos de acumulación, crean situaciones volumétricas, tales como recorridos, espacios autocontenidos.		

Impresión 3D	La impresión 3D de estos prototipos presenta pequeños voladizos dados los machos de los extremos, en donde se procuró la existencia de soportes.	Dinámicas: relación entre niveles. Colaboración. Estética: descubrimiento.
Contexto	Patio interior de edificio de salas. Relación con niveles y con la luz ambiental.	

4 Discusión

Si bien se logra una exploración amplia en cuanto a variabilidad de propagaciones, los proyectos llegan a geometrías de pieza base sencillas, sin tomar riesgos ni explorar formas complejas. Esto puede deberse a la combinación de una serie de factores (alta complejidad de integración de pasos y *softwares*, nivel de desarrollo y conocimiento, limitaciones de trabajar con Shape Grammar, entre otros).

La complementariedad entre prototipos digitales y físicos es relevante. Al observar el comportamiento de sus proyectos en realidad aumentada y en primera persona, los estudiantes pudieron hacer ajustes rápidos en sus diseños y, a su vez, mejorar las piezas que fabricaron a escala. Además de la revisión de prototipos físicos y digitales, se solicitó a los estudiantes entregar textos, como memoria de sus proyectos. Esto es de utilidad como material para una futura evaluación etnográfica de los resultados de aprendizaje y la efectividad de gamificar el proceso de diseño de los equipos de estudiantes (tabla 6).

Tabla 6. Algunos fragmentos de testimonios de estudiantes

Tema	Testimonio de estudiante
Impresión de prototipos	Los prototipos impresos servían de ayuda para explorar las distintas maneras en que era posible ensamblar una propagación. Esta debía cumplir tanto con las reglas como con los objetivos, lo que significaba que las piezas, las reglas y la propagación debían trabajar en conjunto.
Modelación de piezas	*Además de aprender a usar la aplicación correctamente para modelarla, primeramente, se debe partir de un boceto. La propagación tiene que llevarse a cabo siguiendo leyes escritas, debemos decidir cómo se unirán las piezas para tener cierto control de cómo se verán cuando estén ensambladas, en este caso comenzamos con escoger y enumerar cada unión.*
Juego como programa de uso	*Nuestro proyecto abarca un área donde las personas puedan diseñar su espacio de juego en las plazas, parques e incluso en los campus de universidades. Mediante el diseño digital, buscamos resolver diversas opciones de juego que pueden ser implementados a pequeña y gran escala, mediante una serie de piezas de fácil transporte y montaje.*
Propagación de piezas	*El hecho de que la propagación sea en 3D está netamente relacionado al juego propuesto. Con relación a esto, fue necesario diseñar detalladamente*

las juntas. Cualquier fallo en ellas provocaría que el sistema se desarme o que simplemente no pueda armarse. Por esto, el desarrollo del proyecto requirió en todo momento máxima atención al detalle para llegar al resultado final con éxito. Las propagaciones que se presentan son solo unos ejemplos de lo que se puede llegar a hacer con las piezas.

Referencias

Bergson, H. (1998). *Creative evolution. 1911. Trans. Arthur Mitchell*. Dover.

Caillois, R. (1961). *Man, Play, and Games*.

Conway, J. (1970). Game of Life. *Scientific American*.

De Landa, M. (2002). Deleuze and the Use of the Genetic Algorithm in Architecture. *Architectural Design*, *71*(7), 9-12.

Huizinga, J. (1954). *Homo Ludens*.

Hunicke, R., LeBlanc, M. & Zubek, R. (julio de 2004). MDA: A formal Approach to Game Design and Game Research. *Proceedings of the AAAI Workshop on Challenges in Game AI*, *4*(1), 1722.

Mandoki, K. (2008). *Estética cotidiana y juegos de la cultura: Prosaica I* (Vol. 1). Siglo XXI.

Redondo, E., Fonseca, D., Sánchez-Sepúlveda, M., Zapata, H., Navarro, I., Gimenez, L. & Pérez, M. A. (julio de 2020). Edugame4city. A gamification for architecture students. Viability study applied to urban design. En P. Zaphiris & A. Ioannou (Eds.), *International Conference on Human-Computer Interaction* (pp. 296-314). Springer, Cham.

Reynolds, C. W. (1987). Flocks, Herds, and Schools: A Distributed Behavioral Model. *Computer Graphics*, *21*(4), 25-34.

Rocha, J. B., Mascarenhas, S. & Prada, R. (2008). Game mechanics for cooperative games. En N. Zagalo & R. Prada (Eds.), *ZON Digital Games 2008*, 72-80.

Savov, A., Buckton, B. & Tessmann, O. (2016). *20,000 Blocks: Can gameplay be used to guide non-expert groups in creating architecture?*

Schnabel, M. A., Lo, T. T. & Aydin, S. (2014). Gamification and rule based design strategies in architecture education. En *DesignEd Asia Conference*.

Stiny, G. & Gips, J. (1972). Shape grammars and the generative specification of painting and sculpture. *Information Processing 71 Proceedings of the IFIP Congress 1971*, *2*(71), 1460-1465.

Tekinbas, K. S. & Zimmerman, E. (2003). *Rules of Play: Game Design Fundamentals*. MIT press.

Tibbits, S. & Tomas, A. F. (2013). Biomolecular, Chiral and Irregular Self-assemblies. En S. Tibbits y A. Falvello, *ACADIA 2013: Adaptive Architecture - Proceedings of the 33rd Annual Conference of the Association for Computer Aided Design in Architecture* (pp. 261-268).

Light Transmittance Ceramic Design-Computation with Robotics

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Abstract. Building envelope design incorporates a range of light-related analyses, often providing an essential feedback loop for shaping an envelope's performance, geometry, or components. This is true for solar radiation studies of envelopes, calculated irrespective of building material or assembly. Extending our light-related analysis to include diffuse lighting effects on a building interior presents an opportunity to explore the translucency, porosity, and forms of materials. Glazed architectural ceramic components fabricated using adaptive robotic manufacturing provide an opportunity to exploit material dynamics within the design and alleviate fabrication waste from molds, ultimately accelerating the production manufacturing system. In addition to analyzing the solar radiation on the building facade design, lighting effects can be engaged in profoundly different ways depending on the degree of design-production agency. The production process can be extended beyond automatic routines using robotic fabrication with levels of autonomous involvement that allow for alternative form expressions of the dynamic clay material. In addition to negotiating several design criteria, the design research will develop an aesthetic character originating from customized clay materials and robotic manufacturing processes for lighting transmittance architectural ceramics.

Keywords: Robotics Fabrication, Light Transmittance, Architectural Ceramics, Cellular Automata Algorithm, Material Malleability.

1 Introduction

Ceramics carries a wide range of transmittance and deformation potentials for robotics control with the research of its material property. We experiment with architectural clay, as the material of the product that is potentially translucent at a certain stage can respond to light. Studying the relationship between form, material properties, and porosity can help create different interior and exterior light effects and provide architectural product solutions for specific architectural functions. To ensure the ceramic product reach the expected transmittance level, research questions such as: what is the best clay material that can potentially carry the translucency characters? How to

control translucent effects in a ceramic screen? How to accurately map the translucent perforation to the overall form and the individual form of porcelain ceramic parts will be discussed with experiments from digital simulations to robot physical prototype manufacturing.

The research develops a system from design-computation to hardware toolkit through an experiment with the robotic approach to formative material processes. The lighting transmittance architectural ceramics will exhibit bespoke character that is integral to developing manufacturing and design-computation methodologies together, which also considers production effect and efficiency. Our objectives are to investigate the relationship between different clay bodies or ceramics' physio-material properties and their transmittance; to design the hardware toolkit in robotic fabrication to achieve precise lighting effect; to optimize the sufficient robot behaviors for different stages of deformation.

When operating various end effectors in robotics control, the deformation will be able to manipulate the amount of lighting that passes through. We can precisely manipulate the lighting effects by adjusting the robotics control behavior. The foam bead bedding system ensures the deformation to decrease clay thickness with typography variations to create the submarine reef's skin texture. Moreover, CA ruled perforation design with the perforating end effector provide openness for direct lighting passing through. The workflow investigates the light-transmitting effects of robotically perforated ceramic façade components. This paper presents one lighting transmittance design-to-fabrication system that engages with material research, hardware kit design, design-computation experiments.

2 Context

Existing lighting-related design-research are mainly driven by digital solar radiation simulations tools. When Gutiérrez & Wanner (2016) proposed the design methodologies, they explored the materiality of clay by collaborating with renowned ceramicists and artists. Providing real-time optimization of form-finding is one aspect of testing the compatibility and interoperability of different software and design techniques. The full-scale ceramic products are fabricated by digital modelling and slip casting fabrication methodology. In his paper, he presents a production method developed along with construction and analytical data.

Clay material lighting transmittance was discussed in Ketchum's research article. Unlike what was previously assumed, translucency and thickness have an exponential relationship. In the presence of constant porcelain content, an increase in feldspar at the expense of flint results in a higher translucency. This research presents two directions to achieve clay material transmittance if one engages with physical clay deformation and composition. In Stylized Robotics clay sculpting (Ma et al.,2021), designers have developed traditional techniques for creating stylized cultural creations, such as the use of six-axis

robot arms to fabricate stylized cultures. Additionally, an algorithm was used to mimic brushstrokes of oil painting, allowing them to generate toolpaths for creating the styled cultures.

3 Robotic Training Methods

This paper shows the training process of the façade autonomous construction system. It includes the study of material transmittance, the study of robotic arm path behavior and transmittance, and tool fabrication.

3.1 Material Transmittance

The experiment for identifying clay body lighting transmittance, including stoneware, earthenware, and porcelain, has been testified forehead.

Stoneware

Earthware

Porcelain

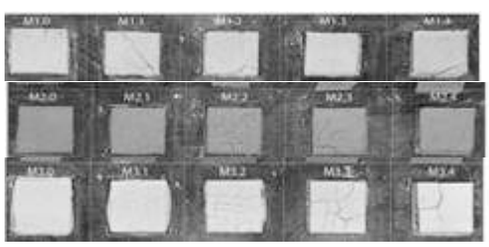


Figure 1. Clay Body Transmittance Test

All samples are 3” x 3” square (Figure 1), and the thickness varies from 1mm to 5 mm. And all samples were placed in a dark room with the same brightness light source at the bottom and a light sensor at the top to capture the luminosity. The results showed that the samples numbered M3.0, M3.1, M3.2, M3.3, M3.4 showed luminosity effect.

Thickness (mm)	Tile to Lighting Source Distance (cm)	Color Variation
5mm	0.5 0.8 1.1 1.5	
4mm		
3mm		

Figure 2. Baked Porcelain Transparency Effect

Understanding that lighting could come from two perspectives: Material Transmittance property itself or creating porosity. The research started with playing with wet clay sheets. By manually manipulating the clay topography by carving, perforating, pressing, and semi-ring, the actions or behaviors can create more action marks on the surface and experience various lighting interfaces: angled lighting tunnels or straight poke holes. This study leaves many specific directions to explore (Figure 1). End effector, clay humidity, and robotics control behaviors can all impact the clay topography, the associated lighting effect, and the amount of lighting passing through.

Under the same quantities research method, another experiment among different baked porcelain samples revealed the desired lighting transmittance expectation. The intensity of transmittance and lighting color has a clear relationship between tiles' thickness, brightness, and the distance between the lighting source and tile surface: the further the distance is, the more separated and the loose the lighting effect. The thicker the tile is, the warmer the lighting color will be. (Figure 2)

3.2 Tooling study

This experiment explored that the light transmission of baked clay was negatively correlated with thickness. Although porcelain is opaque in its unbaked state, the ideal light transmission of clay after baking can still be achieved by finding a relationship between the depth of pressing and the thickness of the clay sheet.

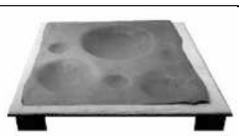
Name	Times	Deformation Result	Force Analysis
Crater Bending System	5 times in each points		The overall force is not uniform, and fractures are likely to occur at the interface between the porcelain clay tile and the base.
Lollipop Bending System	5 times in each points		Overall, the force situation is good, the form is largely intact, and there are unevenly stressed interfaces in places with large deformation.
Rolling Bending System	5 times in each points		The overall force is good, but during the drying process, there are some problems with the shrinkage of the porcelain clay tiles, resulting in cracks at the junction of the clay tiles and the rolling.

Fig.3 Bedding result test and result

By using the same end effector and squeezing down it the same number of times, we tested the stresses on these three bedding systems, as well as the

richness of clay deformation. The final base was chosen based on its best stress and variation. (Figure 3)

During the late stage of the experiment, both the "Rolling bedding system" and "Crater Bedding system" produced severe cracks, which may be the result of water loss and shrinkage in the porcelain clay pieces limited by the base. Furthermore, both systems exhibit very homogeneous deformation, which makes it challenging to produce a façade with rich thickness variation. Therefore, we chose irregular spheres as the base. (Fig.4)

Fig.4 Final Choice—Transformable Foam Beans Bedding System

3.3 Robotic path and Transmittance

This experiment tested the correlation between the extrusion height and light transmission of the ABB 120 robotic arm when using the Transformable Foam Beans Bedding System. As well as the force limits of the porcelain clay under compression by the robot arm.

Fig.5 Progressive Pressing Robot Control Behavior

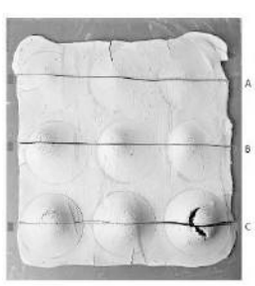


Fig.6 Plan View

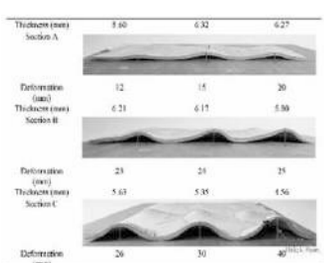


Fig.7 Relationship of Clay Deformation and Robot Pressing Times and Depth

The ABB 120 robotic arm pressed a ceramic sheet with a thickness of 10 mm (Figure 5), with the depth gradually increasing from 12 mm to 40 mm. As the pressing depth increased, the thickness of the ceramic piece decreased from 8.60 mm to 4.56 mm, and when the pressing depth reached 40 mm, the ceramic piece fractured, which indicates that this is the limit of the pressing depth. It shows that this is the limit of its pressing depth. (Figures 6,7)

4 Robotics Manufacturing System Workflow

The purpose of machine involvement in manufacturing decisions is to make the building façade part of the structural, aesthetic and modulating interior light environment and to provide designers with the opportunity to incorporate material behavior as a process driver into their design workflow. Use material behavior as a process driver in the design workflow. Once the system is trained and correlations between fabrication parameters and extruded sculpted geometry are established, it can switch back and forth between these two sets of data and the system can build a structurally sound, evenly lit façade based on the light requirements of the site.

The system uses the Penn Collection as an example to demonstrate the process of machine involvement in the fabrication of the façade system, including inputting the light requirements of the target space, translating the light requirements into the form of the façade, performing structural simulation of the façade, and making real-time decisions on the location and number of openings by the machine through sensors during the construction process. (Fig. 8).

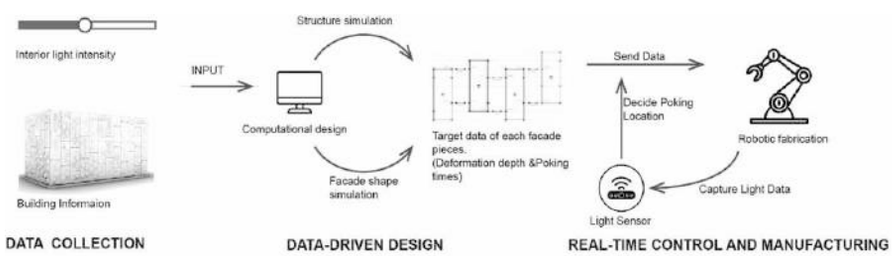


Fig.8 Robotic Manufacturing System Workflow

4.1 Global Structural Analysis Driven Pattern Generation

In the system of force analysis simulation of the facade, the combination of the extrusion experimental data and the facade generation system ensures the stability of the facade structure in the extrusion process and reduces the waste of porcelain clay. Using the mechanical analysis software Karamba 3D, the study first calculates the forces exerted on the panels of the façade, where wind load and self-weight are the main types of external forces, whereas the connection points between the panels and the main structure of the building and between the panels are the points of restraint. Based on the calculation results, red and blue areas correspond to strong tensile and compressive forces, while white represents uniform forces. Perforations will undermine the structural performance of the panel, so we opted to distribute the deformation mainly at locations where the panel is highly stressed (i.e., red, or blue areas) and distribute the perforations at locations where there are even stress distribution as white areas.

At a technical level, random points are first generated in the rectangular border of the panel, and then the color mesh generated by the Karama 3D force calculation is used to provide color data for each point in the same location. The program calculates the radius of the deformation circle of the points automatically based on the RGB value of the mesh vertex. A circle whose color is closest to blue or red has a larger radius, while vice versa, a circle whose color is further from blue or red has a smaller radius, as shown in Fig.9.

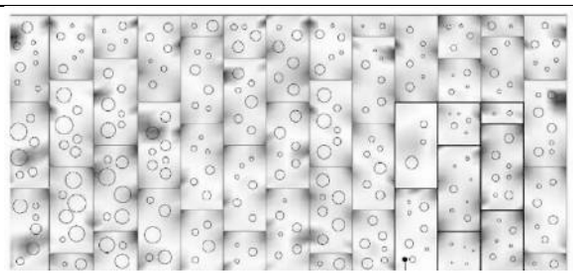
Computation	Deformation sign process
Load Force Blue: Tension Red: Compression	

Fig.9 Relocation Circles According

4.2 Cellular Automata Algorithm for Perforation

The cellular Automata algorithm determines the angular distribution, orientation, and distribution of the hole. In python, each dot represents holes with a diameter of 5 mm. Each point is a class instance with information about the three types of holes we define, which are stored as an instance property called state. In each iteration, the type of the hole changes its type according to the number of types of its neighbours. If the current state is 0 and the number of holes with state 2 is less than a certain number, the state of the instance changes to 2. The three types of holes change cyclically and are finally distributed evenly on each panel. (Fig.10)

```
#Get sums of neighbor states
For i in range(len(neigh)):
     s = neigh[1].state
     if s==0: n0+=1
     if s==1: n1+=1
     if s==1: n2+=1
     n +=1
     total +=s
aver = total/n
if  self.state  ==  0  and
n2<30: self.state =2
elif  self.state  ==  1  and
n2<30: self.state =0
elif  self.state  ==  2  and
n2<30: self.state =1
```

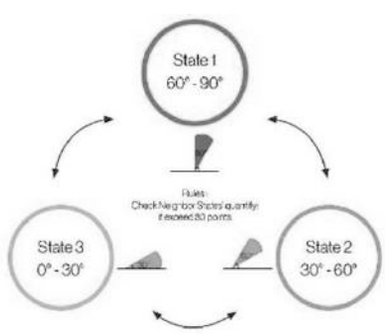


Fig.10 CA State for Perforated Angle

With a hypothesis program set up, an input usage with a gradient grayscale to represent different lighting requirements programs was generated. Different CA rules were applied to different regions of black, gray, and white, so that points located in different color regions were subjected to different scales of gravitational and repulsive forces from different neighbor types, thus affecting their behavior during motion and the final pattern formed, as shown in Figure 11.

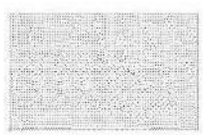
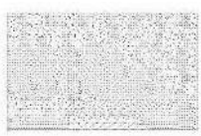
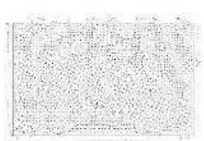
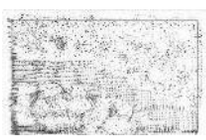
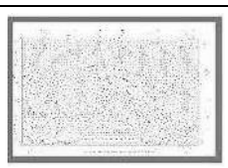
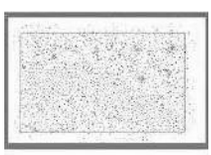
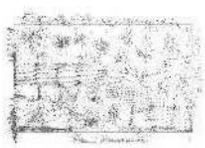
Input image	Time	CA Rules and input Grid					
		Neighbor Range. Attr 1000 Repel300	Gray: 3* Rl 2* A	Neighbor Range. Attr 1000 Repel300	Gray: 3* R 2* A	Neighbor Range. Attr 1800 Repel1800	Gray: 6* R 8* A
Black: more light		Black: 1* R 0* A	White: 3* R 0.6 A	Black: 6* R 2* A	White 3* R 0* A	Black: 8* R 2* A	White: 1* R 0.6*A
Grey: Mid-level light	1						
White: Minimal light	2						
	3						

Fig.11 Lighting Transmittance Analysis for CA Rule

Take the first column as an example, for all points, the points within 1m from the point have gravitational force on the point, and the neighbors within 300 mm have repulsive force on it.

If the point is currently in the black area, the gravitational coefficient is 2 and the repulsive force is 1; if it is in the grey area, the gravitational coefficient is 2 and the repulsive force is 3; if it is in the white area, the gravitational coefficient is 0.6 and the repulsive force is 3. Images 1-3 in Fig.13 represent the calculation results of the distribution corresponding to different iterations and the orientation of the hole in the direction of the combined force of the surrounding neighbors on the point The orientation of the hole in the direction of the joint force of the surrounding neighbors on the point.

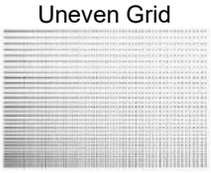
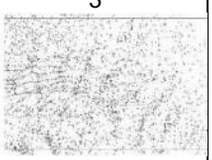
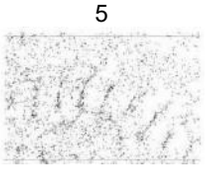
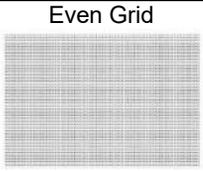
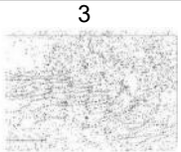
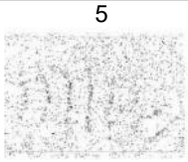
Input Image	CA Rules		
	Black Area Force: Repel 20 Attraction 2 Vector: Repel 2 Attraction 0	Gray Area 8 2 -1 2	White Area: 4 2 -1 [0,0,0]
Input Grid	Iterations		
Uneven Grid 	3 	5 	
Even Grid 	3 	5 	

Fig.12 Perforation Grids and Iterations

In addition, we also try to add the influence of global variables to make the starting grid produce a gradient effect with different distances, as shown in Figure 15.

4.3 Data-driven Manufacturing Workflow

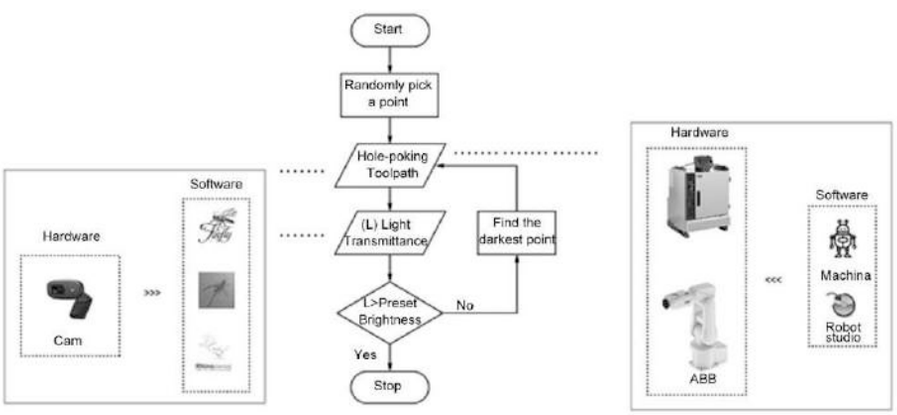


Fig.13 Real-time control process

In order to respond to the influence of solar radiation received by the building façade: since the building façade shows a high to low value of solar radiation from the upper right to the lower left, the distribution of holes follows a gradual increase from the upper right to the lower left The trend is to add more direct light to the poorly lit areas (shown in Figure 12).

First a set of predefined hole information, including location, orientation, and angle, is generated from the interior lighting requirements during the computational design phase. In the first round of poking a hole, the system will randomly pick one from the list of predefined holes and poke a hole in the clay. Then, the robot will return to its origin point. Meanwhile, the system will acquire images from the camera and then find the darkest point and the nearest predefined hole as the next poking location. At the end of each round of hole poking, the system will check whether the light data reaches the target value for indoor lighting. If yes, the system will stop, if not, it will continue to find the darkest location and poke. (Fig.14)

The system uses computer vision technology to find the darkest location for the next poke tool path, which can create an even and consistent light on each ceramic panel.

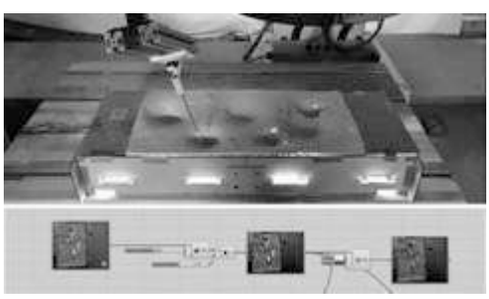


Fig.14 Real-time control computer vision and manufacturing process.

5 Experiment Result and Discussion

The key idea is to maximize the utilization of in-progress robotics fabrication and ceramics materiality to create a highly integrated manufacturing workflow for lighting product design and manufacture. The subsequent digital fabrication will enable the deformation and sculpting to reach all parts of complex panelized geometry and allow for the variable material thickness that can be controlled from each target point forehead. To distribute geometry variations, a computational design approach is employed within the prototype facade, and a robotic construction technique is also introduced: joining leading research in highly bespoke digital robotic fabrication. The design- research proposes handles more than just supporting bespoke transmittance outcomes; it also orchestrates custom manufacturing processes that offer designers greater material engagements, where design aspects can be positioned within material formation processes.

6 Future Use

The natural environment has good physiological and psychological healing effects (Zhang & Xu, 2020). At the level of physiological health, the natural environment helps to prevent chronic diseases (Knight et al., 2010) and enhance the physiological health of the group (Qin et al., 2013) at the level of psychological health, the natural environment can effectively repair attention (Bratman et al., 2015), relieve stress, and improve bad mood and mental fatigue. Especially sunlight, as an important natural factor, the strength of sunlight and the angle of sunlight are very important for treating psychological diseases and regulating the mood of users.

Therefore, creating different kinds of light can make buildings into different types of healing or immersive spaces (Figure 15, 16). In the future, it will become important to create architectural product with different light environments depending on the character of the users and the function of the space.

Fig.15 Ceramic prototype texture

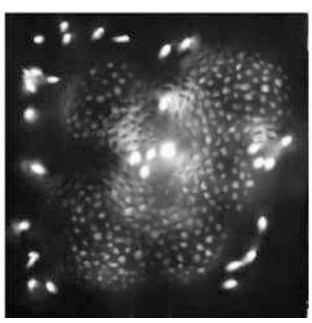


Fig.16 Ceramic light transmittance.

References

Gutiérrez, R. U., & Wanner, A. (2016). Innovations in the production of ceramic luminous environments: Where craftsman meets computer. Informes de la Construcción, 68(544). https://doi.org/10.3989/IC-15-167-M15

Ma, Z., Duenser, S., Schumacher, C., Rust, R., Bächer, M., Gramazio, F., Kohler, M., & Coros, S. (2021, August). Stylized robotic clay sculpting. Computers & Graphics, 98, 150–164. https://doi.org/10.1016/j.cag.2021.05.008

Zhang Zhen, &; Xu Lei-qing. (2020). The Healing Benefits and Application of the Virtual Natural Environment. South Architecture, 34–40. 10.3969/j.issn.1000-0232.2020.04.034

Knight, T. M., Bowler, D. E., Buyung-Ali, L. M., Knight, T., & Pullin, A. S. (2010). A systematic review of evidence for the added benefits to health of exposure to natural environments. BMC Public Health, 10, 456. https://doi.org/10.1186/1471-2458-10-456

Qin, J., Zhou, X., Sun, C., Leng, H., & Lian, Z. (2013). Influence of green spaces on environmental satisfaction and physiological status of urban residents. Urban Forestry & Urban Greening, 12, 490-497. https://doi.org/10.1016/j.ufug.2013.05.005

Bratman, G.N., Daily, G.C., Levy, B.J., & Gross, J.J. (2015). The benefits of nature experience: Improved affect and cognition. Landscape and Urban Planning, 138, 41-50. http://dx.doi.org/10.1016/%20j.landurbplan.2015.02.005.

Manufacturing & Industry 4.0: Internet of Things

Home automation: experiment with a water monitoring device.

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Abstract. This paper presents the results of research that aims to integrate environmental sensors and BIM authoring platforms to monitor and predict water consumption in a residential environment. It also aims to establish strategies to promote sustainable and conscious consumption to the user, in addition to facilitating the operation and maintenance process. Thus, it contributes to an intelligent building, which has this name due to the monitoring of parameters and the collection of data from the internal environment. Therefore, this study presents a prototype for monitoring residential water consumption, being an exploratory and experimental research. The method is based on the association of different digital tools, prototyping boards and sensors to provide the integration of the real building with a digital replica. The prototype was tested in a residential toilet to collect data and evaluate the integration between the tools, indicating through the consumption indication with visual responses based on colors.

Keywords: Internet of things, Computational tools, Automated environment, Interoperability, Digital Twin

1 Introdução

A redução do impacto ambiental com o auxílio de tecnologias na construção civil, atualmente, é importante para a eficiência dos recursos e para o desempenho das construções durante o ciclo de vida (Aste et al., 2016).

Na edificação, além da qualidade construída e da ambiental, a condição das instalações também influencia no bem-estar dos usuários (Lai & Yik, 2011). Visto que atua diretamente em relação à operação e à gestão, em

serviços, tais como: limpeza, reparação e manutenção, característica da fase do pós-obra.

Visando à previsão de possíveis problemas de projeto e corrigi-los ainda na fase de simulação, um Gêmeo Digital é construído com base em dados da realidade, espelhando a edificação, sendo necessário desenvolver uma estrutura bem definida e organizada. Esse sistema deve adquirir, integrar, analisar, simular e sincronizar informações, continuamente, durante os estágios do ciclo de vida da edificação (Lee et al., 2020).

Para isso, esta pesquisa envolve diferentes sistemas e tipos de dados, os quais geram uma base heterogênea, originados e mantidos por sensores, onde a comunicação é efetuada por rede *wireless* (Lu et al., 2019). Espera-se que as estratégias resultem em um protótipo de dispositivo para o monitoramento do consumo de água, que permita a replicabilidade na residência, colocando parte do processo nas mãos dos usuários, como uma maneira de apoiar o consumo consciente dos equipamentos sanitários.

1.1 Gêmeo Digital no contexto da construção civil

O ciclo de vida das edificações envolve as fases: de produção, construção, uso e o fim da vida (*EN 15978:2011 — Sustainability of construction works - Assessment of environmental performance of buildings — Calculation method.*, 2011). Sendo assim, o *Facility Management* contribui para a gestão na construção civil influente no desempenho da edificação.

Este termo, relacionado à sétima dimensão da metodologia BIM (Modelagem da Informação da Construção), é uma representação virtual tridimensional da edificação física com o compartilhamento de informações e eficiência na colaboração entre os profissionais da Arquitetura e Construção (AEC) (IFMA, 2013). Envolve diversas disciplinas, visando à melhoria na funcionalidade do ambiente construído, àquele que integre pessoas, lugares, processos e tecnologia (Aziz et al., 2016).

Porém, os modelos BIM podem ser considerados estáticos e, atualmente, há uma oportunidade de sincronizá-los com outras fontes de informação, tais como sensores sem fio e sistemas de automação predial, tornando-se capaz de aprender e atualizar em tempo real ativos físicos da AEC (Lu et al., 2019). Essas réplicas digitais de edificações chamam-se Gêmeos Digitais (*Digital Twins*), o conceito teve origem na NASA (*National Aeronautics and Space Administration*) e tem: uma simulação do modelo físico, a qual integra e armazena informações por meio da mineração de dados - processo para encontrar padrões em dados -. Com essas informações, é possível recomendar mudanças para aumentar a probabilidade de sucesso na missão espacial (Shafto et al., 2012).

O paradigma de Gêmeos Digitais expandiu-se para além do setor aeroespacial, em outras indústrias como o da manufatura e, recentemente, o da AEC, aplicado em contextos de cidades e edificações mais inteligentes (Lu et al., 2019). Estas têm essa denominação pela coleta de dados do ambiente interno por meio de IoT (*Internet of Things*), *Wi-fi*, WSN (*Wireless Sensor*

Network), 5G, LP-WAN (*Low-power wide-area network*) e câmeras de vigilância (Deng et al., 2021). Promove uma conexão bidirecional à construção digital e à real, atualizando, instantaneamente, o *status* da edificação no modelo simulado (Lu et al., 2019).

A partir deles, é possível realizar monitoramento em tempo real, previsão de desempenho e melhorias estratégicas (Deng et al., 2021). Porém, o controle do desempenho da edificação ainda está em expansão na indústria da construção, visto que edifícios convencionais, muitas vezes, não foram projetados pensando no impacto que poderiam incorrer no meio ambiente. Somado a questões globais, há o aumento da demanda de consumo e do desperdício pelo usuário.

1.2 Demanda da água e perspectivas para o uso sustentável

Conforme a ONU, o consumo de água recomendado é de 110 litros por habitante/dia, enquanto o consumo médio do brasileiro é de 154 litros por habitante/dia (Breda, 2019).

Atualmente, o monitoramento hidrológico residencial indicado pela companhia de água e saneamento do Estado de Santa Catarina (CASAN), sugere a leitura periódica do hidrômetro e cálculos para a compreensão do consumo médio diário (Casan, 2022). Além dos programas de conscientização no Brasil, aconselhando algumas atitudes como a diminuição do tempo de banho, escovar os dentes com a torneira fechada e a reutilização de água da máquina de lavar roupa para limpezas gerais, maneiras de controlar o desperdício e de incentivar um consumo consciente de água.

Tais medidas, não proporcionam uma relação de causa-efeito para o consumo dos equipamentos hidrossanitários, não havendo um retorno do processo de uso e o usuário não tem consciência do seu consumo pessoal na residência, visto que apenas 5% dos consumidores brasileiros são designados como conscientes (Akatu, 2007).

Com isso, a fim de reduzir o desperdício de água, em Botsuana, por exemplo, foi desenvolvido um estudo sobre o monitoramento da qualidade da água fornecendo resultados em tempo real de maneira proativa sobre a contaminação deste recurso. Na China, foi desenvolvido um mecanismo de monitoramento de água online baseado em *ZigBee* e GPRS - sistemas de comunicação de redes sem fio (Ramya et al., 2011) - possibilitando uma infraestrutura de baixo custo e fácil de construir. Há, também, estudos que abordam a inteligência computacional para prever o consumo doméstico de água, por meio de redes neurais artificiais (RNAs), as quais estimam em função de fatores econômicos e climáticos (Cutore et al., 2008).

2 Metodologia

O estudo pode ser considerado aplicado com caráter exploratório e empírico, baseando-se em diferentes estratégias computacionais coletar e analisar dados de modo a estimular a criação de modelos que podem ser atualizados e modificados em tempo real.

Durante este processo, uma base de dados sobre consumo de água foi obtida a partir de sensoriamento remoto para compor aspectos que viabilizem a avaliação de questões relacionadas ao ambiente construído residencial. O processo de pesquisa baseou-se na associação de diferentes ferramentas digitais, placa de prototipagem digital e sensor para proporcionar a integração da edificação real por meio de um Gêmeo Digital.

A metodologia estrutura-se em cinco estágios: (1) compreensão da problemática do desperdício de água na residência e como a implantação de Gêmeos Digitais contribui para o aspecto de desempenho da edificação; (2) realização da primeira medição por uma placa de prototipagem eletrônica, para a obtenção de dados vindos do ambiente; (3) uso da plataforma *Blynk.io* para armazenamento dos dados em nuvem e disponibilização via URLs (4) uso do ambiente de desenvolvimento *Processing* para processamento dos dados brutos e disponibilização em tempo real via arquivo CSV; (5) uso dos *softwares* BIM *Autodesk Revit Architecture* e *VisualARQ* para a modelagem e recepção dos dados; do *Rhinoceros/Grasshopper* com programação visual e realização de processos de computação automatizados, extraindo informações do sensor para alimentar o protótipo digital. O sistema foi testado em um ponto de água de um banheiro residencial, visando coletar dados preliminares e avaliar a integração entre as diferentes ferramentas (figura 1).

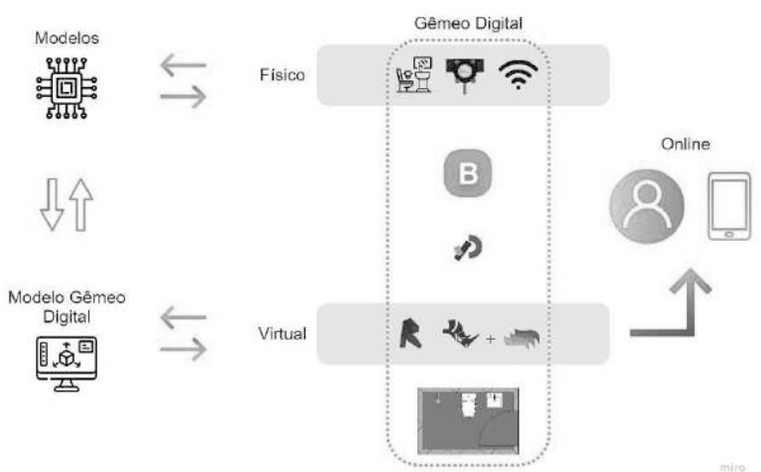

Figura 1. Diagrama da implantação do Gêmeo Digital. Fonte: Autores, 2022.

2.1 Etapa 01: Desenvolvimento do protótipo e a disponibilização dos dados brutos

A fim de proporcionar a interoperabilidade de informações entre os dispositivos físicos hidrossanitários e o modelo da construção, constituindo um gêmeo digital, foi necessário, primeiramente, desenvolver um protótipo de monitoramento de água para coletar os dados brutos de consumo e enviá-los em tempo real para o modelo digital da construção. Dessa forma, foram utilizados como *hardware* para constituir o protótipo uma plataforma de *Internet* das coisas com módulo *Wi-fi (NodeMCU),* a qual recebe e envia dados a partir de um *chip* ESP8266, é um sensor de fluxo de água de 1/2 polegada.

A placa da plataforma de IoT foi programada a partir do ambiente de desenvolvimento *Arduino*. Os dados coletados pelo sensor foram salvos de modo que cada registro apresenta-se: um identificador, data e hora de consumo, volume e tempo de consumo. A partir destes, é possível calcular a vazão média da peça monitorada (torneira) e inferir outros padrões de uso (figura 2). Para evitar a necessidade de manter a placa de prototipagem eletrônica ligada ao computador, esta foi conectada à rede de energia e à rede local de *Internet* da residência, permitindo enviar a coleta para uma plataforma em nuvem voltada à criação de soluções para a Internet das coisas (*Blynk.io*).

Inicialmente, o *Blynk.io* foi selecionado pela possibilidade de transmitir os dados em tempo real para um arquivo CSV (*comma separated values*), porém houve dificuldade de realizar esta operação. Como resultado, optou-se por utilizar os *links* de URL disponibilizados pelo próprio ambiente (figura 3). Neles, os valores coletados são atualizados automaticamente, o que possibilita a interoperabilidade com outra plataforma (*Processing ide*).

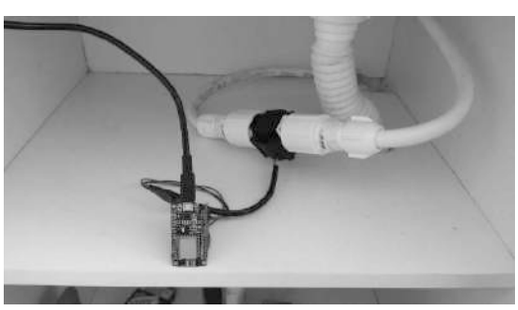

Figura 2. Instalação do sensor de fluxo de água e placa de prototipagem eletrônica instalado no ponto de água. Fonte: Autores, 2022.

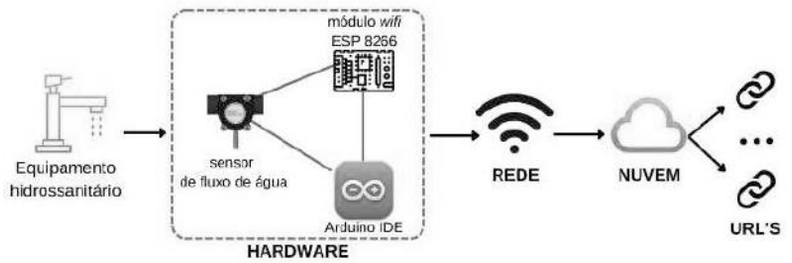

Figura 3. *Framework* da primeira etapa. Fonte: Autores, 2022.

2.2 Etapa 02: Uso do *software Processing* e a disponibilização em tempo real via arquivo CSV

Visando tratar os dados brutos transmitidos a partir da plataforma *Blynk.io*, estes foram coletados por meio da utilização do ambiente de desenvolvimento *Processing*. Neste, foi calculada a vazão média do ponto de água para cada utilização realizada pelo usuário. Além disso, foram definidos outros parâmetros para identificação de cada acionamento da torneira, tais como: um identificador, dia e hora de acionamento. Estas informações foram transmitidas a um arquivo CSV salvo em um serviço de armazenamento e sincronização de arquivos. A opção, por disponibilizar o arquivo em uma plataforma de computação em nuvem, possibilitou que os diferentes participantes da pesquisa tivessem acesso ao conjunto de informações remotamente. A figura 4 mostra um trecho do arquivo CSV, um exemplo dos dados salvos, e a interface do ambiente de desenvolvimento do *Processing*.

Além de possibilitar a exportação dos dados em CSV, a utilização do ambiente *Processing* trará outros benefícios em etapas futuras da pesquisa. Esta linguagem de programação e plataforma de desenvolvido integrado tornou-se uma ferramenta difundida e com inúmeras bibliotecas que permitem o tratamento de dados a partir de técnicas estatísticas e estratégias de visualização de dados. Outro aspecto importante é sua integração com o ambiente de modelagem paramétrica *Grasshopper* e seu modo que possibilita a criação de aplicativos para *smartphone*. Este último recurso possibilita a criação de aplicativos que podem retornar informações sobre o consumo de água de uma residência para o próprio usuário.

Figura 4. (1) Ambiente de desenvolvimento *Processing*; (2) Dados coletados em arquivo CSV. Fonte: Autores, 2022.

2.3 Etapa 03: Compatibilização do modelo na interface digital

Para a integração do ambiente real com o digital, dois modelos foram desenvolvidos em ferramentas computacionais distintas com o intuito de se interpretar os possíveis resultados disponibilizados por cada uma das "interfaces". Assim, um ambiente semelhante ao real foi modelado em dois *softwares* BIM, *Autodesk Revit* (Autodesk, 2022) e *Rhinoceros* 3D (McNeel, 2022), utilizando o *plug-in VisualARQ* (Asuni, 2022) e testar diferentes aplicações e diálogos que podem ser desenvolvidos entre os dispositivos digitais e o real.

Dentro de cada *software*, busca-se facilitar a interação com os dados virtualizados da realidade, empregando recursos informativos e visuais para a representação dos consumos. Tais dados são integrados aos ambientes e interpretados, de modo que possam ser transformados em informações visuais, por números e sinais visuais baseados em cores (verde, azul e vermelho).

2.4 Integração com o *Revit*

O software BIM *Autodesk Revit* 2021 foi utilizado como ferramenta para a modelagem do espaço, sendo monitorado o controle das características e propriedades que refletem o ambiente doméstico. Utilizou-se também, o *Grasshopper* como plataforma de "interface" entre os dados registrados e o modelo digital. Os recursos de *scripting* em linguagem *Python*, nativo da ferramenta, são empregados para importar o banco de dados CSV, sua extração e transformação em informações úteis. Por meio do *plug-in Rhino.Inside Revit* ® (McNeel, 2022), as instâncias de famílias existentes no *Revit* são conectadas ao *Grasshopper*, onde seus parâmetros podem ser selecionados e os valores originais alterados para corresponder aos dados reais de consumo (figura 5). A interoperabilidade de ferramentas permite a conexão contínua e o *stream* de dados em tempo real, permitindo o uso do modelo como meio de registro, verificação e interação para sensibilização sobre o consumo de água.

A “interface” de informações do modelo ocorre de duas formas: (1) A exibição de valores sobre o consumo por uso, empregando identificadores dos valores atribuídos a esses parâmetros da instância; e (2) a representação desses valores frente às métricas esperadas para consumo, avisando ao usuário por cores no próprio modelo, o valor abaixo do esperado (verde), dentro de uma variação média (azul) e acima do limite (vermelho).

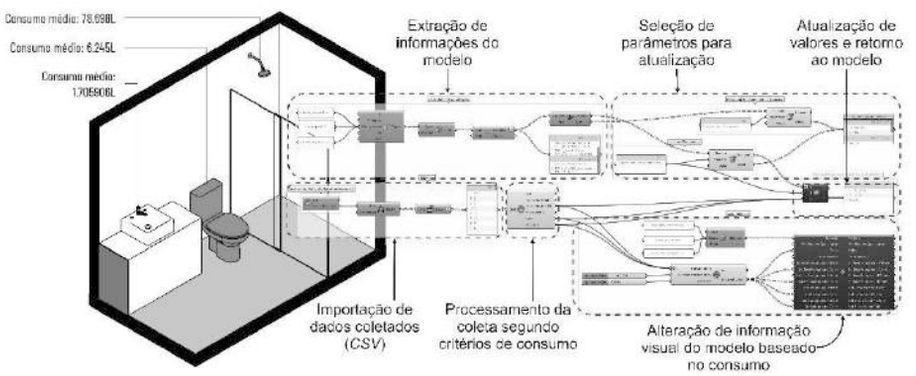

Figura 5. Sinais visuais do modelo digital desenvolvidos com os componentes do *Revit* integrados ao *Grasshopper*. Fonte: Autores, 2022.

2.5 Integração com o *VisualArq*

Para a aproximação do ambiente real no programa *Rhinoceros 3D* (Mcneel, 2014), o *plug-in VisualARQ* (Asuni, 2022) foi utilizado em duas interfaces, diretamente como ferramenta de modelagem tridimensional e como programação visual no *Grasshopper*. Sendo que, em um primeiro momento, seu uso permitiu a modelagem digital do ambiente, recriando as divisórias verticais e horizontais e adicionando componentes IFC que representam peças de instalação hidráulica reais, como pia, torneira, vaso sanitário e chuveiro. E, em um segundo momento, através da programação visual dentro do *Grasshopper*, utilizando os componentes do *VisualARQ*, para representar os dados coletados do sensor e armazená-los nas famílias do modelo digital, visualizando no *Rhinoceros 3D 7*.

Para a coleta de dados do ambiente físico, o componente *Colibri*, do *TT Toolbox* (Tomasetti, 2017) foi utilizado, possibilitando coletar e ler os dados gerados e armazenados pelo sensor. As informações lidas são organizadas e somadas, possibilitando que a numeração possa ser transformada e encaminhada para o modelo digital desenvolvido no *Rhinoceros*. Assim, é possível observar a mudança de consumo do ambiente real diretamente no virtual, além do que os padrões de cores, desenvolvidos em RGB, ainda podem ser retransmitidos para o ambiente real, apresentando o seu rendimento (figura 6).

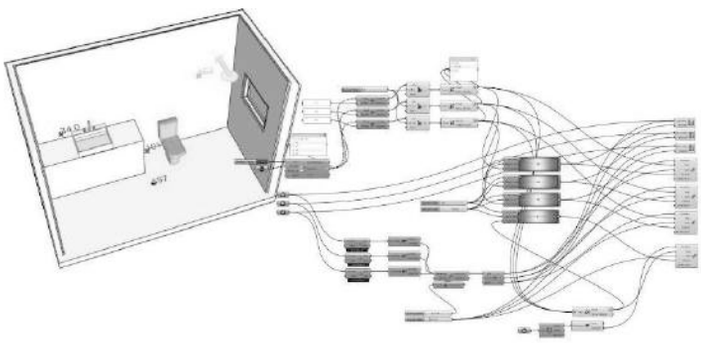

Figura 6. Sinais visuais do modelo digital desenvolvidos com os componentes do *VisualARQ* na interface do *Grasshopper*. Fonte: Autores, 2022.

Para potencializar a utilização do leitor e testar mais possibilidades na "interface" do *Grasshopper*, uma equação simplificada foi utilizada, permitindo que o resultado coletado pelo sensor se transforme em outros dois números fictícios. Contudo, a escolha dos padrões de cores e limites numéricos foram fundamentadas na pesquisa Barreto (2008), que atribui um consumo médio de 29 litros de água por dia, para torneira de lavatórios. Esse número foi multiplicado por 31 — representando uma média mensal —, para obter um intervalo numérico de 1 a 899 que organiza as cores da programação. Esses quantitativos foram utilizados para se verificar o funcionamento do padrão de cores proposto, conferindo se, ao aumentar o nível de consumo, as cores iriam alterar, ilustrando assim, o padrão de consumo do ambiente. Com o aumento de resultados, também foi possível fazer uma somatória que pode ser visualizada no centro do cômodo, simulando o consumo total dos equipamentos do ambiente. O desenvolvimento do diálogo entre o ambiente real e o virtual, por uma plataforma de modelagem paramétrica, propiciou uma gama de alterações visuais, como cores tamanhos e posições. Uma amostra dessa interação entre as informações do sensor do ambiente real que alimentaram protótipo digital, são apresentadas na figura 6, que demonstra o ambiente, os equipamentos de infraestrutura — reais e fictícios-, o consumo de cada, o consumo total, um ponto RGB e uma mensagem de texto que apresenta essa informação.

3 Resultados

Esta pesquisa realizou o gerenciamento de dados, com a integração e sincronização com o modelo, onde foi possível intercambiar informações com os diferentes membros da equipe, as quais proporcionam a interoperabilidade entre sistemas (Vanlande et al., 2008). Assim, durante o processo para conceber um gêmeo digital ao nível do edifício, o estudo teve como dificuldade,

a padronização de processos, visto que o modelo digital foi desenvolvido em *softwares* distintos.

O fluxo de trabalho no *VisualARQ* permitiu conciliar a modelagem tridimensional e a programação visual, facilitando a homogeneidade de comunicação entre os dados na simulação. A operacionalização dentro dos programas integrados ou amigáveis com o *Rhinoceros* permitem que os dados possam ser utilizados em outros *plug-ins*, permitindo um conjunto amplo de simulações e representações geométricas sem a necessidade de migrar de um *software* para outro. Além de permitir a programação *scripting* para a criação de novos componentes, em linguagem escrita.

O *Revit* possui como principais recursos o projeto tridimensional e a visualização em qualquer fase do projeto (Autodesk, 2022), porém, em relação ao processo de conexão em tempo real, foi necessário integrar um *plug-in* ao *Grasshopper* para a simulação.

Sobre os dados gerados nos *softwares*, segundo a Sabesp (n.d.), o fluxo médio de água em uma torneira é de 260ml/s na residência e, com a coleta de dados no ambiente físico, foi observado um consumo ultrapassando o limite (figura 7). Sendo assim, conforme a ONU, seria uma solução relacionada ao objetivo 11 (cidades e comunidades sustentáveis) da Agenda 2030 para o Desenvolvimento Sustentável (Nações Unidas no Brasil, n.d.), auxiliar o usuário a identificar possíveis problemas com o consumo total de água na residência.

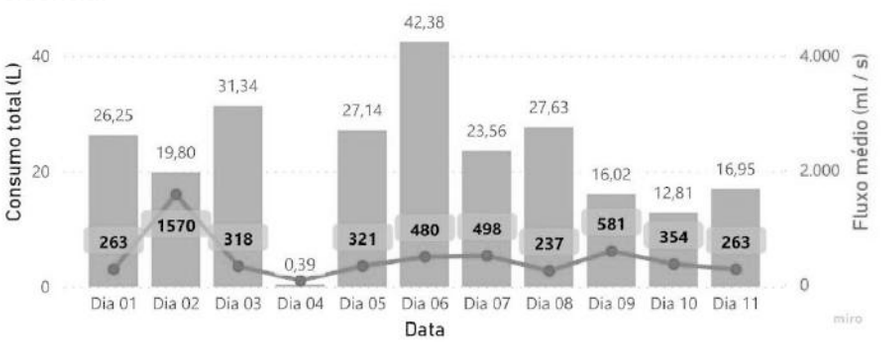

Figura 7. Consumo total (L) e fluxo médio (ml/s) por data. Fonte: Autores, 2022.

4 Discussão

A partir dos dados de consumo, o protótipo tem como potencial, identificar padrões comportamentais, criando regras e sugestões para os usuários otimizarem a utilização da água no ambiente estudado. Em trabalhos futuros, pretende-se criar previsões do consumo em outros cômodos da residência, baseadas em uma rede neural artificial (Cutore et al., 2008), identificando as limitações. A capacidade preditiva pode auxiliar no desempenho da edificação, antecipando o consumo de água diário, semanal, além de armazenar as informações para compará-las.

Em relação à obtenção de um gêmeo digital, tem como potencialidade, a etapa de *feedback* e avaliação pelo usuário (figura 8), sendo uma maneira de visualizar e interagir com as informações obtidas nas etapas anteriores (físico e virtual) e alertar o usuário em relação ao seu consumo. Assim, poderá ser demonstrado o sentido do modelo digital para o real, visto que nesta pesquisa, o enfoque foi dado para a integração de diferentes ferramentas digitais.

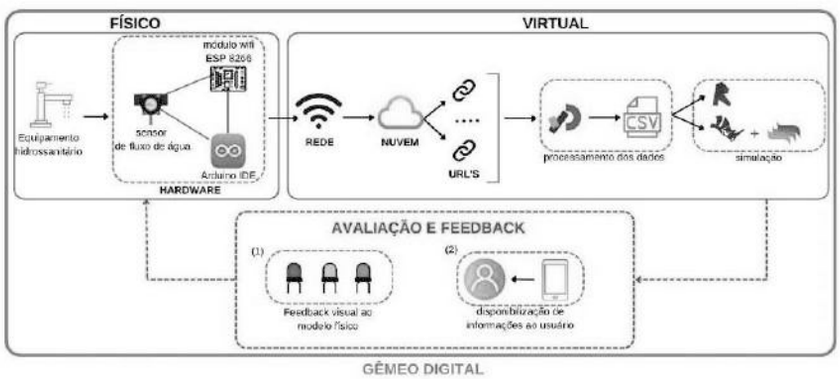

Figura 8. *Framework* do Gêmeo Digital. Fonte: Autores, 2022.

Referências

Akatu. (n.d.). Instituto Akatu pelo Consumo Consciente. https://akatu.org.br/

Aste, N., Manfren, M., & Marenzi, G. (2016). Building Automation and Control Systems and performance optimization: A framework for analysis. Renewable and Sustainable Energy Reviews, 75. https://doi.org/10.1016/j.rser.2016.10.072

Asuni. (Barcelona) (org.). VisualARQ: flexible bim for rhino. Flexible BIM for Rhino. Asuni Soft. https://www.visualarq.com/legal/about-us/

Autodesk. (2022). Revit: software BIM para projetistas, construtores e desenvolvedores. https://www.autodesk.com.br/products/revit/overview?term=1-YEAR&tab=subscription

Aziz, N. D., Nawawi, A. H., & Ariff, N. R. M. (2016). Building Information Modelling (BIM) in Facilities Management: Opportunities to be Considered by Facility Managers. Procedia - Social and Behavioral Sciences, 234, 353–362. https://doi.org/10.1016/j.sbspro.2016.10.252

Barreto, D. (2008). Perfil do consumo residencial e usos finais da água. Ambiente Construído, Porto Alegre, v. 2, n. 8, p. 22-40. ISSN 1678-8621.

Breda, J. (2019). Dia mundial da água e o desperdício que não se vê. UFSC. https://ufscsustentavel.ufsc.br/2019/03/22/dia-mundial-da-agua-e-o-desperdicio-que-nao-se-ve/ https://doi.org/10.1061/(ASCE)ME.1943-5479.0000763

Casan. (2022). Companhia Catarinense de Águas e Saneamento. https://www.casan.com.br/#0

Cutore, P., Campisano, A., Kapelan, Z., Modica, C., & Savic, D. (2008). Probabilistic prediction of urban water consumption using the SCEM-UA algorithm. Urban Water Journal, 5, 125–132. https://doi.org/10.1080/15730620701754434

Deng, M., Menassa, C., & Kamat, V. (2021). From BIM to digital twins: A systematic review of the evolution of intelligent building representations in the AEC-FM industry. Journal of Information Technology in Construction, 26, 58–83. https://doi.org/10.36680/j.itcon.2021.005

EN 15978:2011—Sustainability of construction works—Assessment of environmental performance of buildings—Calculation method. (2011).

IFMA. (2013). BIM for Facility Managers. John Wiley & Sons.

Lai, J. H. K., & Yik, F. W. H. (2011). An analytical method to evaluate facility management services for residential buildings. Building and Environment, 46(1), 165–175. https://doi.org/10.1016/j.buildenv.2010.07.012

Lee, J., Azamfar, M., Singh, J., & Siahpour, S. (2020). Integration of digital twin and deep learning in cyber-physical systems: Towards smart manufacturing. IET Collaborative Intelligent Manufacturing, 2(1), 34–36.

Lu, Q., Parlikad, A. K., Woodall, P., Xie, X., Liang, Z., Konstantinou, E., Heaton, J., & Schooling, J. (2019). Developing a dynamic digital twin at building and city levels: A case study of the West Cambridge campus. Journal of Management in Engineering, 36. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000763

Mcneel, R. (2014). Associates. Rhinoceros 3D modeling Software. v. 5.

Nações Unidas no Brasil. (n.d.). *Objetivo de desenvolvimento sustentável.* https://brasil.un.org/pt-br/sdgs/6

Ramya, C. M., Shanmugaraj, M., & Prabakaran, R. (2011). Study on ZigBee technology. 2011 3rd International Conference on Electronics Computer Technology, 6, 297–301. https://doi.org/10.1109/ICECTECH.2011.5942102

Sabesp. (n.d.) Dicas e testes. https://site.sabesp.com.br/site/interna/Default.aspx?secaoId=184

Shafto, M., Conroy, M., Doyle, R., Glaessgen, E., Kemp, C., LeMoigne, J., & Wang, L. (2012). Modeling, simulation, information technology & processing roadmap. National Aeronautics and Space Administration, 32(2012), 1–38.

Tomasetti, T. (2017). TT toolbox for Grasshopper, CORE studio. http://core.thorntontomasetti.com/colibri-release/

Vanlande, R., Nicolle, C., & Cruz, C. (2008). IFC and building lifecycle management. Automation in construction, 18(1), 70–78.

Manufacturing & Industry 4.0: Blockchain

Deciphering CryptoArchitecture: The architectural design studio as a vehicle for exploring the integration between blockchain and architectural design

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Abstract: In this paper we are using the outputs of research led architectural design studios, originally articulated as pedagogical projects at the Edinburgh School of Architecture and Landscape Architecture, University of Edinburgh and the Robert Gordon University in Aberdeen to explore and evaluate the possible transformative effects of blockchain/Decentralised Ledger technologies and decentralisation in the architecture discipline. After describing the pedagogical studio experiments, we frame a classification of relevant thematic clusters, where distributed ledger technologies can be applied to architectural design and thinking. The design studio, is treated as a methodological research tool, appropriate for the identification of existing knowledge gaps around the topic. The emerging classifications in terms of blockchain and decentralisation implementation is used to synthesise a map of future pedagogical and research activity.

Keywords: Blockchain, Cryptoeconomics, Tokenization, Pedagogy, Codesign

1 Introduction

Since 2009 Blockchain has been developed as an infrastructure technology powering decentralised finance (DeFi) and decentralised autonomous organisations (DAO), plus Non-fungible Tokens, NFTs. However, the engagement of architects with blockchain has been minimal, even if the first architecture decentralised organisation, ArchiDAO, has emerged. Employing blockchain in architectural design takes considerable effort in setting up the infrastructure, plus there are very few ready-made tools to interact between blockchains and digital design tools architects use. Thus, for the past two years, we have explored conceptually the application of the technology into architectural design through the means of the architectural design studio in four

architecture schools: University of Edinburgh (UoE,) University of Dundee (UoD), Xi'an Jiaotong-Liverpool University (XTLU) and Robert Gordon University (RGU).

The motivation of the paper lies with exploring the application of blockchain in architectural design and speculating on the impact it might have on architectural practice. The key question that the paper attempts to address is: Given blockchain's transformative features in terms of organizational and structural forms, which vectors does blockchain affect architectural design with? Which are the possible and discrete categories and envelopes of practice where blockchain can be applied into architectural design? In close affinity is the question of the economy of architectural design: Are the structural economic changes that Cryptoeconomics introduce visible in the architectural form produced?

1.1 Background

Blockchain and Distributed Ledger Technologies provide with a technical infrastructure, on top of which other applications can be developed to exchange value, encode conditions, communicate. A basic technical description of Blockchain, Smart Contracts and Cryptoeconomics follows.

Blockchain is a distributed computer network that maintains a decentralised ledger of transactions. The network does not have a centralised coordinating node, but derives consensus using an algorithm that incentivizes computer nodes to correct behaviour, i.e., agreement to a single truth for the ledger. The ledger changes in blocks of information, where each one contains a Merkle tree, (a structure to efficiently verify the integrity of data in a set), of transactions and the cryptographic hash of the previous one creating thus a chain of blocks. Due to the distributed nature of the ledger, the embedding of cryptographic hashes chaining the blocks of transactions and the use of incentives consensus algorithms it is technically very hard for an attacker to change past information recorded on a blockchain. While the first blockchain was invented to maintain a ledger of simple sums and subtractions (bitcoin white paper), blockchains allow the execution of autonomous software classes on them, transforming them into distributed stack computation machines. The software classes are called smart contract due to the implicit guarantee that the code will executed every time as written with no human intervention (Nick Szabo 1994). Consequently, blockchains encapsulate the concept of trust, as agents and parties can record to them information without it ever being changed or deleted, the concept of incentivised participation, i.e., one gets rewarded for contributing to the common pool resources of the system, and the concept of automatic execution of code in the form of smart contracts. These ideas are then the foundation of modern cryptoeconomics, i.e., economic systems where incentives and performance are secured through advanced cryptography of the blockchain. Most economic constructs on blockchain take the form of tokens,

i.e., special smart contracts that represent either some kind of uniqueness, have some utility in specific contexts, represent some value in other contexts. This introduces further the idea of tokeneconomics, which operates on a layer above cryptoeconomics. For example, a particular community might issue their own fungible token that is used for transactions within the community, while another might issue a non-fungible token that grants the holder governance rights over common pool resources or the organizations. In other example tokens might have the function of securities i.e., they represent the ownership of an asset of value, for example a building or a stock.

2 Methodology

2.1 The studio as an investigation field for emerging technologies in architectural design

The paper uses hybrid methods in order to tackle the key research questions. We use qualitative analysis as a framework for encapsulating a rich field of primary data, generated through design methods in four distinct architectural design studios. The four architectural design studios are an undergraduate course in UoE, and three postgraduate courses in UoD, RGU, and XTLU, where design briefs were given to the students with the question of developing a series of exercises: Decentralisation and blockchain technologies in RGU and XTLU, Decentralisation, blockchain technologies and urban analysis and design of systems in bigger scales in UoD, and more elaborate three exercises in UoE. Core to the case studies thus, is the deployment of “research in design”, as operationalised in the architectural design studios, which coupled with the qualitative analysis leads into “research for design” [Frayling 1993] [Rendell 2003].

Christopher Frayling’s foundational paper on research in art and design produced three practical classifications of the types of research that arise from the studio design process; research into design, research through design and research for design. Frayling considers research through design the least straightforward of the three categories but still identifiable, including materials research, development work, and action research. The development work in this context includes the customisation a rethought of a piece of technology to accomplish that has not been explored in depth before and communicate the results.

The paper analyses numerous design projects developed in UoE, UoD, XTLU, RGU. Empirical, grounded analysis of the data generated by the architectural design studios results in the constructivist formation of thematic clusters of interests. We thus avoid the failure of confusing the design practice that has been developed in the design projects with the systemic knowledge

developed through their analysis. [Friedman 2008] The paper also acts as an initial confirmation of the idea that blockchain, beyond the relatively predictable effects as a technological framework for certain aspects of the AEC industries, provides a series of pathways/clusters for future research.

2.2 The conceptual deployment of blockchain in the design studio to frame future research on the topic

All four briefs developed to be explorative and experimental, in the sense that they presented a well laid out table of concepts but did not prescribe types of architectonic output. Instead, students were free to engage with the concept of BC/DLT on the systemic level and develop their own systems, from which then they presented specific output in each studio. Some of the studios had more of a focus on the urban scale such as the ones from UoD and XTLU while others had more of a focus on the architectonic scale and artefact such as the ones from RGU and UoE.

We used then the developed projects as case studies subject to qualitative analysis to frame a classification on how blockchain technologies can affect architectural design. To construct the classification, we employed a discursive method in analyzing the dimensions of the projects but also the knowledge gaps they potentially respond to.

There was knowledge, practical and methodological reasons for these deployed methods. Key orchestration of these were the apparent lack of existing projects, apart from known examples of the authors' research that use blockchain and smart contracts in architectural design. In terms of knowledge, we needed thus to create a field within which to deploy the conceptual understanding of blockchain in architectural design, without the burden of the practical overhead of having to deploy and manage a blockchain ourselves. As such all of the case studies analyzed within the paper remain on the conceptual design level, without a corresponding implementation. This is obviously a limitation and a constraint in terms of validating the full potential impact of the technology on design, however this is a much needed first practical step in framing the discussion so that then we can later deploy the infrastructure to continue our investigation. As such, the present paper is a part of an initial conceptual deployment and discussion that we hope will affect and shape future research.

3 Results

This research uses a combination of critical reflection on design outputs and a systematic review of existing literature to construct two maps: a cluster of themes developed by architectural designers in their early stage of their

careers or during their education, and a map of future research, in synthesizing the findings from the studios while addressing knowledge gaps in the field of DLT/Blockchain in architectural design. The methodological constraints are the limited number of architectural design studios /designers examined so far, and the attempt to examine an early and developing field. The co-relation and overlap between gaps in the design clusters and gaps in the knowledge are also further examined, establishing mechanisms for validation of future research.

3.1 Emerging Classifications

After spending a year supervising the development of the projects and analysing the findings, the identified trajectories where blockchain infrastructure integrates with architectural design and thinking, revolve around a shift in the discipline of architecture towards a non-extractive, collective vision. First of all, the rediscovery of a sustainable vision for the Commons, based on positive incentivisation and a celebration of individual contribution to a collective authorship. Within this strand we observe the re-framing of design as a Commmon Poll Resources Problem, and the subsequent application of the Ostrom Principles on architectural design. This allows the development of resilient and sustainable manner treating design as a collective action, rather than a lone-hero vector. Moreover we see the further promise of the development of decentralised – distributed manufacturing, which includes the condition to democratise and make accessible complex fabrication processes empowering local creators, enhancing the resilience of supply of certain chains and cutting down transportation related emissions. Moreover, these models include bigger operational shifts about the ways that buildings are designed in collective and reconfigurable ways, utilising smart contracts in a way that buildings become the summaries of various architectural vectors, for example connecting digital twins with their physical counterpart, via smart contracts.[Dounas et al – Cryptotwin Ascaad 2022] They also include a possibility for strengthening collaborative design and the manner in which space is produced, and “decentralising” problem solving utilising cryptoeconomics, I,e allowing a collective hive of designers solve a problem through stigmergy, enabled via the common medium of smart contracts; smart contracts that record and act as the work medium of the collective (Dounas et al, ArchiDAO eCAADe). Another vector raised is modularity, the tokenisation of physical objects and the application of a stigmergic logic in the assembly, extending collective hive approaches from design to construction. Finally, the projects created raise relevant questions on the role of the metaverse not only as a parallel digital reality, but as a potential augmented digital social space that acts as a link between distant physical spaces and actors.

In order to classify and further analyse the aspects of blockchain and decentralisation that are addressed by every output of the architectural design studios, we have constructed seven thematic clusters. Each cluster corresponds to an identifiable way in which blockchain technologies and logic can be relevant to architecture. Most projects addressed more than one themes, and it is important to note that these themes were not imposed to the participants by the briefs, but they emerged as viable solutions to the briefs in different contexts, and were reinforced during the weekly design tutorials. The classifications, which will be further explained in the discussion section of the paper, are: Modularity, Stigmergic Assembly, Metaverse, CryptoEconomics, Collaborative Design/Fabrication, and Circular Economy.

3.2 Short project descriptions and classifications

A short description of select output from the studios follows. GreenCoin, Designing the city, Trustportation and CryptoHaus are titles that UoE students used to describe their projects.

GreenCoin, Fig.1, was a project that engaged with cryptoeconomics, modularity in terms of design, stigmeric assemply of the modules and physical/digital twins. GreenCoin as a token is an attempt incentivise participants to engage with green spaces and urban furniture maintenance, increasing the social trust on a city level and creating an ecosystem to spend the acquired tokens. It then engages with public event infrastructure, prototyping a module than can be bought and stored independently and then deployed in public spaces when large scale events ned pop-up spaces.

De-signing the city, Fig.4, engages with modularity, Cryptoeconomics, Collaborative design and digital twins. It begins with the hypothesis of a shift in terms of trust, according to which because of the rise of autonomous vehicles and digital maps, visual demarcations in cities will not be needed. They then develop an ecosystem of solutions to incentivise people to reclaim this freed up vertical real estate, as NFT exhibition spaces, transparent governance systems, or displays of any information that will be relevant to the different stakeholders. It then suggests autonomous living pods, placed, organised as DAOs, in the obsolete parking spaces, where people can stay by spending their acquired tokens for participating to the system.

Trustportation, Fig.2 & Fig.3, engages with modularity, stigmergic assembly, cryptoeconomics and collaborative design. It first recognises the need for mixed-use spaces adjacent with transportation nodes in big cities. After that, it suggests open-ended buildings, both in terms of architectural form and function, treating them as Decentralised Autonomous Organisations. Different stakeholders can vote to decide the program distribution within the building, which has non-fungible cores and structure and fungible temporary infill parts, than can get 3Dprinted and then recycled, based on the evolving needs of the building.

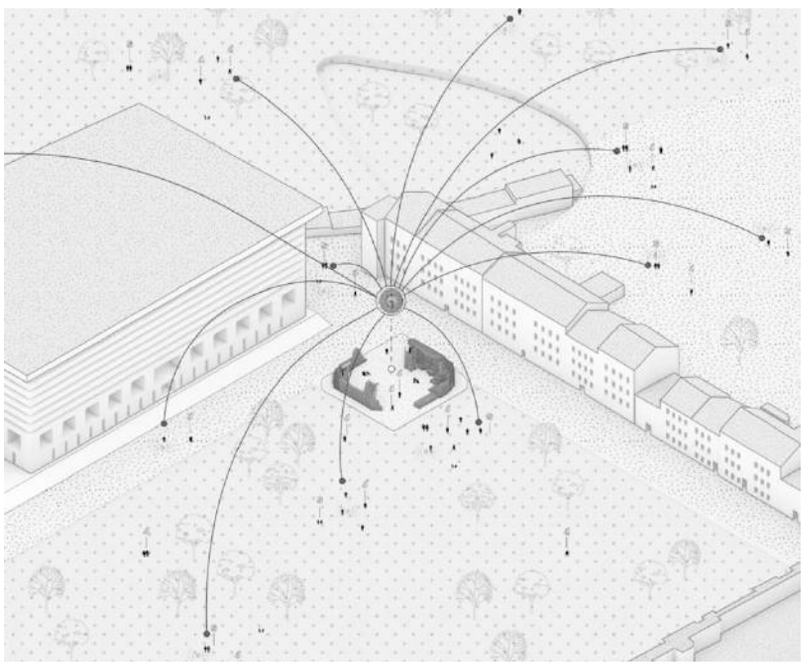


Figure 1. GreenCoin, modular structure, modules dispersed across the city, Source: UoE, diagram by Lucy Boyd, Sam Elliot, Yunan Wang 2022**.**

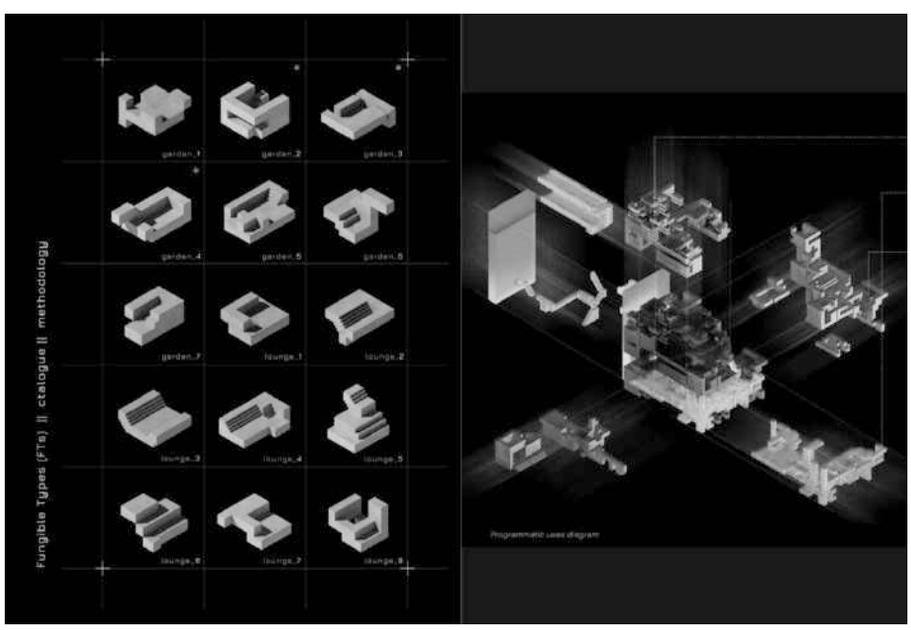


Figure 2. Trustportation, fungible parts and program distribution Source: UoE, visualization by Leo Chiu, Panagiota Mousa, Be Yang, 2022**.**

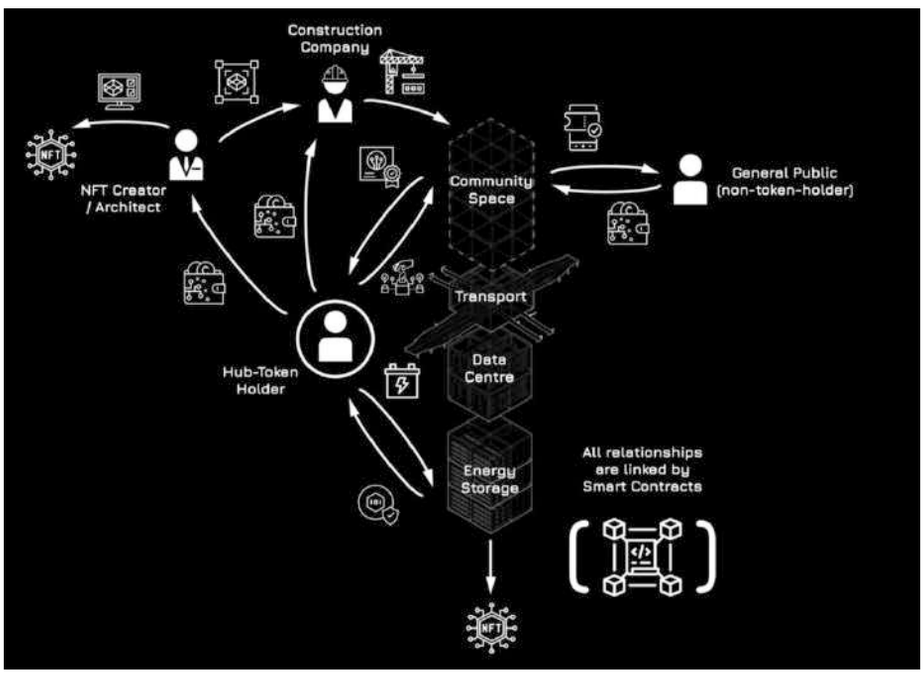


Figure 3. Trustportation, building as a DAO, Source: UoE, visualization by Leo Chiu, Panagiota Mousa, Be Yang, 2022**.**

CryptoHaus engages with cryptoeconomics, digital twins and mapping. It begins by identifying suitable areas with a lack of social housing of with housing infrastructure that needs updating. It then suggests a scheme in which the construction costs are offset in the whole lifespan of the building and the rent is equivalent to a fractional ownership of each apartment. The low rent becomes possible because the interests of all the stakeholders are aligned in a way that the initial investors, the tenants and the participants from the AEC industry get rewarded by the success of the building over time rather than a specific instance in the present.

In UoD, the brief had a focus on urbanism in terms of scale and level of investigation. Therefore, most of the projects revolved around mapping and incentivizing participants to help maintain accurate information for different uses. One project for example used a system to identify empty buildings in a city inspired by FOAM (FOAM provides the tools to enable a crowdsourced map and decentralised location services). The participants were rewarded to map and verify the location, condition, ownership status, and design of the buildings by taking pictures and scanning them. The complete database of empty building of different sizes, conditions and location could then be used for varying functions, based on the needs of the city over-time. Another project used a similar system to identify and rank green spaces, that could be used to deploy temporary housing solutions in case of natural disasters. Lastly, another project

focusing on urban farming created an ecosystem where participants were invited to identify potential areas that are appropriate for urban farming, and were rewarded for taking care of the crops, collect them and transport them to the distributed final selling points.

In the RGU and XJTLU workshop, the collective medical centre explored the idea of constructing a health system and its physical infrastructure including the buildings as a form of a common pool resources problem, where participants not only contribute through crypto-economics, but also participate in its governance through tokens. The project included a formulation of the design and construction of a medical centre through collective decision making.

In RGU, the collective factories for buildings project focused on a modular flying factory that could be assembled on demand in a particular area, create a factory for buildings, and then disassemble and fly to another location. The flying mechanisms and assembly were formed via an imaginative frame structure on air balloons. The whole system would operate with the logic of cryptoeconomics and digital twins where participants could either be a constructor operating a unit, or a community requesting the construction of a building. Apart from its imaginative infrastructure architecture idea the project was also innovative in turning a factory into a common pool resource problem that operates via cryptoeconomics.

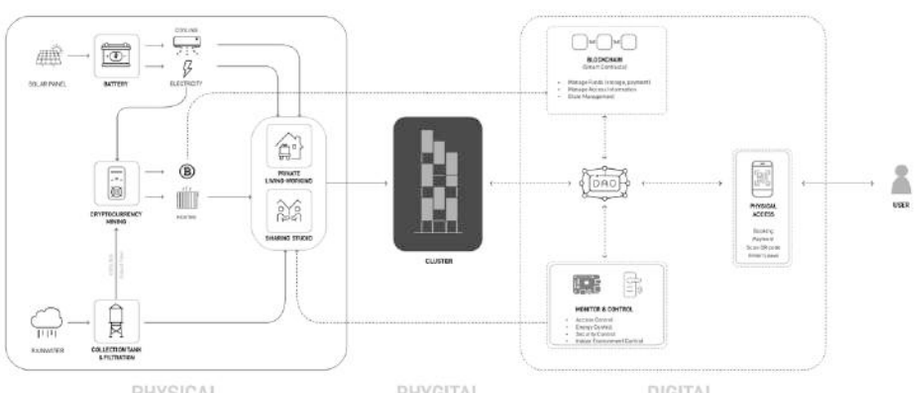


Figure 4. De-Signing the city, Building as a DAO, Source: UoE, diagram by Ice Chitmeesilp, Ciel Peng, Yolanda Wang, 2022

4 Discussion

After directly engaging with the attempts to constructively use the notion of blockchain for architectural design, we observed a series of current technical

and conceptual limitations that need to be addressed before the two fields produce viable prototypes. Firstly, in the technical domain, designers need scripting plug-ins, compatible with the already industry leading tools for computational design like Grasshopper, Dynamo, and Blender, to allow for linking the design process to smart contracts. Also, appropriate and useable smart contract templates that address the classifications that have emerged are needed, as well as their respective plug-ins for digital design tools. Furthermore, we need ways of communicating and saving transparently files from decentralised file storage systems like IPFS and Swarm. Finally, we need wallets natively embedded in CAAD applications, to handle private/public key infrastructure as current implementations are risky, exposing private keys in plain text.

As mentioned before, the classifications emerged as a result of the initial analysis of the responses to the briefs, and were not superimposed. However, the terms used to describe them, were chosen or synthesized by the authors, with some of them having different meanings in different contexts. Cryptoeconomics, which in short describe the incentivazation system that allow blockchain based finance to happen, were described in further detail earlier in the paper. Modularity refers to the design of structures that can be broken down to discrete parts. The Stigmergic Assembly refers to the collaborative assembly of structures, where the actors who participate on the process do not have knowledge or control over the final outcome. The Collaborative Design/Fabrication describes the situations where different actors are incentivised to participate in the design or production of parts of an artefact. Digital Twins, refer to the digital models of objects that approximate many characteristics beyond form. The Metaverse and Circular Economy are popular terms but lack all agreed definitions. In this context Metaverse is a digital, three-dimensional space for socialisation and Circular Economy is a model of production and consumption that encourages sharing and reusing.

Conceptually, cryptoeconomics, collaborative design and modularity were topics where architects seemed to excel and were able to synthesize creatively. However, we need to engage with projects that improve the understanding of the processes of circular economies, digital twins, and stigmergic assemblies; fabrication and production processes where the interests of multiple parties involved are aligned, the divisions between the various actors involved are blurred, and the co-ordination happens bottom up without centralised control.

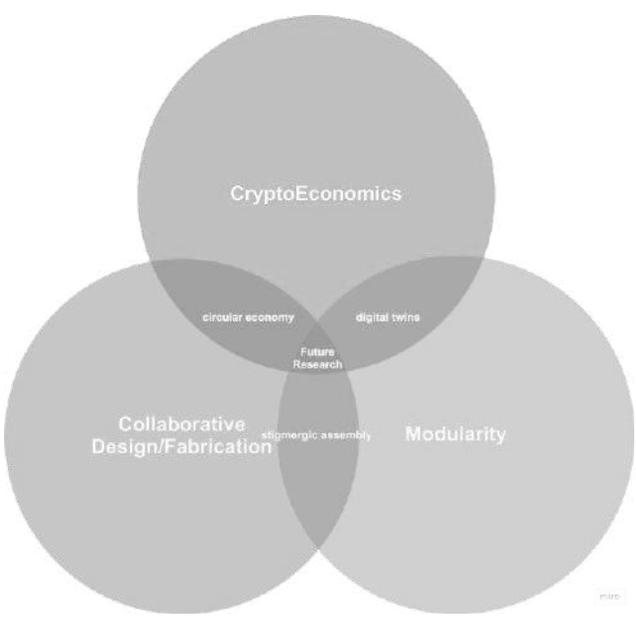
All the outputs from the four distinct academic design studios were evaluated, cross-referenced and graded against the seven emerging thematic clusters, with the grades ranging from zero to three based on their level of affinity (Table1.). After adding the grades from all the individual projects, the three highest graded themes were Cryptoeconomics (41), Modularity (32), and Collaborative Design/Fabrication (28). Analysing table 1, we constructed a Venn diagram, where we included the six most highly graded thematic clusters, creating overlaps based on thematic affinities that emerged after analysing the

projects. We believe that future research should be shaped by the emerging clusters and areas of focus.

Table 1. Classifications of different projects based on the thematic clusters

Studios	Modularity	Stigmergic Assembly	Metaverse	CryptoEconomics	Collaborative Design/Fabrication	Digital Twins/Mapping	Circular Economy
ESALA							
GreenCoin	3	3	0	2	0	1	1
TrustPortation	3	3	0	3	2	0	0
DeSigning the city	3	0	0	2	1	1	0
CryptoHaus Coop	0	0	0	3	0	1	1
ReciproCity	0	0	3	1	0	1	0
UoDundee							
Urban Farming	0	0	0	3	0	3	2
Resilient Athens	1	1	0	1	2	3	0
Universal Design (abandoned buildings)	2		0	2	3	3	0
XJTLU - MArch							
Brandless Architecture	3	3	1	1	1	0	2
Decentralised Augmented Space	2	1	1	3	3	2	1
Spontaneous Growth-Coastal Cities	3	3	0	2	2	1	1
RGU - MSc AAD							
East of Eden - Urban Planning	0	2	0	3	1	0	0
Hyperloop Station	1	1	0	1	2	2	1
Geodesic Portable Pods	3	1	0	1	3	0	2
Community Centre	3	1	2	3	2	0	3
Decentralised Community Centre	1	1	0	3	1	0	0
Sports Hall and communinty Centre	1	3	0	3	2	1	1
Smart Contract Community Centre	3	1	0	1	2	3	0
Health Centre	0	1	0	3	1	1	0

Table 2. Venn Diagram



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References

Dounas, Theodoros. 'Smart Contracts for Decentralised Building Information Modelling'. In *Werner, L and Koering, D (Eds.), Anthropologic: Architecture and Fabrication in the Cognitive Age - Proceedings of the 38th ECAADe Conference - Volume 2, TU Berlin, Berlin, Germany, 16-18 September 2020, Pp. 565-574*. CUMINCAD, 2020. http://papers.cumincad.org/cgi-bin/works/paper/ecaade2020_190.

Dounas, Theodoros and Lombardi. 'Blockchain Grammars - Designing with DAOs - The Blockchain as a Design Platform for Shape Grammarists' Decentralised Collaboration'. In *M. Haeusler, M. A. Schnabel, T. Fukuda (Eds.), Intelligent & Informed - Proceedings of the 24th CAADRIA Conference - Volume 2, Victoria University of Wellington, Wellington, New Zealand, 15-18 April 2019, Pp. 293-302*. CUMINCAD, 2019. http://papers.cumincad.org/cgi-bin/works/paper/caadria2019_136.

Dounas, Theodoros, Davide Lombardi, and Wassim Jabi. 'Framework for Decentralised Architectural Design BIM and Blockchain Integration', 2021. https://journals.sagepub.com/doi/full/10.1177/1478077120963376.

Enriken, William, Dieter Shirley, Jacob Evans, and Nastassia Sachs. 'EIP-721: Non-Fungible Token Standard'. Ethereum Improvement Proposals. Accessed 17 January 2022. https://eips.ethereum.org/EIPS/eip-721.

Frayling, Christopher. 'Research in Art and Design',. Royal College of Art, n.d.

Friedman, Ken. 'Research into, by and for Design'. *Journal of Visual Art Practice* 7, no. 2 (November 2008): 153–60. https://doi.org/10.1386/jvap.7.2.153_1.

Hunhevicz, Jens Juri, Pierre-Antoine Brasey, Marcella M. M. Bonanomi, and Daniel Hall. 'Blockchain and Smart Contracts for Integrated Project Delivery: Inspiration from the Commons'. In *EPOC 2020 Working Paper Proceedings*. Engineering Project Organization Society (EPOS), 2020. https://doi.org/10.3929/ethz-b-000452056.

Nakamoto, Satoshi. 'Bitcoin: A Peer-to-Peer Electronic Cash System', n.d., 11.

Rendell, Jane. 'Architectural Research and Disciplinarity'. *Architectural Research Quarterly* 8 (1 June 2004): 141–47. https://doi.org/10.1017/S135913550400017X.

Vogelsteller, F, and V Butterin. 'EIP-20: Token Standard - ERC20: A Standard Interface for Tokens., EIP: Ethereum Improvement Proposals'. Accessed 17 January 2022. https://eips.ethereum.org/EIPS/eip-20.

Manufacturing & Industry 4.0: Decision Making

Lost in Architectural Designing: Possible cognitive biases of architects during the early design phases

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Abstract. In order to meet the housing demands of the future, architects need to work faster and more efficiently while improving architectural quality. The metis projects aim to create an intelligent design assistant supporting architects during the early design stages through suggesting further design steps for spatial layouting, based on the best practice of reference buildings. By enhancing suggestions with explainability, the system offers insight to improve Human-System-Interaction (HSI), bridging the 'black box' problem. The explanations aim to either support the reasoning process or mitigate possible biases of architects, which can be rooted in the heuristic 'System 1', as well as the analytical 'System 2', drawing from the 'dual process model'. Within this paper, we propose our approach to clarify the four main heuristic biases and the logical errors of architects, when using reference buildings, and their respective representation during the architectural design decision-making process.

Keywords: Decision Making, Biases, Explainability, XAI, Human System Interaction

1 Introduction

The world's population is expected to reach the ten billion mark by 2050, for which about two thirds of the population will live in the urban area (United Nations, 2019). In order to meet the increasing demands for residential housing, concerning both quantity and sustainability, architects need to be able to work faster, and more efficiently, while increasing architectural quality. The decisions of the early design stages are of significant importance for satisfying these requirements of a fully constructed building (Harputlugil et al., 2014). The sooner well-informed decisions are made, the higher the quality of the final building. Vice versa, the later fatal flaws are recognised during the architectural

design, the more difficult correcting them and changing the design becomes (Buxton, 2007). Thus, the design decisions of the early design stages have a high impact on the duration, architectural quality, and sustainability of the entire building, in terms of design and construction process. Further, efficient design, designing and information management of the early design stages can result in an estimated material waste reduction of 33 percent (Haeusler et al., 2021).

Through adaptation for the workflow of Computer-Aided Architectural Design (CAAD), the methods of intelligent systems are applied to support architects in fulfilling complex tasks of architectural designing and planning. Derived from these principles, the metis projects pursue an intelligent design assistant suggesting further design steps for spatial layouting during the early design stages. In order to propose methods of explainability for such an intelligent system to facilitate more intuitive work and high-quality architecture by the means of Human-Computer-Interaction (HCI), specifically Human-System-Interaction (HSI) methods, we examine the reasoning process of architects for the use of reference buildings, i.e. ‘architectural precedents’ (Richter, 2010). From the inquiry methods and reasoning goals, we derive possible biases and logical errors of architects, using the ‘dual process model’ of the human mind, based on cognitive sciences and psychology (Wang et al., 2019). Within this paper we describe our triangulated approach, using a theoretical literature review and a limited case study, for clarifying the four main heuristic biases (‘representative’, ‘availability’, ‘anchoring’, ‘confirmation’) of pattern-matching ‘System 1’ and logical errors or weaknesses (i.e. ‘misplaced trust’) of analytical ‘System 2’, as well as their respective representations for the use of reference buildings during the early design stages.

2 Related Work

The field of eXplainable Artificial Intelligence (XAI) is a quickly expanding area of research and industry. Barredo Arrieta et al. (2020) aim to define XAI for machine learning (ML) on the backdrop of existing research and findings, as well as its projected future development. Palacio et al. (2021) focus on establishing a consensus and framework for XAI strategies for implementation. Meanwhile, Wang et al. (2019) shift from a view point of performance and system possibilities to an HCI focus, proposing a conceptual framework, initially created for medical diagnoses, to design explainability for any target group and steps for a theory-driven adaptation for a specific user group (see Figure 1).

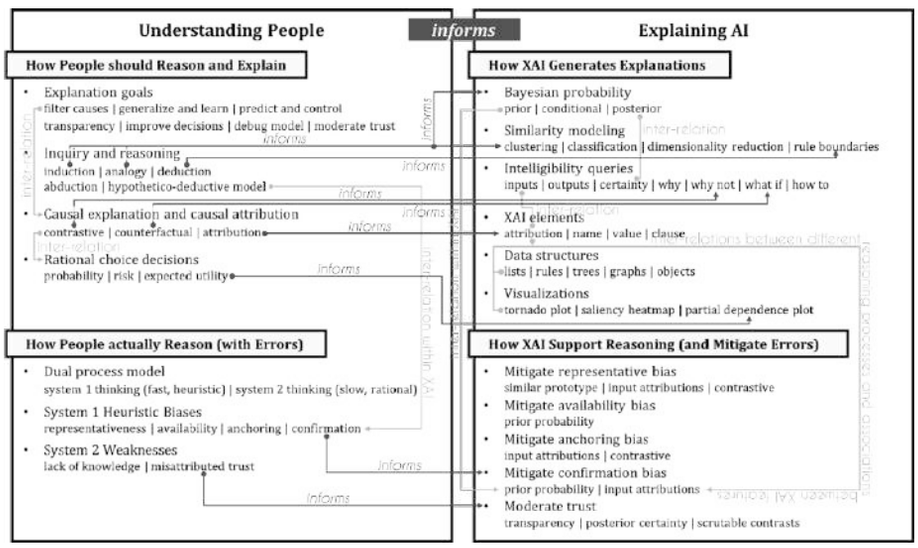

Figure 1. Conceptual framework for reasoned explanations (Adapted from Wang et al., 2019, p. 4).

The framework is divided into the human reasoning process to the left and explainable intelligent system methods to the right. The human reasoning to ‘Understanding People’ on the left-hand side of Figure 1 is separated into ideal reasoning ('should reason') and true human reasoning ('actually reason with errors’) of heuristic ‘System 1’ and analytical ‘System 2’, which inform the corresponding intelligent system facilities to the right for generating explanations as an ‘Explaining AI’. The system answers to both the ideal and true human reasoning with different strategies through either the support of human reasoning or the mitigation of biases of heuristic 'System 1' of *representative* or *representativeness*, *availability*, *anchoring*, and *confirmation*, as well as errors of analytical 'System 2', such as *lack of knowledge* and *misattributed trust*. Wang et al. (2019) summarise the following four steps for adaptation of the framework for a specific target group, based on the respective goals, inherent inquiry methods and best practices:

1. Clarifying the user's reasoning goals through a literature review, ethnography, and/or participatory design
2. Identifying possible biases for the respective applications through a literature review, ethnography, and/or participatory design
3. Deducing appropriate explanation ways for reaching reasoning goals and/or mitigating cognitive biases using the framework’s pathways
4. Integrating the explainable intelligent system facilities to create an explainable user interface

The common practice of architects of using reference buildings (e.g. floor plans and other visualisations), is a well-recognised approach in architectural designing with exemplary designs to be used with originality and for creating innovation (Richter, 2010). Architects utilise these 'architectural precedents' as examples to create a basis for their design process: as a source of inspiration, design conditions and explicit information, as a tool for evaluation of their own design, and as a medium for communication (Ibid.). They are synthesised with their mental collection of architectural objects, knowledge from other sources and previous experiences into new original architectural designs using their personal design philosophy, Lawson's 'Guiding Principles' (2005).

In order to deduce the inference and explanation methods, the decision-making process of architects needs to be examined. Rational choice decisions are applied through value-risk-measurement and expected utility. However, due to the highly complex and ill-defined decision-making process because of unique design problems, involved stakeholders, designers and environmental circumstances, the architectural design decision-making process can neither be described as linear, nor standardisable. By assuming the position of Harputlugil et al. (2014), it can be described as an order-less analytical hierarchy process (AHP) with Multi-Criteria Decision-Making (MCDM) to design an individual solution for the unique problem to achieve the best possible quality of architecture. Thus, the design decisions of the early design phases, especially forming and framing the design problem and creating a mental hierarchy of the different criteria, have significant influence on the architectural quality of the final building (Ibid.; Buxton, 2007). The sketching process, a supportive practice to make ideas of the early design stages tangible and to advance design development (Laseau, 2000; Lawson, 2004; Lawson, 2005; Suwa & Tversky, 1997; Lertsithichai, 2005), can be described as a constant back-and-forth of elaboration of ideas into many alternatives or variants and reduction through selecting the most promising solutions or solution aspects (Laseau, 2000; Buxton, 2007).

Aiming to provide the best possible HCI - or HSI - for architects designing during the early design stages, the interface of the architect and the system should assimilate to the best practises of the respective design stage, sketching for the early design stages. Nevertheless, contemporary Computer-Aided Architectural Design (CAAD) tools, as well as their Graphic User Interfaces (GUIs), largely focus on the system possibilities (Lertsithichai, 2005). However, the incorporation of genuine tools and practices, a basis of User-Centred-Design (UCD), facilitates a short learning process and the mitigation of errors of application usage by considering the user's needs and goals. It improves efficiency and effectiveness of an interactive system (Lee, Chuang & Wu, 2011), especially when considering the design of an intelligent design assistant built on XAI strategies.

3 Approach

Using the methodology of triangulation derived from cognitive sciences, we propose the following approach. The described steps of Wang et al. (2019) are used to adapt their conceptual framework (see Figure 1), created for medical diagnoses, for the specific target group of architects using reference building during the early design stages (see Section Related Work). A literature review is conducted on the workflow, architectural quality, design requirements, design tools and architectural design process (Laseau, 2000; Lawson, 2004; Lawson, 2005; Buxton, 2007; Schön & Wiggins, 1992; Darke, 1979; Harputlugil et al., 2014; Suwa & Tversky, 1997; Negroponte, 1973; Lee, Chuang & Wu, 2011; Lertsithichai, 2005; Richter, 2010) in order to clarify the user's reasoning goals (Step 1), as well as identify possible biases during the process and for supporting intelligent systems (Step 2). This theoretical research is triangulated in Bielski, Langenhan, Ziegler, Eisenstadt, Petzold et al. (2022) through a case study utilising a digital paper prototype, based on the deduced explanation methods and explanation visualisations (Step 3), and implemented as a high-fidelity clickdummy of a hypothetical application of an intelligent design for tablet devices (Step 4). Within this paper, we focus on Steps 1 and 2 for clarifying possible biases of architects, deduced from their inquiry and reasoning methods, as well as explanation goals and methods of architects during the early design stages.

4 Literature Findings

4.1 Inquiry and Reasoning

Based on the formalisation of the architectural design process as an AHP with MCDM, as well as the use of reference buildings, the inquiry methods of architects can be deduced. It is presumed that architects use inductive and analogical reasoning for reference buildings to be a source of inspiration and design conditions, but also as a tool for evaluation of the own design. The AHP-based generation of alternatives, a characteristic of the architectural design process of the early design stages, serves the purpose of applying these reasoning methods to select the most promising solutions or solution aspects.

4.2 Explanation goals and methods

The architectural design decision-making as an MCDM process is supported by contrastive explanations, where architects heavily rely on counterfactual reasoning by using 'What if?' - and its transfactual derivation 'How to?' – for causal chain scenarios of interchanging both criteria or sub-criteria themselves and/or the values of criteria within the AHP (see Table 1). Further, the pair-wise

comparison of tangible and intangible, and subjective and objective criteria for highlighting relationships is sought to support contrastive reasoning.

Table 1. General description and description for the architectural design process of explanation methods.

Explanation methods	General Description	Description for Architectural Design
Contrastive	Why? Why not?	Comparison of different architectural designs
Counterfactual	What if?	Exploration of impacts of different architectural designs
Transfactual	How to?	Exploration of goals through different architectural designs

Derived from the explanation goals and methods answering to the inductive and analogical reasoning of architects, possible biases are presented. This includes each of the different heuristic biases, caused by human thinking using quick pattern matching by 'System 1', and the weaknesses of slow, logical thinking of 'System 2', as defined by Wang et al. (2019). They are individually described in nature and occurrence within the architectural design process and their respective impact, as well as illustrated with an example.

4.3 Heuristic 'System 1' Biases

The 'Representative Bias', also called the 'Representativeness Bias', is misjudging the similarity of the conditions of two or more items and consequently, applying their respective solutions, even though they are not transferable. This kind of bias lets architects misinterpret the design conditions of a reference building to be the same or similar to the project's. Even though the design conditions differ, non-applicable reference buildings are perceived as a possible source of inspiration. Example: A floor plan from the 1920s, which was built with outdated architectural style, materials and construction technology, is applied as a reference for contemporary residential housing.

The 'Availability Bias' is an error of perceiving memorable, unusual and adverse events, objects or solutions as a common outcome. Thus, an architect might perceive certain reference buildings or aspects thereof as highly likely, while it is actually of low probability. Thus, non-applicable reference buildings might be selected as an inspiration or highly uncommon features are integrated. Example: The architect reviews a plan of an extravagant home, where a shower connects the bathroom to the living room. Due to its memorability, the architect integrates this highly uncommon feature into the design of a family home.

A skewed perception of the value of an item, event or feature constitutes the 'Anchoring Bias'. Assuming the architectural design decision-making process

to be an AHP with MCDM, the skewed interpretation of the weight of a criterion leads to the misalignment of priorities. Architects typically identify a preferred design direction - 'anchor' - at the beginning of the process, the *primary generator* (Darke, 1973) around which the design revolves. Focusing on a false 'anchor' causes a chain of misaligned priorities, disrupting the entire architectural design, design process and quality. Further, the anchoring bias can happen in each level of the hierarchy, but the higher the level, the more fatal it is. Example: Within the study of Laseau (2000) post-graduate students often focus on shape of rooms and building, instead of their use and flexibility.

The 'Confirmation Bias' describes the collection of redundant information for confirming a hypothesis instead of evidence for other possibilities. It can occur within the architectural design process, through the review of reference buildings, which solely confirm the pre-conceived design ideas. Consequently, the elaboration process only generates a limited number of variants, no alternatives. The architect neglects to use a variety of reference buildings of the same design conditions as a source of inspiration and tool for evaluation. Example: The architect uses for referencing, as well as evaluating, solely their own previous works and standard floor plans, simply out of habit.

4.4 'System 2' Weaknesses

Misplaced trust is an issue of analytical, logical 'System 2', operating at a slow, but thorough rate. Due to lack of knowledge, information provided by authority figures, or presumed authority figures with larger knowledge, may be assumed to be true without any further research or validation. This is also applicable if the architect has overconfidence in the own abilities.

An intelligent system is created and debugged by humans, mostly computer scientists, generating suggestions based on its data and implemented rules. Thus, it can have flaws, i.e. due to inferior system capabilities, bad coding, and lack of quality or volume of data. The intelligent system may make skewed assumptions, suggesting false further design steps. If the user of such an application has complete trust in the system ('oracle'), all suggestions are presumed correct and applicable without further questioning, especially if the architect has little experience and knowledge. Example: Based on a disproportionate amount of floor plans of the 1980s with enclosed rooms in the database, the system presumes their high probability. Because of an unconditional trust in the system, the inexperienced architects unconditionally accepts the generated suggestion.

4.5 Cognitive Biases of the Architectural Design Process

The previously detailed biases of 'System 1' and 'System 2' have been summarised within Table 2. It consists of the general description of the individual biases, as well as their respective representation within the architectural design decision-making process for the use of reference buildings.

Table 2. General description and description for the architectural design process of heuristic biases of heuristic ‘System 1’ and logical errors of analytical ‘System 2’.

Heuristic Biases	**General Description**	**Description for Architectural Design**
Representative	Misjudging the similarities of two events/objects due to matching unrelated conditions	Misinterpretation of a reference building of different design conditions as a source of inspiration
Availability	Perceiving memorable, unusual or adverse events/objects to be a more likely outcome than they truly are	Perception of a reference building or a certain feature as a source of inspiration due to it memorability, even though it is of low likelihood
Anchoring	Skewed weight of a feature value of an event/object, referred to as ‘anchor’	Skewed perception of the value of a criterion or sub-criterion within the architectural design decision-making process (for AHP with MCDM)
Confirmation	Collecting information to confirm existing hypothesis, instead of different events/objects for same conditions	Collection of redundant references buildings as source of inspiration, even though the design conditions allow for a wider variety
Logical Errors	**General Description**	**Description for Architectural Design**
Misplaced trust	Unquestioned trust in provided information of probability of event/object	Overconfidence in recommendations for reference buildings (e.g. by tool, colleagues, other stakeholders) as a source of inspiration, design conditions and value within architectural design process
Lack of knowledge	Lack of access to situational information, as well as collected knowledge through e.g. experience	Inability of discerning applicability of reference building as a source of inspiration, design conditions and value within architectural design process

5 Study results

As mentioned within the Section Approach, a digital paper prototype, integrating the deduced explanation visualisations in the graphic user interface, (Bielski, Langenhan, Ziegler, Eisenstadt, Petzold et al., 2022) was used within a case study with architects of different backgrounds (from Europe and Asia; approximately 30 years of age) working in Central Europe for three to five years. A digital prototype demonstration is followed by a semi-structured interview, consisting of three question sections: *explanations*, *explanation visualisations* and *user perception*. Based on the expressions of the participants, the first question section is indicates, if and how the implemented explanations could support the reasoning process or mitigate the targeted biases.

It becomes clear that all targeted biases were successfully addressed. However, it was observed that the handling of the individual explanations - the information within the explanation visualisation - determined which biases were mitigated. The same information was used by the architects in different ways and thus, other described biases were additionally addressed, e.g. the multitude of different suggestions on the backdrop of their design conditions targeted the 'Confirmation Bias', but also influenced the 'Anchoring Bias'.

The study participants (P[n]) themselves identified possible biases, which the intelligent design assistant may mitigate. They expressed how the big database and suggestions of an intelligent design assistant could support them in getting rid of '*old habits'* (P2, P5, P8, and P10). Thus, the participants themselves identified the opportunity to overcome the heuristic biases of 'Availability', 'Anchoring' and 'Confirmation' by the means of the support of an intelligent design assistant. P3, P4, P5, P7 and P9 even identified the opportunity to customise the intelligent design assistant through the personal input and requested manual debugging of the floor plans to incorporate specific buildings. They wanted to change, rearrange, add or remove reference buildings for maximised moderation of trust and scrutability to use their knowledge to examine the system and avoid 'Misplaced trust'.

6 Discussion

However, negative effects of the explanations targeted at the biases of the architects could also be observed. P2 expressed insecurity and a deprived ownership over the own design and design decisions due to suggestions of the system introducing a new level of self-awareness and thus, possible biases towards the own design ideas. The presumption of an intelligent design assistant, offering recommendations through AI technology, being an omniscient oracle seemed to mislead some participants into valuing the suggestions of the system higher than designs based on their own knowledge and experience. P4 expressed similar thoughts - even though positively - that they would simply choose the first suggestion of the intelligent design assistant as *'it is an artificial intelligence, it knows what it is doing*'. Nevertheless, most participants found the trust well moderated, based on the 'transparency' of the intelligent design assistant. The insight into the 'black box' mechanisms, e.g. raw data, provided the architects with unexpected opportunities for scrutability. They were excited at the idea of removing, re-arranging the priority of reference buildings, and introducing floor plans of their mental collection into the training data, personalising and debugging the system for original designs.

Finally, the approach needs to be discussed, which is largely based on a theoretical literature review synthesised with the framework by Wang et al. (2019) and use of reference buildings as defined by Richter (2010). The remote case study, using a presentation of the digital paper prototype and semi-

structured interview, has a limited number of participants (n=11). As the amount is scientifically insignificant, the case study serves as a pilot study for determining further persuasion of the topic, evaluation of the approach and pointers for future work. Because of the encouraging results, we consider our triangulated approach with the adaption of the framework by Wang et al. (2019) for the identification and mitigation of biases of architects during the early design stages successful and consequently, worth further pursuing.

7 Conclusion and Future Work

By applying the methods of social sciences, like triangulation, we further developed and evaluated our theoretical findings of a literature review of the cognitive reasoning process of architects and their respective biases for the use of reference buildings through a pilot study with working architects. Our results show that architects may present the four heuristic biases of ‘Representative’, ‘Availability’, ‘Anchoring’ and ‘Confirmation’ and the logical error of ‘Misplaced Trust’, while we are able to specify in which way these biases present themselves. Thus, we contribute the basis for creating a design support approach by transferring the theory-driven methods of Wang et al. (2019) to the domain of architecture, by creating theory-driven explanations for architects. Our approach can be further transferred to other design domains. By better understanding the specific user, we facilitate more intuitive work with an intelligent design assistant and consequently, high quality architecture, while speeding up the process and reducing the work-related stress on architects.

In the future, we aim to determine the right timing for explanations and thus, we plan on investigating the temporal aspect of the presented biases during the architectural design process (Bielski, Eisenstadt et al., 2022). In a first step, we analyse the design process by the means of sketch protocol studies (Suwa & Tversky, 1992), as described in Bielski, Mete et al. (2022), segmented into design phases (Lawson, 2004; Laseau, 2000; Barelkowski, 2013), as explored in Bielski, Langenhan, Ziegler, Eisenstadt, Dengel et al. (2022) and Mete et al. (2022). By utilising these findings, we are able to present the information for mitigation of biases at a useful time. Thus, we can reduce the amount of explanations permanently visible for the user to avoid information overload. It enables the user to focus on the design activity, which ultimately assertives the ownership over the own design. By reducing the permanent input of the intelligent design assistant, while highlighting the fallibility of an AI system through scrutability and debugging options, we aim to provide insight into ‘black box’ systems to avoid undisputed acceptance of possibly subpar suggestions.

As mentioned in the beginning, quick, efficient and sustainable work is essential for meeting the future demands on the construction industry. The intelligent design assistant envisioned by the metis projects aims to support the design decision-making through suggestions, enriched with explanations

targeting possible biases of the architects of the early design stages. Finally, we hope that our work may inspire and guide future research for supporting architects to design in more informed ways and with more confidence early on to create high quality architecture more efficiently and sustainably.

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References

Barelkowski, R. (2013). Designing more by knowing less, Verbeke, J., Pak, B., *Proceedings of the Conference 'Knowing (by) designing'* at LUCA, Sint-Lucas School of Architecture Brussels, 22-23 May 2013 (pp. 522-531). Ghent, Brussels.

Barredo Arrieta, A., Diaz Rodriguez, N., Del Ser, J., Bennetot, A., Tabik, S., Barbado González, A., Garcia, S., Gil-Lopez, S., Molina, D., Benjamins, V., Chatila, R., & Herrera, F. (2020). Explainable Artificial Intelligence (XAI): Concepts, Taxonomies, Opportunities and Challenges toward Responsible AI. Information Fusion, 58, 82-115.

Bielski, J., Eisenstadt, V., Langenhan, C., & Mete, B. (2022). The Morphological Echo of Architects - Concept for a Conversational Artificial Intelligence to Support Architects during the Early Design Stages. *Proceedings of 33rd Forum Bauninformatik*. (pp. -). Technical University of Munich.

Bielski, J., Mete, B., Eisenstadt, V., Langenhan, C., Petzold, F., Dengel, A., & Althoff, K.D. (2022). Chasing the White Rabbit – A case study of predicting design phases of architects by training a deep neural network with sketch recognition through a digital drawing board. *Proceedings of International Conferences on Computational Creativity*. Association for Computational Creativity. Retrieved August 29, 2022 from https://computationalcreativity.net/iccc22/wp-content/uploads/2022/06/ICCC-2022_1S_Bielski-et-al..pdf

Bielski, J., Langenhan, C., Ziegler, C., Eisenstadt, V., Dengel, A., & Althoff, K.D. (2022). Quantifying the Intangible - A tool for retrospective protocol studies of sketching during the early conceptual de-sign of architecture. *Proceedings of 27th* International Conference of the Association for Computer-Aided Architectural Design Research in Asia*, CAADRIA* (pp. 403-411). Association for Computer-Aided Architectural Design Research in Asia.

Bielski, J., Langenhan, C., Ziegler, C., Eisenstadt, V., Petzold, F., Dengel, A., & Althoff, K.D. (2022). The What Why, What-If and How-To for Designing Architecture - Explainability for auto-completion of computer-aided architectural design of floor plan layouting during the early design stages. *Proceedings of 27th International Conference of the Association for Computer-Aided Architectural Design Research in Asia, CAADRIA* (pp. 435-444). Association for Computer-Aided Architectural Design Research in Asia.

Buxton, W. (2007). Sketching user experience: Getting the design right and the right design. San Francisco, California: M. Kaufmann, 2007.

Darke, J. (1979). The primary generator and the design process. Design Studies, 1(1), 36-44.

Haeusler, M.H., Butler, A., Gardner, N., Sepasgozar, S., & Pan, S. (2021). Wasted... again: Or how to understand waste as a data problem and aiming to address the reduction of waste as a computational challenge. *Proceedings of 26th International Conference of the Association for Computer-Aided Architectural Design Research in Asia, CAADRIA* (pp. 371 – 380).

Harputlugil, T., Gultekin, A., Prins, M., & Topcu, Y.I. (2014). Architectural Design Quality Assessment Based On Analytic Hierarchy Process: A Case Study. Metu Journal of the Faculty of Architecture, 31, pp. 139-161.

Laseau, P. (2000). Graphic Thinking for Architects and Designers. Wiley, USA.

Lawson, B. (2005). How Designers Think, 4th edition. Elsevier, Oxford.

Lawson, B. (2004). What Designers know, 1st edition. Elsevier, Oxford.

Palacio, S., Lucieri, A., Munir, M., Hees, J., Ahmed, S., & Dengel, A. (2021). XAI Handbook: Towards a Unified Framework for Explainable AI. *Proceedings of International Conference on Computer Vision Workshops, CVF* (pp. 3766-3775).

Lee, B., Chuang, T., & Wu, I. (2011). Design and Implementation of Interactive GUI for BIM Systems. *Proceedings of International Conference on Construction Applications of Virtual Reality, CONVR* (pp. 106-116). Weimar, Germany: Verlag der Bauhaus-Universität Weimar.

Lertsithichai, S. (2005). A tangible modelling interface for computer-aided architectural design systems. *Proceedings of 10th International Conference on Computer Aided Architectural Design Research in Asia, CAADRIA* (2), pp. 357-363.

Mete, B., Bielski, J., Eisenstadt, V., Langenhan, C., Petzold, F., & Althoff, K.D. (2022). Predicting semantic building information (BIM) with Recurrent Neural Networks. *Proceedings of European Conference on Product and Process Modeling, ECPPM*. European Association of Product and Process Modelling. [Accepted]

Negroponte, N. (1973). *The architecture machine: Toward a more human environment*. The MIT Press.

Richter, K. (2010). Augmenting Designers' Memory: Case Based Reasoning in der Architektur. (Doctoral Dissertation, Bauhaus-Universität Weimar).

Schön, D., & Wiggins, G. (1992). Kinds of seeing and their functions in designing. Design Studies, 13(2), 135–156.

Suwa, M and Tversky, B 1997, 'What do architects and students perceive in their design sketches? A protocol analysis', Design Studies, 18(4), pp. 385-403.

Wang, D., Yang, Q., Abdul, A., & Lim, B. (2019). Designing Theory-Driven User-Centric Explainable AI. *Proceedings of Conference on Human Factors in Computing Systems, CHI,* pp. 1–15.

United Nations (2019). World Urbanization Prospects: The 2018 Revision (ST/ESA/SER.A/420). New York: United Nations.

Concrete Construction for Social Housing in Colombia: Towards a higher productivity supported by the use of Digital tools and off-site processes.

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Abstract. This paper presents the outcomes of a collaborative project between UK and Colombian researchers, aimed at increasing productivity and lowering emissions for the construction of social housing in Colombia, particularly when using concrete as the main building material. Based on the findings of a previous project that focused on the automation of concrete construction within the UK context, and following the implementation of interviews with local industry experts, the researchers analyzed the opportunities and challenges of incorporating digital technologies in order to improve the construction process, and found out that there was higher potential in the design and management areas rather than in the actual production of components, where standard prefabrication was perceived as the most fitting solution. This paper will introduce some of the advances in the project, which include a diagnosis of the challenges and obstacles of prefabricated systems used in construction, obtained from interviews with leaders and actors in the sector, a meta-analysis of barriers and opportunities of the use of concrete prefabrication in other contexts, the development of a typology as an example of an application developed as part of the project development, and finally a software tool to support the proposed case of application.

Keywords: Concrete construction, Prefabrication, Social housing, FEA Analysis, Generative tools

1 Background and Research Problem

The project presented here is the result of an ongoing collaboration between Colombian and UK academic and industrial institutions, with support from the UK's Royal Academy of Engineering. The project addresses a particular challenge in the Colombian construction sector, that of optimizing

concrete construction for social housing applications. By partnering with a larger research project with similar goals, and by involving local industry, this project advanced the state-of-the-art in concrete construction, and is currently building a network group of stakeholders working towards sustainability and economic benefits.

The partner project, titled Automating Concrete Construction (known as ACORN), was a three-year project carried out in the UK by the Universities of Bath, Cambridge, and Dundee, in collaboration with 12 Industry Partners and 14 Industry Affiliates, and funded by "UK Research & Innovation" under the Transforming Construction programme. Its primary objective was to drive acceptance of a new culture in the construction industry, one that embraces the concept of only putting material where it is needed, to enhance sector-wide sustainability and productivity. Its solution was to move concrete production off-site and use computer-controlled robotics and adaptable molds to optimize geometry and reduce material consumption (Oval et. al., 2021). Previous research had shown that it is possible to remove more than 50% of the concrete from a typical office building via this approach (Hawkins, et. al, 2020). The more recent full-scale physical ACORN demonstration (Figure 1) used form-found geometries (Costa et. al, 2020; 2021) to ensure concrete was predominantly used in compression, with therefore minimal bending and reduced reinforcement. This shell-floor needed only 25% of the concrete of an equivalent flat-slab for the same load-case, with only 40% of the embodied carbon.

Figure 1. Robotic thin-shell spraying system and adaptable mold (left) with the resulting final 4.5m span demonstration shell (right)

The aim of the Colombian project detailed in this paper was to explore ways in which the same philosophy might be translated into the very different social and economic contexts of Latin America, with a focus on social housing.

2 Methodology

Three differentiated stages were implemented. The first one, "Planning" involved a literature review of meta-analysis concerning the application of

novel concrete construction technologies in different countries, but also implemented 30 interviews with representatives of Colombian concrete construction stakeholders, namely Developers, General contractors, Structural and design consultants, Manufacturers, Governmental institutions, and Academics working on the specific field. The second stage, “Development”, entailed extensive use of structural simulations in conjunction with economic analyses to select possible design configurations for prefabricated components. It also included the development of an online application and the production of real scale prototypes of the main construction components proposed. Finally, a “Dissemination” stage, currently in progress, includes the execution of a focused conference with local stakeholders, as well as the publication of project results in international conferences.

The planning stage, which defined the scope of the project, yielded the first important result from the analysis of interviews with stakeholders, which determined the advantages of prefabrication using conventional techniques over the employment of more advanced customized digital production processes. However, digital processes were particularly valued as design tools to assist both the designers and final users of the system, i.e., developers.

An expert analysis carried out by the researchers in collaboration with relevant Colombian concrete construction stakeholders, following a material-design framework (Ashby, 2005), highlighted significant aspects of comparison between the UK and the Colombian projects, as seen in Figure 2. Two main characteristics appeared as distinctive and with central consequences on the work to be carried out. Firstly, the repetitive nature of housing projects as opposed to custom office buildings, reinforced by the extreme low budget for social housing as given by the law and the market, but secondly, the high relative cost of digital manufacturing methods and the general lack of specialized production and transportation infrastructure, meant that standard prefabrication had highest potential for development.

	UK PROJECT			COLOMBIA PROJECT
USE	MULTIPLE FUNCTIONS, STRUCTURAL FRAME SYSTEMS	≠	SOCIAL HOUSING IMPLYING LOW COST REQUIREMENTS AND REPETITION	> MID RISE BUILDINGS EMPLOYING MIXED CONSTRUCTION SYSTEMS (OFFSITE + IN-SITU CASTING) TO ALLOW FOR LOCAL SEISMIC REGULATIONS
MATERIAL	HIGH PERFORMANCE CONCRETE, WITH FIBRE REFORCEMENT - CFRC	≠	HYBRID LOW COST MATERIALS, INCLUDING RECYCLED AGGREGATES	> CONFIGURATIONS THAT CAN ALLOW FOR FUNCTIONAL REQUIREMENTS INCLUDING SOUND INSULATION AND THERMAL MASS
SHAPE	STRUCTURALLY OPTIMIZED CONFIGURATION TO REDUCE MATERIAL USE	=	STRUCTURALLY OPTIMIZED CONFIGURATION TO REDUCE MATERIAL USE	> SURFACE ACTIVE ELEMENTS TO ALLEVIATE STRESS CONCENTRATIONS AT JOINTS
PROCESS	AUTOMATED PRODUCTION ALLOWING FOR CUSTOMIZATION	≠	REPETITION AND LOW COST REQUIREMENTS, ALLOWING FOR STANDARD PREFABRICATION	> PANEL SYSTEMS PREFERRED, AS MODULAR SYSTEMS ARE NOT VIABLE DUE TO LACK OF LOCAL TRANSPORTATION INFRASTRUCTURE, AND DO NOT COMPETE WITH LOW WAGES

Table 1. Comparison of projects according to scope and environment.

3 Results

Optimized component configurations were produced from the correlation of Finite Element Analyses with material, production, and estimated costs, which resulted in the fabrication of prototypes, still in progress, and an online design tool to generate possible residential project layouts using the proposed construction system in specific plots of land given by the user is already available.

Though still work in progress, a detailed analysis of the production process as well as testing of prototypes should be available for presentation of the present paper. Additionally, a report of the network group created should also be available for presentation.

The first round of interviews with experts along with an initial literature review indicated five crucial areas to take into account when introducing prefabricated concrete building systems in developing economies, those were: Cultural and information related, Structural and construction regulations related, Functional and architectural related, Onsite- construction management related and Financial and business model related

All of them entailed specific barriers to the introduction of prefabricated concrete systems, as described below.

-Cultural and information related: Lack of clear information (structural, construction, costing) for designers to specify such systems, Lack of qualified labor to build with them.

-Structural and construction regulations related: Joints among components require very specific technical solutions, the current local regulation penalizes de use of such systems

-Functional and architectural related: These systems restrict flexibility in design, require very specific and non-standard design solutions, if completely prefab, do not allow for high rise constructions

-Onsite - construction management related: Local general contractors do not have the infrastructure to build using prefab components, Transportation and storage are perceived as highly problematic in terms of site logistics, Quality control is challenging due to the significance of certain details.

-Financial and business model related: There are not enough suppliers in the market to allow for variety and competitive prices, with specialized-partial suppliers it is difficult to allocate responsibility and provide insurance, Local regulations to tax construction penalize the inclusion of external subcontractors.

The last three areas, however, also indicated specific advantages of such systems.

-Functional and architectural related: Better quality finishes of components, Possible shape complexity of components, Less weight of construction

-Onsite- construction management related: Higher construction productivity implying lower construction time, less waste and better control

-Financial and business model related: Possible economies of scale.

The defined areas were revised with meta-analyses found in literature, including studies previously carried out in India (Verghese & Thomas, 2021),

where all areas were represented, and financial factors appeared with more relevance in terms of barriers, China (Gan et al, 2021), where again all areas were represented, but management aspects had particular relevance, Malaysia (Nawi et al, 2011) where design factors were not taking into account but it was assumed that it may had been due to the supplier emphasis of the research, Australia (Steinhardt et al, 2013), where cultural factors were less important presumably due to a more mature nature of the market, and Egypt (Bakathy & Kalaurachchi, 2020), where all factors were marked as relevant.

Additionally, 30 interviews to representatives of the main local stakeholders (Suppliers, General contractors, Consultants, Academia, Government) were carried out during the first stage of the project, giving further support to the previous analysis as shown below.

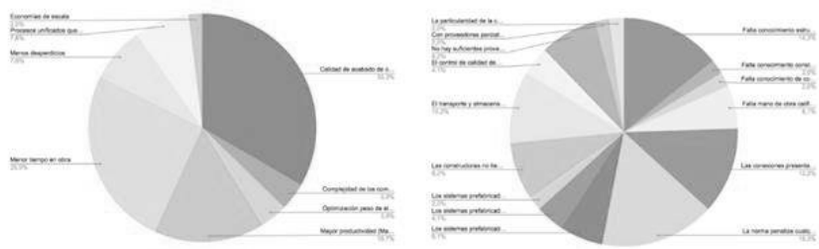

Figure 2. Perceived barriers and advantages of concrete prefabrication for housing in Colombia as resulting from interviews (Color coded by areas - Grey=1, Blue=2 Red=3 Yellow=4 Green=5)

3.1 Structural and production analyses

Based on the results obtained from the interviews and with the aim of implementing prefabricated systems in the mezzanines, an architectural distribution of an apartment tower with 12 levels and 4 bays was proposed, with structural cores at the ends of each apartment, with the objective to provide a large available space that the end user can distribute at their convenience, as shown in Figure 3.

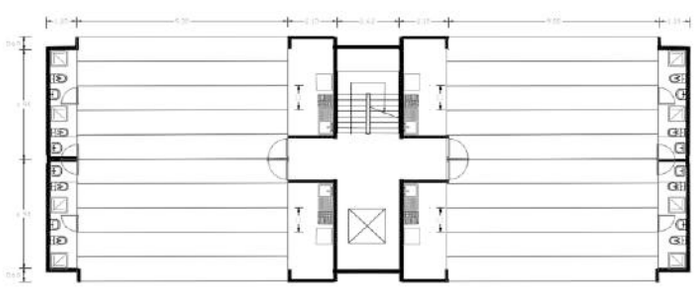

Figure 3. Architectural proposal for an apartment tower

From this architectural distribution without walls within each apartment, the need arises to use prefabricated modular elements that allow saving the length between walls of 9 m, for which a total of 7 prestressed modular mezzanine systems were proposed that would give solution to the developed architectural proposal, these are observed in Table 2.

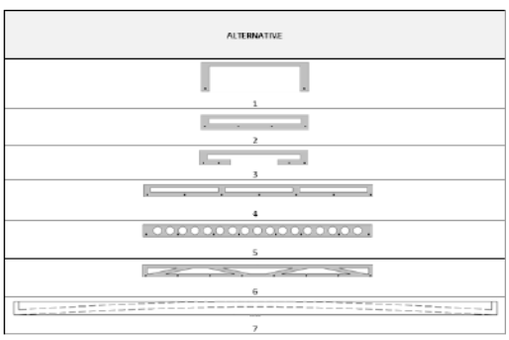

Table 2. Proposed alternatives of modular mezzanine systems

These modular prefabs will be supported by prefabricated elements embedded in the walls, which will make up the wet area of each apartment (bathrooms, kitchen, and laundry area). Similarly, between modular prefabricated elements, a shear connection must be designed to ensure the behavior of the entire mezzanine as a rigid diaphragm.

Due to the fact that in wall-slab systems the slab does not support seismic loads, the prefabricated elements will only support vertical loads, 3.64 kN/m2 for dead load and 1.8 kN/m2 for live load in accordance with NSR-10 depending on their use.

These alternatives were optimized manually based on their dimensions, and the number, diameter and location of their prestress tendons from the SAP2000 software, which allows the use of finite elements and prestress cables, taking as a sample the model of Alternative 1 presented in Figure 4.

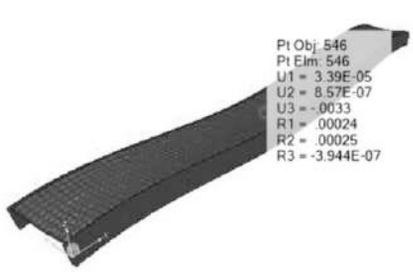

Figure 4. Alternative 1 structural model for maximum deflection in the final stage of service

The optimized sections present the following maximum deflections.

DEFLECTIONS FOR EACH LOAD CONDITION

LOAD CONDITIONS	1. CONSTRUCTION	2. LIFE LOAD			3. LONG TERM
MAXIMUM DEFLECTION	3/4 in (m)	L/360 (m)	INITIAL PRESTRESS	FINAL PRESTRESS	L/480 (m)
ALTERNATIVE	0.020	0.025			0.019
1 - U Section	0.0180	0.0125	0.0026	-0.0033	-0.0059
2 - Box Section	0.0075	-0.0027	-0.0157	-0.0197	-0.0039
3 - C Section	0.0130	0.0030	-0.0202	-0.0250	-0.0048
4 - Composite Box Section	0.0144	0.0073	-0.0171	-0.0209	-0.0037
5 - Alveolar Section	0.0176	0.0067	-0.0169	-0.0247	-0.0079
6 - Truss Section	0.0136	0.0047	-0.0182	-0.0250	-0.0068
7 - Curved Section	0.0187	0.0084	-0.0125	-0.0222	-0.0097

Note: Negative deflections indicate sag deflection and positive deflections countershaft

Table 3. Maximum deflections in each load condition

Having optimized the different alternatives, an analysis of alternatives was carried out to determine the optimal option based on the following parameters:

Material Cost: Corresponds to the total cost of concrete and prestressing steel necessary to build the mezzanine system with the proposed section, measured in COP.

Manufacturing Cost: This includes the cost of the skilled labor required to manufacture the element, the space, the formwork, the prestressing equipment, the time and the minor tool required, measured in COP.

Transportation Cost: Approximate cost of transporting the element from the Prefabricated Plant to the city of Bogotá, measured in COP.

Placement Cost: Cost involved in placing the element on site, includes labor, crane service to the highest floor of the tower and material for anchoring between elements, measured in COP.

Cost of Walls: Cost associated with the additional height of construction of walls necessary for the implementation of the mezzanine.

Acoustic insulation: Evaluates the difficulty generated by the precast to a wave that crosses the mezzanine system.

CO2 emissions: Evaluates the amount of CO2 emissions that would be generated on average with the manufacture, transport, and placement of prefabricated elements.

The total cost of implementing the mezzanine has an influence of 75% on the final score, acoustic insulation of 15% and CO2 emissions of 10%.

MATERIAL COST

ID	CONCRETE VOLUME (M3)	MODULES PER APARTMENT	PRESTRESSED TENDONS	CONCRETE COST ($)	STEEL WEIGHT (KG)	STEEL COST ($)	TOTAL COST ($)	SCORE
FE-UI	4.09	5	2 x 0.6"	$ 1,896,257	104.4	$ 819,579	$ 2,715,836	3.7
FE-CR	5.61	5	4 x 0.5"	$ 2,601,841	147.2	$ 1,155,607	$ 3,757,448	2.7
FE-CI	4.23	5	4 x 0.5"	$ 1,962,638	147.2	$ 1,155,607	$ 3,118,244	3.2
GF-CR	5.53	2	7 x 0.6"	$ 2,566,562	146.2	$ 1,147,411	$ 3,713,973	2.7
GF-AL	5.3	2	8 x 0.6"	$ 2,460,724	167.0	$ 1,311,327	$ 3,772,051	2.7
GF-CH	5.34	2	8 x 0.6"	$ 2,478,364	167.0	$ 1,311,327	$ 3,789,691	2.6
GF-BV	8.17	1	16 x 0.6"	$ 3,792,514	167.0	$ 1,311,327	$ 5,103,841	2.0

Table 4. Material Costs of the Proposed Alternatives

The cost of the materials required for its construction is initially determined, which are shown in COP in Table 4.

In the same way, the costs associated with manufacturing in the plant, transport, and placement of the prefabricated element in its final disposal were defined, obtaining the associated costs and scores observed in Table 5.

ANALYSIS OF ALTERNATIVES - COST AND SCORES

ID	MANUFACTURING COST	MANUFACTURING SCORE	TRANSPORTATION COST ($/100 km)	TRANSPORTATION SCORE	PLACEMENT COST	PLACEMENT SCORE
FE-UI	$ 1,750,805	2.9	$ 391,667	2.6	$ 1,385,566	2.9
FE-CR	$ 2,982,325	1.7	$ 341,667	2.9	$ 1,118,360	3.6
FE-CI	$ 2,880,125	1.7	$ 333,333	3	$ 1,118,360	3.6
GF-CR	$ 2,915,394	1.7	$ 303,333	3.3	$ 1,293,554	3.1
GF-AL	$ 4,442,452	1.1	$ 303,333	3.3	$ 1,293,554	3.1
GF-CH	$ 4,442,452	1.1	$ 303,333	3.3	$ 1,293,554	3.1
GF-BV	$ 3,986,518	1.3	$ 816,667	1.2	$ 1,590,281	2.5

Table 5 Manufacturing, transportation and placement costs and scores

Adding some other criteria such as acoustic insulation, the need to increase the height of walls and CO2 emissions, the final analysis scores for each alternative were obtained, as shown in Table 6.

ANALYSIS OF ALTERNATIVES - TOTAL SCORE

ID	MANUFACTURING SCORE	TRANSPORTATION SCORE	PLACEMENT SCORE	ACOUSTIC ISOLATION	WALL HEIGHT NEED	CO_2 EMISSIONS	COST OF SUPPLIES	COST SCORE	WEIGHTED OVERALL SCORE	SCORE %
FE-UI	2.9	2.6	2.9	1	2	3.7	3.7	4.5	3.87	77%
FE-CR	1.7	2.9	3.6	3	3.9	2.7	2.7	4.2	3.88	78%
FE-CI	1.7	3	3.6	1.5	3.9	3.2	3.2	4.3	3.78	76%
GF-CR	1.7	3.3	3.1	3	3.9	2.7	2.7	4.2	3.84	77%
GF-AL	1.1	3.3	3.1	3.5	3.9	2.7	2.7	3.2	3.2	64%
GF-CH	1.1	3.3	3.1	4	3.9	2.6	2.6	3.2	3.27	65%
GF-BV	1.3	1.2	2.5	4	2.4	2	2	2.9	2.95	59%

Table 6. Total Scores per Alternative

Finally, alternatives 1 and 2 were chosen as the ones that obtained the highest score within the analysis of alternatives, however, Alternative 1 was chosen as the most viable since Alternative 2 requires the use of a lost form for its construction, which would increase production costs significantly.

ANALYSIS OF ALTERNATIVES

ID	WEIGHTED OVERALL SCORE	SCORE %
FE-UI	3.87	77%
FE-CR	3.88	78%
FE-CI	3.78	76%
GF-CR	3.84	77%
GF-AL	3.2	64%
GF-CH	3.27	65%
GF-BV	2.95	59%

Table 7. Final Scores per Alternative

Once the optimal section was defined for the specific case of application, a production process was proposed in two phases: the first consisted of the manufacture of a scale prototype that allowed studying the manufacturing process of the element, and the testing of its supports and connections, which is shown in Figure 5.

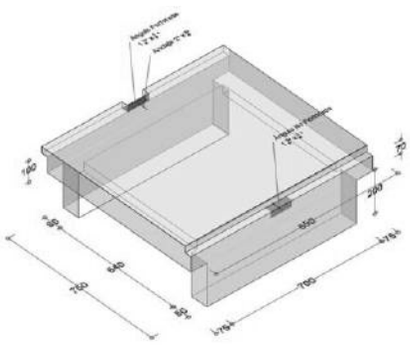

Figure 5 Proposed Prototype Isometric

The full-scale model has the same characteristics as the prototype, but with a width of 1.1 m and a length of 9 m, as shown in Figure 6.

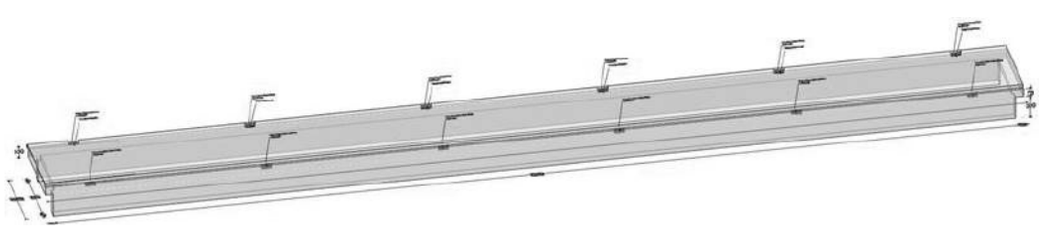

Figure 6. Isometric of mezzanine module

3.2 Online tool

The online application was developed and deployed with two primary aims; first to prototype a computational framework that enabled the generation of residential layouts, and second to develop a user interface that provides affordance to a diverse range of users to access workflows made using the framework.

The framework produces massing models that can be queried for basic programmatic data and evaluated according to a measure of access to natural light in the residential units. The primary parameter in the generative process is the precast unit defined above and how this is used to determine the archetypal floor plate (figure 3). The system is designed as an extensible

framework into which different layout methods and analysis modules can be added.

The code base for the tool was developed as a Toolkit for the BHoM Framework(ref) using c# .net. This same Toolkit is leveraged by a Blazor (https://docs.microsoft.com/en-us/aspnet/core/blazor/?view=aspnetcore-6.0) + three.js(https://threejs.org/) web framework that defines an online generative platform with three-dimensional output. The BHoM Framework is software agnostic and provided developers follow basic architectural principles the code is available as visual programing components within the Grasshopper3d (https://www.grasshopper3d.com/), dynamo(https://dynamobim.org/) interfaces and as functions in Excel (https://www.microsoft.com/en-ie/microsoft-365/excel). Users already confident with one of the BHoM user interface applications may therefore use the project tools in a non-web environment (https://github.com/rolyhudson/TSP_Toolkit).

A BHoM Toolkit requires an object model with classes containing properties only and a set of object modifier functions located in higher level classes according to the modification performed. This architecture means initial functional testing and development can be performed in one of the typical BHoM user interface platforms (such as Grasshopper3d) before using the framework within a web platform. Where higher-level functions were needed for the web interface, we simply created new functions that wrapped a series of lower-level modular elements. This wrapping provides direct and simplified access to complex workflows to users who do not want or are not interested in understanding the lower-level functionality of the system.

Within the scope of the project, we developed three specific layout modules (bar, parameter and hybrid) and the ability to configure facilities block that includes parking, social and communal spaces. The bar layout (Figure 7) takes a principal direction and generates collinear blocks. The height of the blocks is configured to try and minimize overshadowing between blocks. The perimeter layout (Figure 8) creates blocks of apartments that run parallel to the site boundary.

The hybrid layout combines the bars and perimeter layouts. The facilities block responds to the total number of apartments on the site as this determines the number of parking spaces and area of commercial and communal space. A maximum number of floors constraints the facilities block vertically, and the site boundary and surrounding apartments constrain it horizontally. A basic solver attempts to seek a working combination of the maximum number of apartments and permitted valid volume to contain the required facilities.

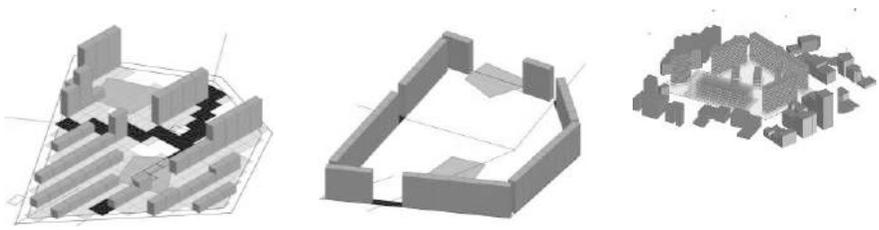

Figure 7. Bars layout method. Road network is shown in black and open areas in dark green, Perimeter layout method and Hybrid mode including facilities block

The underlying approach for both layout methods operates on a voxel space that is defined by the base units of the archetypal floor plate. The user provides geometry defining a site boundary, road networks, open areas and facilities parameters. Based on this a grid is generated within the boundary, grid cells intersecting roads or within open areas are tagged as not available for development. Space required for the facilities block is determined (or initialized in the first iteration). The perimeter layout fills all available grid cells along the boundary with units. The bars layout method follows a growth algorithm where each block ground plan is determined by 'growing' incrementally at either end. Each bar tracks its own curtilage and later bars are blocked from developing too close together.

The daylight access assessment module is a quantitative and comparable measure. Users define the latitude of the site and a set of points on the annual sun path model is created. Rays from the façade of each apartment and each of the sun points are cast, any ray occluded by the surrounding blocks causes the daylighting score to be reduced by one point. Results of this analysis were represented using a colour scale to render the units (Figure 10).

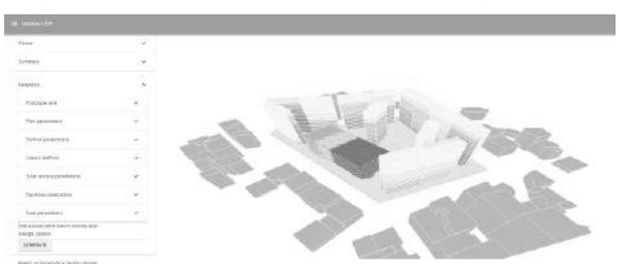

Figure 8. View of the online application (apartments coloured after daylight analysis)

References

Ashby, M. F. (2005). Materials selection in mechanical design. Amsterdam: Butterworth-Heinemann.

Mohd Nawi, Mohd Nasrun & Lee, Angela & Nor, K. (2011). Barriers to Implementation of the Industrialised Building System (IBS) in Malaysia. The Built & Human Environment Review. 4.

Wuni, Ibrahim & Shen, Geoffrey. (2020). Barriers to the adoption of modular integrated construction: Systematic review and meta-analysis, integrated conceptual framework, and strategies. Journal of Cleaner Production. 249. 1-17. 10.1016/j.jclepro.2019.119347.

Gan, X., Chang, R., Zuo, J., Wen, T., & Zillante, G. (2018). Barriers to the transition towards off-site construction in China: An Interpretive structural modeling approach. Journal of Cleaner Production, 197(1), 8-8. https://doi.org/10.1016/j.jclepro.2018.06.184

Alan Verghese Ittyeipe & Anu V. Thomas (2021) "Barriers to Adoption of Precast Concrete Construction in Buildings", International Web Conference in Civil Engineering for a Sustainable Planet, Habilete Learning Solutions, India in association with American Society of Civil Engineers (ASCE), TKM College of Engineering, Kollam, and Baselios Mathews II College of Engineering, March 5-6, 2021

Erwin Hofman, Hans Voordijk & Johannes Halman (2009) Matching supply networks to a modular product architecture in the house-building industry, Building Research & Information, 37:1, 31-42, DOI: 10.1080/09613210802628003

Samad, Taimur, Nancy Lozano-Gracia, and Alexandra Patman, eds. 2012, Colombia Urbanization Review: Amplifying the Gains from the Urban Transition. Directions in Development. Washington, DC: World Bank. doi:10.1596/978-0-8213-9522-6

Hawkins, W., Orr, J., Ibell, T. & Shepherd, P., 2020, “A Design Methodology to Reduce the Embodied Carbon of Concrete Buildings using Thin-shell Floors”, Engineering Structures, 207, 110195, doi:10.1016/j.engstruct.2020.110195 accessed June 2022.

Costa, E., Oval, R., Shepherd, P. & Orr, J., 2021, “Fabrication-aware parametric design of segmented concrete shells”, International Conference on Spatial Structures (IASS) 2021, Available online from https://automated.construction/s/IASS2020-21-SURREY7_DES.pdf

Oval, R., Costa, E., Nuh, M., Thomas-McEwen, D., Orr, J. & Shepherd, P., 2021, “A path towards the off-site automated fabrication of segmented concrete shells for building slabs”, International Conference on Spatial Structures (IASS) 2021, Available online from https://automated.construction/s/IASS2020-21-SURREY7_FAB.pdf accessed June 2022.

Costa, E., Shepherd, P., Velasco, R., Hudson, R., 2020, “Automating Concrete Construction: Sustainable social housing in Colombia”, Sociedad Iberoamericana de Gráfica Digital (SiGraDI 2020).

Aouf, R. S., 2022, “New concrete vaulted floor suggests path to cutting carbon emissions”, Dezeen, available online from https://www.dezeen.com/2022/03/04/concrete-vaulted-floor-suggests-path-to-cutting-carbon-emissions/ accessed June 2022.

NSR-10, 2010. Norma de diseño Sismo Resistente colombiana.

Interactions & Collaborations: User Experience

Microinteractions study in user experience: a systematic literature review of research perspectives

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Abstract. To broaden the understanding of what has been studied on the topic of microinteractions in human-computer interaction, this article conducts an exploratory study to survey the scientific production in articles and dissertations that work with the microinteractions framework, by Saffer (2013), applied to the scope of the user experience. As a method, a systematic literature review is proposed. For this, the following scientific bases are used: Scopus Elsevier, Capes Periodicals, EBSCO and Proquest. From the perspective of design and human-computer interaction, the quantity and approaches used are investigated. Of the 731 scientific works found, 14 were filtered and selected to compose the panorama of scientific research in microinteractions. The article brings the main approaches used in microinteractions research that focus on user experience in the last decade and points out perspectives on how to investigate microinteractions in future academic research.

Keywords: User experience, Microinteractions, Human-computer interaction, Systematic review, UX.

1 Introdução

Ao desenhar e desenvolver produtos interativos há que se pensar em maneiras de iterar e constantemente aprimorar a experiência do usuário (UX). A experiência é, possivelmente, um dos fatores de diferenciação mais contundentes entre produtos concorrentes, uma vez que ambos tenham a capacidade de entregar a funcionalidade principal proposta. A experiência do usuário é composta por dimensões que integram tanto a usabilidade (Nielsen, 1993) de um produto e suas qualidades pragmáticas quanto a emoção (Norman, 1988; 1993; 2004) que o produto desperta e suas qualidades hedônicas (Hassenzahl, 2008; Hassenzahl et al., 2010). Sendo assim, a UX de um produto, de modo global, leva em consideração uma gama de fatores e momentos de interação com uso e não-uso dentro de uma faixa temporal em relação com o produto ou sistema.

São muitas as fases e etapas de desenvolvimento de produtos interativos que levam em consideração a UX. Em estágios mais avançado do desenvolvimento, quando todas as definições de alto nível já estão descritas, definidas, bem como seus requisitos, chega-se ao nível da interface e da usabilidade, onde são materializadas as microinterações.

Parte das interações sob o escopo da Interação Humano Computador (HCI) são consideradas microinterações. Elas englobam uma gama que vai desde o *status* do sistema, passando por suporte e prevenção de erros e até a comunicação com usuário. Microinterações são pares de gatilho-*feedback* em que o gatilho pode ser uma ação do usuário ou uma alteração no próprio sistema, o *feedback* por sua vez é a resposta do sistema ao gatilho que é então contextualizada ao usuário, geralmente com uma mudança visual na interface, podendo ou não modificar alguma regra ou *loop* do sistema.

1.1 Microinterações

Um dos trabalhos pioneiros a trazer o conceito de microinterações ainda em fase inicial é do autor Ashbrook (2010) que define o termo como interações entre usuário e sistema que sejam breves e possam ser completadas em no máximo quatro segundos. Essa definição ainda é amplamente utilizada em trabalhos focados exclusivamente em ergonomia física. Um conceito mais amplo, elaborado por Saffer (2013), é adotado neste trabalho, pois considera a ergonomia cognitiva da interação em adição da funcionalidade da microinteração no sistema.

De maneira mais aprofundada, o autor Dan Saffer (2013) explica que as microinterações podem ser decompostas em uma estrutura de quatro partes. O gatilho, que pode ser uma ação humana (ou do próprio sistema), a regra que define o que aquele gatilho representa, o *feedback* que é a resposta do sistema e o modo/*loop*, que determina se há uma mudança a partir daquela interação, se ela modifica alguma regra ou se ela se repete. Essa estrutura pode ser aplicada em diferentes interações, no entanto é preciso destacar que as microinterações são interações de propósito único e em geral estão conectadas diretamente com a usabilidade do sistema. Elementos que estão sempre visíveis na interface não são microinterações, assim como fluxos compostos por múltiplas ações também não são microinterações.

Algumas utilizações de microinterações podem ser relacionadas com heurísticas de usabilidade. Uma delas tem como foco a visibilidade do *status* do sistema. Uma microinteração que comunica o estado atual do sistema possui como gatilho qualquer mudança no sistema que então comunica ao usuário seu *status*. Um sistema que comunica seu *status* dá ao usuário a sensação de empoderamento e controle. Outro exemplo de heurística seria em relação à prevenção de erros. Em um formulário de *password* ao digitar a senha, o formulário pode mudar de cor indicando se a senha cumpre os requisitos para aquela aplicação, e por consequência, diminui a frustração do usuário ao tentar senhas que o sistema não permite.

As microinterações adquirem funções claras ao estarem alinhadas com heurísticas de usabilidade, mantendo o usuário informado e engajado. Apesar de sua brevidade são mais do que "detalhes" e sem eles a UX sofre as consequências. Microinterações, quando utilizadas de forma apropriada, transparecem sinais de cuidado com o usuário final, onde cada pequena interação pode despertar um sentimento positivo.

1.2 Experiência do usuário (UX)

De acordo com Hassenzahl, a abordagem da experiência do usuário é direcionada com foco no desenho da experiência e na qualidade de preencher as necessidades psicológicas dos usuários. Necessidades que incluem popularidade, autonomia, estímulo, dentre outras questões, e carregam consigo um meio para incutir significado e felicidade na utilização dos produtos. Sua proposta é descobrir "padrões de experiência" em atividades humanas que possam derivar práticas de satisfação das necessidades psicológicas (Hassenzahl et al., 2010).

O conceito de experiência do usuário inclui dois elementos-chave que são a experiência do significado (qualidade pragmática e usabilidade) e a experiência da emoção (afeição e qualidade hedônica). A usabilidade, por sua vez, é amplamente estudada e compreendida no campo da Interação Humano-Computador (IHC), do *design* e da ergonomia. Além de garantir as necessidades funcionais da usabilidade é necessário gerar um efeito positivo, emocional, que relacione a experiência com elementos de sucesso, popularidade, alegria entre outras sensações positivas. O estímulo positivo resultante da experiência é o elemento-chave da qualidade hedônica (Hassenzahl et al., 2010).

A experiência do usuário (UX) permite uma gama de critérios e demanda cuidados especiais na avaliação dos produtos interativos. Por assim dizer, a avaliação da UX torna-se mais complexa ao mesmo tempo em que também aumenta significativamente sua importância. Além de apenas considerar a utilização de um produto interativo a experiência influencia também se o usuário vai retornar a utilizar e possivelmente tornar sua utilização algo recorrente.

A partir disso, os avanços da tecnologia combinados com os conhecimentos disponíveis em ciências cognitivas, psicossociais e reações psicofisiológicas, podem de fato expandir os conceitos e a aplicação do campo da experiência do usuário. As possibilidades tornam-se muito maiores ao permitir explorar e mensurar, potencialmente, as emoções dos usuários durante sua utilização. Essa contribuição é otimizada e aplicada nas diversas etapas de desenvolvimento iterativo de um produto, serviço ou sistema.

Com base nos conceitos apresentados este artigo objetiva um estudo exploratório. Buscando, por meio de um levantamento da produção científica, estudos que utilizam os conceitos expostos de microinterações direcionados à experiência do usuário.

2 Metodologia

O desenvolvimento desta pesquisa utilizou-se de uma Revisão Sistemática da Literatura (RSL) (Levy, Ellis, 2006) como processo metodológico. Com o objetivo de elucidar a paisagem da produção científica que compreende as relações entre estudos que utilizam microinterações e experiência do usuário publicados a partir de 2012. A observação de publicações científicas na última década utilizou as bases de dados Scopus (Elsevier), Periódicos Capes, EBSCO e Proquest Dissertations & Thesis. A RSL resultou em um total de 731 trabalhos, somadas as quatro bases de dados. A pesquisa foi feita entre os dias 19 de maio e 1º de junho de 2022. A Tabela 1 mostra as linhas de comando (*strings*) que foram utilizadas nas buscas em cada uma das bases de dados. Ao todo foram realizadas cinco buscas pois na base Periódicos Capes fez-se a pesquisa por trabalhos em português e em inglês.

Tabela 1. Comandos de Busca (*strings*) com respectivos filtros e bases de dados

Scopus	**TITLE-ABS-KEY(“microinteractions”)**
Periódicos Capes (PT)	**“microinterações”**
Periódicos Capes (EN)	**“microinteractions”**
EBSCO	**"microinteractions" (Todos os campos) and "interface" (Todos os campos) Data de publicação: (2012-2022)**
Proquest Dissertations & Thesis	**"microinteractions" (Todos os campos) Data de publicação: (2012-2022)**

Fonte: Autor, 2022.

A opção por adicionar outras palavras de busca além de microinterações demonstrou um número de resultados muito pequenos e seriam necessárias muitas *strings* para compor o panorama. Por conta da natureza multidisciplinar dos estudos que se utilizam de microinterações os pesquisadores utilizaram uma *string* mais abrangente e uma estratégia de executar um trabalho mais efetivo durante a filtragem.

Após a coleta inicial nas plataformas foi utilizado o *software* de gerenciamento bibliográfico EndNote 20.2 para organizar as cinco buscas, agrupar os resultados, excluir duplicatas e aplicar os filtros de seleção.

No primeiro filtro, foram excluídos artigos que não tinham relação com o campo do Design, da Ergonomia e da Interação Humano-Computador (Boy, 2011; Rogers et al., 2011). O segundo filtro selecionou trabalhos que consideram aspectos de ergonomia cognitiva a partir do framework de Saffer (2013) e excluiu trabalhos que contemplam apenas a perspectivas de

ergonomia física. O terceiro filtro selecionou trabalhos que analisam a experiência do usuário e, por fim, o quarto filtro trouxe como resultado os estudos selecionados para apresentação e discussão neste artigo, como mostra a Tabela 2.

Tabela 2. Bases de dados, filtragem e resultados quantitativos

Base de Dados	**Resultados *String***	**Filtro 01 Resultados**	**Filtro 02 Resultado**	**Filtro 03 Resultados**	**Filtro 04 Resultados**
Scopus (Elsevier)	60	25	14	9	9
Periódicos Capes (PT)	13	0	0	0	0
Periódicos Capes (EN)	362	37	13	4	3
EBSCO	160	44	19	2	0
PROQUEST D&T	136	24	5	3	2

Fonte: Autor, 2022.

No total, dos 731 materiais encontrados, foram filtrados e selecionados 14 trabalhos científicos para apresentação, discussão e exploração das relações entre os campos das microinterações e da experiência do usuário.

A natureza multidisciplinar dos estudos em microinterações revelou durante a triagem a utilização do termo microinterações em muitos contextos externos a essa pesquisa. As diferentes ontologias atuaram como critérios excludentes. A exemplo: microeconomia, microbiologia, microssociologia, energia nuclear e explosões, engenharia química, direito e música. O que justifica um número relativamente pequeno de estudos em comparação com a coleta inicial anterior aos filtros. Após a apresentação dos resultados a discussão, posteriormente, traz uma análise crítica dos trabalhos.

3 Resultados

Dentre os 14 trabalhos selecionados, foram identificadas três abordagens principais, sendo elas: o teste com usuários (*user testing*), a análise de interface (*UI analysis*) e o desenvolvimento de diretrizes de *design* (*Design Guidelines*). O exposto demonstra apenas de maneira descritiva o número de ocorrências sem qualquer pretensão de inferência estatística. As abordagens podem ser visualizadas graficamente na Figura 1.

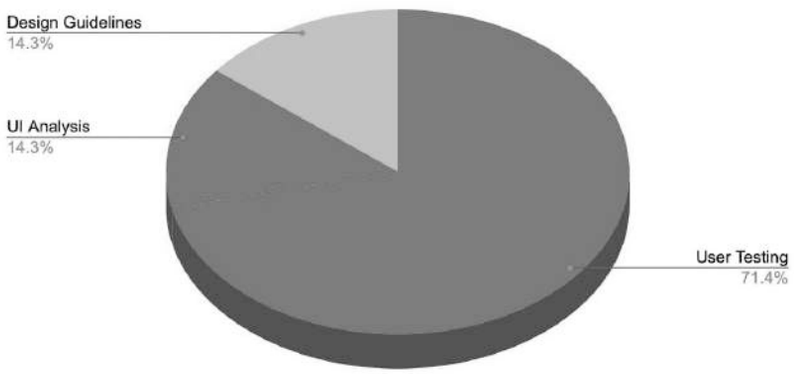

Figura 1. Descrição de abordagens utilizadas nos estudos. Fonte: Autor, 2022**.**

Considerou-se, de acordo com a sequencia de filtros, publicações que participam do campo do Design, da Ergonomia Cognitiva e da HCI, que reconhecem microinterações a partir do *framework* de Saffer (2013) e que estejam relacionados com a experiência do usuário. Na Tabela 3, são apresentados os trabalhos selecionados, os autores, o ano e o tipo de material.

Tabela 3. Resultado da filtragem final com trabalhos selecionados.

	Título	**Autores**	**País**	**Ano**	**Tipo**
01.	**Evaluating user perception and emotion of microinteractions using a contradictory semantic scale**	Jia Yang Ma,Chun-Ching Chen	Taipei, Taiwan	2022	Artigo Journal
02.	**User Burden of Microinteractions: An In-lab Experiment Examining User Performance and Perceived Burden Related to In-situ Self-reporting**	Xinghui Yan, Yuxuan Li, et al.	Toulouse, França	2021	Artigo Conferência
03.	**User testing with microinteractions**	Sara Gonzales, Matthew B. Carson, et. al.	Chicago, EUA	2021	Artigo Journal
04.	**Microinteractions of Forms in Web Based Systems Usability and Eye Tracking Metrics Analysis**	Julia Falkowska, Barbara Kilijańska, et. al.	Warsaw, Polônia	2019	Paper Conferência

05.	**Designing Outrage, Programming Discord: A Critical Interface Analysis of Facebook as a Campaign Technology**	Jennifer Sano-Franchini	Virginia, EUA	2018	Artigo Journal
06.	**Low-Investment, Realistic-Return Business Cases for Learning Analytics Dashboards: Leveraging Usage Data and Microinteractions**	Tom Broos, Katrien Verbert, Et. al.	Leuven, Bélgica	2018	Paper Conferência
07.	**Microinteractions and a Gamification Framework as a Mechanism for Capturing 21st Century Skills**	Evangelos Kapros, Kathy Kipp	Dublin, Irlanda	2016	Paper Conferência
08.	**Microinteractions in Mobile and Wearable Computing**	Markus Aleksy, Jonas Bronmark, et. At.	Crans-Montana, Suiça	2016	Paper Conferência
09.	**Design Principles of Hand Gesture Interfaces for Microinteractions**	Ivan Golod, Felix Heidrich, et. At.	Aachen, Alemanha	2019	Paper Conferência
10.	**Understanding the Effect of Animation and its Speed on User Enjoyment**	Kusum Ijari	Arizona, EUA	2019	Dissertação
11.	**Determining the Optimum Duration of User Interface Animation in Microinteraction Design: Comparing Mouse vs. Touch Input**	Motian Wang	Filadélfia, EUA	2018	Dissertação
12.	**Communicative Functions in Human-Computer Interface Design: A Taxonomy of Functional Animation**	Raquel Avila-Munoz, Jorge Clemente-Mediavilla	Madrid, Espanha	2021	Artigo Journal
13.	**Improving Interactive User Experience with Microinteractions: an Application of Biometric and Affect Detection Systems on Landing Pages**	Rupert Reyneke	Massachusetts, EUA	2019	Dissertação
14.	**Self-Archiving with Ease in an Institutional Repository: Microinteractions and the User Experience**	Sonya Betz, Robyn Hall	Edmonton Canada	2015	Artigo Journal

Fonte: Autor, 2022.

Com maior número de ocorrências, a utilização de testes com usuário se demonstra como metodologia de utilização mais ampla para abordar microinterações em pesquisas de experiência do usuário. Já abordagens

relacionadas à análise de interface e desenvolvimento de diretrizes de design, ainda que gerem uma contribuição para o campo, não possuem o elemento crucial da UX que é a participação e percepção do usuário em relação a um produto ou sistema.

4 Discussão

De acordo com os resultados selecionados para compor a paisagem dos estudos que relacionam microinterações e experiência do usuário, é possível destacar uma série de perspectivas que contribuem para pesquisas futuras. Um item que fica bastante claro é que a maioria dos estudos se apoia em testes com usuários (*user testing*) seja com o produto ou sistema final ou com o suporte de protótipos desenvolvidos apenas para determinado estudo.

Dentre os dez trabalhos que fazem experimentos e pesquisas diretamente com usuários, apenas três deles se utilizam de coleta de dados psicofisiológicos e/ou biométricos. O trabalho "*Microinteraction of Forms In Web Based System Usability And Eye Tracking Metric Analysis*" (Falkowska et al., 2019) utiliza o *eye tracking* e explica algumas limitações devido à dificuldade de configuração do equipamento, que porventura, ocasionou perda de alguns dados, reduzindo sua amostra durante o experimento. Mesmo com ressalvas, os pesquisadores acreditam que uma combinação de métodos que utilize dispositivos de rastreamento ocular agrega dados interessantes aos experimentos. Já o *paper* de conferência: "*Design Principles of Hand Gesture Interfaces for Microinteractions*" (Golod et al., 2013) utiliza sensores de captura de movimento infravermelho (*PIR Motion Sensors*) para observar tensão muscular e fatiga na interação com o protótipo de menu gestual com microinterações. O trabalho mais completo a se utilizar de capturas biométricas é a dissertação: "*Improving Interactive User Experience With Microinteractions: And Application of Biometric and Affect Detection Systems on Landing Pages*" (Reyneke, 2019). O autor da dissertação utiliza uma combinação de coleta com rastreamento ocular (*Eye-tracking*), atividade eletrodérmica (*Galvanic Skin Response*) e leitura de expressões faciais via *software* (*Imotion*).

Já o artigo: "*Evaluating User Perception and Emotion of Microinteractions Using a Contradictory Semantic Scale*" (Yang-Ma: Chen, 2022) consegue fazer um tratamento estatístico relacionado à percepção emocional da interação a partir de escalas de diferencial semântico. A inferência na experiência do usuário se dá a partir de 16 escalas de diferencial semântico que servem de instrumento para avaliar a interação com uma interface que contêm microinterações. De acordo com os autores, há uma correlação direta entre a microinteração e movimento dos objetos nas interfaces. O equilíbrio entre uma interface estática e o movimento promove satisfação emocional no nível psicológico. Microinterações visualmente apropriadas são efetivas ao

promover conforto e identificação, estimulando positivamente as emoções e mantendo o usuário mais tempo engajado (Yang-Ma: Chen, 2022).

Em uma corrente similar, três trabalhos correlacionam microinterações diretamente com a animação em interfaces. O artigo: "*Communicative Functions in Human-Computer Interface Design: a Taxonomy of Functional Animation*" (Munoz; Mediavilla, 2021) propõe uma taxonomia para animações funcionais. Fica bastante claro desde o *framework* de microinterações proposto por Saffer (2013) que sendo uma animação ou não a microinteração deve sempre estar alinhada à uma funcionalidade no sistema ou interface. Além deste, outros dois trabalhos de dissertação utilizam animações em interfaces como conceito intercambiável com microinterações, são eles: "*Determining the Optimum Duration of User Interface Animation in Microinteraction Design: Comparing Mouse vs. Touch Input*" (Wang, 2018) e a dissertação: "*Understanding the Effect of Animation and its Speed on User Enjoyment*" (Ijari, 2019). Ambos os trabalhos investigam questões relacionadas à duração das animações dentro de microinterações, no entanto Ijari (2019) conclui que os usuários de sua amostra, em grande parte, não perceberam a diferença na velocidade das animações entre seus protótipos. Sem uma diferenciação significativa por parte dos usuários, o autor destaca que é necessário delimitar o papel funcional (pragmático) da animação antes do desenvolvimento, uma vez que o tempo desprendido e o custo para implementação de animações de curta duração em *softwares* costuma ser bastante alto.

Já Wang (2018) não aborda apenas a duração das animações mas também outras dimensões relacionadas ao tipo de animação e de interface em um estudo comparativo. O autor pontua que animações curtas devem ter entre 0.2 e 0.6 segundos, animações grandes devem ficar entre 1 e 2 segundos e recomenda que nenhuma animação de interface tenha mais de 2 segundos. De modo geral, a utilização de animações em interfaces aprimora não só o nível estético, mas também o nível da usabilidade (Wang, 2018). Considera também animações de interface que não sejam funcional ou tenham cunho apenas estético não configuram microinterações.

Outro grupamento possível de ser feito são trabalhos que investigam sistemas de biblioteca e repositórios institucionais, 2 dos 14 trabalhos utilizam como objeto microinterações presentes em interfaces de biblioteca. "*User testing with microinteractions"* (Gonzales et al., 2021) destaca a qualidade das microinterações a partir da perspectiva da usabilidade. Motivado pela dificuldade na utilização dos repositórios institucionais, a partir da percepção de carga cognitiva e trabalho extra na limpeza, inserção e catalogação dos títulos. O estudo conclui que funções únicas, mesmo que pequenas, fazem grande diferença na percepção e na motivação dos usuários ao utilizar sistemas de bibliotecas.

A conclusão vai ao encontro do trabalho: "*Self-Archiving with Ease in na institutional Repository: Microinteractions and the User Experience*" (Betz; Hall, 2015) que destaca breves interações fazendo grandes diferenças na

percepção de UX. As autoras ainda afirmam que a utilização do *framework* de microinterações de Saffer (2013) é bastante adequada para a observação e teste de usabilidade de interfaces. No entanto, segundo elas, o sucesso de um repositório institucional não pode ser somente baseado em uma interface amigável, esteticamente adequada ou uma boa UX. Há outros fatores institucionais que desempenham no engajamento com o repositório. De todo modo, estudos com usuário possuem a capacidade de oferecer *insights* qualitativos para o desenvolvimento, implementação e aprimoramento da usabilidade do sistema.

Uma perspectiva adicional utilizada pelos trabalhos acadêmicos é a da carga cognitiva. Yan et al. (2021) e Kapros e Kipp (2016) observam o grau de intrusividade da interação de modo que ela não interrompa a atividade do usuário, assim promovendo microinterações que tenham uma baixa carga cognitiva. Uma das ferramentas utilizadas para mensuração da carga cognitiva no trabalho é o NASA-TLX, publicado em *"User Burden of Microinteractions: an In-Lab Experiment Examining User Performance and Perceived Burden Related to In-situ Self-reporting"* (Yan et al., 2021).

Outras correntes são a da análise de interfaces (*UI analysis*) e da proposição de diretrizes (*guidelines*) para o *design* e desenvolvimento de interfaces. Franchini (2018) e Aleksy et al. (2016) utilizam análise de interfaces. O primeiro trabalho tem como foco a interface da plataforma *Facebook,* enquanto o segundo analisa diversas interfaces e propõe sugestões de microinterações adaptadas para diferentes modalidades, incluindo realidade aumentada.

5 Considerações Finais

O panorama dos trabalhos demonstra congruência em pontuar que microinterações, quando desenvolvidas de forma adequada e alinhadas às funcionalidades de um sistema ou interface agregam valor tanto na sua usabilidade quanto na sua experiência de uso. O impacto das microinterações, mesmo que breve, é percebido (Reyneke, 2019) e contribui com a percepção geral do artefato (Betz; Hall, 2015; Gonzales et al., 2021). O cuidado com a utilização de microinterações deve, principalmente, ser sua relação direta com uma funcionalidade do sistema. Outra preocupação a ser considerada é o grau de intrusividade que uma microinteração pode gerar (Yan et al., 2021). Dado que microinterações podem atuar de modo negativo na percepção e usabilidade de um sistema se utilizadas de modo equivocado.

Esta pesquisa, portanto, avança em direção à fundamentação, alicerce e grupamento de estudos que abordam microinterações, especificamente na experiência do usuário. Na medida em que a origem das pesquisas que abordam microinterações é dispersa e multidisciplinar tal grupamento se faz

necessário. Em adição, o panorama apresentado indica possíveis caminhos e aponta pesquisas futuras que se utilizem de microinterações nos estudos de experiência do usuário.

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Referências bibliográficas

Aleksy, M., Bronmark, J., & Mahate, S. (2016). Microinteractions in mobile and wearable computing. 30th IEEE International Conference on Advanced Information Networking and Applications.

Avila-Munoz, R., Clemente-Mediavilla, J., & Perez-Luque, P.-L. (2021). Communicative Functions in Human-Computer Interface Design: A Taxonomy of Functional Animation. In *Review of communication research*, *9*, 119-146. https://doi.org/10.12840/ISSN.2255-4165.030

Ashbrook D. L. (2010). Enabling Mobile Microinteractions. Ph.D. Dissertation. Georgia Institute of Technology. Atlanta.

Barrington, S. (2007). Usability in the lab: Techniques for creating usable products. Journal of the Association for Laboratory Automation, p. 6-11.

Betz, S., & Hall, R. (2015). Self-Archiving with Ease in an Institutional Repository: Microinteractions and the User Experience. *Information technology and libraries*, *34*(3), 43-58. https://doi.org/10.6017/ital.v34i3.5900

Boy, G. A. (2011). The handbook of human-machine interaction: a human-centered approach. UK: Ashgate Publishing/MPG Books Group.

Broos, T., Verbert, K., Langie, G., Van Soom, C., & De Laet, T. (2018). Low-Investment, Realistic-Return Business Cases for Learning Analytics Dashboards: Leveraging Usage Data and Microinteractions. In *13th European Conference on Technology Enhanced Learning, EC-TEL 2018* (Vol. 11082 LNCS, pp. 399-405): Springer Verlag.

Falkowska, J., Kilijańska, B., Sobecki, J., & Zerka, K. (2019). Microinteractions of forms in web based systems usability and eye tracking metrics analysis. In *AHFE International Conference on Human Factors and Systems Interaction, 2018* (Vol. 781, pp. 164-174): Springer Verlag.

Golod, I., Heidrich, F., Möllering, C., & Ziefle, M. (2013). Design principles of hand gesture interfaces for microinteractions. In 6th International Conference on Designing Pleasurable Products and Interfaces, DPPI 2013, Newcastle upon Tyne.

Gonzales, S., Carson, M. B., Viger, G., O'Keefe, L., Allen, N. B., Ferrie, J. P., & Holmes, K. (2021). User testing with microinteractions [Article]. *Information technology and libraries*, *40*(1). https://doi.org/10.6017/ITAL.V40I1.12341

Hassenzhal, M. (2008). User experience (UX): towards an experiential perspective on product quality. In: 20th Conference On I'interaction Homme-Machine. Proceedings. p. 11-15, 2008.

Hassenzhal, M., Diefenbach, S., Goritz, A. (2010). Needs, affect, and interactive products – facets of user experience. Interacting Comput., v. 22, n. 5, p. 353–362.

Ijari, K. (2019). Understanding the Effect of Animation and Its Speed on User Enjoyment. Ph.D. Dissertation. Arizona State University. Tempe.

Kapros, E., & Kipp, K. (2016). Microinteractions and a gamification framework as a mechanism for capturing 21st century skills. In P. *3rd International Conference on Learning and Collaboration Technologies, LCT 2016 and 18th International Conference on Human-Computer Interaction, HCI International 2016* (Vol. 9753, pp. 25-35): Springer Verlag.

Levy, Y., Ellis, T. J. (2006). A systems approach to conduct an effective literature review in support of information systems research. Informing Science Journal, v. 9: 181-212.

Nielsen, J. (1993). Usability engineering. USA: Academic Press/Morgan Kaufmann.

Norman, D. (1988) The design of everyday things. USA: Basic Books.

Norman, D. (1993). Things that makes us smart: defending human attributes in the age of the machine. USA: Perseus Book.

Norman, D. (2004). Emotional design: why we love (or hate) everyday things. USA: Basic Books.

Ma, J. Y., & Chen, C. C. (2022). Evaluating user perception and emotion of microinteractions using a contradictory semantic scale [Article]. *Journal of the Society for Information Display*, *30*(2), 103-114. https://doi.org/10.1002/jsid.1075

Reyneke, R. (2019). Improving Interactive User Experience with Microinteractions: an Application of Biometric and Affect Detection Systems on Landing Pages. Master's thesis, Harvard Extension School.

Rogers, Y. Sharp, H. Preece, J. (2011). Design de interação: além da interação humano-computador. 3. ed. Porto Alegre: Bookman.

Saffer, D. (2013). Microinteractions: designing with details. USA: O'Reilly Media.

Sano-Franchini, J. (2018). Designing outrage, programming discord: A critical interface analysis of facebook as a campaign technology [Article]. *Technical Communication*, *65*(4), 387-410.

Wang, M. (2018). Determining the Optimum Duration of User Interface Animation in Microinteraction Design: Comparing Mouse vs. Touch Input. Ph.D. Dissertation. Drexel University. Philadelphia.

Yan, X., Li, Y., Huang, B., Park, S. Y., & Newman, M. W. (2021). User Burden of Microinteractions: An In-lab Experiment Examining User Performance and Perceived Burden Related to In-situ Self-reporting. In 23rd ACM International Conference on Mobile Human-Computer Interaction: MobileHCI 2021.

BitaLab. Data Visualization Interface and Guidance in Technological Skills for Designers in Visual Communication

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Abstract. The objective of the project is to facilitate the perception of the distance between the technological skills built during the academic journey of the students in Visual Communication Design, and the skills demanded by the labor market. For this research, the Vision in Product (ViP) methodology was used, transferring the results to a possible 2027 scenario. We defined seven professional technological profiles which will help students in their professional insertion, and their adaption to the fast changes in the labor area. Our collaborative and interactive interface was designed to display the data obtained in the survey and the design profiles that will be most in demand in the future. The differential value of our research lies in the possibility of showing the obtained results in a collaborative interface.

Keywords: data visualization, user experience, interface design, graphic design, future strategic design

1 Introducción

Esta investigación se origina con la observación de una distancia entre las competencias tecnológicas desarrolladas por los estudiantes en Licenciatura Diseño de la Comunicación Visual (LDCV) de la Universidad Nacional del Litoral (UNL) durante su recorrido académico y las demandadas por el mercado laboral regional. El objetivo de este proyecto es colaborar en la percepción de dicha distancia y orientar a los estudiantes de la carrera en la construcción de sus perfiles profesionales y que puedan adaptarse a los acelerados cambios tecnológicos que provoca la Industria 4.0 en el campo laboral.

La hipótesis inicial planteaba que el diseño de una interfaz para la visualización de los datos relevados en el mercado laboral de nuestra región posibilitaría la percepción de la distancia entre las competencias tecnológicas construidas académicamente y las demandadas por el mercado. Los datos

fueron proyectados a un posible escenario 2027 para anticiparnos a las competencias que demandará el mercado laboral futuro, lo que permitirá guiar a los estudiantes avanzados de la LDCV en su proceso de inserción laboral.

2 Fundamentos

A fin de ordenar los fundamentos de la investigación, planteamos tres ejes que se basan en las categorías peirceanas que retoma Güerri (2014) en su nonágono semiótico. En cada eje temático, se desarrollan y entrelazan conceptos y principios de distintos campos de conocimiento. Sintetizamos la estructura y las relaciones del marco teórico en el esquema de la figura 1.

2.1 La Industria 4.0 como contexto

Vivimos un momento histórico de cambios profundos y acelerados en la forma en que percibimos e interactuamos con el mundo. Diversos autores nos sitúan en la cuarta revolución industrial, que se caracteriza por avances tecnológicos extraordinarios que fusionan los sistemas físicos, biológicos y digitales de diseño y producción.

Este contexto tecnológico ha desencadenado una serie de conceptos e innovaciones disruptivas como *big data*, inteligencia artificial, impresión 3D, realidad virtual y aumentada, drones, etc. Podríamos decir que las tecnologías digitales están en el núcleo del paradigma emergente, ya que introducen una característica innovadora tanto en el campo disciplinar como en el mercado (SIGraDi, 2019).

En base a nuestro relevamiento —que incluyó el testimonio de más de 100 estudiantes, 90 graduados, 18 empleadores y 8 docentes de la LDCV—, definimos las siguientes tecnologías como las más demandadas en la región:

- Diseño generativo, algoritmos e inteligencia artificial
- Internet de las cosas
- *Big data*
- Realidad virtual (VR) y realidad aumentada (AR)
- *Motion graphics* y modelado 3D
- Lenguajes de programación
- *Marketing* digital

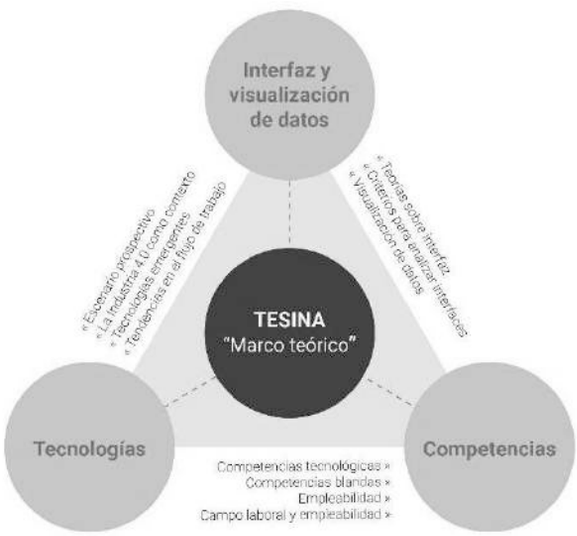

Figura 1. Relación tríadica de los ejes teóricos

Cabe mencionar algunos aspectos destacables de estas tecnologías que, en muchas oportunidades, brindaron respuestas frente a contextos ambiguos y cambios acelerados (Day & Schoemaker, 2001): su aplicabilidad, que convergen y migran hacia diferentes campos de conocimiento, su fácil aceptación por la sociedad, que tienden a desarrollarse en escenarios inciertos, que presentan funciones y modos de aplicación inexplorados, y que generan nuevas oportunidades en mercados emergentes.

Otro concepto fundamental para nuestra investigación es el de interfaz, que retomamos de Scolari (2018-2020), quien propone diez leyes para caracterizarla. Una de ellas refiere a que la interfaz se ha vuelto el lugar de la innovación. Este enunciado nos impulsó a publicar los resultados y las conclusiones de la investigación a través de una interfaz.

Como futuros profesionales del diseño, consideramos que debemos ser capaces de interpretar el espacio-interfaz (Tosello, 2016) como un umbral que provoca el diálogo, posibilitando la comunicación, adaptando el lenguaje, y simplificando la navegación y la experiencia del usuario.

2.2 Campo laboral y empleabilidad de los diseñadores

Las pasantías y experiencias que conectan el ámbito académico con el productivo constituyen un puente entre los conocimientos adquiridos durante la formación y las expectativas y demandas reales del mercado.

Las oportunidades que pueden ofrecer las universidades para fomentar las primeras experiencias laborales de sus estudiantes son de suma importancia para su futura inserción profesional (Garrido & García, 2018). Con base en la

información relevada, proyectamos un escenario laboral futuro con los siguientes pronósticos:

- Los diseñadores especializados en diseño digital serán cada vez más demandados.
- El diseñador adquirirá nuevas competencias y cumplirá un rol fundamental trabajando en equipos multidisciplinarios.
- Las competencias blandas, como la capacidad de trabajo en equipo y la comunicación asertiva, serán muy valoradas en las postulaciones.

2.3 Competencias a futuro

Si bien es difícil que una institución universitaria garantice una enseñanza que se adecúe constantemente a las tendencias del campo, es importante que prepare a sus graduados con las competencias mínimas demandadas para la inserción laboral a nivel regional.

Según las encuestas realizadas a 90 graduados de la LDCV de la UNL, el 77% señaló que poseer conocimientos en diseño UX/UI será la competencia tecnológica más demandada en el futuro. Otras competencias destacadas fueron *community management* (67%), diseño audiovisual (60%), diseño web y lenguajes de programación (53%), *big data* (32%), etc.

El campo laboral de los diseñadores requerirá profesionales cada vez más especializados, particularmente en competencias digitales, dado el protagonismo actual de las TIC y la tendencia creciente a realizar trabajos de manera remota.

Las competencias blandas serán características muy requeridas a futuro en los diseñadores, de las cuales destacarán la adaptabilidad y resiliencia, la capacidad autodidacta, el trabajo remoto con equipos multidisciplinarios, la facilidad de aprendizaje, entre otras.

3 Metodología

La metodología Vision in Product (ViP) desarrollada por Hekkert y Van Dijk (2011), que organiza y guía el proceso global de la investigación (figura 2), posee las siguientes características:

- Indaga y prevé alternativas posibles, lo que brinda una mirada a futuro y evita soluciones obsoletas a mediano plazo.
- Se centra en la interacción y empatía con usuarios concretos. A partir de un relevamiento, se interpretan sus necesidades para proyectar soluciones que no se limiten a ideas subjetivas.
- Se basa en un contexto, que puede ser actual o futuro. Dado que la interacción está determinada por el contexto para el que está diseñada, los contextos futuros exigen comportamientos nuevos y diferentes.

La metodología ViP se puede adaptar a dos espacios temporales:

- Retrospectivo: se realiza un relevamiento de la situación actual del contexto regional.
- Prospectivo: se proyectan los resultados del relevamiento, buscando delinear un posible escenario 2027 a nivel regional.

Tomamos el 2027, dado que en ese año se estarían graduando —en promedio— los estudiantes que ingresaron el año que iniciamos la investigación.

Figura 2. Esquema de Hekkert y Van Dijk (2011) adaptado para esta investigación

3.1 Definición de población objeto de estudio

Partiendo de la base de que no existe investigación libre de supuestos teóricos, optamos por realizar una investigación mixta (cuali-cuantitativa), la cual incluye guías de observación, encuestas y entrevistas. Entrevistamos de manera virtual, utilizando plataformas como Zoom o Meet, a 16 graduados, 8 docentes y 18 empleadores. Estas entrevistas fortalecieron y profundizaron los datos recopilados a través de las encuestas previas.

Los diversos instrumentos de investigación fueron utilizados con cuatro grupos muestrales, cada uno orientado a los datos necesarios para construir un posible escenario laboral regional en competencias tecnológicas. Las características de estos grupos son las siguientes:

- Empleadores: responsables del área de recursos humanos de grandes empresas, dueños de pymes, agencias y estudios de diseño que en el último tiempo han realizado búsquedas laborales para diseñadores o que ya emplean diseñadores (preferentemente graduados de la FADU UNL).
- Docentes: del área de tecnología de la LDCV.
- Estudiantes avanzados: estudiantes de la LDCV que tengan un mínimo del 50% de la carrera aprobada y que, preferentemente, hayan tenido alguna experiencia de entrevista o postulación laboral.
- Graduados: de la carrera, exestudiantes y estudiantes avanzados que ya se encuentran trabajando hace por lo menos dos años y poseen perfiles con una orientación tecnológica.

3.2 Construcción, procesamiento y lectura de datos

- Guías de observación: a través de las mismas se recopilaron diferentes ofertas laborales disponibles en la región y destinadas a diseñadores. Se relevaron plataformas y bolsas de empleo *online* en el periodo de julio a diciembre de 2020.
- Encuestas: se diseñaron en Google Form, con cuestionarios estandarizados para graduados y estudiantes avanzados de la carrera.
- Entrevistas: se diseñaron y coordinaron entrevistas en profundidad semiestructuradas con preguntas abiertas para cada grupo muestral.

Cada instrumento para obtener información enfatiza diferentes variables. Los datos recabados de las distintas entrevistas y encuestas fueron distribuidos en los diferentes niveles de la metodología ViP.

3.3 Formación en competencias tecnológicas

Según lo relevado, la LDCV tiene una marcada perspectiva social que prioriza el desarrollo de las capacidades analítica y crítica, mientras que las competencias técnicas quedan relegadas. Los docentes argumentan que los estudiantes tienen la posibilidad de escoger una especialización una vez graduados; sin embargo, la realidad nos muestra que estos egresan con una edad promedio mucho mayor a la planificada en la currícula. Esto provoca una temprana necesidad de especialización e inserción laboral que genera un gran interés por la capacitación externa o autoformación, que se superpone a la formación universitaria.

Actualmente, existe una marcada diferencia entre lo que los empleadores y los docentes interpretan como tendencias tecnológicas a futuro. La totalidad de

los entrevistados concuerdan, en mayor o menor medida, en que el plan de estudios se encuentra desactualizado. En relación con la integración de las tecnologías digitales en los talleres de diseño, se mencionan como principales dificultades la masividad de las comisiones y la desigualdad de recursos de los que dispone cada estudiante.

4 Resultados

El proyecto, tanto en la etapa de relevamiento como en la prospectiva, busca reconocer la distancia existente entre las competencias tecnológicas solicitadas por el mercado laboral regional y las adquiridas por los diseñadores durante su formación.

La interfaz diseñada constituye un aporte al campo del diseño y a los futuros diseñadores de la comunicación visual. Es un instrumento que aporta desde el propio campo.

La construcción de un posible escenario 2027 nos permite explorar el presente, así como también investigar las posibilidades futuras para anticipar las repercusiones en el campo laboral del diseño. La construcción de escenarios futuros no produce soluciones ni certezas, sino preguntas a partir de las cuales dialogar, repensar y elaborar múltiples perspectivas. Diseñar posibles escenarios futuros nos permite convertir las debilidades en acciones. Nuestro plan de acción se centra en construir un espacio colaborativo, de exploración y visualización de datos sobre posibles escenarios. La interfaz diseñada posibilitará que cada estudiante pueda elegir cómo actuar frente a la información visualizada y a las alternativas sugeridas.

En base a aquellas competencias y características que obtuvieron una mayor frecuencia de conteo en las encuestas y entrevistas realizadas, se identificaron y construyeron siete perfiles de diseñadores que organizaron y clasificaron los resultados brindando un panorama futuro más preciso acerca de la demanda laboral. Dichos perfiles son el resultado de un intenso trabajo de investigación y profundización en subáreas profesionales del campo del diseño, ya que como egresados de FADU UNL poseemos competencias laborales muy generales. Esta sistematización permite sugerir orientaciones y especializaciones a los diseñadores en comunicación visual.

Los perfiles construidos son los siguientes:

- Diseñador de productos digitales (incluye diseño UX/UI, webs, etc.)
- Diseñador de *packaging*
- Diseñador editorial (medios impresos y digitales)
- *Community manager* y *marketing digital*
- Diseñador de videojuegos
- Diseñador audiovisual
- Diseñador generalista (incluye a aquellos especializados en *branding*).

5 Etapa proyectual

Luego del procesamiento de los datos y la definición de los perfiles, se diseñó un prototipo de interfaz para la orientación y visualización de datos en competencias tecnológicas para los diseñadores en comunicación visual. En la misma se presenta la información recopilada y procesada mediante los diferentes instrumentos, los resultados obtenidos y los lineamientos a futuro.

El nombre BitaLab nace de la combinación de las palabras *bitácora* y *laboral*, y refleja la idea de tomar apuntes para una mejor inserción laboral del estudiante o graduado. Interactuando con la interfaz, estudiantes y graduados encontrarán los medios y recursos necesarios para fortalecer sus competencias tecnológicas y especializarse en lo que necesiten y/o deseen.

5.1 Arquitectura de la información

La interfaz BitaLab se compone de cuatro secciones: Punto de partida, Mi bitácora, Orientador en competencias y Biblioteca de recursos (figura 3). Cada sección tiene su propósito y juntas logran una experiencia integral. La información se visualiza de manera interactiva y dinámica a través de diferentes gráficos: de barra, cartográficos, rizomas jerárquicos, gráficas polares e infografías, que entrelazan y relacionan datos cuantitativos y cualitativos.

5.2 Secciones de la interfaz

Punto de partida

En esta sección, el usuario podrá interiorizarse sobre el relevamiento realizado a través de diferentes gráficos, y visualizar los resultados y las alternativas propuestas por docentes, estudiantes, graduados y empleadores frente a la problemática planteada. También podrán conocer las proyecciones y tendencias para el año 2027. Se visualiza una organización jerárquica e interactiva con los seis ejes principales de nuestra investigación, que se ramifican configurando el resto de las jerarquías, permitiendo un recorrido rizomático de la sección (figura 4).

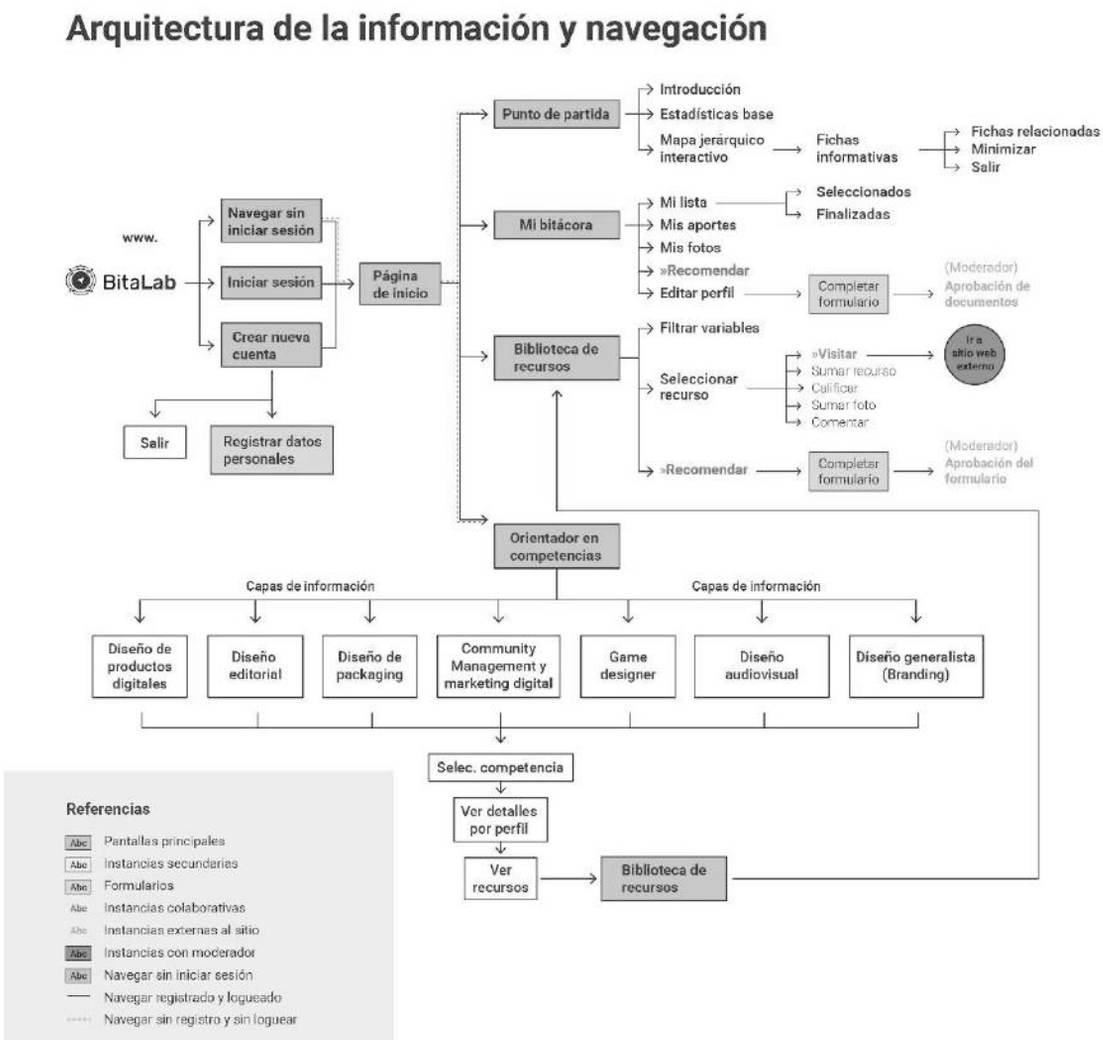

Figura 3. Esquema de la arquitectura de la información y navegación de la interfaz

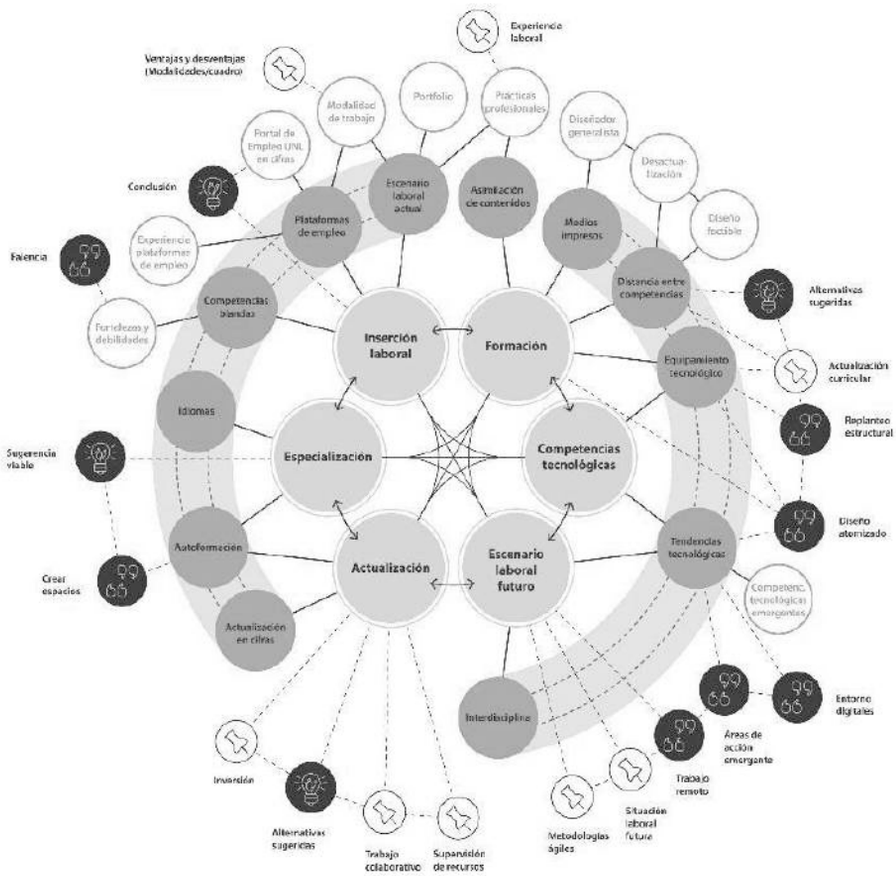

Figura 4. Mapa jerárquico contextual completo. Este mapa es interactivo.

Mi bitácora

La sección simula el uso y edición de perfiles personales en redes sociales. Esta estrategia se empleó para facilitar las tareas al usuario, quien podrá editar y visualizar sus datos personales y sus aportes, así como guardar todos los recursos de su interés.

Orientador en competencias

El orientador en competencias (figura 5) permitirá al usuario explorar los perfiles tecnológicos más demandados, las competencias más buscadas y las proyecciones a futuro. El objetivo de esta sección es facilitar el acceso a la información y guiar virtualmente al usuario. El orientador posee dos tipos de filtros para diferenciar y segmentar la información.

Biblioteca de recursos

En esta sección colaborativa el usuario podrá compartir información, guardar, comentar e interactuar con otros usuarios para intercambiar información y conocimientos.

Figura 5. Orientador en competencias. Gráfica polar con información interactiva

6 Conclusiones

Esta investigación tuvo como objetivo reconocer y visualizar los campos de acción emergentes para el diseñador en comunicación visual. Como profesionales nos vemos obligados a estar en la búsqueda constante de la especialización para alcanzar un óptimo desarrollo profesional. Ponemos en evidencia los nuevos roles laborales que el diseñador debe tomar y cómo se acerca cada vez más a los límites del campo disciplinar.

Debido a la complejidad y extensión de la problemática, consideramos que una solución integral demandaría la mirada y el trabajo de un equipo multidisciplinario con profesionales de diferentes campos.

A modo de cierre de este proyecto dejamos planteados algunos lineamientos para la optimización de la interfaz, en caso de que el proyecto se continúe o se retome en otros ámbitos.

- Proceso iterativo: este tipo de trabajos conlleva procesos iterativos necesarios para la optimización del proceso; por ejemplo, entre el relevamiento bibliográfico y el relevamiento de campo.

- Acceso a información y bases de datos: considerando que este proyecto, como muchos otros, busca realizar un aporte a la comunidad académica creemos relevante que la institución permita el acceso a la información institucional para el uso de su comunidad.
- Continuidad de los proyectos: a través de licencias Creative Commons, se podrían continuar proyectos ya desarrollados. Este procedimiento fomentaría la investigación y el vínculo entre colegas e instituciones académicas.
- Refuerzo de la relación entre agentes: consideramos que reforzar la relación triádica estudiantes - docentes - mercado laboral, a través de proyectos en conjunto, beneficiaría a todas las partes y brindaría a los estudiantes una proyección más clara para su inserción laboral.

Agradecimientos. Agradecemos a la UNL por el subsidio que posibilitó este proyecto de investigación.

Referencias

Bonsiepe, G. (2012). *Design como prática de projeto*. Editorial Edgard Blücher.

Day, G., Schoemaker, P. & Gunther, R. (2001). *Gerencia de las tecnologías emergentes*. https://www.researchgate.net/publication/44330750_WhartonGerencia_de_tecnologias_emergentes/link/0f3175352- fd966844c000000/download

Garrido, C. & García, D. (2018). *Políticas y acciones de las universidades para promover el empleo de sus egresados. Estudio de casos en Iberoamérica*. http://reduealcue.org/website/content/publicaciones/Libro-empleabilidadold.pdf

Guerri, C. & Acebal, M. (2014). *Nonágono semiótico: un modelo operativo para la investigación cualitativa*. Ediciones UNL.

Hekkert, P. & Van Dijk, M. (2016). *VIP Vision in Design: A Guidebook for Innovators*. Laurence King Publishing.

Scolari, C., (2018). *Las leyes de interfaz*. Editorial Gedisa.

Scolari, C. (2020). Las leyes de la interfaz. *Hipermediaciones*: https://hipermediaciones.com/2018/02/04/las-leyes-de-la-interfaz/

Tosello, M. (2016). *El espacio-interfaz: un lugar habitable* (tesis doctoral). Universidad Nacional del Litoral. doi: 10.5151/despro-sigradi2016-70

User and Environment Interactive Parasol

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Abstract. Within the framework of a research project on inmotic urban-microarchitecture in public spaces, this paper presents the results of a prototype analysis, based on ergonomic and universal access-criteria, as well as material, technical and technological requirements necessary for its construction in Córdoba (Argentina). The main objective is to increase the services provided while improving the interactions with users with disabilities or movements limitations, as well as older adults and children.

Keywords: users experience, inclusive design, inmotic, parametric, microarchitecture

1 Introducción

La pandemia de la COVID-19 puso en relevancia la importancia del ocio y distracción en la vida de las personas, en relación con las actividades de trabajo y subsistencia. Frente a los altos niveles de estrés presentes en la vida diaria, surge como estrategia dedicar tiempo a practicar *hobbies*, quedar con los amigos y desconectar.

Debido a esto, este equipo trabaja en un proyecto de desarrollo de microarquitectura localizada en espacios públicos que responda a un programa de servicios complementarios a actividades de esparcimiento al aire libre. Proponemos una microaquitectura con diseño paramétrico (figura 1) que se adecúa al medio y al usuario, dando respuesta a distintas solicitaciones. También se propone una interacción entre el usuario y el medio, los cuales, a la vez, se articulan con la microarquitectura en el espacio público, generando un microclima de confort.

Los servicios que presta el parasol, así como su nombre lo indica, consisten en proteger al usuario del sol y del viento, con aletas que se ajusten a las distintas condiciones ambientales. Además, brinda servicios de salud, (mediciones de oxígeno en sangre, pulso y presión arterial), *step* (ejercicio), agua potable, hidratación para perros, wifi, entre otros. Finalmente, se cuenta con sistemas de recuperación de agua de lluvia y colectores solares como fuente de energía.

Esta investigación considera que los espacios arquitectónicos o urbanos interactúan con el ambiente, modificando, aprovechando y también sufriendo las preexistencias ambientales. Esta interacción puede darse en múltiples escalas; para Monroy (2006), una adecuada calidad ambiental del hábitat construido se alcanza a partir de un conjunto de técnicas, infraestructuras y equipamientos que en conjunto definen el concepto de acondicionamiento ambiental.

Sumado a lo anterior, la interacción con el usuario debe contemplar sus distintos requerimientos con el objetivo de ser accesibles a la mayor cantidad posible de personas para responder a las necesidades de entretenimiento y bienestar, ya sea realizando actividad física, recibiendo sugerencias sobre alimentación saludable, e información sobre sus estadísticas de salud y signos vitales.

Figura 1. Imagen propia de conjunto

Trabajar con materiales, tecnologías y equipos de vanguardia nos ayuda a cumplir los objetivos de sustentabilidad, ergonomía, inclusión, entre otros. Además, la *inmótica* nos permite proponer partes móviles y ajustables automáticamente, e integrar los diferentes sistemas de funcionamiento del dispositivo.

Recordamos que la domótica surge con el objetivo principal de otorgar al usuario el máximo confort y seguridad con la mayor economía y eficiencia energética. Pero cuando se orienta a edificios terciarios, no viviendas, estamos ante la presencia de la *inmótica*, que realiza la gestión de la energía incluyendo las automatizaciones de las actividades y el trabajo (Romero *et al.*, 2006). Debido a esto, el prototipo de parasol que presentamos en este trabajo es inmótico.

Tomamos dos sitios, próximos entre sí, uno circundando la Plaza España, acordando su modo intersticial urbano; el otro en el Río Suquía, con las nuevas intervenciones realizadas de recuperación de la zona.

2 Metodología

El trabajo es realizado por un equipo interdisciplinario, formado por arquitectos, diseñadores industriales, especialistas en ergonomía, en estructuras e ingenieros, que trabajan sobre los resultados obtenidos en instancias anteriores, donde se determinaron requerimientos funcionales, de forma, prefiguración paramétrica y modelado.

Se trabajó con sondeos para determinar las necesidades y, luego, el equipo interdisciplinario fue acotando requerimientos de proyectos. El ajuste y aporte de los ingenieros para el trabajo con la domótica define y avanza el diseño.

En este caso, hay un cambio de escala en el planteamiento del proyecto, enfocándonos en el diseño de componentes y elementos. Las premisas que guían esta etapa son los criterios de holgura, de alcance y de diversidad de medios de comunicación y otros dispositivos esenciales para el diseño inclusivo. Se pretende con este enfoque ajustar el diseño y los implementos necesarios para que posibiliten su uso por parte de usuarios con diferentes requerimientos de interacción. Las verificaciones de los prototipos se realizan en gráfica 2D, 3D y animaciones para simular su puesta en funcionamiento.

3 Desarrollo del prototipo

3.1 Desarrollo de las aletas mutantes

El prototipo está pensado como un parasol móvil que responde a los requerimientos de adaptación del sitio y del clima. Los elementos móviles reciben el nombre de aletas mutantes.

Como parte de los ensayos, determinamos la gama de movimientos posibles para distintas áreas según el asoleamiento local y las consecuentes necesidades de sombra o protección.

Como fuente de energía de las aletas, se contemplaron colectores solares, con un sistema de células fotovoltaicas impresas que son flexibles y nos permiten una adecuación a la morfología usada (figura 2).

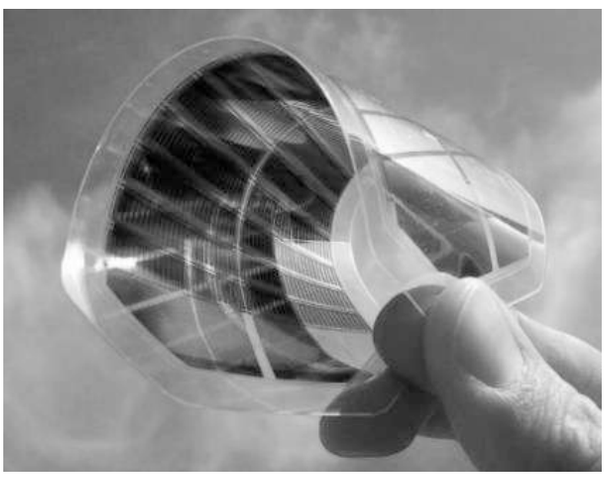

Figura 2. Células impresas tipo Exel Solar. Fuente: @ExelSolarMX.

La estructura de cada aleta consiste en una malla irregular que otorga la rigidez necesaria con relativamente poco material, haciendo más ligeros los elementos, lo que facilita su movimiento y estabilidad (figura 3).

Figura 3. Estructura de malla de las aletas mutantes

3.2 Diseño y cálculo de la estructura

El prototipo tendrá un sistema estructural diseñado integralmente con los sistemas de envolventes y redes inmóticas. Este sistema se desarrollará según premisas de

eficiencia estructural en cuanto forma y materiales de todos los elementos que componen el sistema y trabajan en conjunto (figura 4).

Las cargas propuestas para su verificación son de servicio cotidiano, de mantenimiento, solicitaciones por eventos climáticos extremos (horizonte a 25 años), solicitaciones por sismos, cargas extraordinarias por vandalismo, y cargas extraordinarias sobre los elementos durante su traslado y montaje. Todas estas cargas se verificarán según las disposiciones de los reglamentos dictados por el Cirsoc vigente en Argentina (Cirsoc, s. f.).

La premisa de desarrollar elementos livianos con menores requerimientos de energía para su montaje y movimiento nos lleva a trabajar con barras de aluminio extruido y membranas plásticas. Sin embargo, también se considera la posibilidad de utilizar elementos moldeados en resina epoxi combinada con fibra de vidrio, lo que evita el aluminio en la superficie de cubierta del parasol, y usar chapa DWG (más económica y resistente) en el fuste de las columnas.

En efecto, algunos autores están trabajando con las resinas epoxi modificadas, que se utilizan ampliamente en la fabricación de compuestos reforzados con fibra natural y en la fabricación de sus diferentes productos industriales debido a sus propiedades mecánicas, térmicas y eléctricas superiores (Saba *et al.*, 2016).

Esto nos permitiría, de continuar en esta dirección, trabajar con una estructura elaborada con epoxi síntesis, epoxi modificado, resina bioepoxi, etc., logrando así más flexibilidad y menor peso.

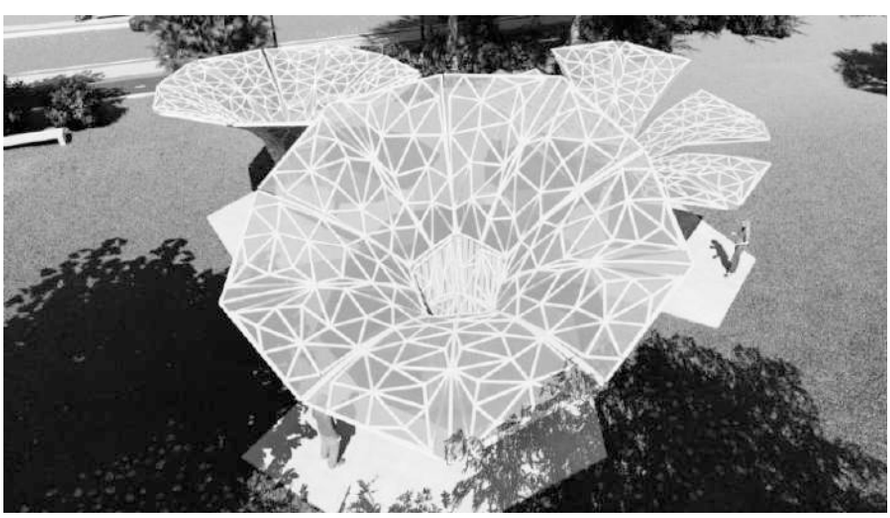

Figura 4. Vista superior de conjunto

3.3 Inclusión ergonómica y diseño universal

Ergonomía es la disciplina que estudia las interacciones entre el hombre y los elementos de un sistema. Además, es la profesión que aplica en el diseño tanto las

teorías, los principios, los datos como los métodos para optimizar el bienestar humano y el rendimiento global del sistema (International Ergonomics Association, s. f.). Su nombre proviene de dos raíces griegas: *ergo* 'trabajo' y *nomos*, 'ley o norma'.

La importancia de considerar los distintos tipos de usuarios para un diseño inclusivo es fundamental. “Primero las personas, luego forma y función” es una de las principales premisas del proyecto. El que personas de distintas edades y con distintos grados de capacidades y limitaciones puedan hacer un uso seguro de la microarquitectura es nuestro objetivo en cada una de las etapas del proceso de diseño (Flores, 2001).

En este caso, se aplicaron principios ergonómicos en el enfoque del proyecto contemplando la variabilidad de personas como usuarios y las distintas situaciones de uso. Se busca optimizar la interacción entre las personas y el sistema que se propone en el ambiente urbano, atendiendo a sus necesidades, de niños, adultos mayores, personas con discapacidad y/o con mascotas, centrándose en las capacidades, limitaciones y necesidades, en pos de facilitar y optimizar las actividades que se realizan.

Complementando lo anterior, el diseño universal o diseño para todos es un término que involucra diseñar para el máximo de usuarios posibles, sin que esto involucre el hacer diseños especiales o adaptados para lograrlo (Connell *et al.*, 1997). Crear e instalar mobiliarios urbanos en el espacio público que no puedan ser utilizados por las personas con discapacidad es generar procesos excluyentes e inequitativos, que faltan a los derechos humanos. Para ello, se propone trabajar con premisas de diseño universal, tanto para objetos físicos como en el diseño de interfases interactivas. Entre los mecanismos contemplados en el prototipo para facilitar el uso universal, se encuentran los siguientes:

- Accesibilidad visual. Ampliación personalizable, colores y contraste; utilidades; lectores de pantalla; reconocimiento de voz y tecnología de texto a voz.
- Accesibilidad auditiva. Características de programa a las que se accede mediante traducción escrita y gráfica.
- Destreza. Características de programa a las que se accede mediante traducción verbal o táctil. Se puede vincular a través de Bluetooth algún dispositivo propio del usuario que facilite la navegación, que su uso sea sencillo de entender; es decir, que cada usuario pueda comprender la forma de uso y la información presentada.
- Accesibilidad motriz. Brindar facilidad de uso, de modo que las personas en sillas de ruedas puedan operar el sistema. Ubicar la pantalla de tal modo que quede visible y legible, que alcancen sin sobre esfuerzos los botones. Aquí se aplicó el *criterio de alcance*: si las personas en sillas de ruedas alcanzan, los demás usuarios también (niños y demás adultos).
- Accesibilidad para su mantenimiento. En el caso de diseño de cada uno de los subsistemas (ej. asientos, pantallas, techo, otros), que sea de fácil acceso para reparar y/o cambiar partes o piezas.
- Seguridad e higiene. Considerando que las terminaciones y las partes no generen riesgo eléctrico, estrés de contacto, golpes, caída de objetos de

partes móviles. Además, tanto el agua y los alimentos se presentan higiénicos y seguros.

Se han tenido en cuenta las siguientes dimensiones antropométricas utilizadas en el dimensionamiento de la microarquitectura: altura poplítea mujer percentil 5 (altura desde el suelo al hueco detrás de la rodilla), alcance frontal brazo extendido mujer percentil 5. Ancho de cadera mujer percentil 95, ancho y profundidad de la silla de rueda (Panero & Zelnik, 1998). También se tuvieron en cuenta los ángulos de confort; es decir, los planos de trabajo en posición sedente o de pie elaborados por Alain Wisner (1994), los cuales estudian los rangos de ángulos que forman los segmentos corporales, donde las articulaciones no están sometidas a tensiones por encima de lo normal, evitando así la lesión (Mondelo *et al.*, 2004).

3.4 Medición de estadísticas vitales

A nivel de criterios de parámetros fundamentales de chequeo se implementará un oxímetro de pulso (figura 5), con un rango de visualización de saturación de oxígeno y la frecuencia del pulso adaptable a rango de edad de 10 años a mayores adultos. Este dispositivo cuenta con una conexión directa de un largo de cable 2.7 m o más, lo que permite llegar a diferentes alturas. Contemplando el criterio de diseño para los extremos podremos medir a través del dedo índice a la persona más pequeña (imagen baja) como a la persona 5 (figura 6).

Rango de visualización de saturación de oxigeno y la frecuencia del pulso.

Conexión directa cable largo de 2.7 metros.

Figura 5. Producto. Oxímetro extensible marca Biotek, modelo cardiotécnica

Fuente: https://feaselectronica.mercadoshops.com.ar/MLA-898858924-cable-prolongador-de-sensor-de-oximetro-db9mgdb9f-_JM

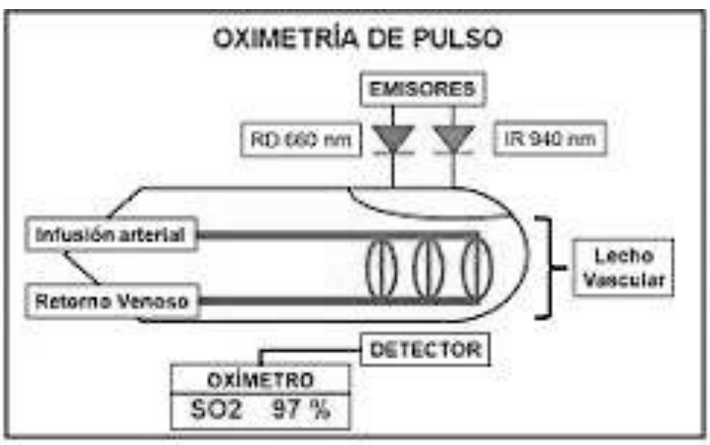

Figura 6. Producto, oxímetro. Fuente: https://www.researchgate.net/figure/Figura-1-Pulsioximetro-de-dedo-14_fig1_337447960; https://www.epn.edu.ec

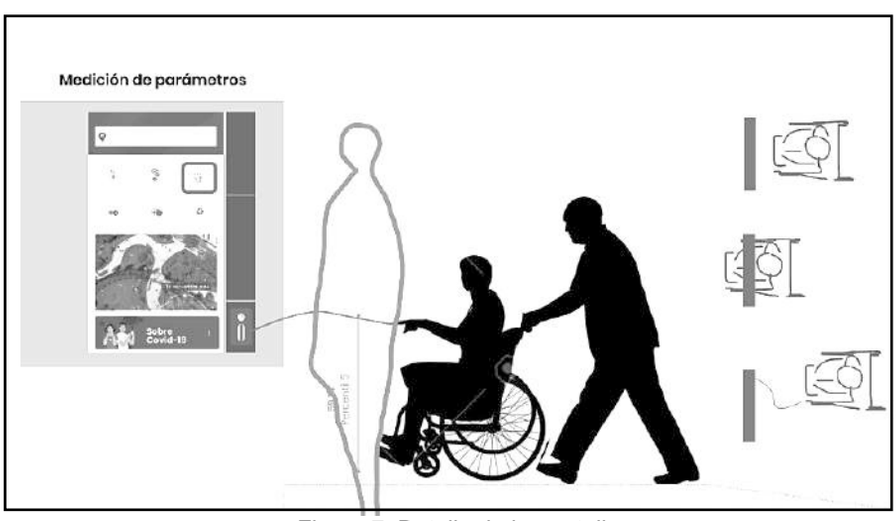

Figura 7. Detalle de la pantalla.

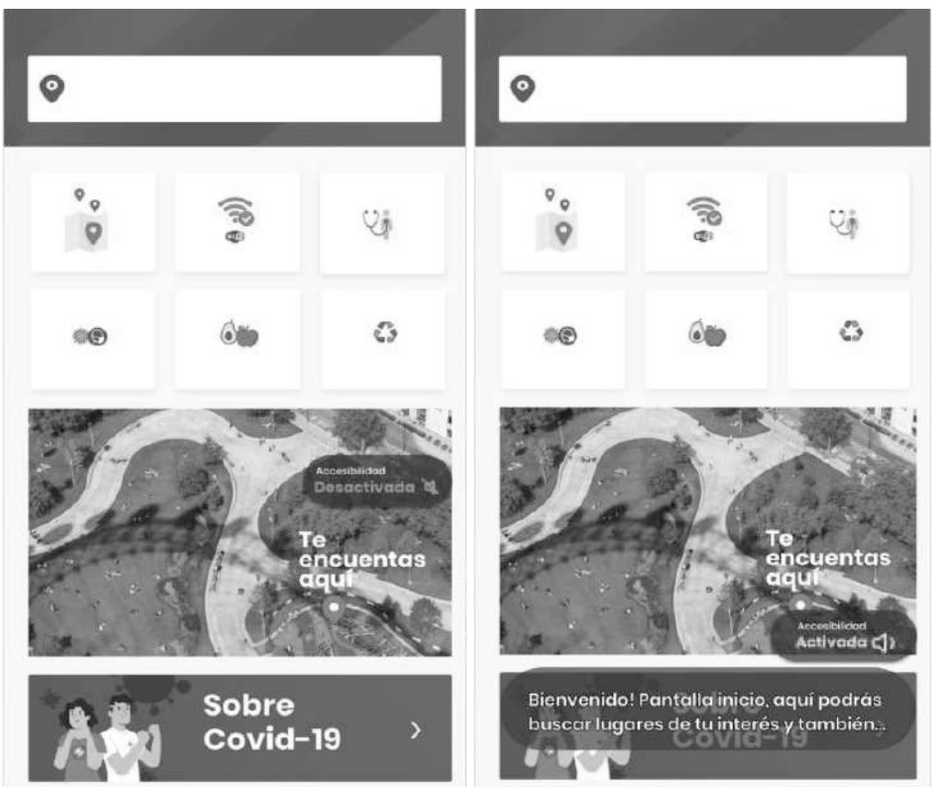

Figura 8. Tipos de pantalla. Accesibilidad activada. Navegabilidad verbal subtítulos activados

3 Resultados y discusión

Esta microarquitectura que presentamos tiene dos líneas de trabajo principales: por un lado, el diseño paramétrico, que le otorga una impronta visual fuerte; por otro lado, el diseño sustentable e inclusivo, teniendo en cuenta los aspectos físicos, cognitivos, culturales y emocionales de las personas para su vida en los espacios públicos porque, como ya manifestamos, primero las personas.

Proyectar un parasol que se adapte al clima de un sitio, que funcione con energía solar, que recoja agua de lluvia y la filtre, y a su vez permita la interacción de todos los usuarios, niños, adultos mayores y usuarios con discapacidad, adecuando los equipos para que estén al alcance, resulta un desafío tecnológico en estas latitudes.

Sin embargo, la aplicación de recursos digitales y tecnología inmótica nos permite diseños mutantes, que se adecúan más al usuario y al medio. Podemos así lograr espacios más confortables y saludables.

La indagación crítica creativa es nuestro proceso. ¿Será que la sociedad se está concientizando en que la distracción es parte de la salud?, ¿debería estar organizada y a disposición en las ciudades como una responsabilidad social?

Agradecimientos. Tenemos un especial agradecimiento a todo el equipo, que no son solo los autores de esta ponencia, a los asesores y al colaborador paramétrico, arquitecto Carlos Matías Rossio.

Referencias

Cirsoc. (s. f.). Publicaciones tecnológicas Cirsoc [INTI]. https://www.inti.gob.ar/areas/servicios-industriales/construcciones-e-infraestructura/cirsoc/reglamentos

Connell, B., Jones, M., Ron, M., Mueller, J., Mullick, A., Ostroff, E., Sandford, J., Steinfeld, E., Story, M. & Vanderheiden, G. (1997). *Principles of Universal Design*. North Carolina State University, The Center for Universal Design. https://projects.ncsu.edu/ncsu/design/cud/about_ud/udprinciplestext.htm

Flores, C. (2001). *Ergonomía para el diseño*. Designio. D. R. Libraría. S. A. de C. V.

International Ergonomics Association. (s. f.). *What Is Ergonomics (HFE)?* IEA. https://iea.cc/what-is-ergonomics/

Mondelo, P., Bombardo, P. B., Busquets, J. B. & Torada, E. G. (2004). *Ergonomía 3: diseño de puestos de trabajo.* Universitat Politecnica de Catalunya. Iniciativa Digital Politècnica.

Monroy, M. (2006). *Manual de diseño ICARO de calidad ambiental en la edificación para Las Palmas de Gran Canaria, Islas Canarias* [Vol. VI]. Ayuntamiento de Las Palmas de Gran Canaria.

Panero, J. & Zelnik, M. (1998). *Dimensiones humanas en los espacios interiores*. Gustavo Gili Editorial.

Romero, C. R., Serrano, F. J. V. & Lozano, C. de C. (2010). *Domótica e inmótica. Viviendas y edificios inteligentes* (3.ª ed.). RA-MA.

Saba, N., Jawaid, M., Alothman, O. Y., Paridah, M. & Hassan, A. (2016). Recent advances in epoxy resin, natural fiber-reinforced epoxy composites and their applications. *Journal of Reinforced Plastics and Composites*, *35*(6), 447-470. https://doi.org/10.1177/0731684415618459

Wisner, A. (1994). *A inteligência no trabalho: textos selecionados de ergonomia*. Fundacentro.

Gaming Engine as a Tool for Designing Smart, Interactive, Light-Sculpting Systems

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Abstract. Even though interactive (Offermans et.al., 2013), adaptive (Viani et.al., 2017), and self-optimizable (Sun et.al., 2020) lighting systems are becoming readily available, designing system automations, and evaluating their impact on user experience significantly challenges designers. In this paper we demonstrate the use of a gaming engine as a platform for designing, simulating, and evaluating autonomous smart lighting behaviors. We establish the Human - Lighting System Interaction Framework, a computational framework for developing a Light Sculpting Engine and for designing occupant-system interactions. Our results include a. a method for combining in real-time lighting IES profiles into a single 'combined' profile - b. algorithms that optimize in real-time, lighting configurations - c. direct glare elimination algorithms, and d. system energy use optimization algorithms. Overall, the evolution from designing static building components to designing interactive systems necessitates the reconsideration of methods and tools that allow user experience and system performance to be tuned by design.

Keywords: User Experience, Human-Building Interaction, Smart Lighting, Lighting Simulation, Gaming Engine

1 Introduction

Gaming Engines are increasingly being perceived as useful design platforms by virtue of their ability to actively engage and immerse users. (Akanmu et.al., 2018) The architectural field is also progressively embracing the integration of gaming engines as tools that allow designers to interrogate concepts of immersion, interaction, and human collaboration. (Hoon et.al., 2002) At the same time, recent technological advances have significantly improved the visual realism afforded by gaming engines which has transformed them into

powerful tools for simulating and evaluating the aesthetics and performance of highly complex building systems.

Intelligent lighting systems are an integral component to smart building design. Simulating them in a gaming engine allows for more than visualizing their static effect on the built environment; it enables designers to dynamically test in real-time lighting automations and controls as well as their impact on user experience. Even though studies on smart lighting systems have primarily focused on energy savings, improving user experience is another field that is gaining attention. (Sun et.al., 2020) As a result, balancing the need to accommodate occupants with the need to ensure the system's energy efficiency is central for modern lighting system design. (Aldrich et. al., 2010)

Modern LED based lighting systems are composed of digitally programmable parameters such as intensity and color temperature (Offermans et.al., 2013) which allow designers to regulate the quality and distribution of lighting. By dynamically controlling each individually addressable lighting element, visual and non-visual effects on user experience can be customized. (Linhart, 2010) The higher the number of LEDs the higher the resolution of the outputted lighting configurations and the more personalized the impact imparted to humans. Acknowledging the visual and physiological effects each lighting configuration has on humans (Bellia et.al., 2011) (Hatori et.al., 2017) is key to deliberately configuring lighting to improve occupant comfort, well-being, and performance (van Bommel et.al., 2004) (van Bommel, 2006).

2 Human - Lighting System Interaction Framework

Against this backdrop, we propose the Human - Lighting System Interaction (HLSI) Framework, a computational framework for designing smart lighting systems that acknowledge user-system interactions and regulate lighting to accommodate user and system needs (Figure 1). The HLSI framework is comprised of three components: the Sensor Network, the Interaction Protocols, and the Light Sculpting Engine. The Sensor Network provides system awareness on three levels: temporal, spatial, and human. The Interaction Protocols allow for user-system interactions to take place and the Light Sculpting Engine generates optimal lighting configurations that interface user-system interactions. The HLSI framework is evaluated by virtually simulating the generated lighting configurations and physically visualizing them in the testbed where the lighting hardware are installed. The effectiveness of the framework is collectively validated by comparing virtual and physical lighting configurations. Ultimate goal of the HLSI framework is to assist with tuning user experience and lighting system performance by design.

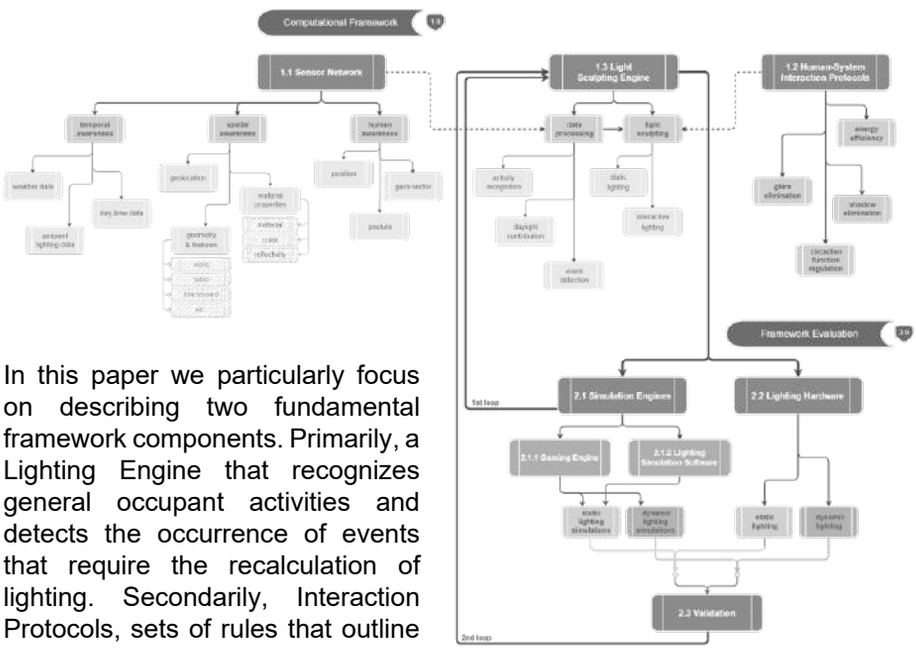

Figure 1.
[1.0] HLSI Framework
[2.0] HLSI Framework Evaluation

In this paper we particularly focus on describing two fundamental framework components. Primarily, a Lighting Engine that recognizes general occupant activities and detects the occurrence of events that require the recalculation of lighting. Secondarily, Interaction Protocols, sets of rules that outline interactive behaviors between the occupants and the system; protocols that regulate the system's efficiency and eliminate glare on an occupant level.

2.1 Light Sculpting Engine

"Light Sculpting" constitutes a strategy based on which the right amount of illumination is automatically delivered where and when needed (Department of Energy, 2020). Such an occupancy-centric lighting approach is highly contingent upon utilizing digitally programmable LED based lighting fixtures that allow designers to dynamically adjust the spectral content and directionality of each individual lighting element and employ the system's full resolution to deliver "sculpted illumination".

Digitally programmable lighting fixtures coupled with dynamic lighting controls collectively contribute to the development of light sculpting systems. Light sculpting engines control such systems by computing each time the optimal, for the circumstances, lighting configuration. Hereafter, we outline a method for developing a light sculpting engine by addressing the two fundamental tasks of setup and optimization.

2.1.1 Optimally Sculpt Lighting Configurations

To optimize lighting configurations based on occupancy requirements, physical and digital spaces are set up and calibrated to ensure that the Lighting Engine accounts for the geometrical specifications of the environment, the manufacturer specifications of the lighting system, and the relationship between programmatical functions and lighting requirements. This process happens only once for each space where the lighting system is installed and allows for future system operability. The setup process is completed in three stages: space setup, hardware setup, and activities setup.

Space Setup. In the physical space, features whose illumination is to be controlled are identified and virtually discretized; that is, their surfaces are reduced to a discrete collection of points. Lighting scenarios are designed by referencing all sample points and assigning specific illuminance levels to each one, therefore, by allocating levels of illumination in space (Figure 2).

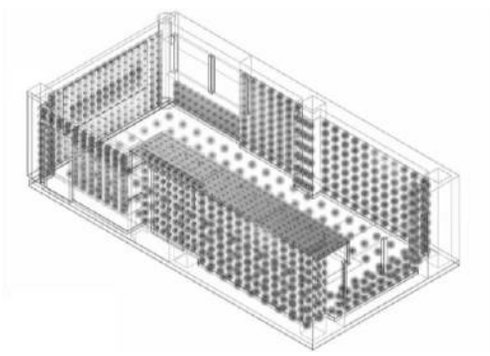

Figure 2. Space Setup

Hardware Setup. The lighting hardware are project specific. They are configured by the manufacturer based on the illumination requirements of the environment in which they will be installed. During hardware setup, the structure of each fixture is encoded so that virtual lighting elements in the Gaming Engine correspond to respective physical ones; both physical and virtual elements can be simultaneously controlled. Furthermore, during hardware setup the amount of illumination each lighting element individually contributes to each sample point in space is recorded in the Contribution Matrix, a space and hardware specific input that is fundamental for optimizing lighting.

Activities Setup. Given the programmatical function of each space prospective occupant activities and their lighting requirements need to be registered. To that end, lighting scenarios dictating the general illumination levels of all sample points in space are designed per registered activity. These scenarios afford general activity lighting and are later adjusted to customize lighting per occupant.

Optimization. Having completed all three stages of setup, optimally sculpted lighting configurations can be computed in real-time. To optimize lighting configurations we individually control the intensities of all light directionalities and assign desired illumination values to all sample points. Optimizing lighting

is a matter of identifying the multipliers (values from 0 to 1) that will adjust (activate, dim, deactivate) the intensity of each light directionality and deliver the right amount of illumination where and when needed.

To optimize lighting we use the Bounded-Variable Least-Squares (BVLS) algorithm which solves linear least-squares problems with predefined upper and lower variable bounds (Stark et.al., 1995). The solver computes multipliers (x's) for all light directionalities so that each feature point in space gets the targeted amount of lighting (y's) generating a uniquely sculpted lighting configuration. To estimate the optimal x's the solver minimizes the error (e), the difference between the targeted and the computed y's ($y_{tp} - y_p$) (Stark et.al., 1995):

$$e = \arg \min_{l \leq x \leq u} \|\mathrm{Ax} - \mathrm{y}\|_2 \qquad (1)$$

where l, x, u ∈ Rn, y ∈ Rp, and A is a p by n matrix. Bounds l=0 (lower) and u=1 (upper); thus, 0 ≤ x ≤ 1

Circumvent the Gaming Engine's Lighting Limitations. To represent lights with visual accuracy Gaming Engines support the application of IES Profiles on lights, profiles that deliver information about the distribution of photometric data and represent emission patterns based on manufacturer specifications. (Sisson et.al., 2018) The IES file format was created so that photometric data (total luminous flux, luminous intensity) (Kelechava, 2020) are transferred electronically. When imported in Gaming Engines, IES files are used as masks that modify default light patterns to achieve physical accuracy. (Dravid, 2015)

Modern LED fixtures are comprised of hundreds of lighting elements. To accurately visualize them in a Gaming Engine, IES profiles have to be applied to each individual element. However, modeling as many lights and applying IES profiles to each one is computationally expensive. To circumvent software performance limitations (we use UNITY (version 2021.1.0f1) which is limited to rendering up to 24 real-time lights per tile) we developed an algorithm that computationally combines IES profiles into a 'combined' fixture profile which is applied to a single virtual light affording the same visual result. The algorithm sums elementwise the light distribution data of the various IES files into a single 'combined' profile. By computationally combining and updating IES profiles, fixture emission patterns are updated near real-time, qualifying the Gaming Engine as a design tool for simulating and evaluating modern lighting systems.

2.1.2 Software Communication Architecture

The Architecture that interconnects the Lighting Engine with the rest of the software and hardware elements (Figure 3) is composed of, firstly, sensing devices that capture occupant movement and photometric measurements from the built environment and transmit them to the Data Processing Component (DPC) of the Lighting Engine. The DPC is responsible for denoising the collected data, applying activity recognition algorithms, and generating events (notifications) that inform the Light Sculpting Component (LSC) about required

illumination updates. The results (optimally sculpted profiles/configurations) are transmitted to both Simulation Engine **and** Lighting Hardware where the optimized lighting configurations are virtually and physically represented, validating the effectiveness of the Engine.

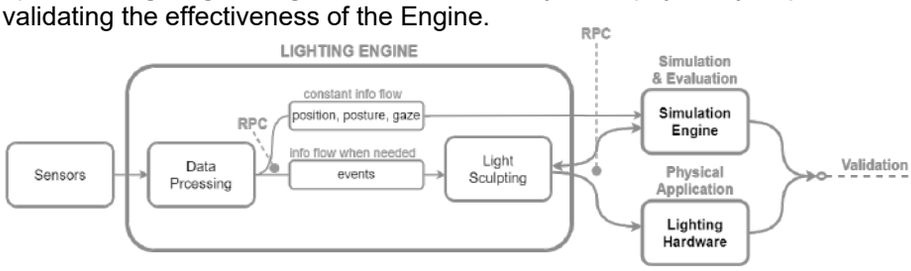

Figure 3. Software Communication Architecture

The employed communication protocol, that allows for the exchange of real-time data between the Lighting Engine, the Simulation Engine, and the Lighting Hardware, is an Open Network Computing (ONC) Remote Procedure Call (RPC) protocol. This protocol allows for an active client (Simulation Engine & Lighting Hardware) to make a call to a server (Lighting Engine) which, in turn, sends back a reply. (Thurlow, 2009) Transport protocols underneath RPC define how messages are passed. We use the TCP/IP Transmission Control Protocol as it provides a reliable connection between applications. (IBM Corporation, 2015) Most importantly, the preceding protocol allows the Lighting Engine to similarly control both simulation software and lighting hardware.

2.2 Human – Lighting System Interaction Protocols

To address occupant-system interactions, the Engine needs advanced levels of human awareness, however, by setup it can only recognize the general activity. To improve the Engine's awareness and increase the resolution of its capacity to interact, it has to be coupled with Interaction Protocols, sets of rules that outline interactive behaviors amongst occupants and the lighting system. We have developed two Interaction Protocols that regulate the system's energy use and eliminate direct glare based on occupant activity. The resulting configurations integrate preliminary scenarios (static, activity-based lighting) with energy or glare preferences that personalize configurations on an occupant level (dynamic, human aware lighting).

Regulate Energy Use. To regulate the system's efficiency we have designed three energy modes: eco, eco^{+}, eco^{++}. The first affords energy savings by delivering activity-based lighting. The second mode builds upon the first but also uses an energy savings algorithm to lower imperceptibly the lighting levels away from occupants. The third mode uses the same algorithm but lowers the lighting levels away from occupants much more perceptibly, affording increased energy savings. We recompute this algorithm whenever significant occupant movement occurs so that lighting updates accordingly.

The energy savings algorithm operates as follows. Around the center of each occupant's body two spheres (radii R1, R2) are formed (Figure 3). Values R1 and R2 are parameters that can be adjusted in advance by the designer of the system. For each sample point (p) in the room the *targeted lux value* of the sample point (y_{tp}) is calculated. It is a value between the *general activity lux value* (y_{gp}) and the *energy efficient activity lux value* (y_{ef}) and it is computed as a function of the point's distance (r) to the closest occupant. Lux values (y_{gp}, y_{ef}) are retrieved from a chart that contains predetermined lux values for each energy mode and activity. Specifically:

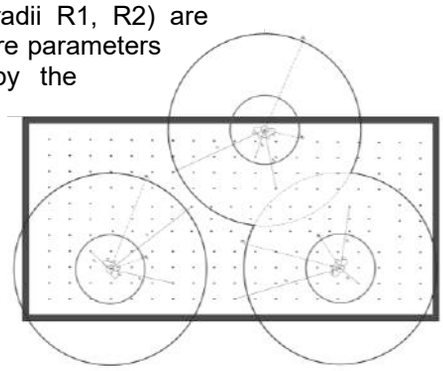

Figure 4. Determination of Targeted Activity Lux Values per Sample Point

if r < R1, then $y_{tp} = y_{gp}$ | if r > R2, then $y_{tp} = y_{ef}$ | if R1 ≤ r ≤ R2, then y_{tp} is a. or b.

a. Linear Behavior of y_{tp} as a function of y_{gp} and r:

$$\mathrm{ytp} = \frac{(\mathrm{R2}-\mathrm{r})\times(\mathrm{ygp}-\mathrm{yef})}{(\mathrm{R2}-\mathrm{R1})} + \mathrm{yef} \qquad (2)$$

b. Cosinusoidal Behavior of y_{tp} as a function of y_{gp} and r:

$$ytp = \left\{\cos\left[\pi - \frac{(\mathrm{R2}-\mathrm{r})\times\pi}{(\mathrm{R2}-\mathrm{R1})}\right]\times\frac{(\mathrm{ygp}-\mathrm{yef})}{2}\right\} + \frac{(\mathrm{ygp}+\mathrm{yef})}{2} \qquad (3)$$

Glare Elimination. To eliminate direct glare (We define as direct glare the glare that occurs when looking directly at the source of light. It does not include any light bouncing on surfaces before reaching the eye.) we limit the amount by which directionalities with glare potential contribute to achieving the targeted illumination. The glare potential is computed by interrelating each light vector with the gaze vectors of each occupant. If a directionality has glare potential, we dim or completely deactivate it to mitigate or respectively eliminate its effect. The directionalities that do not have glare potential we can fully utilize. We recalculate the glare elimination algorithm and update lighting whenever occupants significantly move or look around to account for their updated positions and gaze directions.

More specifically, a glare multiplier (g) that ranges within the domain [0,1] is assigned to each directionality retaining, mitigating, or eliminating its contribution. The glare multiplier is calculated as a function of the non-reflex or straight angle (θ) formed between each occupant's gaze vector and each of

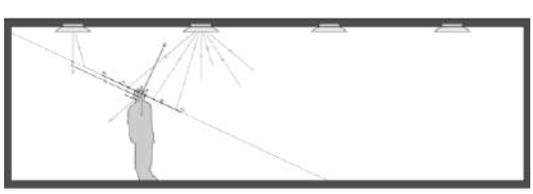

Figure 5. Gaze Vector (red) | Light Vectors (yellow) | Angles (θ) | Distance (δx)

the troffer's light vectors, and the distance (δx) from the human visual system (eyes) to the point where each light vector intersects with the plane whose normal is the occupant's normalized gaze vector (Figure 5). To simultaneously consider the contribution of θ and δx we primarily define and calculate g_θ, a multiplier that indicates the effect of glare solely based on θ, which is then used to calculate g as a function of g_θ and δx.

The glare elimination algorithm operates as follows. For each occupant the magnitude of g_θ is computed for all light directionalities by means of comparing θ against two threshold values θ1 and θ2 which are parameters adjusted in advance by the designer of the system. For $0 \leq \theta 1 < \theta 2 \leq 180$:

if $0 \leq \theta < \theta 1$, then $g_\theta = 1$ | if $\theta 2 < \theta \leq 180$, then $g_\theta = 0$ | if $\theta 1 \leq \theta \leq \theta 2$, then g_θ is a. or b.

a. Linear Behavior of g_θ as a function of θ:

$$g\theta = \frac{(\theta 2 - \theta)\times(g\theta\max - g\theta\min)}{(\theta 2 - \theta 1)} + g\theta\min \qquad (4)$$

b. Cosinusoidal Behavior of g_θ as a function of θ:

$$g\theta = \left\{\cos\left[\pi - \frac{(\theta 2 - \theta)\times\pi}{(\theta 2 - \theta 1)}\right]\times\frac{(g\theta\max - g\theta\min)}{2}\right\} + \frac{(g\theta\max + g\theta\min)}{2} \qquad (5)$$

For the light vectors that indicate glare potential based on θ ($g_\theta \neq 1$) a secondary calculation has been established to determine whether distance δx allows for glare. For each occupant, light fixture, and directionality with glare potential based on θ the intersection point of the light vector and the plane whose normal is the occupant's normalized gaze vector is identified. If the intersection point is located above the light fixture the light vector does not cause glare (g = 1). Otherwise, distance δx is computed and compared to thresholds x1 and x2, parameters adjusted in advance by the designer of the system.

if $0 \leq \delta x < x1$, then $g = g_\theta$ | if $\delta x \geq x2$, then $g = 1$ | if $x1 \leq \delta x \leq x2$, then g is a. or b.

a. Linear Behavior of g as a function of gθ and δx:

$$g = \frac{(\delta x - x1)\times(g\max - g\theta)}{(x2 - x1)} + g\theta \qquad (6)$$

b. Cosinusoidal Behavior of g as a function of g_θ and δx:

$$g = \left\{\cos\left[\pi - \frac{(\delta x - x1)\times\pi}{(x2 - x1)}\right]\times\frac{(g\max - g\theta)}{2}\right\} + \frac{(g\max + g\theta)}{2} \qquad (7)$$

3 Results

General result of our study constitutes the HLSI Framework which uses a Gaming Engine as a design tool for developing smart, interactive, light-sculpting systems. The HLSI Framework and the resulting algorithms (for overcoming software performance limitations, regulating system energy use, and eliminating direct glare) will be applied and discussed in the context of a case study.

Particularly, the HLSI framework was applied to a virtual conference room where eight smart lighting fixtures were installed. Each fixture is composed of hundreds of digitally controllable LEDs that collectively afford 53 distinct directionalities (color mapped in Figure 6) which can be individually controlled (activated, dimmed, deactivated) allowing for light to be sculpted.

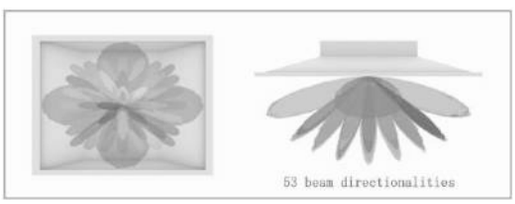

Figure 6. Case Study Hardware Specifications

To virtually represent each light fixture with physical accuracy and without exceeding the Gaming Engine's performance limitations we employed the algorithm we developed for merging multiple IES Profiles into a single 'combined' profile. Given that light intensity cannot be accurately represented and therefore evaluated in the Gaming Engine, the algorithm was assessed based on the projected light emission patterns (Figure 7). The results prove that the single combined profile (Figure 7, right) properly captures the light pattern of the uncombined ones (Figure 7, left), validating the capacity of the developed algorithm to overcome performance limitations without compromising on accuracy.

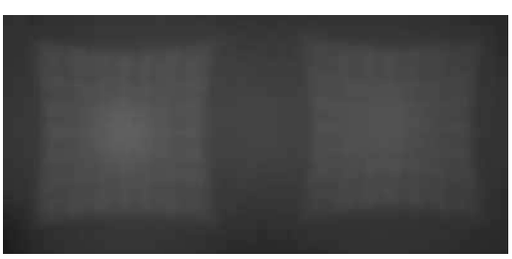

Figure 7. Light Emission Patterns projected on Horizontal Plane; Combined IES Profile (right) and Singular IES Profiles (left)

Having completed the setup, the BVLS solver was employed to compute static, activity-based lighting configurations. The implemented lighting scenarios center on delivering Uniform Lighting (uniformly 300 lux), Highlighting the Conference Table (table 300 lux, rest 50 lux), and Highlighting the Blackboard (blackboard 300 lux, rest 50 lux). By simulating these lighting configurations we visually evaluate whether the distribution of light matches the intended distribution per designed scenario. According to the simulations (Figure 8) the targeted lighting scenarios are successfully computed and the Lighting Engine's capacity to compute static, activity-based lighting is validated.

Figure 8. Static, Activity-Based Lighting Configurations
(left to right) Light Uniformly, Light the Conference Table, Light the Blackboard

To evaluate the interaction protocols we implemented primarily the energy savings algorithm for each energy mode (eco, eco+, eco++) and for each lighting scenario. Uniform lighting in eco mode constitutes the benchmark for our calculations. The results are strongly dependent on the values of the parameters R1 and R2; in Figure 9 we used R1=0.5, R2=1.0. Based on these values, the energy savings range from 45% to 76% for the Uniform scenario and reach 93% when Highlighting the Blackboard. The employed algorithm couples moderate energy savings with imperceptible lighting changes (eco+) and increased energy savings with perceptible lighting changes (eco++). This lighting strategy is limited in that system performance and user experience constitute conflicting design parameters.

Figure 9. Dynamic, Human Aware Lighting Configurations | Regulate Energy Use

By implementing the direct glare elimination algorithm upon the benchmark lighting scenario (Uniform, eco mode) we computed lighting configurations for varying occupant positions and gaze directions and calculated the associated energy savings. The results are strongly dependent on the values of the parameters θ1 and θ2 as well as x1 and x2; in Figure 10 we used θ1=120°, θ2=165°, x1=1m, x2=2m. Based on these values the energy savings range from 0.16% to 1.54%. This means that eliminating glare improves user experience without affecting negatively nor significantly system performance.

Figure 10. Dynamic, Human Aware Lighting Configurations | Red: eliminated directionalities | Purple: dimmed directionalities | Blue: fully utilizable directionalities

4 Conclusions/Discussion

To address the increasing complexity associated with smart lighting systems, in this paper we introduced a framework that uses a gaming engine as a tool for designing, simulating, and evaluating the behavior of interactive light-sculpting systems. We demonstrated the application of this framework in a case study and explored the associated affordances and limitations. Explicitly, we verified the capability to deliver static, activity-based lighting as well as to personalize lighting configurations on an occupant level. We determined that saving energy and imperceptibly changing lighting are competing design drivers as well as that eliminating direct glare improves user experience without significantly affecting the efficiency of the system.
The evolution from designing static building components to designing dynamic systems that interact with occupants necessitates the reconsideration of the employed design methods and tools. In the field of lighting design, this calls for the implementation of a system-oriented design approach where strategies and tools allow designers to simulate and evaluate system controls and behaviors as they change in response to users. Gaming Engines, as opposed to static, time-invariant modes of representation, allow designers to negotiate between competing parameters in real-time. This fact qualifies them as platforms where smart, interactive, light-sculpting systems can be trained and tuned by design.

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References

Akanmu, A. A., Ojelade, A., & Bulbul, T. (2018). Gaming Approach to Designing for Maintainability: A light Fixture Example. ISARC 2018 - 35th International Symposium on Automation and Robotics in Construction and International AEC/FM Hackathon: The Future of Building Things, July. https://doi.org/10.22260/isarc2018/0154.

Aldrich, M., Zhao, N., & Paradiso, J. (2010). Energy efficient control of polychromatic solid state lighting using a sensor network. Tenth International Conference on Solid State Lighting, 7784, 778408. https://doi.org/10.1117/12.860755

Bellia, L., Bisegna, F., & Spada, G. (2011). Lighting in indoor environments: Visual and non-visual effects of light sources with different spectral power distributions. Building and Environment, 46(10), 1984–1992. https://doi.org/10.1016/j.buildenv.2011.04.007

Department of Energy. Office of Energy Efficiency and Renewable Energy. (2020). Spatially Adaptive Tunable Lighting Control System with Expanded Wellness and

Energy Saving Benefits. Available: https://www.energy.gov/eere/ssl/downloads/spatially-adaptive-tunable-lighting-control-system-expanded-wellness-and-energy. Last accessed 04 June 2022.

Dravid, A. (2011). Understanding IES Lights. Available: http://www.cgarena.com/freestuff/tutorials/max/ieslights/. Last accessed 2 March 2021.

Hatori, M., Gronfier, C., Van Gelder, R. N., Bernstein, P. S., Carreras, J., Panda, S., Marks, F., Sliney, D., Hunt, C. E., Hirota, T., Furukawa, T., & Tsubota, K. (2017). Global rise of potential health hazards caused by blue light-induced circadian disruption in modern aging societies. Npj Aging and Mechanisms of Disease, 3(1), 5–7. https://doi.org/10.1038/s41514-017-0010-2

Hoon, M., Jabi, W., & Goldman, G. (2003). Immersion, interaction, and collaboration in architectural design using gaming engine. Proceedings of the 8th CAADRIA Conference, 721–738. http://orca.cf.ac.uk/27295/.

IBM Corporation. (2015). TCP/IP TCP, UDP, and IP protocols. Available: https://www.ibm.com/docs/en/zos/2.2.0?topic=internets-tcpip-tcp-udp-ip-protocols. Last accessed 14th June 2022.

Kelechava, B. (2020). IES Standard File Format for Photometric Data, IES LM-63-19. Available: https://blog.ansi.org/2020/02/standard-file-photometric-data-ies-lm-63-19/#gref. Last accessed 11th June 2022.

Linhart, F. (2010). Energetic, Visual and Non-Visual Aspects of Office Lighting. 4634, 295.

Offermans, S., Van Essen, H., & Eggen, B. (2013). Exploring a hybrid control approach for enhanced user experience of interactive lighting. HCI 2013 - 27th International British Computer Society Human Computer Interaction Conference: The Internet of Things, 1–9. https://doi.org/10.14236/ewic/hci2013.16.

Sisson, D, Pedersen, L. (2018). IES Profiles. Available: https://renderman.pixar.com/ies-profiles. Last accessed 2 March 2021.

Stark, P., & Parker, R. (1995). Bounded-variable least-squares: an algorithm and applications. Computational Statistics, 394, 1–13. http://www.stat.berkeley.edu/users/stark/Preprints/bvls.pdf.

Sun, B., Zhang, Q., & Cao, S. (2020). Development and implementation of a self-optimizable smart lighting system based on learning context in classroom. International Journal of Environmental Research and Public Health, 17(4). https://doi.org/10.3390/ijerph17041217.

Thurlow, R. (2009). RPC: Remote procedure call protocol specification version 2. RFC 5531, May.

van Bommel, W. J. M. (2006). Non-visual biological effect of lighting and the practical meaning for lighting for work. Applied Ergonomics, 37, 461–466.

van Bommel, W. J. M., Wout & Beld, G. J. (2004). Lighting for work: A review of visual and biological effects. Lighting Research and Technology, 36(4), 255–269. https://doi.org/10.1191/1365782804li122oa.

Ubiquent Narratives for the Design of Natural and Invisible Interfaces

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Abstract. The article proposes to explore the concepts of storytelling (Lupton, 2020 and Xavier, 2015) and ubiquity (Santaella, 2013 and Santos, 2021) applied to the design of natural and invisible interfaces (Benyon, 2011). With Natural Interface it is possible to interact with devices directly, without needing the help of a mouse or keyboard. To do so, it presents as a case study the project "Criatura de Luz" (2015), by Estúdio Guto Requena, carried out to compose the new facade of the WZ Hotel (São Paulo). The purpose of this research is to understand the role of the designer in the creation of interfaces that are not only interactive, but that begin to propose immersive and ubiquitous narratives in design projects and the method for this analysis will be the case study from the design perspective as storytelling proposed by Lupton (2020). The aim is to do exploratory research to provide greater familiarity with the problem.

Keywords: Storytelling. Ubiquity. Natural and Invisible Interfaces.

1 Introdução

A frase "design é a solução de problemas" pode ser uma verdade para diversas situações do nosso cotidiano. A sinalização do metrô de Londres, projetada em 1931 pelo designer inglês Harry Beck, é um exemplo de design funcionalista, pois o projeto ajuda as pessoas a usarem o transporte de forma simples e prática.

O principal objetivo do projeto de Beck era substituir o mapa confuso e caótico da época. No seu desenho, ele eliminou as curvas dos trilhos e colocou no lugar ângulos de 90 e 45 graus, além de padronizar as distâncias das estações.

O trabalho de Herry Beck não apenas cumpre a função de comunicar e orientar os usuários do metrô londrino, ele se tornou um símbolo cultural da

cidade, tendo sido premiado em 2006, pelo Museu do Design Britânico e pela BBC, como a segunda obra de design do Reino Unido desde 1900, ficando apenas atrás do projeto do avião Concorde.

O projeto ultrapassou fronteiras e se tornou um clássico, servindo de referência para a sinalização de metrôs em diversas cidades do mundo. Por exemplo, a sinalização do metrô de São Paulo, projetada na década de 1960 pelo escritório de João Carlos Cauduro e Ludovico Martino, foi inspirada no projeto londrino. O trabalho foi implementado na década de 1970 e sofreu pouquíssimas alterações, portanto pode-se afirmar que é uma solução de problemas bastante eficiente.

Por outro lado, a sinalização do metrô não é apenas uma ferramenta de comunicação para o uso do transporte, ela está presente na vida das pessoas e é um elemento cultural e representativo da nossa cidade. É muito comum encontrar camisetas, quadros e outros acessórios com os desenhos do mapa, dos totens de comunicação ou com as placas das plataformas das estações do metrô. Assim como o Metrô de Londres, o design não é apenas um solucionador de problemas, é linguagem, sensações e pode ser ubíquo, criando narrativas que extrapolam o seu contexto.

Se olharmos a história das interfaces digitais de comunicação, vamos perceber algo parecido – as interfaces de linha de comandos (ILC) –, encontradas nos primeiros computadores. As ações de execução de tarefas eram feitas por meio de textos digitados e tinham como principal premissa a funcionalidade do sistema. A tecnologia era limitada, e o principal instrumento de interação com a máquina era o teclado. Após a invenção do mouse, deu-se início a uma nova maneira de interagir com a máquina, o método point-and-click (apontar e clicar), que abriu caminho para uma nova era na história da interface digital de comunicação – a Interface Gráfica de Usuário (GUI - Graphical User Interface). Nesse momento os elementos de design começaram a ser mais explorados, com tipografias digitais, ícones, cores, efeitos sonoros, janelas e outras possibilidades. A Interface Gráfica de Usuário, no seu início, também priorizou a usabilidade dos sistemas e, com o passar do tempo e o avanço das tecnologias, a experiência do usuário começou a ganhar espaço, mas essas experiências estavam limitadas às possibilidades que o computador oferecia.

Hoje estamos vivenciando a terceira geração das interfaces – a Interface Natural do Usuário – e com ela é possível interagir com os dispositivos de forma direta, sem precisar do auxílio de um mouse ou teclado. Ao pressionar a tela, falar algo, fazer gestos ou colocar o aparelho em posições diferentes, é possível acionar os comandos dos sistemas. Ainda assim, sem nenhuma destas ações ou atividades, os comandos são acionados, pois o histórico das nossas ações faz com que a máquina aprenda e, dessa forma, se antecipe, apresentando o que “queremos”.

A proposta deste estudo é compreender o papel do designer neste cenário que se projeta: com interfaces mais invisíveis e naturais, experiências mais imersivas e ubíquas. O objetivo é fazer uma pesquisa exploratória para

proporcionar uma maior familiaridade com o problema. Dessa forma, usaremos como procedimento a pesquisa bibliográfica para uma maior compreensão dos conceitos que envolvem o tema, tais como: as narrativas ubíquas, as interfaces naturais e invisíveis. Será utilizado também o estudo de caso, a fim de explorar todos os conceitos abordados em um projeto.

2 Narrativas Ubíquas

Para compreender o que são as Narrativas Ubíquas, serão apresentados os conceitos da estrutura narrativa e, para isso, vamos entender como funciona o processo de Storytelling.

Segundo Xavier (2015, pag. irreg.), “Storytelling é a tecnarte de elaborar e encadear cenas, dando-lhes um sentido envolvente que capte a atenção das pessoas e enseje a assimilação de uma ideia central”.

Ellen Lupton (2020) , por sua vez, apresenta o conceito Storytelling usando a metáfora da Montanha-russa:

> (...) as montanhas-russas de fato têm um padrão em comum com as histórias. A jornada começa ao nível do solo e vai se desenvolvendo até chegar ao clímax. À medida que o carrinho vai subindo lentamente os trilhos, ele armazena a energia que será liberada em uma queda vertiginosa depois que os passageiros alcançarem o ponto mais alto. A energia liberada pela montanha-russa não é apenas física, mas também emocional, e pode ser ouvida nos gritos de êxtase dos passageiros. (Lupton, 2020, p. irreg.)

Assim como as montanhas-russas, as histórias terão diversos níveis de emoção. Por exemplo, antes do momento do clímax, sempre vem o momento da pausa silenciosa. A subida do carrinho da montanha-russa antes de chegar ao ponto mais alto do brinquedo, para depois descer em alta velocidade, causando o momento mais emocionante do trajeto, é a pausa silenciosa do trajeto – durante a subida, as pessoas não conseguem ver o topo, criando uma expectativa misteriosa, e o silêncio logo será substituído por gritos emocionados.

Se compararmos com um filme, não será diferente. Todos nós lembramos da famosa cena do filme E.T.: O Extraterrestre (1982), do diretor Steven Spielberg, em que o personagem Elliott (Henry Thomas) voa junto com ET em sua bicicleta, essa é uma das cenas mais importantes da história do cinema, que, todavia, só se tornou relevante pelo fato ocorrido antes, a pausa silenciosa. Elliott e ET estavam sendo perseguidos pela polícia, a expectativa que a cena apresentava é de que eles não teriam saída e o final não seria o

mais desejado por todos, porém acontece o inesperado: a bicicleta começa a voar e os perseguidos viram o jogo contra os perseguidores – o clímax do filme.

Em um cartaz também podemos encontrar uma sequência narrativa. Nossos olhos "passeiam" pelos elementos da composição, a hierarquia visual da peça é fator norteador da narrativa do projeto.

Além da estrutura narrativa, outro conceito que devemos levar em consideração para um melhor entendimento das Narrativas Ubíquas são os estímulos sensoriais. De acordo com Lupton (2020, pag. irreg.), "nosso fluxo óptico se mistura com informações dos outros sentidos. Nosso 'ângulo de câmera' muda cada vez que viramos a cabeça. Os estímulos visuais se misturam com os auditivos, olfativos, táteis e com o peso e a localização de nosso corpo no espaço".

Para que as experiências possam ser mais imersivas, devemos ampliar nosso processo perceptivo com os artefatos. Diversas marcas têm usado o marketing sensorial para se relacionar com o seu público:

> O marketing sensorial utiliza como base o estudo dos cinco sentidos e as estratégias de como empregar esses recursos para marcas e lojas, através da persuasão das pessoas em ambientes de compra, gerando-lhes experiência, o que permite que os clientes mantenham as marcas ou os ambientes na memória. (BENITES, 2016, p. 10)

Em 2012, para fazer a divulgação da sua fragrância Floratta, a empresa O Boticário distribuiu, nas estações do metrô do Rio de Janeiro, cataventos coloridos e perfumados com o cheiro do produto. Essa ação trouxe um contato lúdico e imersivo com a marca. Da mesma forma, o efeito sonoro da Intel já se tornou uma extensão para reconhecimento da marca.

Outro exemplo é a embalagem da cerveja Heineken, que em 2010 criou Heineken Touch, uma lata com acabamento em verniz e uma superfície em alto relevo que provoca uma sensação tátil no momento em que seguramos o produto.

E por fim, outro conceito que devemos discutir é a computação ubíqua, que Benyon explica da seguinte maneira:

> A computação ubíqua, ou computação também chamada ubicomp (do inglês *ubiquitous computing*) ou computação pervasiva preocupa-se em 'quebrar a caixa'. Ela prenuncia o dia em que as tecnologias de computação e comunicação irão desaparecer, integrando-se à trama do mundo. E isso pode ser literalmente a trama dos tecidos que vestimos, das construções e dos objetos que transportamos ou usamos. Um telefone celular poderá ser instalado no seu dente e talvez você se comunique com um parceiro distante esfregando um brinco. No outro

> extremo desse espectro poderemos ter dispositivos de exibição do tamanho de paredes ou ambientes físicos aumentados com objetos gráficos; ou, ainda, objetos físicos usados para interagir com paredes e outras superfícies habilitadas com sensores. A IHC e o design de interação em ambientes ubicomp preocupam-se com a interação de muitos dispositivos de computação entre si. (Benyon, 2011, p. 316)

O conceito de ubiquidade está vinculado à ideia de onipresença e, na computação, isso acontece quando podemos encontrar e usar os artefatos tecnológicos em qualquer lugar. Por exemplo, fazer um pedido de um lanche de uma hamburgueria mesmo não estando presente fisicamente no local – os aplicativos de entrega de comida pela internet podem fazer isso hoje. Durante a pandemia de Covid-19, o conceito de ubiquidade esteve presente em diversas situações, como reuniões por videoconferência, aulas não presenciais, atendimentos médicos por teleconferência, entre outras.

Já as Narrativas Ubíquas vão explorar não apenas a onipresença dos artefatos tecnológicos, mas também o conteúdo, as histórias e a linguagem. Por exemplo, um álbum de fotografias não é apenas um lugar para guardar fotos. É uma maneira de editar e compartilhar histórias pessoais com outras pessoas que não estiverem no local. Alguns museus interativos vão trazer esse conceito das Narrativas Ubíquas, como, por exemplo, o Museu do Futebol, localizado na cidade de São Paulo dentro do Estádio Paulo Machado de Carvalho (Pacaembu), onde é possível ouvir o som da torcida de um jogo em que não estamos presentes, ou interagir com cenários e personagens que fizeram parte da história futebol. E toda essa interação irá acontecer por meio de Interfaces Naturais e Invisíveis.

3 Interfaces Naturais e Invisíveis

Segundo Benyon (2011), podemos dividir as interfaces digitais em três gerações: i) a interface de linha de comandos (ILC), encontrada nos primeiros computadores, cuja principal ferramenta de interação era o teclado; ii) a Interface Gráfica de Usuário (GUI - Graphical User Interface), encontrada nos primeiros computadores que usavam o mouse como ferramenta de interação – esse hardware propicia uma interação mais lúdica através de elementos gráficos, ícones e janelas flutuantes, e nesse momento os comandos são ampliados, pois as possibilidades de interação também aumentaram; e iii) as interfaces Naturais, cuja interação é direta, sem a necessidade de um segundo hardware (como mouse ou teclado) para ativar um determinado comando. Nesta terceira geração, vamos nos aproximar do conceito de “tecnologia como extensão do homem”, de Marshall Mcluhan (2007), se pensarmos, por

exemplo, na função das roupas. Mcluhan (2007, p.140) afirma que elas são a extensão da nossa pele – “a roupa ajuda a armazenar e canalizar energia (…)”.

A ideia de extensão dos artefatos digitais com interfaces naturais, como o aparelho de celular, vai nos ajudar na locomoção por lugares que não conhecemos por meio do GPS, ou a conversar com pessoas de outras cidades ou países através das mensagens instantâneas:

> Uma interface natural é aquela que nos permite interagir com um computador da mesma maneira como interagimos com o mundo físico, pela utilização de nossa voz, nossas mãos e corpos. Em vez de usar um teclado e um *mouse* (como é o caso das interfaces gráficas), uma interface natural nos permite falar com máquinas, bater em suas superfícies, gesticular com elas no ar, dançar em tapetes que detectam os movimentos de nossos pés, sorrir para elas para obter uma reação e assim por diante. (Benyon, 2011, p. 215)

Dessa forma, a nossa interação com as interfaces são expandidas, sem condicionar os comandos apenas ao toque, mas também por gestos, voz, ou basicamente a nossa presença. Amazon Alexa, uma assistente virtual, é um exemplo de interação por meio da voz, com ela é possível configurar alarmes, informar a situação do trânsito ou a previsão do tempo, executar uma lista de músicas ou reproduzir podcasts.

Outro exemplo é o Microsoft Kinect do Xbox One, a proposta da empresa foi ampliar a experiência do jogo eliminando o controle e naturalizando os comandos por meio de gestos pré-configurados no sistema.

O aprendizado das máquinas também vai condicionar a forma como interagimos com as interfaces. Quando assistimos a uma série ou a um filme em uma plataforma de streaming, como Netflix ou Amazon Prime, ensinamos à máquina o que gostamos e o que não gostamos e, com o passar do tempo, essa interface vai sendo moldada com um conteúdo mais próximo do nosso gosto fazendo com que nossas as escolhas sejam definidas não mais pela busca, mas pelo que aparece na tela do dispositivo. Podemos dizer que esse tipo de interface faz parte de um sistema autopoiético.

Para Maturana e Varela (2001, p. 55), “a característica mais peculiar de um sistema autopoiético é que ele se levanta por seus próprios cordões, e se constitui como diferente do meio por sua própria dinâmica, de tal maneira que ambas as coisas são inseparáveis”.

Esses sistemas também vão se aproximar do que chamamos de cidades inteligentes, a diferença aqui é que, na maioria das interações com esses sistemas, não conseguimos enxergar as interfaces, que se tornam invisíveis.

Nas cidades inteligentes, os sistemas são alimentados por sensores e câmeras que nem sempre estão visíveis para os moradores. Barcelona é um exemplo de cidade que vem se organizando dentro dessa perspectiva, incorporando sensores inteligentes e análises de big data a tudo, desde

estacionamento, transporte, coleta de lixo, qualidade do ar e irrigação de terrenos. Além disso, de acordo com Francesca Bria (2019), diretora de tecnologia de Barcelona, a cidade vem ampliando a participação do cidadão em decisões de políticas públicas. Para ela, a tecnologia pode melhorar a qualidade de vida das pessoas.

4 Estudo de Caso

4.1 Criatura de Luz, Guto Requena (2015)

O projeto “Criatura de Luz” (2015), do Estúdio Guto Requena, teve como briefing a criação da nova fachada do WZ Hotel. O prédio tem 30 andares e foi construído na década de 1970. A fachada fica toda acesa quando começa a anoitecer, a luz apresenta dinâmicas diferentes de acordo com o barulho e a qualidade do ar do local. Foram instalados sensores para captar, em tempo real, o som em torno do prédio, e conforme a intensidade do barulho, o desenho das luzes se altera. Toda a fachada foi coberta por chapas metálicas, que se intercalam entre coloridas e brancas e funcionam como rebatedores para refletir as tonalidades das luminárias de LED em RGB.

Guto Requena, designer responsável pelo projeto, usou os softwares Grasshopper e Processing para criar o projeto paramétrico da fachada, que foi desenvolvido da seguinte maneira: primeiro foi feita uma captação do áudio do local por meio de um gravador polifônico posicionado no terceiro andar do prédio, a partir dos dados sonoros foram desenhados os parâmetros de luz da fachada, que segue a seguinte regra: Som mais intenso - cor dourada; menos áudio - azul-marinho; pouco barulho - azul-claro; e silêncio - cinza, conforme Figura 1 a seguir.

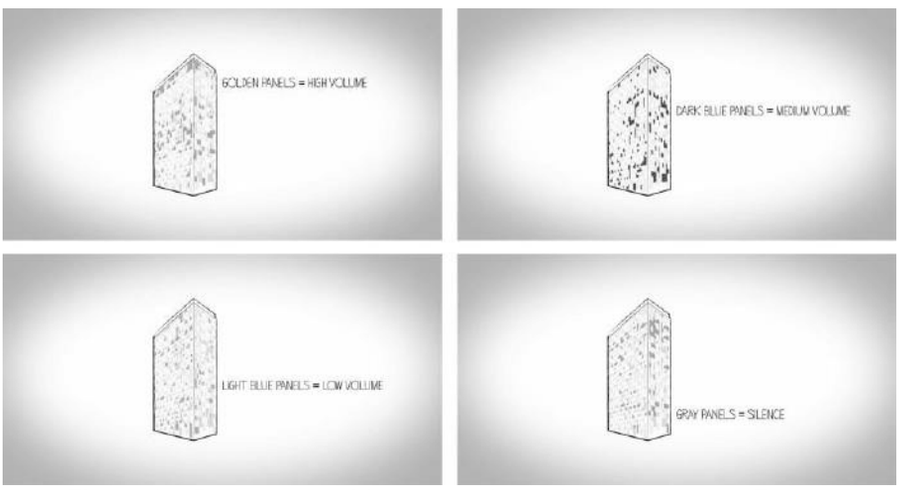

Figura 1 – Padrão cromático para a intensidade dos sons. Fonte: www.gutorequena.com

A dinâmica de apresentação das cores para a qualidade do ar é semelhante, seguindo os seguintes parâmetros: cores mais quentes, como o vermelho e o laranja, para qualidade ruim e cores mais frias, como azul, roxo e verde, quando a qualidade está boa. O critério da escolha para cores quentes e frias, de acordo com Requena em entrevista ao site Galeria da Arquitetura em 2015, era para mostrar o "humor" da Criatura de Luz (nome do projeto), como ilustra a Figura 2 a seguir.

Figura 2 – Padrão cromático para a intensidade do ar. Fonte: www.gutorequena.com

Além disso, também foi desenvolvido um aplicativo para as plataformas Android e iPhone pela empresa de Tecnologia, Design e Conteúdo YDreams Global, permitindo também uma participação do público. Com ele, os usuários podem interagir com o prédio escolhendo uma cor e desenhando na própria tela como as luzes podem aparecer, conforme exemplifica a Figura 3 a seguir.

Figura 3 – Aplicativo WZ Hotel Luz. Fonte: www.gutorequena.com

5 Considerações Finais

Concluímos que projeto Criatura de Luz (2015), de Guto Requena, pode ser considerado uma Narrativa Ubíqua pelos seguintes motivos: o projeto “conta” a história da cidade onde ele está situado – o ônibus passando, o motoboy buzinando, a ambulância correndo para uma emergência são sons que já entraram na rotina do morador da cidade e podem ser visualizados a partir de uma perspectiva da arquitetura que também faz parte dessa narrativa caótica, com prédios super altos e com o mesmo desenho – a Criatura de Luz (2015) se propõe a ser o contraponto dessa história.

Outro fator importante é colocar a pauta da cidade sustentável na história que é contada, apresentar como está a qualidade do ar que respiramos em um painel de 30 andares, que, por si só, talvez não chame tanto a atenção para o assunto, mas gera mídia espontânea e a história passa a ser contada por outras pessoas, em outros lugares, em formatos diferentes. O aplicativo do celular pode ser considerado a quebra da narrativa, pois ele interrompe a

apresentação da poluição sonora e do ar da cidade para mostrar a interação de um indivíduo, morador ou não da cidade.

As interfaces naturais e invisíveis estão presentes nos sensores de captação do som e do ar, além da própria interface do aplicativo. A interface natural também se torna presente quando começa a fazer parte do cenário da metrópole com uma arquitetura híbrida e interativa.

Referências

Benites, Tatiana. Marketing sensorial: como utilizar os cinco sentidos para atrair clientes São Paulo: Comunica T. (Edição do Kindle), 2016.

Benyon, David. Interação humano-computador. Tradução Heloísa Coimbra de Souza; Revisão técnica Illana de Almeida Souza Concílio. 2. ed. São Paulo: Pearson Prentice Hall, 2011.

Lupton, Ellen. O design como storytelling. Tradução Mariana Bandarra. Osasco: Gustavo Gili, 2020.

Maturana, Humberto R.; Varela, Francisco J. A árvore do conhecimento as bases biológicas da compreensão humana. Editora Palas Athena, 2001. 288p.

McLuhan, Marshall. Os meios de comunicação como extensão do homem (understanding media). São Paulo: Cultrix, 2007.

Morozov, Evgeny; Bria, Francesca. A cidade inteligente: tecnologias urbanas e democracia. São Paulo: Ubu, 2019.

Xavier, Adilson. 1955-Storytelling [recurso eletrônico]. 1.ed. Rio de Janeiro: BestSeller, 2015.

Archdaily. Disponível em: https://www.archdaily.com.br/br/770171/estudio-guto-requena-cria-fachada-de-luz-interativa-em-sao-paulo. Acesso em: 12 dez. 2020.

Arquitetura hackeada: criatura de luz por Estúdio Guto Requena. Disponível em: https://www.youtube.com/watch?v=V0mkktCzLhw. Acesso em: 12 dez. 2020.

Galeria da Arquitetura. Disponível em: https://www.galeriadaarquitetura.com.br/projeto/estudio-guto-requena_/wz-hotel/1647. Acesso em: 12 dez. 2020. GUTO REQUENA. Disponível em: https://gutorequena.com/. Acesso em: 12 dez. 2020.

Ydreams Global. Disponível em: https://ydreamsglobal.com.br/site/. Acesso em: 12 dez. 2020.Solemma. (2020). ClimateStudio (version 2.4) [Computer software]. https://www.solemma.com/cs-trial

Iberoamerican Society of Digital Graphics, SIGraDi. (2021). Autoridades. http://www.sigradi.org

The Role of Visual Platforms —Visual Social Media— in the Creative Design Process

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Abstract. In the current design practice, new digital tools have emerged -visual- also called Infrastructures (Perkel, 2011) such as; Behance 2003, Pinterest 2009, Archdaily 2008, Instagram (2010) -to cite the most recognized in the creative field in Argentina-, which promote different opportunities and support the creative process and problem solving, making it easier for designers to find inspiring material through the Internet. However, very little is known about how these new practices affect professional work, how they themselves see it and the tensions they generate.This article will present the results of a general survey applied to expert designers as part of the first stage of the Doctoral Research project. Which investigates the behavior referred specifically to the use of visual platforms -visual social media- in order to understand, characterize, describe the use and involvement of them within the design process.

Keywords: design process, creativity, inspiration, plataformas visuales, curatorial practice

1 Introducción

El creciente número de soluciones de diseño en línea, junto con el aumento global de diseñadores conectados —usuarios *online*—, ha llevado al desarrollo de servicios y plataformas dedicados a apoyar la inspiración y búsqueda de información (Koch *et al*., 2018).

En la última década el incremento de herramientas digitales visuales fue ganando notablemente un lugar en el desarrollo del proceso creativo de diseño. La aparición de plataformas visuales de diseño, como Pinterest Behance, Archadaily, Instagram, permite la creación de muestras en línea de galerías que otorgan a los diseñadores la posibilidad de encontrar inspiración a través de internet. Algunos ejemplos se muestran a continuación (figuras 1-4).

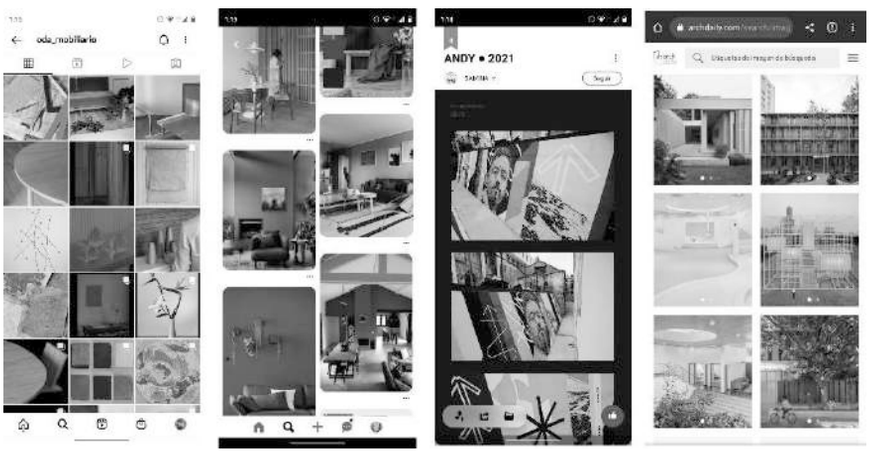

Figura 1. *Collage* plataformas visuales. Fuente: Toledo Jimena, 2022.

Esta investigación parte de la premisa de dar a conocer cómo es el proceso de diseño actual, donde el uso de infraestructuras de diseño —concepto elaborado por Perkel (2011)— define que los artistas jóvenes utilizan la web para distribuir su trabajo y en el proceso producen la web como infraestructura para la práctica creativa. Además, sostiene que los ideales contradictorios del arte, la creatividad y la web, cuando se ponen en práctica, dan lugar a nuevas plataformas como infraestructura técnica e ideológica, tales como las plataformas visuales (*visual social media*). Estas son una herramienta cotidiana y cada vez más indispensable a la hora de buscar fuentes de inspiración creativa (Eckert & Stacey, 2000) o fuentes de referencias (Goldschmidt, 1998).

Las plataformas visuales de diseño funcionan como infraestructuras (Perkel, 2011) que permiten recopilar y organizar fuentes de inspiración y dan lugar a lo que luego denominaremos como bibliotecas virtuales. Esta tarea puede llevar mucho tiempo en la práctica individual y *offline* (fuera de línea). De este modo, fomentan el trabajo colaborativo, en equipo y en red, mejorando la eficiencia y la eficacia en la resolución de problemas.

Algunas de las plataformas en línea, tales como Pinterest o Behance, ofrecen al usuario la posibilidad de crear tableros (*pins boards* o *portfolios* online) facilitando la confección, categorización y organización de estas bibliotecas virtuales y permitiendo la continua retroalimentación de la información, lo que genera un intercambio ilimitado de conocimiento.

Sin embargo, se sabe muy poco acerca de cómo estas nuevas prácticas afectan el quehacer profesional de los diseñadores, como ellos mismos las usan, las ven y las tensiones que estas generan.

1.1 Comunidad creativa

Los diseñadores son una comunidad creativa de interés único porque su experiencia en la curación de imágenes es fundamental para su trabajo profesional. Diseñadores de interiores, gráficos, industriales, escenógrafos arquitectos, etc., a menudo recopilan imágenes precedentes, ejemplos existentes de diseño, como parte del proceso de diseño para desarrollar sus conocimientos, así como identificar patrones y tipologías para futuros problemas de diseño. Además, descubren y buscan puntos de partida para innovar en la práctica (Lawson, 2004). Estas imágenes precedentes actúan como fuentes de inspiración y a menudo se organizan en diseños de tableros (Eckert & Stacey, 2000).

Los diseñadores cada día están más familiarizados con las nuevas prácticas tecnológicas en lo que se refiere a *softwares* de diseños o plataformas visuales (infraestructuras) que sirvan de ayuda y soporte para su labor profesional. Cuando hablamos de recopilación de datos y fuentes de inspiración, en esta investigación, nos referiremos específicamente a fuentes digitales que pueden influir directa e indirectamente en el resultado final del producto/artefacto de diseño, ya que sostenemos que las fuentes de inspiración creativa juegan un papel importante en el proceso de diseño, tanto en la definición del contexto para los nuevos diseños como en la información de la creación de diseños individuales. En palabras de Eckert (2000): “El diseño sirve como punto de partida para el diseño, es un precedente, un elemento para la reutilización, un patrón y un generador primario para nuevas ideas”.

Además, Koch *et al.* (2018) explica que la comparación de soluciones de diseño en la misma industria ayuda a los diseñadores a formar ideas generales sobre estructuras para nuevos diseños. Los diseñadores se comunican entre sí sobre nuevos diseños, estilos, en gran parte por referencia a las fuentes de sus ideas (Eckert & Stacey, 2000).

1.2 La práctica curatorial

El concepto de “curación de contenidos” aún es reciente, pero es un término cada vez más utilizado. Según Sergio Ortega (2011), diseñador multidisciplinar y doctorando en Educación (UPSA, Salamanca), la curación de contenidos se entiende como “la capacidad por parte de un sistema o del ser humano de encontrar, organizar, filtrar y dotar de valor, relevancia, significatividad, en definitiva, de utilidad el contenido de un tema específico que procede de diversas fuentes” (Ortega, 2011).

El curador de contenidos —traducción del término en inglés *curator*, del latín *cura* o *curare*, 'cuidar'— puede aplicarse a los diseñadores, ya que según Cullinane (2013) el trabajo de estos es la reorganización o recombinación de elementos existentes en una nueva configuración de acciones o

intervenciones. El curador es alguien que continuamente encuentra, agrupa, organiza y comparte los mejores y más relevantes contenidos sobre un tema específico en línea.

La curación de contenidos permite filtrar la inmensa cantidad de información que encontramos en internet y presentarla en un modo coherente y organizado por temas o tópicos.

A pesar de la importancia de la curaduría en la cultura del diseño, hoy sigue siendo una tendencia de diseñadores, educadores en diseño y diseño en general el "sobrevalorar la diferenciación y originalidad" a la que Cullinane (2013) se refiere como la "paradoja de la originalidad" en el diseño.

1.3 De la web 2.0 a la web semántica

En 1991, cuando Tim Berners-Lee logró vincular la tecnología de hipertexto a la internet, con la creación de la World Wide Web (Red de Extensión Mundial, WWW), fundó las bases de un nuevo tipo de comunicación en redes. Los blogs, los distintos medios de suscripción a noticias y actualizaciones y los servicios de correo electrónico contribuyeron a la conformación de comunidades *online* y sirvieron de ayuda a grupos *offline* (Van Dijck, 2013). Hasta el cambio de milenio, los medios de la red eran en su mayoría servicios genéricos a los que el usuario podía suscribirse o de los que podía hacer uso de manera activa para construir grupos, pero estos servicios no lo conectaban a otros usuarios de manera automática. Con la llegada de la web 2.0, los servicios *online* dejaron de ofrecer canales de comunicación en red y pasaron a convertirse en vehículos interactivos y retroalimentados de sociabilidad en red (Castells, 2007).

Es en este contexto, a principios de 1990, donde encontramos a los pioneros de la arquitectura digital. Arquitectos/diseñadores tales como Greg Lynn, Frank Gehry, Stan Allen, Mario Carpo —a modo de citar algunos de los nombres más reconocidos de ese movimiento— lograron manifestar nuevos modos de pensar la arquitectura, producto de la aparición de nuevos *softwares* de diseño (CATIA/Autodesk), es decir nuevas competencias tecnológicas. Es entonces en este periodo donde el diseño generativo y el diseño paramétrico comienzan a fundar las bases de otro modo de proyectar, donde los recursos tecnológicos no son una herramienta que sirve de soporte al diseño, si no que es la herramienta a través de la cual el diseño comienza, se comparte se retroalimenta y se produce. Sin embargo, las redes sociales todavía permanecían al margen del campo disciplinar del diseño.

Con la evolución de la web 2.0 surge la web semántica, término también acuñado por Berners-Lee (2000) para describir una red en la que las máquinas procesarían el contenido de forma similar a la humana y en la que todos los datos estarían conectados y se entenderían tanto contextual como

conceptualmente (conocido también como web 3.0); es este nuestro escenario en la actualidad.

Retomando el campo disciplinar de la arquitectura, podríamos afirmar que cada vez son más los estudios de arquitectura y empresas internacionales que trabajan de manera *online* colaborativa con *softwares* de diseños, tales como los sistemas Building Information Modeling (BIM) que permiten el trabajo participativo, en comunidades diversas, interconectados desde diferentes partes del mundo. Si a este fenómeno le añadimos la complejidad de las redes sociales y las aplicaciones móviles como nuevo espacio de interacción laboral y social, espacio que cohabitamos y que cada día interviene más en el desarrollo de nuestras prácticas cotidianas, nos encontramos con un nuevo escenario conocido y reconocido por todos. Sin embargo, todavía existe muy poca literatura que haga referencia a cómo estas nuevas prácticas, sociales/virtuales, influyen en los procesos proyectuales a la hora de resolver un problema del campo disciplinar.

1.4 Sobre la literatura

Investigaciones anteriores trabajaron con plataformas específicas, y determinaron diferentes categorías y aportaron diferentes reflexiones en lo referido a la práctica de diseño mediante el uso de plataformas virtuales *online,* tales como Behance (Llopis, 2016), Pinterest (Scolere, 2016), DeviantArt (Perkel, 2011). Mientras, otras estudiaron cómo es el proceso de búsqueda inspiracional comparando el uso entre varias infraestructuras en línea como es el caso del trabajo de Koch *et al.* (2018).

Mediante esta investigación se busca complementar las perspectivas antes mencionadas formulando los siguientes interrogantes: ¿cómo operan las plataformas visuales de diseño (*visual social media*) y qué nuevas lógicas plantean, en la praxis proyectual, en diseñadores expertos —entendiendo a este como la búsqueda inspiracional y creativa de reflexión y resolución de problemas en el proceso de diseño—? ¿Cómo afecta al pensamiento de diseño en la búsqueda de material inspirador?

2 Metodología

Como primera instancia de esta investigación se trabajó con una metodología descriptiva. Para ello se elaboró una encuesta general aplicada a diseñadores expertos indagando sobre el comportamiento referido específicamente al uso de plataformas visuales (*visual social media*) en el desarrollo del proceso de diseño para poder acercarnos a resolver la hipótesis de este trabajo.

2.1 Sobre la encuesta

La encuesta aplicada a diseñadores expertos fue realizada en el mes de julio del 2022 mediante un formulario de Google Forms. La misma se estructuró en dos partes: la primera parte recopila datos demográficos (edad, género y nacionalidad); mientras que la segunda parte cuenta con cinco preguntas, cuatro de ellas cerradas para obtener información cuantificable y estadística, y una abierta, a modo de introducirnos sobre el uso específico en cuanto a plataformas visuales se refiere.

El objetivo de esta primera etapa del proyecto de investigación fue validar el uso de las plataformas digitales en el campo de diseñadores expertos y de esta manera validar la hipótesis de la investigación, para luego interiorizarse específicamente sobre el uso exclusivo de las mismas como segunda etapa de la tesis doctoral.

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3 Resultados

3.1 Tablas y figuras

La encuesta contó con 83 participantes, 97% de nacionalidad argentina, de los cuales 70,7% corresponden a género femenino; 23,2%, masculino; 4,9%, no binario; y el 1,2%, otro.

Tabla 1. Datos demográficos de los encuestados (83 en total)

	Nacionalidad				
Género con el que te identificas	Argentina	Argentino-española	Boliviana	Ítalo-argentina	Total general
Femenino	56	1	1	1	59
Masculino	19				19
No binario	1				1
Otro	4				4
Total general	80	1	1	1	83

Fuente: Toledo, 2022

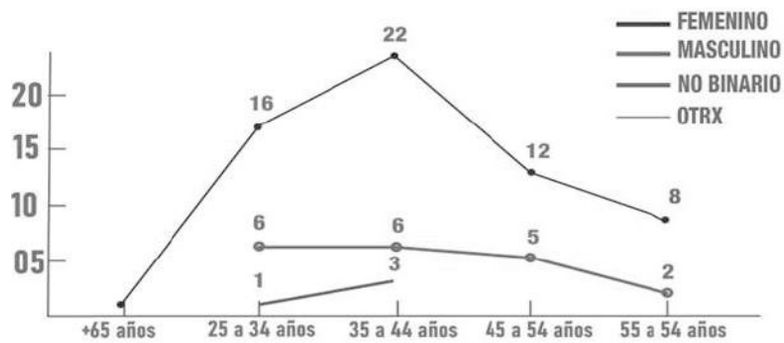


Gráfico 1. Datos demográficos: edad + género

Fuente: Toledo, 2022

Entre los encuestados preponderan participantes entre 25 y 44 años de edad —60%—, acompañados del 20,5 %, diseñadores entre 45 y 54 años.

De los 83 encuestados, 56 afirmaron ser diseñadores independientes, 19 contaron con un trabajo en dependencia y ocho de ellos optaron por ambas opciones para definir su actividad laboral.

	Diseñador			
Edad	Independiente	Independiente, trabajo en dependencia	Trabajo en dependencia	Total general
Más de 65 años	1			1
25 años a 34 años	11	1	11	23
35 años a 44 años	22	6	4	32
45 años a 54 años	13	1	3	17
55 años a 64 años	9		1	10
Total general	56	8	19	83

Fuente: Toledo, 2022

3.2 Aspectos significativos

Uno de los aspectos más significativos resultó en que 77 participantes, correspondientes al 92% de los encuestados, afirmaron usar plataformas visuales (*visual social media*) durante el proceso creativo de diseño, respondiendo a la pregunta: durante el proceso de ideación/proyectación, ¿utiliza plataformas visuales *online* para la búsqueda inspiracional? Ejemplo: Plataforma Arquitectura/Archdaily/Pinterest/Instagram/Behance/otras. Luego, se pidió a los participantes que especifiquen qué plataformas utilizan con mayor frecuencia, posicionándose Pinterest como la más utilizada a la hora de buscar inspiración *online* con un valor del 60%, acompañando Archdaily con el 58%, Instagram con el 47% y Behance con el 30%. Solo el 26,5% optó por la opción "otras" manifestando utilizar plataformas, tales como Dribble, El Croquis, Porfoliox, Dezeen.

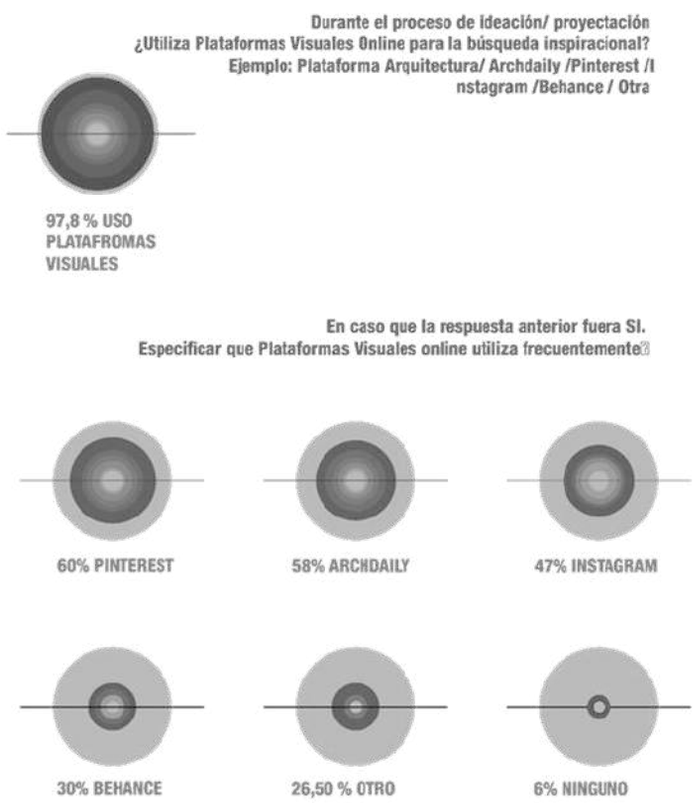


Gráfico 2. Fuente: Toledo, 2022

Otra de las variables significativas se obtuvo bajo la premisa de determinar cuáles plataformas visuales eran sus preferidas a la hora de comenzar el proceso de ideación; podían seleccionar tres opciones como máximo. Las opciones propuestas fueron las siguientes: 1) búsqueda inspiracional a través de internet; 2) búsqueda inspiracional en plataformas visuales; 3) *software* de diseño: Cad/Revit/Sketchup/otros; 4) hoja y lápiz; 5) otros. De esto se obtuvieron los siguientes resultados: el 80% afirma preferir la hoja y el lápiz a la hora de comenzar a proyectar. Valores iguales se obtuvieron en cuanto a búsqueda inspiracional a través de internet o en plataformas visuales se refiere. Así, se puede deducir que el 80% de los diseñadores recurre a herramientas/recursos *online* y solo el 50% de ellos tiene preferencia por las plataformas visuales enunciadas. El 30% también optó por herramienta preferida la opción *software* de diseño, quedando solo el 7% (correspondiente a seis personas) que confirma no utilizar ningún tipo de acceso a internet durante el proceso creativo de diseño.

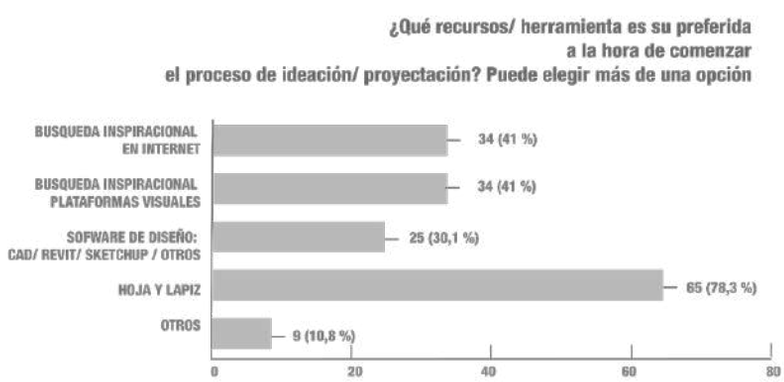


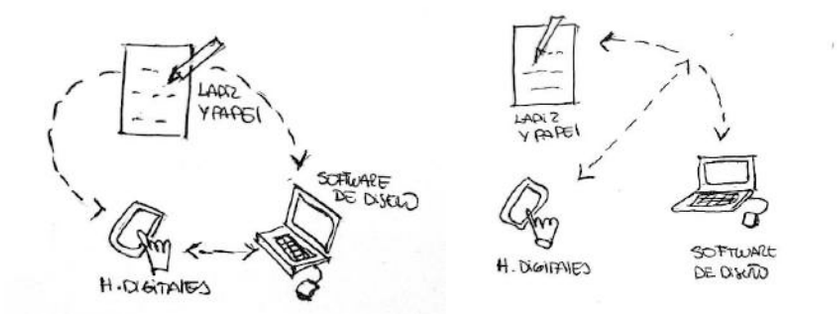
Gráfico 3. Fuente: Toledo, 2022

4 Discusión

Los resultados obtenidos, además de confirmar un uso relevante de plataformas visuales —cuando de búsqueda inspiracional se trata—, también demuestran, aunque se los encuentre predecibles, que la mayoría de los participantes que afirmaron no utilizar plataformas visuales corresponde a una población de más de 55 años. Por ello, se hace necesario reconfigurar las metodologías de diseño tradicionales, y entender que las generaciones presentes y futuras configuran y establecen sus prácticas de diseño a través de herramientas digitales.

A la hora de comenzar el proceso de diseño, las opciones más elegidas resultaron ser hoja y lápiz, y quedó como segunda opción búsqueda inspiracional en internet y plataformas visuales seguida por *software* de diseño. Los resultados marcan la notable y emergente presencia que las herramientas digitales tienen en el desarrollo del proceso de diseño actual, por lo que nos deja varios interrogantes: ¿dónde se comienza a gestar la idea? ¿En lápiz y papel? ¿Recurriendo a herramientas digitales *online*? ¿Netamente es *software* de diseño? ¿Comienza en lápiz y papel para luego dicha idea definirse con herramientas digitales, o viceversa? ¿Se trabaja en simultáneo cooperando entre las diversas tecnologías?

Como puede verse, surgen varios interrogantes como puntos de inflexión donde dicha investigación deberá indagar en la segunda etapa de su desarrollo con el objetivo de dilucidar —y en el mejor de los casos caracterizar— el uso de estas herramientas digitales. Se pretende así comprender, reflexionar y describir los nuevos modos o metodologías de diseño actual.



Figuras 4 y 5. Ideogramas posibles del proceso de búsqueda inspiracional.
Fuente: Toledo, 2022.

4.1 Tensiones y deliberaciones

Perkel (2011) en su investigación doctoral *Making Art, Creating Infrastructure: deviantART and the Production of the Web* presenta varios autores (Benkler, 2006; Shirky, 2010) que discuten sobre la democratización de la producción y creatividad de los medios gracias a las nuevas tecnologías digitales, sosteniendo que las nuevas tecnologías no solo hacen que más personas sean más creativas con más frecuencia, sino que también esa creatividad es producto de actos sociales y colectivos, anclados en la comunidad.

Otra investigación contemporánea que reflexiona sobre esta temática sostiene que en el mundo académico todavía está presente la idea de que las herramientas digitales inhiben la creatividad (De Lima & Ribeiro, 2021) y responden a dicho planteo afirmando que “el primer paso para crear una cultura

creativa para el estudio del proyecto es la presentación de la creatividad como habilidad y no como genio o talento" (De Lima & Ribeiro, 2021). Para ello, resulta necesario que las nuevas herramientas digitales se fusionen en el desarrollo del proceso creativo de diseño y no sean procesadas como herramientas meramente auxiliares de apoyo técnico en la fase de proyectación. A tal efecto se hace imprescindible promocionar la creciente literatura a modo de contribuir con la problemática teniendo como objetivo comunicar e informar sobre la práctica de diseño actual.

4.2 Conclusión

Como primera etapa de la investigación, se cumplió con el resultado esperado, el cual valida el uso de la plataformas visuales en el proceso creativo de diseño. También pudimos afirmar el incipiente uso de dichas plataformas para la búsqueda inspiracional en diseñadores expertos tal como la búsqueda *online*.

Como segunda etapa se procederá a ampliar la base de datos de la encuesta realizada para afianzar los resultados elaborados y así poder introducirnos en el estudio específico de dos plataformas visuales (si nos basamos en los resultados obtenidos en esta encuesta, correspondería seleccionar las más elegidas por los diseñadores liderando Pinterest con el 60% y Archdaily con el 58%) para determinar qué cambios sustanciales se observan en el proceso proyectual y cuáles son estas nuevas lógicas de diseño.

La propuesta metodológica se llevará a cabo aplicando entrevistas particulares a estudios de diseño con el objetivo de profundizar sobre las discusiones anteriormente descritas.

Agradecimientos. A mi directora, Dra. Arq. Silvia Patricia Hernández, por su presencia, colaboración y disposición en cada momento; y a mi codirectora, Dra. Arq. Soledad Valeria Guerra Martínez, por su acompañamineto y disposición.

Referencias

Cullinane, K. (13 de marzo de 2013). The original paradox. *The DesignObserver Group*. http://designobserver.com/feature/the-original-paradox/37733/.

De Lima , S. & Ribeiro, D. (2021). Digital Creativity: Pedagogical Strategies for Design Teaching. En P. Gomez y F. Braida (Eds.), *Designing Possibilities - Proceedings of the XXV International Conference of the Ibero-American Society of Digital Graphics (SIGraDi 2021), Online, 8 -12 November 2021*, pp. 401-419.

Eckert, C. & Stacey, M. (2000). Sources of inspiration: A language of design. doi.org/10.1016/S0142-694X(00)00022-3number (issue number), page numbers of the whole article. https://doi.org/xx.xxx/xxxx

Goldschmidt, G. (1998). Creative Architectural Design: Reference Versus Precedence. *Journal of Architectural and Planning Research*, *15*(3), 258-270. *Design Studies*, *21*(5), 523-538. http://www.jstor.org/stable/43030466

Koch, J., László, M., Lucero, A. & Oulasvirta, A. (2018). Surfing for Inspiration: Digital Inspirational Material in Design Practice. En C. Storni, K. Leahy, M. McMahon, P. Lloyd y E. Bohemia (Eds.), *Design as a Catalyst for Change - DRS International Conference 2018* (pp. 25-28). https://doi.org/10.21606/drs.2018.352

Lawson, B. (2004). *Lo que saben los diseñadores*. Elsevier/Prensa Arquitectónica.

Lucero, A. (2012). Framing, aligning, paradoxing, abstracting, and directing: How design mood boards work. *Proceedings of the Designing Interactive Systems Conference, DIS '12*. doi/10.1145/2317956.2318021

Ortega, S. (2011). Simplicidad, UX y curación de contenido. *Blog de Sergio Ortega sobre diseño visual, diseño de interacción y producto digital*. https://blog.sortega.com/simplicidad-ux-y-curacion-de-contenido/

Perkel, D. (2011). *Haciendo arte, creando infraestructura: deviantART y la producción de la web* [Tesis de doctorado en Filosofía]. Universidad de California. https://escholarship.org/uc/item/6fg9f992

Scolere, L. & Humphreys, L. (2016). Pinning Design: el trabajo curatorial de los profesionales creativos. *Social Media + Sociedad*. https://doi.org/10.1177/205630511663348

Llopis, A. (2016). *Redes sociales creativas para portafolios: el caso de Behance en España* [Tesis de grado]. Universidad de Valladolid. http://uvadoc.uva.es/handle/10324/18604

Van Dijck, J. (2013). *La cultura de la conectividad: una historia crítica de las redes sociales*. Siglo Veintiuno.

Collaborative design and construction of reconfigurable wood structures in a Mixed Reality environment

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Abstract. Mixed Reality tools offer new possibilities for cyber-physical design and construction and promote novel collaboration protocols. This work tackles a multi-user open-end design and construction of reconfigurable timber structures in Mixed Reality by introducing a computational workflow, physical setup and custom-designed interface. The developed procedures are demonstrated in the design and making of a real-scale architectural mock-up based on a discrete construction kit that allows for numerous assembly combinations. The results show that such a construction system that is characterized by rich design and assembly data is processed faster and with fewer mistakes by the builders using Mixed Reality. This opens the possibility to execute, change and update the construction directly in the physical environment in real-time. Moreover, the projected holographic analytics and construction data allowed for more structured decision-making and understanding of the impacts that each building action had.

Keywords: Mixed Realities, Reconfigurable Timber Construction, Collaborative Design, Collaborative Assembly, Wood Architecture Automation

1 Introduction

Mixed Reality (MR) tools are opening possibilities for real-time engagement with digital design and construction data within the physical space and supporting the experimentation of novel human/machine collaboration protocols (Alizadehsalehi et al. 2020, Zolotová et al. 2020). In digital timber construction in particular, MR has been involved in facilitating the interaction with complex material behaviour (Jahn et al. 2020), to enable the design of structural systems with wood logs of irregular forms (Lok and Bae 2022), to support data-driven assembly (Gramazio Kohler Research 2019), and to advance carpentry procedures (Settimi et al. 2022).

Figure 1. The collaborative assembly process of reconfigurable timber structures by two users wearing Microsoft Hololens 2 headsets © CREATE

Furthermore, MR has been coupled with robotic fabrication processes to investigate opportunities for human-robot interaction, where robot simulation in physical space (Hughes et al. 2021) and online operation (Kyjanek et al. 2019, Amtsberg 2021) are enabled through augmented interfaces and interactive human-robot processes for co-design and assembly are unfolded (Atanasova et al. 2021).

In this paper, complex robotic operations for the assembly of reconfigurable timber structures, which were previously developed by the authors (Kunic et al. 2021a, 2021b; Naboni et al. 2021), are translated into MR-supported human processes. In particular, we describe an experimental study for an immersive in-space and open-end collaborative *design* and *construction* of timber frame structures that can be reconfigured in real-time. A custom User Interface (UI) is designed to facilitate human interaction with complex and rich construction data effortlessly and foster the integration of human decision-making into automated processes (Fig. 1).

2 Methodology

In this research project, reconfigurability is seen as a central concept of circular construction, which promotes material reuse and the evolution of structures over time, unlike typical construction processes which lack flexibility,

openness, and capacity to adapt to unpredicted external circumstances (McKinsey 2017). The following methodological procedures are developed to enable an easy-to-follow, flexible and adaptive process that allows non-expert users to conceive, modify and update circular building structures (Fig. 2):

- Cyber-physical MR workflow for an adaptive *design* and *assembly* of reconfigurable wood structures that rely on discrete building blocks with a large number of connections
- A custom-designed UI for managing the navigation between the design and building phases in MR, interaction with their related data and the setup through *holographic projections* and direct *holographic instructions*
- A *physical setup* for collaborative MR assembly

Firstly, reconfigurable wood structures are conceptualized collaboratively among multiple users, directly observing their choices' spatial and material implications. Secondly, starting from a prefabricated construction kit, the designed structure is assembled by the same users in the form of distributed-task construction. The users engage with holographic projections of the analytical structure data and direct construction instructions through the developed UI.

The established workflow, MR functionalities and the UI are developed within Grasshopper, using the Fologram plug-in, and showcased in the design and making of an architectural mock-up, namely *ReconWood Proto 01*. The developed processes and features are evaluated in terms of communication between the phases and between the users, the construction time and users' interactivity with the complex assembly data.

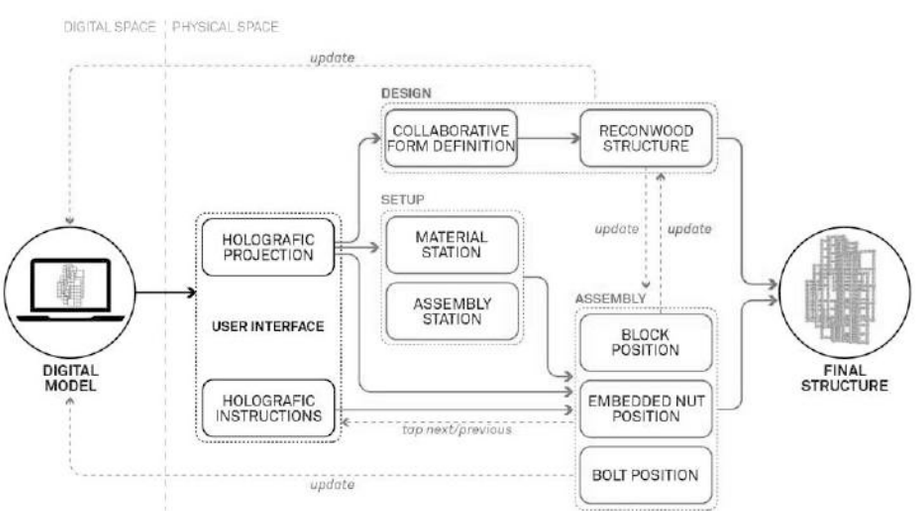

Figure 2. Cyber-physical collaborative design-construction workflow in MR
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2.1 Collaborative Design of ReconWood Proto 01 in MR

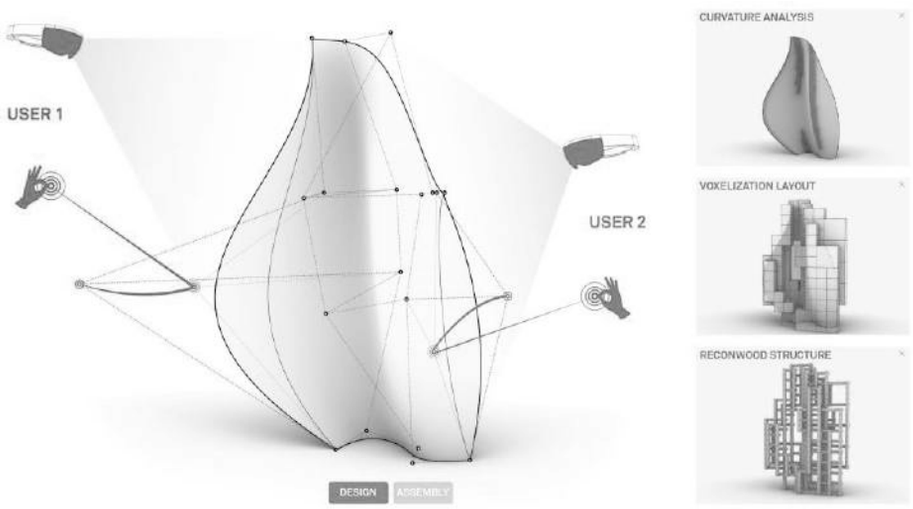

Figure 3. Multi-user collaborative design conceptualization in MR environment
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The design of the *ReconWood Proto 01* is developed through algorithmic procedures that start from a user-defined three-dimensional geometry, which is subsequently discretised into a multi-resolution voxel-based layout in response to a determined scalar field. Voxels are translated into a timber frame system with an optimized structural density, which takes into account the reusability of the discrete building blocks. Inspired by the properties of a LEGO “building brick” (Christiansen 1961), such as (1) the vast variety of assembly combinations achieved with (2) a few block typologies that are (3) interlocked together through a male-female joint, the discrete *ReconWood* blocks are assembled and re-assembled in a layered fashion to achieve a targeted formal configuration.

The immersive shaping of the ReconWood Proto 01 resulted in a doubly curved surface collaboratively manipulated by two users. More specifically, by tracking their hand gestures, the designers first defined the spatial boundaries in the physical environment that were referenced in the digital design algorithm as the bounding box within which to operate. In the following phase, a doubly-curved surface was conceived within the bounding box and further manipulated by dragging its control points (Fig. 3a). As the users changed the surface design, they could track algorithmic, structural and material data, such as:

- Dimensional data of the defined form such as width, height and surface area
- Gaussian *curvature analysis* which has been used as a scalar field to inform the voxelization algorithm (Fig. 3b)

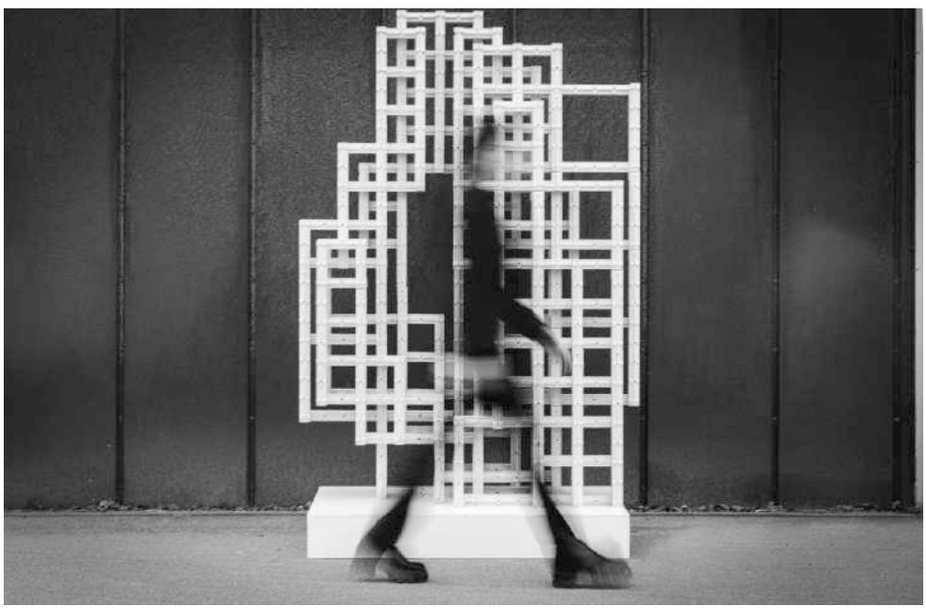

Figure 4. ReconWood Proto 01 © CREATE

- Multi-resolution *voxelization layout* based on the Gaussian curvature values (Fig. 3c)
- *ReconWood frame structure* (Fig. 3d) derived from the voxelized layout
- The resulting structure statistics such as total wood length, number and types of employed *ReconWood* blocks, the amount of the required connections and total weight.

As the input surface design is collaboratively updated, the voxels distribution and subdivisions are constantly re-computed according to the Gaussian curvature values. The resolution range of the used voxel grid is determined by the dimensions of the selected construction elements (i.e. cross-section and length).

With this method, two users conceived a wall-like structure with a differentiated distribution of reconfigurable timber frames (Fig. 4), parametrized on significantly variable Gaussian curvature values of the input surface.

2.2 Collaborative MR Construction

Experiment Setup. The setup for collaborative MR construction of reconfigurable timber structures consists of three main areas (Fig. 5). The *Assembly area* has a plan size of 3000x1500 millimeters with two QR codes placed on opposite corners for accurate referencing between the digital model and the physical setup.

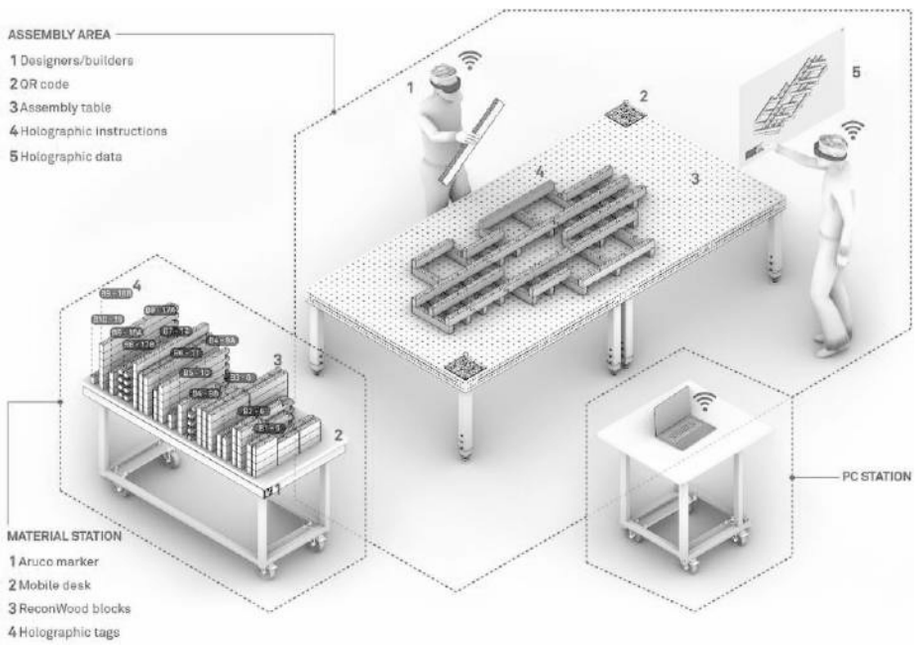

Figure 5. Cyber-physical setup for multi-user collaborative MR construction
© CREATE

The *Material station* hosts timber blocks, steel bolts and insert nuts. It is mobile and tracked through an Aruco marker which is also used as a reference point for the holographic tags of the discrete blocks. This allows for the material station to be freely moved around while preserving an accurate alignment of the materials to their digital twin. The *PC station* provides bi-directional communication between the builders' physical actions and the digital construction model. Each builder is equipped with Microsoft Hololens 2 headset and a cordless electric screwdriver. To enable communication between them, the PC and the two Hololens devices were connected to the same Wi-Fi network.

Collaborative assembly. Two users carried out the collaborative assembly of the *ReconWood Proto 01*. The process consists of (1) block preparation and the application of steel insert nuts; (2) block placement and alignment to their final position within the structure; and (3) insertion of two different types of steel bolts into the assigned joints, according to a statically determined configuration. The two users cooperated within a shared MR environment and accessed the same construction data. They could collaborate on construction tasks of higher complexity, e.g. placing and screwing a long cantilevering block with a large number of bolts or simultaneously executing consecutive operations, e.g. one user places and screws one block while the other user embeds the insert nuts into the next one.

During the construction, consecutive blocks are highlighted through the UI both within the physical assembly space and in the three-dimensional projection of the assembly sequence, providing users with an intuitive overview of their reciprocal actions. For each assembly phase, sequential instructions and data are visually superimposed onto the physical setup. For instance, for each block that is being assembled, its precise position, the types of bolts to be inserted and their corresponding locations are visualized (Fig. 6). As the users modified the design during the construction process, their decisions and building actions were consequently digitalized in real-time, updating the further assembly instructions and data.

Assembly feedback. In particular, once the block is physically taken from the material station, it is synchronized and "solidified" as a Rhino object, and its position is tracked. In case the wrong block has been picked, or the tracking process should be interrupted for any other reason, the implementation of a “delete block” button allowed for the cancellation of the corresponding active Rhino object.

When the two designers decide to place the blocks differently from the initial layout and change the structure's design, the new layout is synchronized with the digital model, and the virtual configuration is updated. Attempts to place the blocks in positions that are not compatible with the system connectivity logic result in a red component highlight, requiring the designer to modify its position.

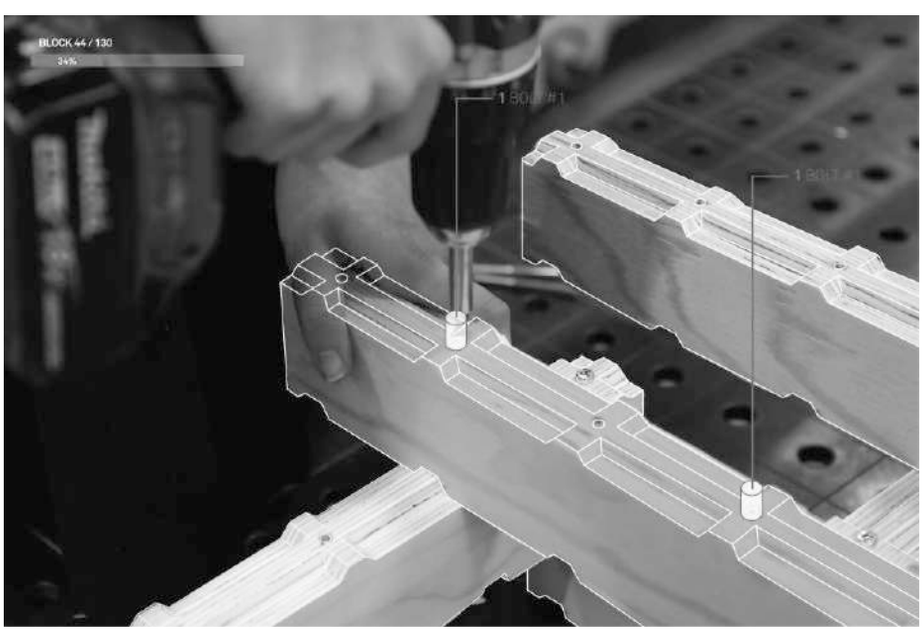

Figure 6. Augmented assembly and screwing of a ReconWood block © CREATE

2.3 User Interface Design

To assure smooth interoperability between two users and their physical operations with the digital model, a custom UI was designed (Fig. 7). This allows the assembly instructions to be dynamically updated based on human actions and superimposed on the ongoing physical activities, as previously described.

In the developed UI, three sets of holographic interactive panels are distinguished. (1) *Assembly instructions panels* were used to provide specific guidance for each *ReconWood* block in action (e.g. bolts and nuts layout and types), the assembly sequence and general construction progress (e.g. position of the current block in the overall construction; percentage of completion regarding bolts, nuts and blocks). (2) *Assembly data panels* show general construction information such as cross-sections, weight, total material length, number of required connections, percentage of each block's recurrence in the structure etc. This data is updated in real-time during the assembly phases and upon emergent design modifications. The holographic panels are interactive and can be dragged by the users, placed anywhere in the augmented space or switched on and off according to their needs or preferences. (3) *Interactive buttons* are used to facilitate specific process navigations (e.g. selection and cancellation of a building block, proceeding to the next block or going back to the previous one, etc), the transition from the design phase to the construction one, and increase interactivity in each phase without the need to consult a 3D model from a PC screen.

Figure 7. Custom-designed UI for the adaptive construction of ReconWood structures © CREATE

3 Results

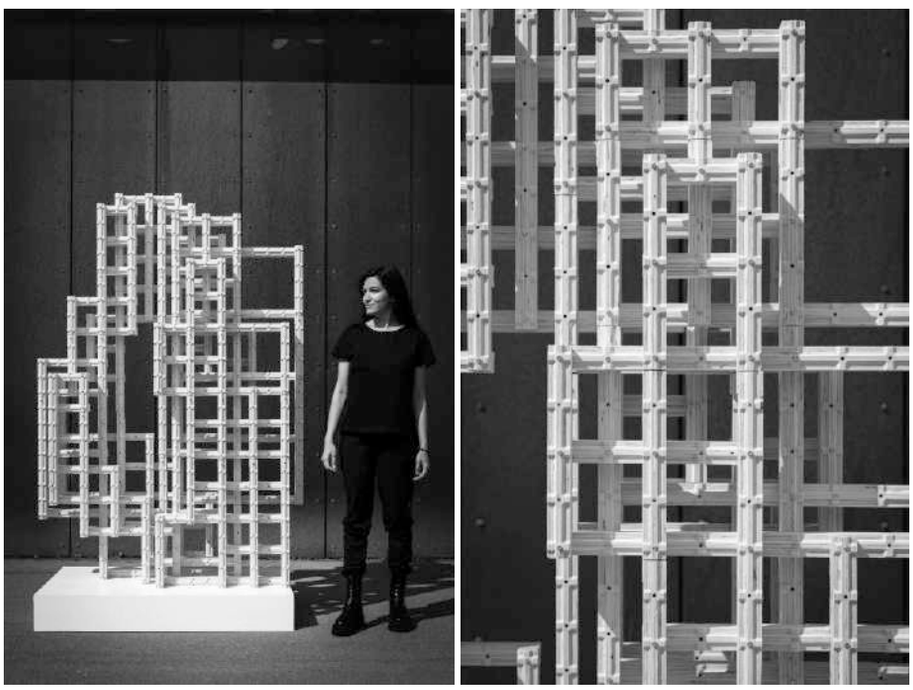

Figure 8. Views of the completed ReconWood prototype © CREATE

The MR collaborative design and assembly of the *ReconWood Proto 01*, a 2000X1400X500 mm wall-like structure with graded material density (Fig. 8), have been successfully carried out by two users who mutually interacted through a custom-designed UI.

The use of Fologram plug-in allowed for achieving seamless communication and interactive dependency between the digital design environment and physical setup, enabling full operational autonomy without the need for time-intensive software implementation. Various gesture-tracking possibilities assured design freedom and interactive decision-making by the users, which would otherwise be complicated to run in a fully manual mode, or with the use of automated robotic processes. The established bi-directional synchronization of actions and geometries was highly relevant for the adaptiveness and openness of the whole design-build workflow. The UI was easily modified and refined several times based on the user experience, leading to better performance over time.

The 130 *ReconWood* discrete blocks, prefabricated out of LVL battens with a 39x66 mm cross-section and varying lengths, were assembled over six hours following complex assembly instructions.

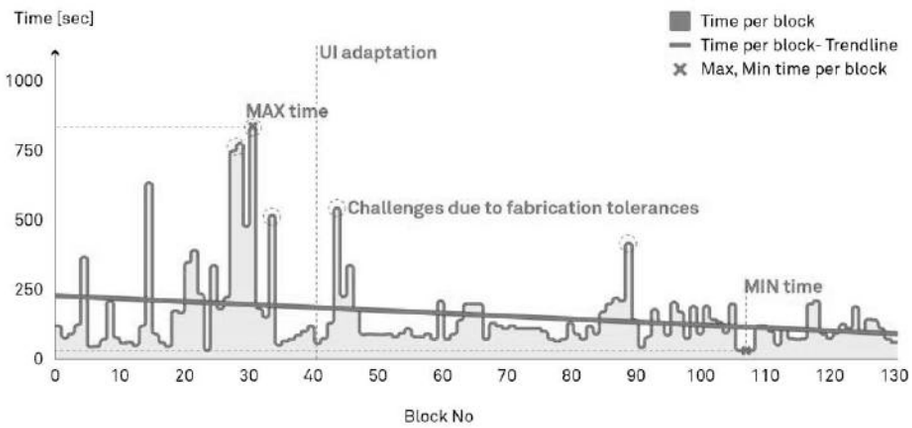

Figure 9. Assembly time tracking of ReconWood prototype in MR © CREATE

The complexity of the assembly data, indeed, increases by the use of a large number of identical blocks within the structure, while the distribution of the bolts and nuts is broadly varying, as well as by the periodical re-configurations based on instantaneous designers' decisions, and the corresponding design updates.

The average time needed to assemble a single block was about 2.5 minutes. Fabrication tolerances in some of the blocks have caused misalignments between the holes of two superimposed blocks which required more time and fatigue for a bolt to be screwed in. This resulted in significant delays in some cases, reaching up to 14 minutes of assembly time required for a single block. However, the general time/block trendline decreased as the construction progressed (Fig. 9), with a minimum time of 30 seconds registered for the assembly of shorter blocks with a few bolts. The reason for this was the adaptation of the UI and the introduction of "previous block" and "delete block" interactive buttons, which initially were not implemented, but became necessary for the two users to control their reciprocal actions better and eventually retrieve precedent operations when needed. Moreover, the designers developed confidence in the process and interaction with the interface over time.

4 Discussion

The presented research introduced an approach for collaborative, open-end design and assembly of reconfigurable wood structures in an MR environment, immersing nonlinear human actions into digital design-construction loops. Two users equipped with MR headsets played the role of both designer and builder to conceive an architectural demonstrator of reconfigurable timber structures designed for automation-prone assembly and re-assembly.

The data-rich construction of the *ReconWood Proto 01* has significantly benefited from the use of MR and custom-designed UI, which reduced space for mistakes and quickly increased productivity. The building actions were driven by human reasoning and intuition, which are the crucial features that the machines still lack and are highly needed in unpredicted and unstructured environments such as building sites. As opposed to the assembly feedback of previously studied robotic assembly (Kunic et al. 2021), this MR process extends design negotiation and brings human creativity and spontaneous decision-making into the digital and automated processes.

Future work will investigate new UI functionalities to render the design/construction process more inclusive to non-skilled users and favour the integration of more relevant real-time construction information, such as structural feedback and data from the material passport (MP) of each building element. Furthermore, a new workflow for human-robot collaborative construction aided by MR will be explored, considering the advantages and challenges of both individual processes.

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References

Alizadehsalehi, S., Hadavi, A., & Huang, J. C. (2020). From BIM to extended reality in AEC industry. Automation in Construction, 116(April), 103254. https://doi.org/10.1016/j.autcon.2020.103254

Amtsberg, F., Yang, X., Skoury, L., Wagner, H.-J., & Menges, A. (2021). iHRC: An AR-based interface for intuitive, interactive and coordinated task sharing between humans and robots in building construction. Proceedings of the 38th International Symposium on Automation and Robotics in Construction, ISARC 2021, November (pp. 25-32). Dubai, UAE. https://doi.org/10.22260/isarc2021/0006

Atanasova, L., Mitterberger, D., Sandy, T., Gramazio, F., Kohler, M. & Dörfler, K. (2010). Prototype as Artefact: Design Tool for Open-ended Collaborative Assembly Processes. In B. Slocum, V. Ago, S. Doyle, A. Marcus, M. Yablonina, and M. del Campo (Eds.), Proceedings of the 40th Annual Conference of the Association of Computer Aided Design in Architecture, Acadia 2020: Distributed Proximities (pp. 350-359). Online and Global.

Barbosa, P., Woetzel, J., Mischke, J., Ribeirinho, M.J., Sridhar, M., Parsons, M., Bertram, N. & Brown, S. (2017) Reinventing Construction: A Route To Higher Productivity. Report. McKinsey & Company. McKinsey Global Institute. https://www.mckinsey.com/business-functions/operations/our-insights/reinventing-construction-through-a-productivity-revolution#%E2%80%8B

Christiansen, G. K. (1961). Toy building brick. Bilund, Denmark, assignor to Inferiego A.G., Zug, Switzerland, a corporation of Switzerland. Patent 3005282. October 24, 1961. United States Patent Office.

Gramazio Kohler Research, ETH Zurich (2019). Augmented Acoustics. https://gramaziokohler.arch.ethz.ch/web/e%20/projekte/408.html

Hughes, R., Osterlund, T. & Larsen, N.M. (2021). Integrated design-for-manufacturing and AR-aided-assembly workflows for lightweight reciprocal frame timber structures. Construction Robotics, 5, 147–157. https://doi.org/10.1007/s41693-020-00048-3.

Jahn, G., Newnham, C. & van den Berg, N. (2022). Augmented Reality For Construction From Steam Bent Timber. Proceedings of the 27th Annual Conference of the Association for Computer-Aided Architectural Design Research in Asia, CAADRIA 2022: Post carbon (pp. 191-200). The University of New South Wales, the University of Sydney and the University of Technology, Sydney.

Kunic, A., Kramberger, A. & Naboni, R. (2021). Cyber-Physical Robotic Process for Re-Configurable Wood Architecture. Closing the circular loop in wood architecture. Proceedings of the 39th eCAADe Conference - Towards a new, configurable architecture. Novi Sad, Serbia, September 2021.

Kunic, A., Naboni, R., Kramberger, A. & Schlette, C. (2021). Design and assembly automation of the Robotic Reversible Timber Beam. Automation in Construction. Elsevier.

Kyjanek, O., al Bahar, B., Vasey, L., Wannemacher, B., & Menges, A. (2019). Implementation of an augmented reality AR workflow for human-robot collaboration in timber prefabrication. Proceedings of the 36th International Symposium on Automation and Robotics in Construction, ISARC 2019, June (pp. 1223–1230). Banff, Canada. https://doi.org/10.22260/isarc2019/0164

Lok, L., & Bae, J. I. Y. (2022). Timber de-standardized 2.0. Mixed Reality Visualizations and User Interface for Processing Irregular Timber. Proceedings of the 27th Annual Conference of the Association for Computer-Aided Architectural Design Research in Asia, CAADRIA 2022: Post carbon (pp. 121–130). The University of New South Wales, the University of Sydney and the University of Technology, Sydney.

Naboni, R., Kunic, A., Kramberger, A. & Schlette, C. (2021). Design, simulation and robotic assembly of reversible timber structures. Construction Robotics. Springer Nature Switzerland AG.

Settimi, A., Gamerro, J., & Weinand, Y. (2022). Augmented-reality-assisted timber drilling with smart retrofitted tools. Automation in Construction, 139(August 2021), 104272. https://doi.org/10.1016/j.autcon.2022.104272

Zolotová, I., Papcun, P., Kajáti, E., Miškuf, M. & Mocnej, J. (2020). Smart and cognitive solutions for Operator 4.0: Laboratory H-CPPS case studies. Computers & Industrial Engineering, 139 (January), 105471. https://doi.org/10.1016/j.cie.2018.10.032

Game Engines in the Historical City: the Panorama of Rio de Janeiro by Victor Meirelles and Henri Langerock

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Abstract. This essay is part of an ongoing research entitled “The 360º immersive: investigation, representation and digital immersion of Rio de Janeiro city during 19th and 20th centuries”, developed in Universidade Federal do Rio de Janeiro / Programa de Pós-Gradução em Urbanismo, Brazil, which presents, analyses and discuss in a theoretical-conceptual approach The Panorama of Rio de Janeiro, by Victor Meirelles and Henri Langerock by the *Unity* Game Engine. To achieve this 360º immersion experience a methodological path was developed: restitution of the Panorama and its visualization in real time; the transition from the *Lumion* model to the *Unity* Game Engine; resizing the model scale; the immersive experience beyond the observation platform: the *faux-terrain* experienced; viewer movement, scenes, scripts, and navigation menus.

Keywords: Panorama of Rio de Janeiro, Virtual Reality, City History, Immersive Experiences, Game Engine.

1 Introdução

As ferramentas de representação digital para Arquitetura e Urbanismo estão em constante evolução. Nos últimos anos, os motores de jogos geraram grande interesse nas universidades e no campo profissional: se antes era necessário possuir um grande conhecimento sobre programação para criar experiências imersivas em 360° com alta verossimilhança, hoje é possível obter resultados bastante satisfatórios graças ao desenvolvimento dos computadores, à possibilidade de renderização em tempo real e à utilização de uma vasta biblioteca de cenários, objetos e ações pré-programadas.

Os motores de jogos apresentam basicamente duas características principais: visualização e interatividade. A primeira está relacionada à apresentação do próprio modelo geométrico em si, por meio de uma cena pré-estabelecida com elementos com cores, texturas e sombras; e a segunda é como o usuário pode se relacionar com essa visualização, com objetos dispostos na cena e estabelecer níveis de interatividade, com movimentos ao andar, descer, subir, inclinar, girar, realizando, assim, seis graus de liberdade.

Mas como essa visualização e interatividade podem ser desenvolvidas a favor de uma experiência imersiva em 360° em modelos de cidades históricas? Quais recortes metodológicos devem ser estabelecidos? Como os cenários, objetos e ações pré-programadas podem ser desenvolvidos para alcançar esse objetivo? O presente trabalho irá analisar essas questões utilizando o Panorama do Rio de Janeiro de Victor Meirelles e Henri Langerock como modelo a ser analisado.

2 Objetivos

O principal objetivo deste trabalho é investigar como os motores de jogos podem potencializar a experiência imersiva em 360° em uma cidade histórica. Para alcançar tal finalidade, o presente trabalho irá analisar, explorar, converter e codificar o modelo geométrico do Panorama da cidade do Rio de Janeiro de Victor Meirelles e Henri Langerock de 1888, elaborado em anos anteriores, para uma nova versão desenvolvida em um motor de jogos. A migração de plataformas visa permitir que o observador possa desfrutar de seis graus de liberdade na realização de sua experiência imersiva em 360°.

3 Metodologia

A presente pesquisa desenvolve uma investigação histórico-interpretativa fundamentada na seleção e na interpretação de documentos históricos

associados à imaginação do investigador (Groat, Wang, 2013). Tal fundamentação analisa o Panorama de Meirelles e Langerock através da interpretação dos documentos existentes e em uma ampla pesquisa sobre o tema dos Panoramas e experiências imersivas (Leitão, 2014).

Cabe ressaltar que embora a discussão sobre motores de jogos na Arquitetura e Urbanismo já exista há algum tempo, nos últimos anos ela vem se tornando cada vez mais presente nas investigações do campo disciplinar da Gráfica Digital, especialmente associada à visualização em renderização em tempo real, à interatividade e à utilização de uma vasta biblioteca de cenários, objetos e ações pré-programadas (Gregory, 2018).

Tal compreensão não está tão distante das crescentes experiências de representação do corpo no Espaço Virtual. É possível afirmar que a constante transformação dos videogames e o consequente estabelecimento dos *níveis de imersão* (Calleja, 2011), do princípio da *incorporação* (Kenderdine, 2010), do *corpo em movimento* (Shaw, Kenderdine, 2017), e da *invisibilidade da interface* em detrimento da representação do corpo (Shaw, Kenderdine, Coover, 2020), podem ser correlacionados aos motores de jogos aplicados à Arquitetura e ao Urbanismo com a possibilidade renderização do corpo do observador em um cenário em tempo real (Valencia-García, et al, 2016). O presente trabalho irá explorar a relação no corpo em uma simulação de cidade histórica.

A partir deste embasamento teórico-conceitual, foi possível selecionar os seguintes trabalhos a serem analisados: o simulador *SIMRIO* desenvolvido no LAURD / PROURB / UFRJ (Vilas Boas, 2015); o projeto *Viagens Pitorescas* com simulações desenvolvidas no Instituto Federal de Ouro Preto (De Paula, Duarte, Bohrer, 2019); e o simulador *The Virtual Rome* desenvolvido na University of Reading (Nicholls, 2019). Todas estas investigações têm como princípio norteador a simulação da narrativa histórica a partir de videogames, onde o observador-jogador não é apenas um agente capaz de aprender, mas principalmente, de interagir com a própria História (Kapell, Elliott, 2013). O presente trabalho terá este mesmo princípio.

Além da reflexão teórico-conceitual sobre pesquisa histórico-interpretativa, Panoramas, imersão em 360°, corpo no Espaço Virtual, motores de jogos, e exemplos de trabalhos, um importante percurso metodológico foi desenvolvido a fim de codificar o modelo elaborado do Panorama do Rio de Janeiro de Meirelles e Langerock para sua nova versão: restituição do Panorama e sua visualização em tempo real; a transição do modelo no *Lumion* para o motor de jogos *Unity*; redimensionamento da escala do modelo; a experiência imersiva para além da plataforma de observação: o *faux-terrain* experimentado; a pesquisa específica: scripts de movimentação do observador, ambientação do cenário e criação dos menus de navegação. Todos serão apresentados, detalhados e discutidos a seguir.

3.1 Restituição do Panorama e sua visualização em tempo real

A tela do Panorama de Meireles e Langerock desapareceu no início do século XX. Apenas seis estudos originais e algumas descrições de suas exposições foram encontrados. Em trabalhos elaborados anteriormente, foi possível restituir a imagem circular do Panorama em 360° a partir de um modelo geométrico da área central da cidade do Rio de Janeiro do final do século XIX e de sua associação com um panorama do fotógrafo Hubmeyer do início do século XX, aproximadamente do mesmo ponto de vista dos pintores Meirelles e Langerock no Morro de Santo Antônio (Leitão et al, 2020).

Além de apreciar o redesenho da paisagem da cidade do Rio de Janeiro naquele momento apresentado pelo Panorama, considerou-se também necessário interpretar e codificar a experiência do observador-visitante das suas exposições. Para tanto, a imagem circular em 360° foi redividida em cinco anéis concêntricos a favor da melhor apreciação possível de sua perspectiva atmosférica, enaltecendo, assim, a sensação de profundidade da experiência imersiva. O modelo final redesenhou a plataforma de observação simulando o 'livre caminhar' do observador-visitante de tal forma a explorar as múltiplas perspectivas da área central da cidade apresentadas no Panorama (Leitão et al, 2021).

Figura 1. O Panorama dividido em cinco anéis concêntricos e a imagem final de sua experiência recriada no programa de visualização em tempo real *Lumion*. Fonte: Autores, 2022.

Cabe ressaltar que este 'livre caminhar' não foi tão livre assim, pois foi necessário determinar previamente o percurso a ser realizado pelo observador-visitante. Embora o programa *Lumion* – mesmo em sua versão *trial* – ofereça uma visualização em tempo real, ele ainda não permite os seis graus de liberdade do corpo do observador no espaço, fator este muito importante para codificação de uma experiência imersiva em 360° de forma plena. Assim, a busca por uma nova alternativa se fez necessária.

3.2 A transição do modelo no *Lumion* para o motor de jogos *Unity*

Após uma investigação sobre a representação do corpo no espaço digital, constatou-se que os motores de jogos seriam as ferramentas mais indicadas para representar a experiência imersiva do observador no Panorama da forma desejada. Por esta razão, duas ferramentas foram analisadas: *Unreal* e *Unity*. Optou-se pelo motor de jogos *Unity* pela interface com experiências de Realidade Virtual e pelo conjunto de *assets* disponibilizados gratuitamente.

De imediato, mostrou-se necessário verificar quais elementos tridimensionais elaborados no *Lumion* poderiam ser transferidos e quais deveriam ser remodelados diretamente no motor de jogos *Unity*. Após uma ampla análise das ferramentas a fim de buscar a máxima integração possível, concluiu-se que a tanto a plataforma de observação quanto os anéis concêntricos que continham a imagem circular em 360° poderiam ser importadas satisfatoriamente. Entretanto, alguns ajustes foram necessários.

3.3 Redimensionamento da escala do modelo

Ao transportar a plataforma de observação e os anéis concêntricos com a imagem circular em 360°, a fim de codificar a experiência do observador em seis graus de liberdade, foi necessário reanalisar e reajustar a escala do modelo utilizado previamente.

Três modelos geométricos foram elaborados com esta finalidade: *o modelo histórico,* semelhante às dimensões originais do Panorama na relação tamanho da pintura x escala do observador; *modelo da paisagem*, onde o tamanho do modelo se adequava ao desenho da paisagem representada no anel mais distante do observador, ampliando sensivelmente a escala, tornando-a mais próxima do que seria a escala real da cidade; e por fim, o *modelo híbrido,* onde o modelo se ajustava aos anéis intermediários, de tal forma a favorecer a combinação entre elementos tridimensionais em primeiro e médio planos, como árvores, arbustos e caminhos existentes no alto do Morro de Santo Antônio, como também escalonar os demais anéis que representam além dos planos intermediários como Morro do Castelo, Pão de Açúcar e a cidade em geral, sempre ajustados proporcionalmente à distância do observador.

A elaboração destes três modelos em escalas diferentes foi fundamental para a realização deste trabalho. O modelo que se mostrou mais adequado à experiência imersiva desejada no motor de jogos *Unity* foi o modelo híbrido.

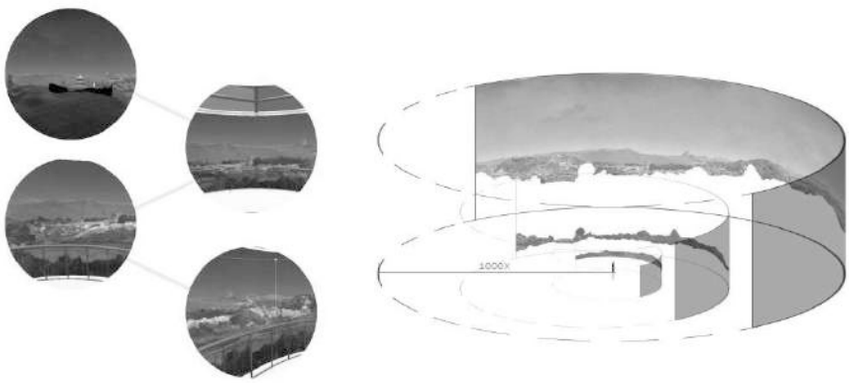

Figura 2. Diagrama com a escala final do modelo elaborado no motor de jogos *Unity o modelo híbrido*. Fonte: Autores, 2022.

3.4 A experiência imersiva para além da plataforma de observação: o *faux-terrain* experimentado

Uma vez decidida a escala do modelo, foi necessário analisar outro elemento muito importante da experiência do Panorama: o *faux-terrain*, o espaço de transição entre a plataforma de observação e tela do Panorama, essencial para o ajuste e acomodação do olhar do observador. No caso do Panorama do Rio de Janeiro, o *faux-terrain* representava vegetações tropicais e caminhos existentes no alto do Morro de Santo Antônio.

Em um primeiro momento, transportou-se o conjunto de vegetações elaborado no *Lumion* para o motor de jogos *Unity*, mas inúmeros problemas foram encontrados. Assim, tornou-se necessário refazer o conjunto de vegetações a partir de *assets* do próprio motor de jogos, com a utilização dos modelos disponíveis na *Unity Asset Store.* A fim de localizar as diferentes espécies ao redor da plataforma de observação a favor do *faux-terrain* em 360°, foi necessária a realização de um diagrama. Após a composição final do conjunto de vegetações, a experiência imersiva final do observador pela plataforma mostrou-se bastante satisfatória.

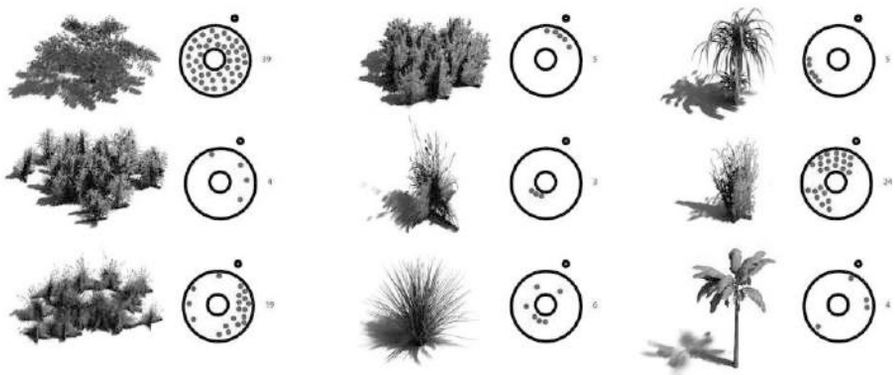

Figura 3. Diagrama com as nove espécies de vegetação utilizadas e suas localizações ao redor da plataforma de observação para a recriação do *faux-terrain* no motor de Jogos *Unity*. Fonte: Autores, 2022.

No entanto, considera-se que desfrutar a experiência de um Panorama unicamente a partir da plataforma de observação desenvolvida em um motor de jogos seria algo bem restrito. A fim de proporcionar uma experiência imersiva rica e diversa estimou-se a ampliação do próprio conceito de *faux-terrain*, de tal forma que o observador pudesse percorrer também no modelo a área por ele representada. No caso no Panorama do Rio de Janeiro, com a utilização do motor de jogos, o observador pode percorrer os caminhos existentes no alto do Morro de Santo Antônio, como também realizar sua própria experiência imersiva em diferentes e múltiplas perspectivas não estimadas anteriormente pelos dois pintores, e ainda, apreciar a imagem da paisagem da cidade do Rio de Janeiro em 360° no final do século XIX.

Para que isso fosse possível, uma pesquisa específica sobre o Morro de Santo Antônio foi realizada, oportunidade em que foram encontradas diversas fotografias da primeira década do século XX, como também um antigo projeto com obras de reformulação urbana do morro em 1915, onde suas curvas nível e as edificações do então *Observatório da Escola Politécnica* estavam desenhadas. Ao analisar esta base documental, percebeu-se a repetição dos tipos de vegetação, edificações, assim como os caminhos existentes no alto do morro, sendo possível estimá-los no período de realização dos estudos iniciais do Panorama. Tal conjunto de documentos forneceu as informações necessárias para a sua modelagem no motor de jogos *Unity*.

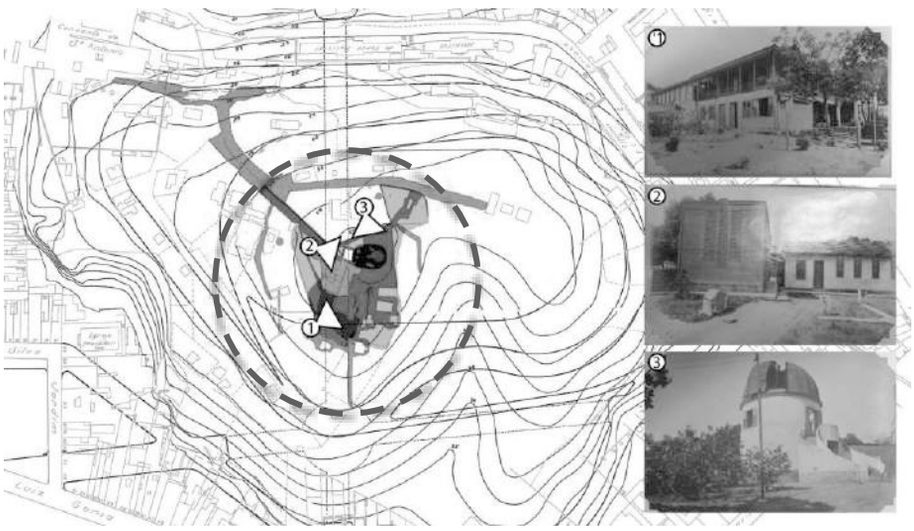

Figura 4. O *faux-terrain* experimentado: projeto com as curvas de nível do Morro de Santo Antônio e fotografia dos principais edifícios do Observatório da Escola Politécnica auxiliam na modelagem da área de ambulação do observador. Em vermelho, o limite dessa área. Fonte: Autores, 2022.

3.5 A pesquisa específica: *scripts* de movimentação do observador, ambientação do cenário e criação dos *menus* de navegação

Certamente, a elaboração das etapas anteriores foi muito importante para a realização desta nova experiência do Panorama no Rio de Janeiro no motor de jogos *Unity*. No entanto, cabe ressaltar que sem a devida investigação sobre a linguagem de programação C+ e scripts de movimentação do observador e dos objetos dispostos na ambientação do cenário do Panorama este trabalho não seria possível.

A fim de permitir a livre movimentação do observador com seis graus de liberdade tanto pelo espaço da plataforma de observação quanto do *faux-terrain* estendido, realizou-se uma investigação específica sobre movimentação de personagens em videogames em primeira pessoa. Diversos códigos abertos foram encontrados disponibilizados gratuitamente por usuários do motor de jogos *Unity*. Assim, fez-se necessário selecionar *scrips* que oferecessem a movimentação desejada do observador no Panorama, como também realizar alguns ajustes em relação ao ponto de vista da câmera. Para o jogador, essa movimentação acontece através da utilização do teclado e mouse. O observador pode caminhar, abaixar e pular em todas as direções.

Outro elemento importante da programação foi a ambientação do cenário do Panorama. O *faux-terrain* de Meirelles e Langerock representava o alto de um morro bastante natural e tal experiência deveria ser codificada para o

motor de jogos *Unity*. A ambientação do cenário foi desenvolvida de tal forma a apresentar uma leve brisa para o deslocamento das árvores e massas arbustivas das espécies tropicais selecionadas. O mesmo também ocorreu para o espelho d'água da Baía de Guanabara ao fundo, ainda que não estivesse em primeiro e médio planos, o sutil movimento e o reflexo da luz na água aumentaram sensivelmente a experiência imersiva em 360°.

Por fim, realizaram-se os *menus* de navegação de entrada, saída e créditos do motor de jogos, através da linguagem de programação C+ (Ferrone 2020).

4 Resultados e Perspectivas

Os principais resultados deste trabalho são a discussão teórica-conceitual e instrumental em si, como também a experiência do Panorama de Meirelles e Langerock com o modelo *híbrido* no motor de jogos *Unity*. Constatou-se que o *faux-terrain* experimentado proporcionou um espaço de fruição ainda maior e mais interessante para o observador do Panorama do Rio de Janeiro. O poder de sugestão dado pela interação 2D x 3D favoreceu consideravelmente a realização da ambientação do cenário virtual, como também permitiu um aprimoramento da experiência imersiva em 360°.

Considera-se como importantes perspectivas a serem investigadas: a criação de um *asset* específico para o céu do Panorama com a possibilidade de movimentação de nuvens; maior detalhamento da Arquitetura das edificações mais próximas; interação com camadas temporais diferentes da área do morro de Santo Antônio a serem selecionadas e combinadas através de menus pelo observador (em 1888 com a experiência de Meirelles e Langerock; em 1915 com o Observatório da Escola Politécnica em funcionamento; em 1950 com parte do desmonte do morro; em 2015 com o trecho remanescente do morro hoje); a jogabilidade em si; a elaboração de uma versão do Panorama para óculos de Realidade Virtual; a possibilidade de exposições acadêmicas, artísticas e culturais sobre Panoramas, experiências imersiva em 360° e motores de jogos.

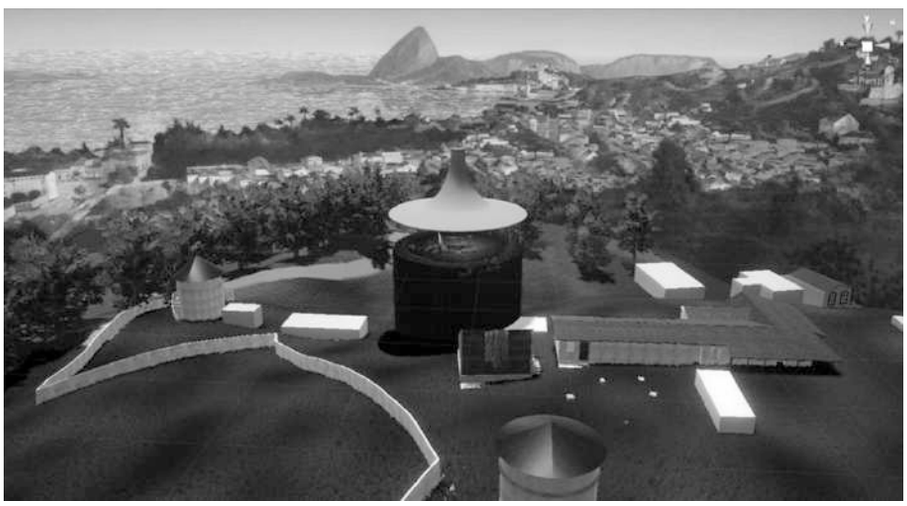

Figura 5. O modelo do Panorama de Meirelles e Langerock com parte do Observatório da Escola Politécnica realizado no motor de Jogos *Unity:* livre movimentação do observador na plataforma e no *faux-terrain* experimentado.

5 Discussão

Esta investigação poderá contribuir de forma geral para discussões sobre Panoramas, motores de jogos, Realidade Virtual e experiências imersivas em 360°; e ainda de forma específica, ao relacionar motores de jogos com modelos de cidades históricas. O método desenvolvido poderá ser aplicado por outros pesquisadores em outros trabalhos.

Agradecimentos

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Referências

Calleja, G. In-Game: From Immersion to Incorporation. Cambridge, MA: MIT Press, 2011.

De Paula, Alan R. G.; Duarte, Jussara E.; Bohrer Alex F. Paisagens Pitorescas: análise das modificações urbanas e arquitetônicas de Ouro Preto através das obras dos viajantes estrangeiros do século XIX. VIII Seminário de Iniciação Científica do IFMG – 12 a 14 de agosto de 2019, Campus Ribeirão das Neves. Disponível em: https://www.ifmg.edu.br/sic/edicoesanteriores/resumos-2019/paisagens-pitorescas-analise-das-modificacoes-urbanase-arquitetonicas-de-ouro-preto-atraves-das-obras-dos-viajantes-estrangeiros-do-seculoxix.pdf. Acesso em: 20 Jul. 2020.

Gregory, Jason. Game Engine Architecture, Third Edition. Boca Raton: Taylor & Francis, CRC Press, 2018.

Groat, Linda; Wang, David. Architectural Research Methods (second edition). John Wiley & Sons, 2013.

Ferrone, Harrison. *Learning C# by Developing Games with Unity 2020: An enjoyable and intuitive approach to getting started with C# programming and Unity,* 5th Edition. Birmingham: Packt Publishing, 2020.

Kapell, Matthew Wilhelm; Elliott, Andrew B.R. (Eds). Playing with the Past: Digital Games and the Simulation of History. New York: Bloomsbury Academic, 2013.

Kenderdine, S. Immersive Visualization Architectures and Situated Embodiments of Culture and Heritage. In: International Conference on Information Visualisation, 14., 2010, Londres. Anais [...].Londres: IEEE, 2010, p. 408-414.

Leitão, T. O panorama e a experiência imersiva em 360°: do espetáculo de entretenimento aos meios digitais. 2014. 260 p. Tese (Doutorado em Urbanismo) – Faculdade de Arquitetura e Urbanismo, Programa de Pós-Graduação em Urbanismo, Universidade Federal do Rio de Janeiro, Rio de Janeiro, 2014.

Leitão, T.; Filho, G. B. L.; Silva, G. L.; Silva, V. C. A 360° history of the city: the digital reconstruction of the Rio de Janeiro Panorama by Victor Meirelles and Henri Langerock from the end of the 19th century. In: SIGraDi 2020 Transformative Design Online Conference / XXIV International Conference of the Iberoamerican Society of Digital Graphics, 24., 2020, Medelim. Anais [...]. Medelim: SIGraDi, 2020. V. 1. p. 563-568.

Leitão, T.; Vereza, C.; Boner, G.; Milhm, J. O. The 360° Immersive Atmospheric Perspective: Interpretation and Creation of Circular Pictorial Layers of the Panorama of Rio de Janeiro by Victor Meirelles and Henri Langerock. In: SIGraDi 2021 Designing Possibilities Ubiquitous Conference / XXV International Conference of the Iberoamerican Society of Digital Graphics, 25., 2021. Online. Anais [...]. Blucher: SIGraDi, 2021. V. 1. p. 915-925.

Nichols, M. 'Bookish places' in Imperial Rome: bookshops and the urban landscape of learning. In: Adams, S. A. (ed.) Scholastic Culture in the Hellenistic and Roman Eras: Greek, Latin, and Jewish. De Gruyter, pp. 51-68.

Shaw, J.; Kenderdine, S. 'Archives in Motion: Motion as Meeting', in Museum and Archive on the Move: Changing Cultural Institutions in the Digital Era, (eds) Grau, O., Coones, W., Rühse, V., De Gruyter, pp. 211–233, 2017.

Shaw, J.; Kenderdine, S.; Coover, R. Re-place: The Embodiment of Virtual Space, T Bartscherer and R Coover (eds). In: Switching Codes: Thinking Through

Technology In The Humanities And Arts Chicago: University of Chicago Press, p. 218-237, 2020.

Valencia-García, Rafael; et al. Technologies and Innovation: Second International Conference, CITI 2016, Guayaquil, Ecuador, November 23–25, Proceedings. *Communication and Computer and Information Science,* Vol. 658. Berlin, Germany: Springer, 2016.

Vilas Boas, Naylor. Simuladores Urbanos Digitais: Representação e Interação com a História das Cidades. In: SIGraDi 2015 Informação de projeto para interação XIX / International Conference of the Iberoamerican Society of Digital Graphics, 19., 2015, Florianópolis. Anais [...]. Florianópolis: SIGraDi, 2015. V. 1. p. 308-316.

The use of visual programming interface for structuring a generic digital framework in a City Information Model (CIM) workflow

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Abstract. One of the great challenges for the urban planner/designer is to establish strategies to deal with the increasing complexity of the contemporary city. Among the possibilities of dealing with it, the emergence of the so-called City Information Models (CIM) has presented itself as a promising direction. This paper seeks to contribute to the problem by describing a way to structure a CIM and proposing the creation of a computational application called Carcará, a plugin for a visual programming interface capable of reading and writing to a georeferenced database, allowing the creation of representations not only of the built space, but also manipulations of its semantic characteristics and calculation of a variety of metrics.

Keywords: City Information Model, Urban planning, Interface design, Parametric analysis, Urban Indicators

1 The challenges of urbanism in the third modern age

Ascher (2010) proposes an interpretation of the history of cities considering the process of technical, social and spatial division of production, linking their dynamics to their potential for transportation and storage of goods, technologies and people. The advance of technologies providing changes in this system of mobility and storage would then be responsible for the evolution of cities, which *crystallize and reflect the logics of the societies that host them* (Ascher, 2010, p.20). Understanding how these logics are established would be the role of Urbanism. For the author, the process of modernization of cities is not gradual and linear, but rather is marked by revolutions caused by specific and particular historical conditions involving dynamics of individualization, rationalization, and social differentiation. From his point of view, we would be in the third modern age of cities, where information and communication technologies play a key

role in changing the material base of contemporary society – a perception that is also shared by Castells (2007).

Given this dynamic, cities become complex systems that can no longer be explained from the metaphor of mechanical systems (which tend to static equilibrium), but rather by the metaphor of biological systems, where negotiation strategies and competition among different actors can reach certain moments of dynamic equilibrium (Batty, 2007; Batty, 2009). This poses some challenges for urbanism, which can no longer be guided by static big plans that establish top-down control mechanisms to guide the system over long periods of time. Otherwise, urban planning must be guided by the production of conflict negotiation devices in a *heuristic, iterative, incremental, and recursive cycle* (Ascher, 2021, p.83). As the complexity of the urban system and the tasks involved in managing and planning it increases, the need to create strategies to deal with this (i.e. the creation of tools that allow not only representing it, but experiencing it at some level) grows. City Information Models (CIM) present themselves as an important step in this direction.

The purpose of this article is to present the development of a specific computational application – Carcará –, a plugin for a visual programming interface that is part of a CIM framework. In section 2, we will discuss a conceptual framework for a City Information Model within which the creation of the computational application in question is relevant. In section 3, the structure of the tool is presented, showing its parts and functionalities, as well as some works already done that use the tool as a framework. Finally, in section 4, the results obtained are critically evaluated and future developments are envisioned.

2 City information Modelling: a theoretical background

2.1 A Concept in Dispute

Information modeling is not a new theme, being present in the field of Computer Science since the first data processing systems in the 1950s (Mylopoulos, 1998). Information models refer to representations of portions of the real world through symbolic structures, replicable in a computational environment, organized from a particular system of categories, that is, endowed with their own ontology (Mylopoulos, 1998; Guarino, 1998).

The idea of information models in the field of disciplines that deal with design first appears in Architecture with the structuring and consolidation of Building Information Models (BIM), having the first mentions of the term appearing in the 1980s (Eastman et al., 2014). Following the consolidation of this field, Khemlani (2005) is pointed out as one of the first authors to refer to the term CIM, assuming that it would be possible to develop a technology that integrates the different urban structures and services just as BIM integrates the different aspects of construction. This starting point generates a stream of research that assumes that structuring a CIM would lie in some extension of the capabilities of BIM platforms in dealing with georeferenced data, with a strong emphasis on

the integration of BIM and GIS technologies (Zhu et al., 2018; Arroyo Ohori et al., 2018; Zhu & Wu, 2021).

The proposal, while raising some interesting points, starts, however, from a conceptual misunderstanding. The knowledge domain of the building differs significantly from the knowledge domain involving the city. Direct adaptations, taking into account only the change of physical scale (and not of complexity scale) are problematic and can lead research results to applications that can do little to aid the task of planning cities (Moreira & Andrade, 2018).

Following a different path, we can point out the City Induction research, reported in depth in Duarte et al. (2012). There, we notice a concern in the creation of specific ontologies to describe the city and urban environment domain, as well as an urban development methodology. For the ontology of the urban environment, the authors build on the seminal work of Lynch (1960) and propose classes (sub-ontologies) based on morphological elements of the city: networks, blocks, zones, landscape and focal points. For the urban development methodology, they propose the structuring in phases, each one based on specific theories, namely: problem formulation – based on Alexander et. al's (1977) pattern language, solution generation – based on Duarte's (2005) discursive grammars, and evaluation – based on the calculation of performance metrics, such as those of Hillier & Hanson's (1989) spatial syntax or Berghouser-Pont & Haupt's (2009) density (Fig 1). For each of the phases, we have the development of derived research, respectively Montenegro (2015) – formulation, Beirão (2012) – generation, and Nourian (2016) – evaluation. A more updated version of the general concepts is presented in Beirão & Duarte (2018).

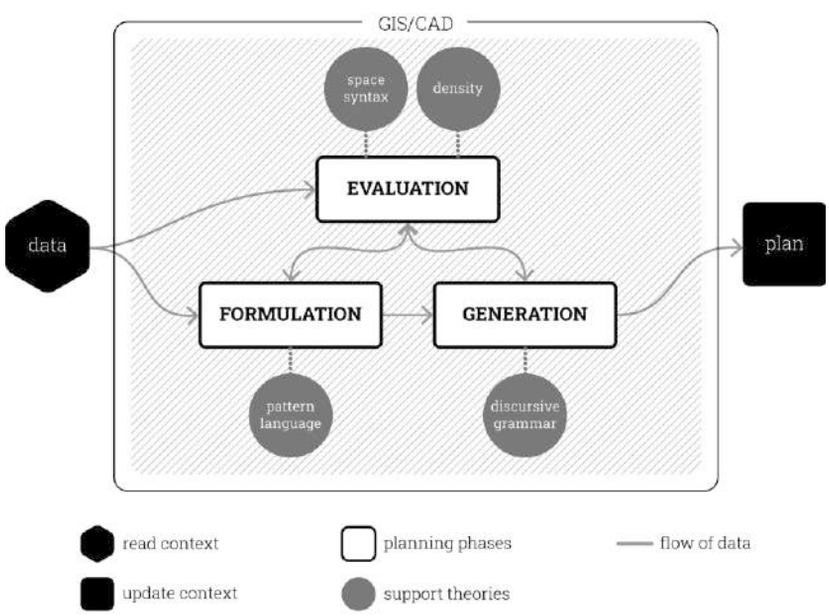

Figure 1. Structure of the ontology for the planning process thought for the City Induction project. Source: Made by the authors based on Duarte et. al. (2012, p.84)

2.2 Choosing a Path and Extending it

The research presented here chooses to continue the vision initiated by the City Induction project for considering it more aligned with the concept of a information model applied to the city. From the technological point of view, to achieve the vision established by the cited authors, it is useful to integrate a set of existing computational applications, allowing the incorporation of several representations of the urban space from the collected data, producing new data from performance metrics (enhancing the perception of the urban environment) and being able to elaborate propositional scenarios. Such scenarios can also be analyzed from the same performance metrics, making possible the comparison between the various states of the system (either the initial state or proposed states), becoming a device that can help in the negotiation between the different stakeholders.

The starting point of such an implementation is the creation of a Database (DB), and it is useful that it is hosted on a remote and accessible server. To organize and manage the data and access, the use of a Relational Database Management System (RDBMS) is extremely convenient. This type of application brings potentialities such as: a) management of different user profiles with different levels of access, b) capacity to manipulate and store a wide range of data types, proving useful in the management of data obtained from various sources, making participatory processes viable, c) functionalities that allow management from a single repository and remote access, maintaining the consistency of the DB and ensuring the access of all stakeholders involved to updated information, avoiding data duplication, and d) possibility of becoming a connector element between various design and analysis platforms, allowing the adaptability of the system to specific demands, as an incremental approach in its implementation (Gil et. al. 2011; Moreira & Andrade, 2018).

Starting from the last potentiality point, it is possible to list a series of useful applications to the urban planning process and that can find in a RDBMS an interoperability node. The use of Geographic Information Systems (GIS) allows not only the feeding of the DB, but also the execution of topological analysis and some geometric manipulations, being a powerful tool in the creation of data visualization through the elaboration of maps. The use of Integrated Development Environments (IDE), especially in notebook format, allows the implementation of data set analysis through Data Science techniques with the use of predictive models, data mining, and chart visualization. The integration with Statistical Analysis Software (SAS) brings functionalities for processing large datasets to perform descriptive statistics, regressions, cluster analysis, non-parametric tests and other procedures, also working on the understanding of urban information through the creation of charts. The connection with Web Applications (WA) makes it possible to build interfaces usable by the population in general, either to display portions of the existing and produced data, or to collect the impressions on scenarios proposed in the elaboration of urban plans. In another way, there is the possibility of integration with existing platforms through data scraping techniques, allowing the capture of spatially localized data through social networks, for example.

The connection with an algorithmic modeler, however, shows itself as one of the greatest potentials for the proposed CIM environment, where the use of Visual Programming Interfaces (VPI) in combination with CAD platforms constitutes an interactive design tool, at the same time showing itself as an environment where several analysis processes can be modeled. A VPI presents itself as an excellent tool for design professionals, providing a programming interface that does not demand the learning of a specific syntax, bringing the creation of algorithms closer to the creation of process diagrams, a type of representation that is familiar to this kind of professional.

An illustrative diagram of the proposed system can be seen in Fig. 2. So far, the research depicted here has adopted as platforms for proof-of-concept PostgreSQL (RDBMS), QGIS (GIS), Jupyter Notebook with Python (IDE), IBM® SPSS Statistics (SAS) and Rhinoceros (CAD) + Grasshopper (VPI) suite as algorithmic modeler.

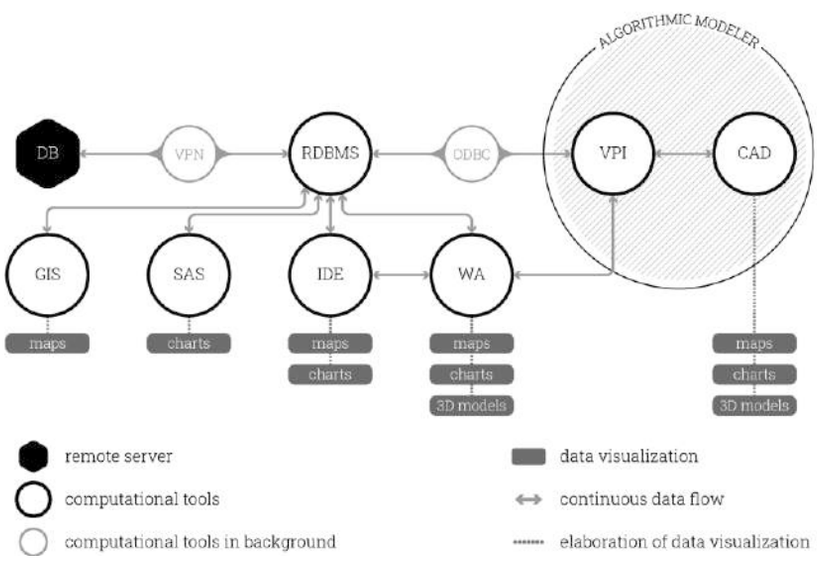

Figure 2. A proposed structure for a CIM system. Source: made by the authors.

While proving to be an important tool, the algorithmic modeler adopted has some limitations that have been identified as important to address. Grasshopper has a very active community of developers, with many add-ons for various tasks. Among these is the Slingshot! plugin by Nathan Miller, which establishes communication between VPI and relational database managers through ODBC protocols, which could be used to communicate with a PostgreSQL structured database. In fact, this is the option used by some works pointed out here, such as Beirão (2012), Beirão et. al. (2012) and Duarte & Beirão (2018). However, the functions provided by Slingshot! are related to direct database queries using SQL (Structured Query Language), and it does not have any specific tools to deal with georeferenced data or geometry processing. Otherwise, it requires the user to know a specific textual syntax (SQL), which kills one of the main potentials of a VPI.

In order to face this limitation, we present Carcará, a Grasshopper plugin that identifies some actions typical of the use of georeferenced databases in urban planning processes and encodes them as functions in VPI, allowing the user to work with the proposed CIM platform within the algorithmic modeler without the use, at first, of any specific textual syntax.

3 Putting the Carcará to fly

Carcará uses the concept of design patterns (Gamma et. al., 1995) and establishes a series of problems typical of the use of databases in urban planning processes, establishing reusable object-oriented functions. These functions have so far been structured in 5 thematic groups: Modelling, Queries, Utilities, Dataviz and Surrounding Analysis (Fig. 3).

Figure 3. Screenshot of the Carcará tools tab. Source: made by the authors.

The "Modelling" group presents some functions that have been identified as recurring in the construction of three-dimensional urban models. The "Building Meshes C#" function, for example, constructs a prismatic building volume from footprint and height data in polygonal mesh format, separating the outputs into "ground faces", "side faces" and "rooftop faces", using textual syntax in the C# module. The task of creating a prismatic volume is not difficult to implement with standard Grasshopper functions by associating nurbs surfaces. However, to create representations of buildings in an urban fabric, we often need to create thousands of volumes, which is very inefficient to do with surfaces, which justifies the choice of polygonal meshes, combined with the use of textual syntax in C#, which makes the processing faster. Otherwise, we chose to separate the different enclosures, since different analyses make use of only some portions of the built volume, such as visibility analyses (which take into account only the side faces) or solar energy production potential analyses (which need to separate the rooftop faces to delimit the evaluation space). Other functions present in this group are: "Identify Duplicate Polylines", since it was identified that the official mapping bases frequently have entity duplication errors; "Offset Python", which uses the python module to build an offset function that is less prone to errors than Grasshopper's default function; Point Inside Polygon, useful for creating associations between entities that contain others, such as lots and buildings; Sort By Container, which rearranges a list of elements based on a list of "containers" (e.g., rearrange a list of lots by the blocks they belong to or a list of building footprints by the lots they belong to).

The "Queries" group is the heart of Carcará, being responsible for establishing the communication between VPI and the database. In a relational

database, the data of an entity is stored in a column, which belongs to a table, which is inside a schema. To access any data, an SQL statement is required, following a well-defined structure. The functions in this group start from the idea of separating from this statement structure and variables, turning the latter into user-visible inputs. Structure and variables are joined through Grasshopper's native text concatenator function, forming a query. This is passed to a function written in the C# module for communication with the database via the ODBC driver, returning the expected result. The whole set is encapsulated in a cluster, creating a Carcará function. A schematic representation of this structure can be seen in Fig. 4.

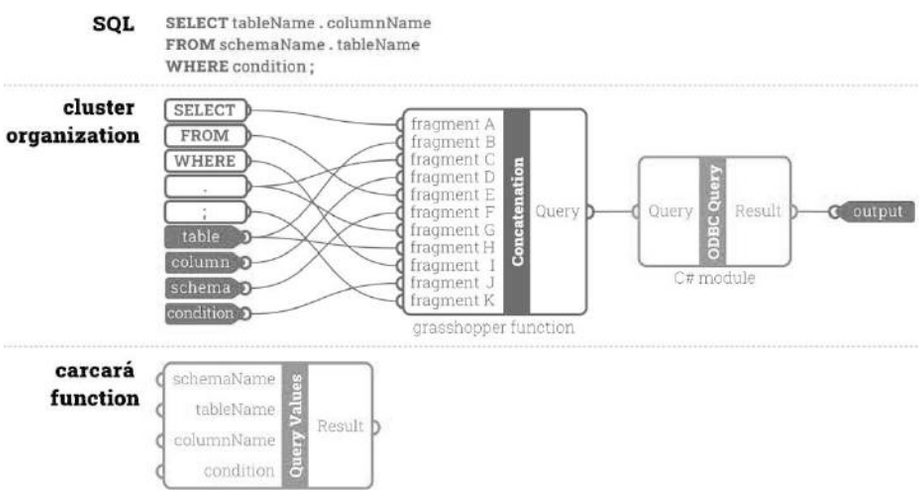

Figure 4. General scheme for creating a function from the "Queries" group. Source: made by the authors.

Another problem is in the translation of geometric entities. In a PostgreSQL database, storing georeferenced data requires the use of the PostGIS extension, which brings with it some extra functions for dealing with this type of object. In the table translation, the geometry becomes another column of alphanumeric data and is translated into the hex-encoded well-known-binary format, which is not readable by Grasshopper. Thus, functions involving the query of geometries use a translation function from the hex-encoded WKB format to a coordinate string of the constituent points of the geometry. This string is processed with Grasshopper's text tools, making it possible to reconstruct the queried geometry, be it a point, polyline, or polygon. A scheme explaining the translation can be seen in Fig. 5.

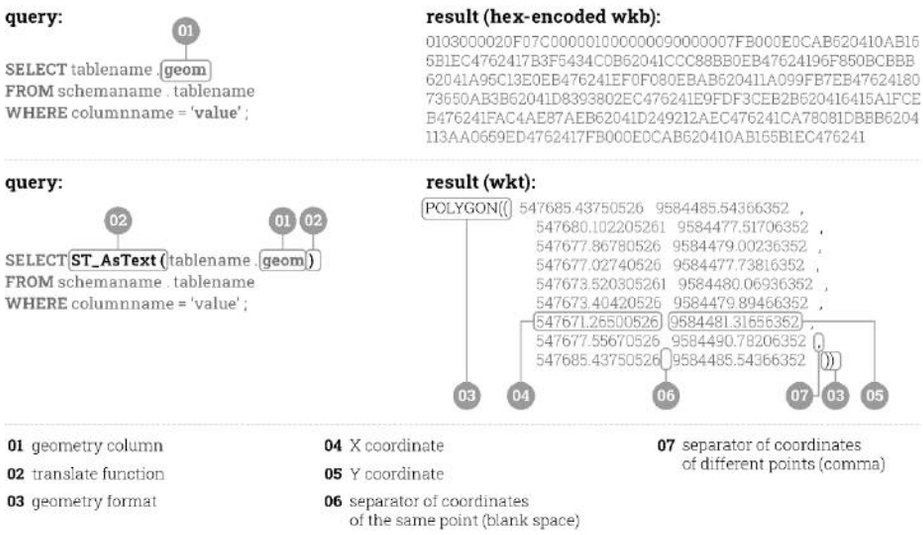

Figure 5. Translation of geometric data. Source: made by the authors.

The third group, called "Utilities", will bring some components that can be used in conjunction with the functions from the "Queries" group, making it possible to get certain input data already formatted for use. In this group, there are functions such as: "Connection String", which builds a structured text string with data about the connection to the database, such as username, password, IP address, and others; "Find Correction Parameters", which can be used to obtain the coordinates of a reference point in the study area, to be used later in queries to correct positions in the generated model; "Geometry Types", which lists the possible types of geometry in a GIS; and SRID, which brings a list of the most used SRIDs.

The fourth group, "Dataviz", brings some graph building functions into the grasshopper environment. In the current state of development, there are 2 subgroups. The first is intended for building graphs on the Rhino screen and features a scatterplot function, which is fully configurable in its appearance. The second sub-group is intended to allow the generated graphs to be saved directly in SVG format files, contributing to the creation of visualizations of the data sets and can be used directly for reporting. The functions in this group are a set of composers (which translate distinct geometries into the corresponding SVG code) and an exporter, which feeds in the data from the composers, builds the contents of the file, and saves it to a folder on the user's computer.

Finally, the fifth and last group (so far) is called "Surrounding Analysis" and is composed of a set of tools that allow the calculation of visibility indexes of objects of interest immersed in an urban context. The tools are the result of research aimed at establishing metrics to evaluate the ambience of built cultural heritage and can be seen in more detail at (Moreira et al., 2019).

Taken together, the Carcará tools provide a generic framework for modeling the urban environment within an algorithmic modeling platform, allowing a number of appropriations for work with different themes. Some research that

has already made use of the tool (in previous versions) are: Filipe et. al. (2019), for the evaluation of the quality of public space; (Moreira, 2018), for the evaluation of the ambience of the built cultural heritage; Lima et. al. (2019), Lima et al.(2020) and Lima et. al (2021), for representing informal settlements and calculating indicators that allow their participatory planning; and Passos Filho & Cardoso (2019), in an application of machine learning for computational bypass in the generation of environmental comfort indicators.

In fig 6 we can see an example of application of the system. In session 01, we have an isometric perspective of the built volumes of 5 neighborhoods in the city of Fortaleza, Ceará, Brazil, where the height information was translated into a color gradient ranging from cyan (lowest value) to magenta (highest value), passing through yellow (average value). For this example, the DB was queried, accessing information of all neighborhoods in the city, retaining the 5 shown based on their official names and using the geometry of their boundaries as a spatial filter for the information of all built volumes in the city, with their respective height data. In session 02, an information layer containing location data of all public open spaces in the city was queried, and it was possible to measure the distance from these to each built volume, selecting the distance to the nearest one, establishing a very simple analysis. The list with these distances was translated with the same color gradient as in session 01, and the result applied to the volumetry.

Figure 6. Results obtained with the use of Carcará. Source: made by the authors.

4 Discussion

The discussion about the concept of City Information Modelling and its applications is still a bit far from reaching some consensus. Until now, some experiments have been made in order to build some tool that operates within this conceptual framework, without yet arriving at something of consolidated use. Thus, we understand that the work presented here is promising as it tries to take advantage of a set of existing tools, establishing protocols for their communication. However, although the use of an algorithmic modeler opens an extremely broad field of application, either in the modeling of analysis processes, or in the construction of generative systems for the production of solution scenarios, some limitations can be pointed out.

The Rhino+Grasshopper platform is quite widespread in the field of product design and Architecture, having still timid applications in Urbanism. In fact, the system is not prepared to deal with geographic entities that, depending on the reference system adopted, may have coordinates that exceed 6 digits, which is transformed into scientific notation by Grasshopper, creating inaccuracies in the representation and requiring the creation of certain workarounds.

On the other hand, making a critical analysis of the theoretical line adopted, it is possible to notice little emphasis given to strategies for creating visualizations with more visual qualities, which is quite present in works that investigate the CityGML protocols in BIM+GIS integration. Such representations, although of little use for analysis processes, are very important in communicating with non-technical sectors, with the general population.

As future developments, the research presented here intends to further investigate the urban environment ontologies proposed in Duarte et. al (2012), Beirão (2012) and Beirão & Duarte (2018) with a view to designing organizational structures for the database, which will allow queries to become more intuitive. We also intend to expand some groups with new tools, especially the "Dataviz" group, with the incorporation of new types of charts, allowing greater integration between this type of representation and three-dimensional or cartographic ones.

References

Alexander, C., Ishikawa, S., Silverstein, M., & Jacobson, M. (1977). *A pattern language:* Towns, buildings, construction (36. print). Oxford Univ. Press.

Arroyo Ohori, K., Diakité, A., Krijnen, T., Ledoux, H., & Stoter, J. (2018). Processing BIM and GIS Models in Practice: Experiences and Recommendations from a GeoBIM Project in The Netherlands. *ISPRS International Journal of Geo-Information*, *7*(8), 311.

Ascher, F. (2010). *Os novos princípios do urbanismo* [The new principles of urbanism]. Romano Guerra.

Batty, M. (2007). *Complexity in City Systems*: Understanding, Evolution, and Design. Working Papers, 117.

Batty, M. (2009). Cities as complex systems: Scaling, interaction, networks, dynamics and urban morphologies. Em R. A. Meyers, *Encyclopedia of complexity and systems science* (p. 1041–1071). Springer.

Beirão, J. N. (2012). *CItyMaker*: Designing grammars for urban design. Delft University of Technology, Faculty of Architecture, Department Architectural Engineering+ Technology, Department of Urbanism.

Beirão, J. N., Montenegro, N., & Arrobas, P. (2012). *City Information Modelling: Parametric urban models including design support data*. Actas da Conferência Internacional PNUM 2012, 1122–1134.

Beirão, J., & Duarte, J. P. (2018). Generic grammars for design domains. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, *32*(2), 225–239.

Berghauser-Pont, M. Y., & Haupt, P. A. (2009). *Space, density and urban form.* Technische Universiteit Delft.

Castells, M. (2007). *A sociedade em rede* [The Rise of the Network Society] (R. V. Majer & F. H. Cardoso, Trads.). Paz e Terra.

Duarte, J. P. (2005). A discursive grammar for customizing mass housing: The case of Siza's houses at Malagueira. *Automation in Construction*, *14*(2), 265–275.

Duarte, J. P., Beirão, J. N., Montenegro, N. F. S. de C., & Gil, J. (2012). City Induction: A model for formulating, generating, and evaluating urban designs. In S. M. Arisona, G. Aschwanden, J. Halatsch, & P. Wonka, *Digital Urban Modeling and Simulation* (p. 73–98). Springer. http://link.springer.com/chapter/10.1007/978-3-642-29758-8_5

Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2014). *Manual de BIM:* um guia de modelagem da informação da construção para arquitetos, engenheiros, gerentes, construtores e incorporadores. Bookman.

Filipe, S., Farias Filho, J. A., Cardoso, D., & Beirão, J. N. (2019). Modelagem da Informação para a Qualidade do Espaço Público. *Anais...* XVIII Encontro Nacional da Associação Nacional de Pós-Graduação e Pesquisa em Planejamento Urbano e Regional, Natal.

Gamma, E., Helm, R., Johnson, R., & Vlissides, J. (1995). *Design patterns: Elements of reusable object-oriented software*. Addison-Wesley.

Gil, J., Almeida, J., & Duarte, J. (2011). *The backbone of a City Information Model (CIM): Implementing a spatial data model for urban design*. RESPECTING FRAGILE PLACES - 29th eCAADe Conference Proceedings. 29th eCAADe Conference, Slovenia.

Guarino, N. (1998). Formal Ontology and Information Systems. Em N. Guarino (Org.), *Formal Ontology and Information Systems: Proceedings of the First International Conference (FOIS'98)* (p. 3–15). IOS Press.

Hillier, B., & Hanson, J. (1989). *The Social Logic of Space*. Cambridge University Press.

Khemlani, L. (2005). Hurricanes and their Aftermath: How Can Technology Help? *AECbytes*.

Lima, M. C., Cardoso, D., & Freitas, C. (2019). Informal Settlements and City Information Modeling. *Proceedings...*, 10. https://doi.org/10.5151/proceedings-ecaadesigradi2019_414

Lima, M. Q. C., Freitas, C. F. S., & Cardoso, D. R. (2021). Invisible informality and the contribution of information modeling to data-based urban regulation. *Gestão & Tecnologia de Projetos*, *17*(1), 199–217.

Lima, M. Q. C., Moreira, E., Farias, S., & Freitas, C. F. S. (2020). A data-driven approach to inform planning process in informal settlements. *Blucher Design Proceedings*, 516–521.

Lynch, K. (1960). *The image of the city*. MIT PRESS.

Montenegro, N. F. S. de C. (2015). *CityPlan: Contributo para o desenvolvimento de uma metodologia e ferramenta computacional para apoio ao desenho urbano* [Doutorado em Urbanismo]. Universidade de Lisboa.

Moreira, E. (2018). *Modelando a percepção:* O ambiente do patrimônio cultural edificado na regulação da forma urbana [Dissertação (Mestrado em Arquitetura e Urbanismo e Design)]. Universidade Federal do Ceará.

Moreira, E., & Andrade, D. (2018). Construção e Cidade: Diferenças ontológicas na elaboração de um conceito de CIM. Em A. M. G. Souza, R. E. Baeta, & N. V. de A. Junior (Orgs.), *Anais...* (Vol. 8, p. 12003–12021). FAUFBA.

Moreira, E., Cardoso, D., & Beirão, J. N. (2019). Modelagem da informação e métodos quantitativos a serviço da preservação da ambiência do patrimônio cultural edificado. *Livro de Actas*, 417–431.

Mylopoulos, J. (1998). Information modeling in the time of the revolution. *Information Systems*, *23*(3–4), 127–155.

Nourian, P. (2016). *Configraphics: Graph theoretical methods for design and analysis of spatial configurations*. Delft University of Technology, Faculty of Architecture, Department Architectural Engineering+ Technology, Department of Urbanism].

Passos Filho, J. A. A., & Cardoso, D. (2019). Machine Learning para a acessibilização de análises em escala urbana. *V!RUS*, *19*.

Zhu, J., & Wu, P. (2021). Towards Effective BIM/GIS Data Integration for Smart City by Integrating Computer Graphics Technique. *Remote Sensing*, *13*(10), 1889.

Zhu, J., Wright, G., Wang, J., & Wang, X. (2018). A Critical Review of the Integration of Geographic Information System and Building Information Modelling at the Data Level. *ISPRS International Journal of Geo-Information*, *7*(2), 66.

Spatial skills and the education of architecture and urbanism: use of Minecraft game for shape and geometry study

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Abstract. The focus of this article is to highlight the use of digital games as a tool for developing of spatial skills, due to their immersive, playful character and for generating environments with creative possibilities through a digital platform, aspects amplified in the simulated environment. As part of ongoing research, the present work presents an experience of the application of the Minecraft game in the first-year class of an Architecture and Urbanism course. As a methodology, the application took place in two meetings, in which, following the structure of Bloom's taxonomy, students developed three creative activities relating to architecture and geometry. What was observed was that the students demonstrated development in the knowledge of the geometry of the architectures studied, creating new relationships between abstract forms and the possibilities of materialization of the built environment.

Keywords: Digital education, Digital games, Spatial skills, Architecture and Urbanism, Teaching Observation

1 Introdução

Ao longo da história, o estudo da compreensão e representação do espaço evoluiu conforme os seres humanos foram sendo capazes de sistematizar esse conhecimento. Nos últimos anos, constantes debates buscavam responder qual era a geometria necessária para a arquitetura da atualidade, o que permitiu uma ampliação do campo de estudo.

Habilidades como visão espacial, capacidade de representar objetos no plano bidimensional, interpretação de desenhos e resolução de problemas espaciais, devem ser estimuladas ao se ensinar Geometria Descritiva,

segundo Valente (2018). A visão espacial se destaca como a principal habilidade para que seja possível adquirir as demais e essencial para compreender o ensino de geometria para projetistas, complementa Valente (2018). Martín-Gutierréz et al. (2010) destacam que um dos pontos relevantes da geometria, para o ensino de arquitetura, é desenvolver a visão espacial, ou seja, o conhecimento geométrico aplicado a operações espaciais. À construção desses conhecimentos, atribui-se o termo habilidades espaciais.

O presente artigo apresenta uma experiência de atividade, proposta com jogos digitais, utilizando o Minecraft, para o desenvolvimento das habilidades espaciais no ensino de Arquitetura e Urbanismo da Universidade Federal de Juiz de Fora. A atividade foi realizada no ano de 2022 e foi voltada especificamente para os alunos recém-ingressos no curso (alunos do primeiro período). O principal objetivo é evidenciar o uso dos jogos digitais como uma ferramenta para o desenvolvimento das habilidades espaciais, principalmente por seu caráter imersivo, lúdico e, por meio da plataforma digital, gerar ambientes com possibilidades criativas além dos limites dos recursos físicos, que se estendem através do ambiente simulado.

Através de um processo de revisão de literatura, reunindo um conjunto de referências bibliográficas, foi obtido com o intuito de formar uma base referencial e conceitual para a pesquisa. Os principais canais de busca de artigos foram os bancos de dados Periódicos CAPES, Google Acadêmico, Banco de Teses da Capes e o SCIELO.

O artigo está dividido em 5 itens que compreendem: conceituação das habilidades espaciais; importância dos jogos digitais e o desenvolvimento das habilidades espaciais, metodologia da atividade proposta, discussão dos resultados e considerações finais.

2 Habilidades espaciais

A compreensão do espaço arquitetônico e urbano envolve diferentes tipos de habilidades ligadas à percepção do espaço e de como as formas se relacionam. Montenegro (2005) situa as habilidades espaciais no intermédio entre a representação geométrica 2D e 3D e a fantasia, ocupando um espaço entre a lógica e a fantasia.

A habilidade espacial é uma capacidade humana que pode ser estimulada ou abandonada, afirma Montenegro (2005). A estimulação constante promove uma melhoria do raciocínio espacial e pode se dar através de exercícios que envolvem rotação mental de figuras, orientação espacial, reconhecimento de rostos, leitura de mapas, analogia de formas, vistas ou perspectivas de outro ângulo, interpretação múltipla de uma mesma figura, a percepção de padrões que parecem confusos, a velocidade e compreensão da visualização espacial e outros aspectos. (Montenegro, 2005, p. 8)

A habilidade espacial de um indivíduo pode ser influenciada por diversos fatores, alguns presentes nas experiências de vida, como apontado por Marunic e Glazar (2014). Para os autores, entre algumas experiências que auxiliam no processo de desenvolvimento da criança estão brincar com blocos de construção, desenhar ao longo da infância e adolescência, jogar jogos de computador que utilizem recursos tridimensionais, praticar esportes e praticar as habilidades matemáticas. Fatores como idade e sexo são reconhecidos como fatores que também podem influenciar no desenvolvimento das habilidades espaciais.

Howard Gardner (1994) aborda o conceito do desenvolvimento das habilidades espaciais, que define o conceito das múltiplas inteligências. Dentre elas, a inteligência espacial é apontada, a qual, para Gardner (1994), envolve as "capacidades de perceber o mundo visual com precisão, efetuar transformações e modificações sobre as percepções iniciais e ser capaz de recriar aspectos da experiência visual, mesmo na ausência de estímulos físicos relevantes." (Gardner, 1994, p. 156)

Segundo Gardner (1994), a inteligência espacial é importante para se orientar pelas localidades e espaços. É bastante utilizada em representações gráficas bidimensionais ou tridimensionais, sejam artísticas, como artes gráficas e esculturas, ou técnicas como plantas, mapas, diagramas e forma geométricas.

3 Jogos digitais e o desenvolvimento das habilidades espaciais

Os jogos eletrônicos (ou digitais), segundo Petry (2016), são frequentemente utilizados na educação básico e médio, mas poucas experiências são focadas no ensino superior. Chandrasekharan et al. (2010) salientam que o jogo utilizado em sala de aula permite experiências que abstraem o indivíduo da realidade, assim como aumentam a correlação entre a narrativa e o aprendizado.

Green e Bavelier (2003) e Spence e Feng (2010) indicam quais são os gêneros de jogos considerados mais efetivos no desenvolvimento das habilidades espaciais. Santos, Dias e Braida (2020), ao analisarem estes dados, apontam que são os de ação, condução, quebra-cabeça, labirinto, sandbox e mundo aberto.

Richardson e Collaer (2011) salientam que as diferenças de habilidades espaciais entre indivíduos desaparecem com a aplicação de atividades com jogos, algo também reconhecido por Lin, Chen e Lou (2014) e Cherney (2008). Já Jirout e Newcombe (2015) indicam que os jogos diminuem, mas não eliminam tais diferenças.

Além disso, Bowman et al. (2014) salientam que videogames menos difíceis são mais prazerosos e efetivos em indivíduos que não são jogadores

frequentes. Cubukcu (2010) também apresenta uma importante contribuição no que tange ao desenvolvimento das habilidades espaciais, ao apontar que não existe diferenças significativas no uso de jogos com gráficos mais ou menos fiéis à realidade, pois a interação com a forma e com o espaço é mais importante do que o aspecto gráfico.

Dos estudos encontrados, apenas o de Valente (2018) estava diretamente relacionado ao tema das habilidades espaciais e o ensino da Arquitetura e Urbanismo, pois as pesquisas, em geral, referem-se, principalmente, a cursos de tecnologia, como no caso de Martin-Dorta et al. (2013) e Lamb, Akmal e Petrie (2014), ou a estudos com alunos de ensino básico e médio, como Kell, Lubinski e Benbow (2014) e Hung et al. (2012). Ainda, de forma indireta, pode-se mencionar as pesquisas de Braida et al. (2015; 2016) sobre o uso dos jogos *Minecraft* e *LEGO Digital Designer* para a concepção de projetos arquitetônicos e para o estudo da forma. Portanto, o direcionamento para Arquitetura e Urbanismo, assim como no processo de manipulação das formas, é um campo ainda em estudo.

4 Metodologia da proposta de atividades com jogos digitais

Os resultados apresentados neste artigo decorrem da experiência de aplicação de atividades para o desenvolvimento das habilidades espaciais com alunos do primeiro período do curso de Arquitetura e Urbanismo da Universidade Federal de Juiz de Fora, no ano de 2022. Esta atividade faz parte da pesquisa de doutorado do primeiro autor deste artigo, sob orientação da segunda autora e coorientação do terceiro autor.

Como o objetivo é desenvolver as habilidades espaciais de estudantes que ainda não se aprofundaram nos conhecimentos sobre a forma da arquitetura, por estarem no início do curso, o jogo digital Minecraft se mostrou adequado, mesmo possuindo formas simples.

No Minecraft, o jogador, com a visão em primeira pessoa, deve explorar ambientes inóspitos, coletar recursos e construir estruturas que o permitam sobreviver e prosperar. Quase todos os elementos do jogo são baseados em cubos regulares e suas transformações, desde o ambiente, elementos naturais e paisagens até os personagens e animais.

Como base temática para o estudo geométrico com a interface do Minecraft, foram utilizadas as operações formais definidas por Di Mari e Yoo (2018). Trata-se de verbos que definem operações sobre a forma, definidas em ações aditivas, subtrativas e de deslocamento, baseando-se nas transformações observadas nas composições.

Com estas questões, os exercícios propostos foram agrupados, em momentos distintos, em dois encontros. Estes dois grupos foram divididos, segundo a taxonomia de Bloom et al. (1956) revisada por Anderson et al.

(2001), que descreve os passos que um aluno deve percorrer para alcançar o desenvolvimento de um conhecimento. A taxonomia compreende as etapas de recordar, compreender, aplicar, analisar, avaliar e criar.

O primeiro encontro compreendeu as etapas de recordar, compreender e aplicar. Neste encontro, foram propostos exercícios que apresentassem as operações formais e desenvolvessem atividades lúdicas de composição de formas arquitetônicas, utilizando as operações formais. O uso do Minecraft, neste encontro, visou explorar exemplos práticos mais simples, antes do exercício de desenvolvimento de uma residência, para que os alunos se familiarizassem tanto com as operações formais quanto com a interface do jogo.

O segundo encontro englobou, primeiramente, as etapas de analisar e avaliar. Focou-se na compreensão e reprodução das formas geométricas das arquiteturas através da identificação das operações formais que as sustentam, passando pelo processo de identificação e análise das descrições obtidas. Neste encontro, foram apresentadas arquiteturas prontas em arquivos salvos de Minecraft, os quais os alunos deveriam, através da observação da interface dos jogos, identificar e postular os princípios das operações formais que as regem. Foram entregues manuais com algumas operações estudadas, para que servissem como guia para o estudo. Ainda no segundo encontro, foi estimulada etapa de criação da taxonomia. Nesta etapa foram avaliadas as operações identificadas sob suas variações, demandando dos alunos decomposição, recombinação e reinterpretação das operações formais, demonstrando, portanto, seu conhecimento das informações absorvidas.

O que o jogo escolhido oferece de mais interessante é que todas estas etapas descritas ocorreram em um ambiente narrativo, onde as formas estão situadas em terrenos que possuem vegetação, água, árvores, sol, chuva e noite, ou seja, não serão formas vazias em um espaço hermético e “frio”, além de ser possível aplicar materiais e texturas. A escolha da temática e do terreno foi essencial em todas as etapas, bem como lidar com as consequências da passagem do tempo. Além disto, o jogo, a todo o momento, coloca o indivíduo na escala do observador, portanto as manipulações formais da arquitetura aproximaram a forma da pessoa, o que se configura como um dos princípios das qualidades dos jogos para o desenvolvimento das habilidades espaciais. Por fim, sobre o jogo, todo o processo é essencialmente ativo, não existindo o aluno passivo (desde que deseje participar do estudo), portanto, configurando o processo de busca por conhecimento atrelado à ação, o que pode tornar a experiência mais memorável.

5 Discussão dos resultados

A aplicação ocorreu no primeiro semestre de 2022, com 23 alunos do primeiro período do curso de Arquitetura e Urbanismo da Universidade Federal

de Juiz de Fora, de forma presencial. A aplicação se deu na disciplina de Estudo da Forma, que tem por ementa: “percepção espacial e manipulação formal. Aportes conceituais da análise bi e tridimensional da forma dos objetos arquitetônicos e urbanísticos. Objetos tridimensionais como ferramentas de concepção e representação projetual em arquitetura e urbanismo”. (UNIVERSIDADE FEDERAL DE JUIZ DE FORA, 2018, P.6).

Os dois encontros, anteriormente mencionados, foram assim estruturados:

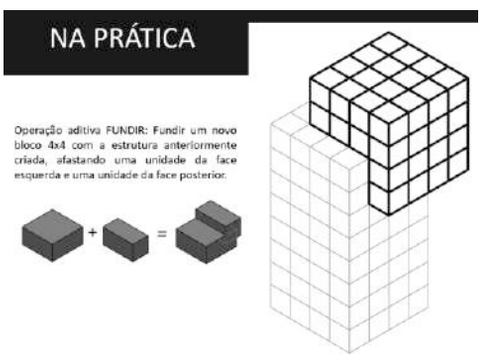

Figura 1. Instruções para a construção da casa 4x4. Fonte: autores.

No primeiro encontro com duração de 3 horas, os alunos foram, inicialmente, introduzidos ao tema das operações formais, composição geométrica aplicada à arquitetura e ao estudo das relações da forma e do espaço. Após essa introdução, os alunos exercitaram o uso do Minecraft, entrando em contato com a sua interface, com a mecânica do jogo e seus princípios básicos. Essas duas etapas iniciais foram essenciais para que os alunos compreendessem as características da atividade que iriam realizar e conhecessem as “regras do jogo”. Todas as atividades utilizaram a escala 1:1 do Minecraft, respeitando, portanto, a escala do personagem controlado. Este ponto é essencial para colocar o aluno no ponto de vista do observador.

Após o primeiro momento, os alunos desenvolveram uma pequena atividade, para que pudessem exercitar a interação com o jogo, na qual, apenas com a construção de cubos, executaram a forma simplificada da Casa 4x4 de Tadao Ando, localizada em Hyogo, Japão. Através de uma narração descrita das operações formais, os alunos puderam fazer a composição (Figura 1). Nesta atividade não foi solicitada a escolha de um terreno, pois se configurava apenas como uma atividade preliminar.

Após a execução, houve discussões acerca da composição da forma da arquitetura estudada. Foram levantadas questões de proporção, medidas, erros e acertos dos alunos. Em geral, utilizando-se da linguagem tridimensional, os alunos conseguiram desenvolver bem e rapidamente a atividade, porém, alguns alunos tiveram dificuldades na execução, errando proporção ou encaixe das peças (Figura 2).

No segundo momento do primeiro encontro, ocorreu o processo de execução de uma arquitetura narrada através das operações formais. A arquitetura escolhida foi Los Miradores, de Andrés Alonso, localizada na Argentina. Salienta-se que, por conta do caráter cúbico do Minecraft, as formas são simbólicas, mas o objetivo era a composição geral, entendimento do terreno e materialidade.

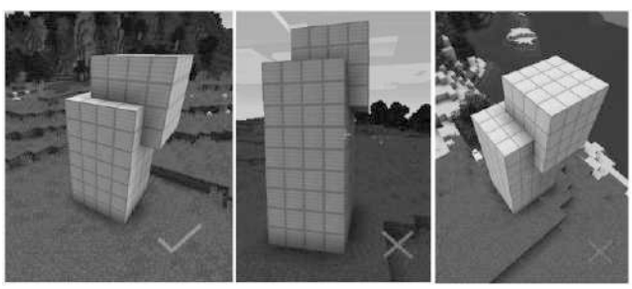

Figura 2. Erros encontrados na primeira atividade. Imagem da esquerda: forma correta. Imagem central: erro na altura do bloco vertical. Imagem da direita: erro no encaixe do bloco superior que está duas unidades afastada da borda. Fonte: autores.

Para a segunda arquitetura, o estudo deveria observar três momentos: 1) escolha de um terreno que atendesse à demanda solicitada (Figura 3); 2) indicação dos materiais que deveriam ser utilizados; e 3) narrativa da forma através das operações formais. Esta narrativa se deu de diferentes formas, alternando entre representações tridimensionais e bidimensionais, com o intuito de verificar o entendimento, dos alunos, das representações dadas. Nota-se, na Figura 3, a imagem da direita representa uma fachada dividida pelos blocos unitários do Minecraft. Após esta etapa, foi desenvolvida uma discussão acerca da composição desta forma, os pontos necessários e os erros e acertos dos alunos.

Figura 3. Exemplo das solicitações feitas em sala de aula. Fonte: autores.

Os erros mais recorrentes envolveram a implantação do edifício, por não se localizar sobre superfícies planas, e a indicação dos materiais solicitados. Nos exemplos da Figura 4, pode-se notar que, na forma, os alunos compreenderam

bem os comandos de operações solicitados, como por exemplo extrudar e sobrepor, porém, nas narrativas mais abstratas, os alunos necessitaram, em algumas vezes, de adaptações para se encaixar na descrição solicitada. Ao final do primeiro encontro, os alunos demonstraram e discutiram o trabalho desenvolvido, conheceram a arquitetura estudada no mundo real e deram suas opiniões sobre o resultado obtido. Em geral, os alunos demonstraram satisfação com o resultado e com a discussão desenvolvida.

Figura 4. Exemplo da modelagem desenvolvida pelos alunos. Fonte: autores.

O segundo encontro com duração de 3 horas, que ocorreu uma semana depois do primeiro encontro, teve como objetivo desenvolver o conhecimento das operações formais através dos processos de analisar, avaliar e criar, seguindo, ainda, os princípios da taxonomia de Bloom revisada. Conforme descrito, os alunos foram solicitados a analisar arquiteturas previamente apresentadas e identificar as operações formais que considerassem que se aplicassem melhor à forma estudada.

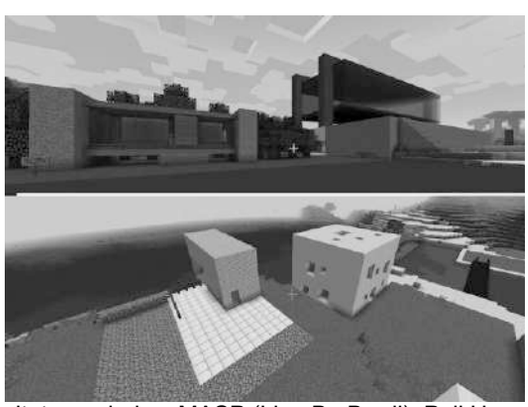

Figura 5. Arquiteturas dadas: MASP (Lina Bo Bardi), Poli House (Pezo Von Ellrichshausen), Casa Rio Bonito (Carla Juaçaba) e Cliff House (Mackay Lyons Sweetapple Architects). Fonte: autores.

Nesta etapa de identificação, os alunos analisaram as arquiteturas através da interface do jogo, passearam por seus espaços e deliberaram sobre a composição destas arquiteturas (Figura 5). Por ser um processo interpretativo, as discussões não se focaram em certo ou errado, mas sim, na compreensão das forças compositivas, nas relações de proximidade e nas diferenças entre as arquiteturas, bem como na complexidade resultante das soluções identificadas. Objetivou-se uma aproximação dos alunos para com o conteúdo estudado. Esta reflexão compreendeu os princípios de analisar e avaliar as arquiteturas.

Figura 6. Terreno dado. Fonte: autores.

Por fim, atendendo à etapa de criação, os alunos criaram uma arquitetura utilizando as operações formais que haviam aprendido. Para esta criação, o enunciado dado foi: “Você foi convidado para fazer uma pequena residência na região dos quatro projetos arquitetônicos. A ideia é um projeto que te permita ver as arquiteturas e as paisagens do entorno, tendo por inspiração as formas dos edifícios vizinhos.” E as seguintes regras foram dadas para a realização da atividade em 30 minutos: 1) utilizar o terreno disponibilizado, não passando dos limites da grama 13x13 unidades (Figura 6), 2) escolher três operações formais da lista dada e aplicar na forma final, 3) utilizar no mínimo dois e no máximo quatro materiais diferentes e 4) não é necessário fazer o interior, apenas a envoltória externa (Figura 7).

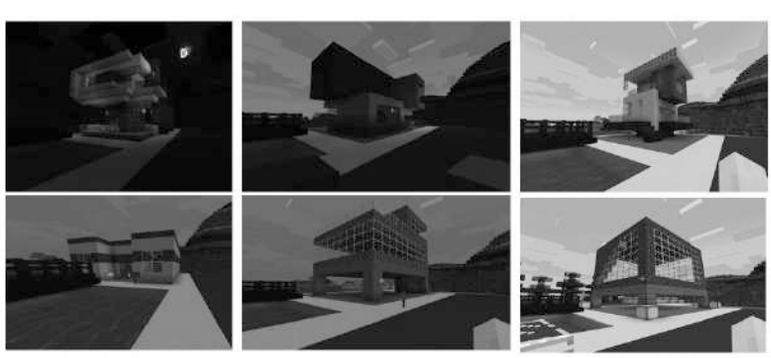

Figura 7. Projetos dos alunos no Minecraft. Fonte: autores.

O terreno possuía algumas características, como estar de frente para uma “rua” com arquitetura em seu lado oposto, possuir um lago e uma ponte em suas extremidades. Os resultados desta etapa foram diversos, com a exploração de composições arquitetônicas variadas.

Os principais pontos observados foram que alguns alunos seguiram fielmente as composições pautadas em formas geométricas básicas; outros, principalmente aqueles mais versados no jogo, se atentaram à estética. Algumas residências estavam integradas ao entorno imediato, localizando entradas e saídas em pontos estratégicos, enquanto outras estavam desconexas com o ambiente.

Da forma complexa à mais simples, a maioria dos alunos se atentou ao tema da residência, prevendo suas aberturas, acessos e relações. O ambiente em sala de aula se tornou lúdico e os alunos demonstraram interesse e proatividade em todas as etapas propostas.

6 Considerações finais

Os novos alunos que entram no ensino superior já nascem imersos nas plataformas digitais, e, dentre elas estão os jogos. O contato com o espaço tridimensional virtual se amplifica, criando relações com o chamado ciberespaço. Isto se reflete até mesmo nas plataformas digitais de trabalho do arquiteto e urbanista, como os softwares de representação 3D que aumentam cada vez mais em complexidade e possibilidades.

Nesta experiência, o ambiente virtual, caracterizado pela simulação de algumas características do mundo real, foi essencial para o desenvolvimento das atividades, pois, além de oferecer uma ferramenta de fácil manuseio aos alunos, o processo criativo se tornou imersivo. Os estudos e as criações arquitetônicas estavam permeados pelas condicionantes ambientais, como geografia, clima, vegetação, paisagens e passagem do tempo, criando uma maior complexidade dos estudos em um ambiente lúdico. Além disso, o Minecraft é um jogo digital popular em que os alunos, em geral, possuem experiência prévia, e por sua característica de interatividade com os blocos, foi possível explorar, além da geometria, o uso dos materiais, cores, transparências e implantações da arquitetura, algo de difícil reprodução fora de um ambiente digital.

O que se observou foi que os alunos demonstraram desenvolvimento nos conhecimentos da geometria das arquiteturas apresentadas. A associação das formas arquitetônicas com as ações criativas dos alunos leva mais clareza e compreensão de como o estudo dos conteúdos de geometria é importante para a formação de arquitetos e urbanistas. Compreender que a geometria não se limita à representação das projeções, e, consequentemente, plantas, cortes e fachadas, mas sim como meio para a atuação do arquiteto no mundo, através da criação de espaços, que por sua vez, são construídos por formas. Isto

promove a racionalização do processo de manipulação formal arquitetônica, a qual pressupõe o desenvolvimento das habilidades espaciais.

Como possíveis desdobramentos, a proposta das atividades permite a variabilidade de aplicação, explorando novos jogos, novas arquiteturas e novos ambientes digitais. O ponto principal caracterizado é a imersão e a associação entre a forma e o objeto construído.

Referências

Anderson, L. W., & Al, E. (2001). *A taxonomy for learning, teaching, and assessing: a revision of Bloom's.* Pearson.

Bloom, B. S. (1956). *Taxonomy of Educational Objectives: The Classification of Educational goals.* Handbook 1, Cognitive Domain. Longman.

Braida, F., Rosa, A. A., Silva, I. F., Homem, D. M., & Jardim, A. da S. (2015). A exploração do mundo projetual dos blocos de montar por meio do jogo digital interativo Minecraft.. In *Anais do Congresso da Sociedade Iberoamericana de Gráfica Digital* (pp. 371–377). Edgard Blücher.

Braida, F., Castro, J. M., Pires, L., Pereira, L., & Cardoso, M. (2016). Projetando com blocos de montar digitais: possibilidades e limitações do jogo LEGO Digital Designer. In *Anais do Congresso da Sociedade Iberoamericana de Gráfica Digital*, 3, 244–251.

Bowman, N. D., Weber, R., Tamborini, R., & Sherry, J. (2013). Facilitating Game Play: How Others Affect Performance at and Enjoyment of Video Games. *Media Psychology*, 16(1), 39–64. https://doi.org/10.1080/15213269.2012.742360

Chandrasekharan, S., Mazalek, A., Nitsche, M., Chen, Y., & Ranjan, A. (2010). Ideomotor design: Using common coding theory to derive novel video game interactions. *Pragmatics and Cognition*, 18(2), 313–339. https://doi.org/10.1075/pc.18.2.04cha

Cherney, I. D., Bersted, K., & Smetter, J. (2014). Training Spatial Skills in Men and Women. *Perceptual and Motor Skills*, 119(1), 82–99. https://doi.org/10.2466/23.25.pms.119c12z0

Cubukcu, E. (2011). Does the level of visual detail in virtual environments affect the user's spatial knowledge? *Environment and Planning B: Planning and Design*, 38(4), 741–752. https://doi.org/10.1068/b37079

Di Mari, A. & Yoo, N. (2018). *Operative design: a catalogue of spatial verbs*. Bis Publishers.

Gardner, H. (1994). *Estruturas da mente: A teoria das intelgências múltiplas*. Artes Médicas.

Hung, P.-H., Hwang, G.-J., Lee, Y.-H., & Su, I-Hsiang. (2012). A cognitive component analysis approach for developing game-based spatial learning tools. *Computers & Education*, 59(2), 762–773. https://doi.org/10.1016/j.compedu.2012.03.018

Jirout, J. J., & Newcombe, N. S. (2015). Building Blocks for Developing Spatial Skills: Evidence from a Large, Representative U.S. Sample. *Psychological Science*, 26(3), 302–310. https://doi.org/10.1177/0956797614563338

Kell, H. J., Lubinski, D., Benbow, C. P., & Steiger, J. H. (2013). Creativity and Technical Innovation. *Psychological Science*, 24(9), 1831–1836. https://doi.org/10.1177/0956797613478615

Lamb, R., Akmal, T., & Petrie, K. (2015). Development of a cognition-priming model describing learning in a STEM classroom. *Journal of Research in Science Teaching*, 52(3), 410–437. https://doi.org/10.1002/tea.21200

Lin, C. H., Chen, C. M., & Lou, Y. C. (2014). Developing Spatial Orientation and Spatial Memory with a Treasure Hunting Game. *Educational Technology & Society*, 3(17).

Martin-Dorta, N., Sanchez-Berriel, I., Bravo, M., Hernandez, J., Saorin, J. L., & Contero, M. (2013). Virtual Blocks: a serious game for spatial ability improvement on mobile devices. *Multimedia Tools and Applications*, 73(3), 1575–1595. https://doi.org/10.1007/s11042-013-1652-0

Martín-Gutiérrez, J., Gil, F. A., Contero, M., & Saorín, J. L. (2010). Dynamic three-dimensional illustrator for teaching descriptive geometry and training visualisation skills. *Computer Applications in Engineering Education*, 21(1), 8–25. https://doi.org/10.1002/cae.20447

Marunić, G., & Glažar, V. (2014). Improvement and assessment of spatial ability in engineering education [Review of Improvement and assessment of spatial ability in engineering education]. *Engineering Review*, 23(2), 139–150.

Montenegro, G. (2005). *Inteligência Visual e 3-D*. Edgard Blücher.

Petry, A. dos S. (2016). Jogos digitais e aprendizagem: algumas evidências de pesquisa. In: ALvez, L & Coutinho, I. (Org.). *Jogos digitais e aprendizagem: fundamentos para uma prática baseada em evidências*. (p. 43-60). Papirus.

Richardson, A. E., & Collaer, M. L. (2011). Virtual Navigation Performance: The Relationship to Field of View and Prior Video Gaming Experience. *Perceptual and Motor Skills*, 112(2), 477–498. https://doi.org/10.2466/22.24.pms.112.2.477-498

Santos, C. E. R., Dias, M. A., & Braida, F. (2020). Geometria, habilidade espacial e jogos digitais: contribuições para o ensino de arquitetura e urbanismo. Revista Brasileira de Expressão Gráfica, 8(1), 1–25.

Universidade Federal de Juiz de Fora. Coordenadoria de Assuntos e Registros Acadêmicos. (2018). *Plano de Ensino: AUR077 – Estudo da Forma para Arquitetura e Urbanismo*. Disponível em: https://www.ufjf.br/estudodaforma/files/2013/05/AULA01.pdf.

Valente, V. (2018). *Desenvolvimento da Visão Espacial por Games Digitais*. Appris Editora E Livraria Eireli.

Walking the Line: UX-XR Design Experiment for Ephemeral Installations in Pandemic Times

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Abstract. Throughout COVID 19 Pandemic since 2020, it was necessary to generate instructional strategies including digital platforms for creative processes in architecture. This article exposes an experience that integrates pedagogical, operational, and technical dimensions in architecture virtual teaching. A pedagogical methodology was designed and implemented, fusing User Experience (UX) and Extended Reality (XR) during the architectural design process in a virtual experimental studio. The use of UX-XR as a designing-reviewing strategy in architecture, positively impacted the creative experience of both students and reviewers by enriching the perception of the space and interactively simulating the user experience. A friendly, fun, and socially inclusive environment was generated for learning architecture using synthetic media and Multiuser Virtual Environments (MUVEs). The successful results of the students' projects by phase are shown, revealing the significance of combining UX and XR, incorporating the metaverse as a canvas to review, recreate, interact, and assess architectural designs.

Keywords: User Experience (UX), Extended Reality (XR), Multiuser Virtual Environments (MUVE), Virtual Campus, Usability.

1 Introducción

El taller de diseño Fundamentales de Diseño I ARCH 310 de la Escuela de Arquitectura y Urbanismo (SARUP) por sus siglas en inglés, en la Universidad de Wisconsin Milwaukee (UWM), fue coordinado por Sarah Aziz, (Becario de Innovación en Diseño) y se llevó a cabo en el otoño del 2020, justo en la crisis de la pandemia del COVID 19. Este taller de diseño tuvo más de 130 estudiantes. El grupo de estudiantes fue dividido en 7 clases de las cuales una fue 100% virtual, cinco presenciales y una híbrida. En este artículo se describe la experiencia de la clase virtual del taller, integrando dimensiones

pedagógicas, operativas y técnicas en la enseñanza virtual de arquitectura. El taller experimental 100% virtual, fue asesorado por consultores invitados expertos en Realidad Extendida (XR) y Experiencia de usuarios (UX). El grupo virtual fue notablemente diverso con estudiantes de diferentes locaciones como Wisconsin, Illinois y Korea, así como con revisores de Brasil, Milwaukee y Hawái.

Este trabajo busca exponer la estrategia metodológica, los resultados y trascendencia del experimento práctico de diseño fusionando UX-XR dentro de un taller arquitectónico online, cuyo producto en un contexto real implicaba: recorrer la línea perimetral del borde de las ciudades o condados de ubicación de cada estudiante, observar la experiencia del usuario transeúnte y de sus contextuales, diseñar una máquina de distancia social como artefacto para la comprensión de las necesidades del usuario, su anatomía y nueva espacialidad ante la pandemia, y finalmente la creación de una instalación urbana o rural que respondiera a las memorias colectivas de un punto de la línea perimetral y de las necesidades del usuario de esa comunidad en particular.

1.1 Marco Teórico

UX, por sus siglas en inglés, Experiencia del Usuario, implica una metodología que apoya los principios del diseño centrado en el usuario, y la usabilidad para crear una mejor experiencia en el uso de un producto o servicio final. (Aguirre et al., 2020).

El término de Experiencia de Usuario fue acuñado en la década de 1990, por el Co fundador de Nielsen Norman Group, Don Norman, una de las consultoras más relevantes en diseño de UX. Este término engloba todos los aspectos relacionados con la percepción del usuario en cuanto a la interacción con un ecosistema, entorno, dispositivo, o servicio. (Garrett, 2011). UX evalúa y se mide aplicando una serie de técnicas propias de la metodología UX, con foco en las visiones de los participantes antes, durante y después del diseño del producto, promoviendo la participación colaborativa del usuario a lo largo del proceso y creación del diseño. UX posee una visión de nivel cualitativo y está enmarcado en la metodología ágil del “design thinking”, en español pensamiento de diseño. (Design Thinking España, s/f) y (Muller-Roterberg, 2020). Esto implica pasos que generan acciones que se configuran a través de las siguientes etapas: Empatizar: entender a los usuarios, investigando sus dolores, esperanzas y hábitos en torno al ecosistema donde se desenvuelven. Definir: Investigar a los usuarios y sintetizar soluciones para plantear respuestas. Idear: Generación de ideas del proyecto en base a la investigación. Prototipar: Generación de prototipos de alta, media y baja funcionalidad y retroalimentación por parte de los usuarios. Testear: Medir la percepción del usuario en el entorno y diseño de un prototipo. Este es un modelo iterativo no lineal, por lo que cada cambio sugerido por los usuarios puede generar

oportunidades en la madurez del proyecto o servicios a diseñar. (Mootee, 2013) y (Osterwalder et al., 2013).

El diseño centrado en el usuario pone a las personas en el centro del universo. Esto se traduce en la calidad que debe tener el usuario para caminar o navegar en una plataforma o espacios. (Nielsen, 2001). Se puede garantizar el éxito de un medio digital al apostar por el diseño centrado en el ser humano (HCD), entrelazar estos principios en XR, al igual que generar una relación con el marco del pensamiento de diseño y las etapas antes mencionadas. Estas etapas apoyan el escenario para la fusión UX-XR, resaltando el medio digital como una oportunidad que responde a las inquietudes del usuario en un mismo escenario, pero que involucra muchos sentidos que detonan emociones. (Hillmann, 2021)

XR por sus siglas en inglés, Realidad Extendida, se define como un "entorno de realidades sintéticas múltiples", que incluyen realidad virtual, realidad aumentada, y realidad mixta. Paralelamente, estas múltiples realidades implican cuatro capas fundamentales: visualización, interacción, percepción e inmersión. El cruce de estas capas con la realidad virtual, aumentada o mixta determina el nivel de realismo y la capacidad de potenciación de la percepción humana. El término XR comenzó a cobrar notoriedad desde el año 2018, sin embargo, los estudios sobre realidad virtual se remontan al final de los años 90´s. (Bustos, 2021)

El uso de la XR potencia la percepción del entorno mediante ambientes sintéticos, asistidos con dispositivos externos que permiten experienciar y estimular los sentidos mediante la recreación digital de diversos escenarios. Para el diseño con XR es necesario implementar estrategias de UX. Los verbos clave para el éxito de un ambiente sintético con XR se centran en: recorrer, descubrir, percibir, interactuar, navegar y sentir. Todos estos verbos llevan al prediseño UX, tanto para recrear experiencias digitales propias del ciberespacio como de contextos físicos.

La implementación UX-XR en el proceso de diseño arquitectónico tiene diferencias marcadas respecto a procesos de diseño digitales donde los sistemas de "design thinking" son originalmente establecidos. La gran diferencia con el diseño arquitectónico es que en éste se crea un producto físico que resuelve una espacialidad de una comunidad y de usuarios con necesidades muy particulares. Este producto debe responder anatómica y funcionalmente a la diversidad de movimientos y medidas antropomórficas del usuario y generar un sistema sensorial-emocional que estimule la creación de memorias íntimas y colectivas. La estrategia UX-XR se convierte en un camino para que el diseñador pueda recrear lo que el potencial usuario puede sentir y evaluar la espacialidad en escala real del producto de diseño. Con el uso de XR también se logra superponer los productos digitales en el contexto físico mediante realidad aumentada/mixta para así identificar las relaciones ambientales, proporciones y funcionalidad. Al implementar estrategias de UX en el proceso arquitectónico se estudia al usuario desde su anatomía y su

espacialidad hasta los elementos emocionales y contextuales tanto individuales como de su colectivo.

2 Metodología

Bajo la estructura de investigación de proyecto factible, se identificaron las capas de conocimiento a estudiar, el proceso para definir el problema y la estrategia de investigación e implementación. Según Dubs, un proyecto factible se define de la siguiente manera:

"*Un proyecto factible consiste en un conjunto de actividades interrelacionadas, cuya ejecución permitirá la consecución de objetivos previamente definidos en respuesta a las necesidades que una institución o un grupo social pueda tener en un momento dado*". (Dubs et al., 2002, pp 6-7).

Para el desarrollo de esta propuesta, fue necesario establecer pautas de base técnica, educativa y teórica en torno a la educación de la arquitectura con medios digitales en situaciones de crisis. En este sentido, se logró definir el problema en términos de eficiencia, pertinencia, accesibilidad, usabilidad, impacto en la mejora de la percepción, toma de decisiones durante el proceso de diseño, sistematización de revisiones remotas y sincrónicas, así como y la importancia y trascendencia de la estrategia propuesta.

Por otro lado, esta estrategia se basa en una propuesta metodológica donde se establece un sistema de red en el cruce de múltiples disciplinas durante el proceso de diseño arquitectónico asistido con tecnología digital. (Bustos, 2009). Estas bases se configuraron de forma tan flexible que aún están vigentes y se adaptan a la vertiginosa evolución de los medios digitales.

Figura 1. Campus Virtual Multiusuario, SARUP 2020. (AltspaceVR.) Fuente: Propia, con Sun et al., 2021.

Dentro del contexto tecnológico, social y profesional, se estableció el diseño de la estrategia considerando la lógica de funcionamiento de las presentaciones, revisiones, operación de conferencias y planes de capacitación y administración del entorno sintético de aprendizaje.

2.1 Estrategia UX- XR

UX es el resultado de la percepción que una persona tiene al interactuar ante un diseño, espacio o contexto. UX es aplicable a un colectivo que está siendo definido por relaciones humanas, y no humanas que implican el ecosistema natural o urbano, y tiene un objetivo participativo y de inclusión. (Aguirre et al., 2021)

A esta dimensión se le apunta otra capa de complejidad que implica la dimensión del ecosistema propio del diseñador. El diseñador, en este caso el estudiante, debe ser capaz de observar e interpretar, tal como lo define la etapa del UX en la empatía y la definición, y debe empatizar con los dolores y esperanzas de los usuarios, para así sintetizar las condiciones contextuales que respondan efectivamente al usuario colectivo y establecer sistemas de trabajo con el resto del grupo de los diseñadores. (Ferrer et al., 2020)

En el planteamiento que se muestra a continuación se identifican las fases de estudio UX y XR en momentos específicos del proceso, que en algunos casos se ejecutan individualmente, pero en otros se complementan paralelamente.

Fase 1. Caminando la línea perimetral de Milwaukee*:* **Empatizar**

Los estudiantes deben “caminar la línea” perimetral de su ciudad o locación como un fragmento diverso de observación dual espacial, natural o urbana, en ambos sentidos del borde, y establecer las relaciones dentro de una línea viva y en movimiento, transitada por grupos que transforman la percepción y el uso de este fragmento perimetral. Los estudiantes tenían que analizar la línea del ecosistema multidimensional y la línea del ecosistema con el humano como centro. Se usó Strava y Google Earth para la definición de líneas perimetrales.

Posteriormente, los estudiantes debían establecer un sistema de entrevistas aleatorias a usuarios en distintos tiempos del día y en un punto del perímetro asignado, para conocer la realidad de los usuarios. Seguidamente se colectó información de acciones cotidianas, como recorridos, percepción de los usuarios y la interpretación de uso actual, al igual que el uso soñado del espacio.

Fase 2. Estudio antropométrico*:* **Definir**

Para entender al usuario se hizo un estudio antropométrico teniendo como ejemplo principal la propia anatomía de cada estudiante. Los estudiantes debían analizar las relaciones proporcionales de su cuerpo tomando como unidad básica de medida una parte de su anatomía y así poder definir lineamientos de diseño. Los estudiantes debían analizar no solo la

antropometría humana sino la espacialidad necesaria en escala real para diferentes acciones, como caminar y sentarse. Seguidamente debían generar un dibujo antropométrico en escala real con un código gráfico único definido por su propio cuerpo como ejemplo de estudio del usuario humano. (Figura 2, a)

Fase 3. Máquina de distancia social: **Idear** – **Prototipar - Testear**

En esta etapa se plantea diseñar una “máquina de distancia social”. Se trata de un diseño portátil rápido de ensamblar y construir que se pudiera vestir como símbolo de la realidad pandémica y como ejercicio de diseño previo a la instalación urbana. Debía ser una máquina efímera con un propósito claro basado en su propia anatomía. (Figura 2, b)

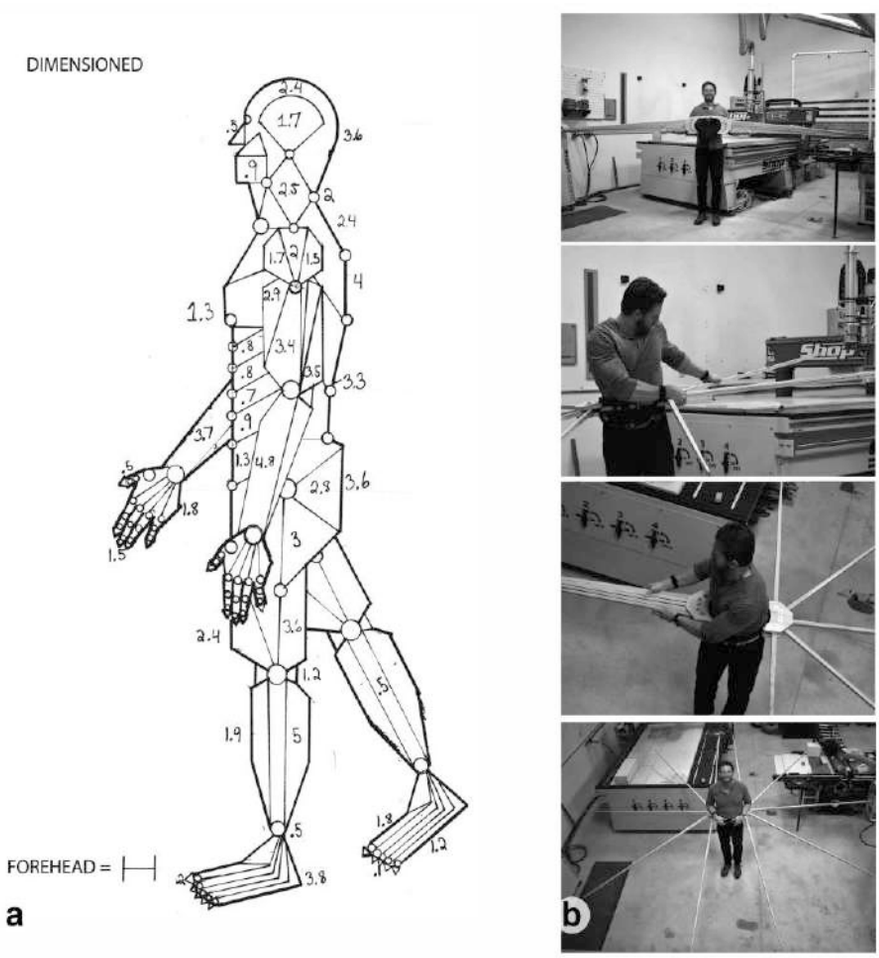

Figura 2. a) Fase 2, Estudio antropométrico. b) Fase 3, Máquina de distancia social. Estudiante autor: Craig Merten. SARUP, Taller Experimental Virtual (TEV) ARCH310 F-2020. Fuente: Propia, 2020.

Fase 4. Diseño de instalación efímera: **Idear - Prototipar – Testear + XR**
El proyecto final del taller consistió en el diseño de una instalación para cuatro personas a 6 pies de distancia con un presupuesto de $200, que pudiera ser instalada y desinstalada en un ciclo circadiano. La instalación no debía dejar huella en el punto del perímetro de ubicación e incluir un elemento que atrajera al usuario para desempeñar alguna actividad.

Figura 3. Fase 4, Instalación efímera desde Enscape (derecha) y Kubity Go (izquierda). Estudiantes autores: Amya Dorsey, Michaela Moore y Drew Running, SARUP, Taller Experimental Virtual (TEV) ARCH310 F-2020. Fuente: Propia, 2020.

Se contempló que los usuarios pudieran comunicarse, compartir, transitar, descansar, contemplar, sentirse en comunidad a pesar de la distancia social implicada. En esta fase se implementó el uso de XR en el taller virtual, tomando en cuenta que los estudiantes de las clases híbridas o presenciales podían construir la instalación efímera en el punto del perímetro elegido, mientras que la clase online tenía que construirlo digitalmente.

En la versión virtual del taller se propuso una evaluación de la navegabilidad e interactividad de los modelos virtuales en Altspace VR que se llevó a cabo el 14 de diciembre del 2020. Se invitó a “La Familia de Arte de Milwaukee”, conformada por un grupo de dos (2) adultos, seis (6) jóvenes y cinco (5) niños quienes formaron parte de la revisión final y ofrecieron retroalimentación en cuanto a los diseños presentados. Varios expertos de Milwaukee, Brasil y Hawái también formaron parte de esta revisión. Se determinó que la usabilidad era eficiente y amigable en la experiencia virtual, sin embargo, era necesario reforzar las interacciones para mantener la atención de los usuarios y hacer la experiencia más intuitiva.

Como parte la evaluación continua del taller y la metodología propuesta se corrió una encuesta semanal que llamamos “F20 Camina la Línea - A4 Project Manager Assessment” para medir la eficiencia del proceso y la metodología. De estas evaluaciones se identificaron dificultades en el proceso para subir los modelos a Altspace VR con Unity. Se propone en el futuro la implementación de otras plataformas con una curva de trabajo más eficiente y expedita.

2.2 Estrategia XR en ARCH 310

Para la integración de la estrategia UX-XR se ofreció entrenamiento en el uso de aplicaciones que permitieran llevar a cabo el experimento XR a toda la clase virtual. Se implementaron diferentes plataformas de realidad extendida (XR) como Enscape, Kubity, Fusion - A360 entre otras, en momentos clave del proceso de diseño. Para el primer ejercicio de recorrido perimetral, se usó Roundme, que facilitó el estudio contextual a través de tour virtuales en panoramas de 360°.

Durante la Fase 4 de diseño, se usó Kubity Go para capturar imágenes y vídeos de la instalación efímera diseñada (formato virtual) sobre el contexto real mediante realidad aumentada-mixta. (Figura 4, a, b y c)

Con Enscape se logró evaluar y tomar decisiones durante el proceso de diseño y realizar una presentación final con alto nivel de calidad gráfica e inmersiva. (Figura 4, d) Durante todo el proceso el uso de Fusión y A360 permitió la corrección interactiva grupal y la administración del contenido con diseño colaborativo. Como plataforma de revisión MUVE, por sus siglas en Ingles, Ambientes Virtuales Multiusuarios, se usó Altspace VR. (Figura 4, e y f). Simultáneamente estas plataformas sirvieron para establecer comunicaciones y feedback desde los teléfonos celulares. La comunicación y estrategia del taller ya no se limitaba a sesiones de Zoom.

Estas son las características que definen un MUVE: “permite a múltiples participantes simultáneos, (a) acceder a contextos virtuales, (b) interactuar con artefactos digitales, (c) representarse a sí mismos a través de “avatares”, (d) comunicarse con otros participantes, y (e) participar en experiencias que incorporan modelos y tutorías sobre problemas similares a los de contextos del mundo real” (Dede, Nelson, Ketelhut, Clarke y Bowman, 2004).

Los esfuerzos colaborativos dieron como resultado una estrategia actualizada de creación de MUVE. Se capacitó a seis estudiantes del Taller Experimental Virtual (TEV) ARCH310, sobre cómo subir sus proyectos al Campus Virtual SARUP 2020. “The Hive” de Danielle Frank, Craig Merten, “Painting Nature” de Morgan Jurka y Jordyn Sufka, y “The Yurt” de Stefan Weber y Chase Opgenorthy, se presentaron en el Campus Virtual 2020 el 14 de diciembre de 2020. La presentación de esos proyectos se instaló en la galería virtual y cada proyecto tenía un portal para acceder a sus respectivos modelos en AltspaceVR.

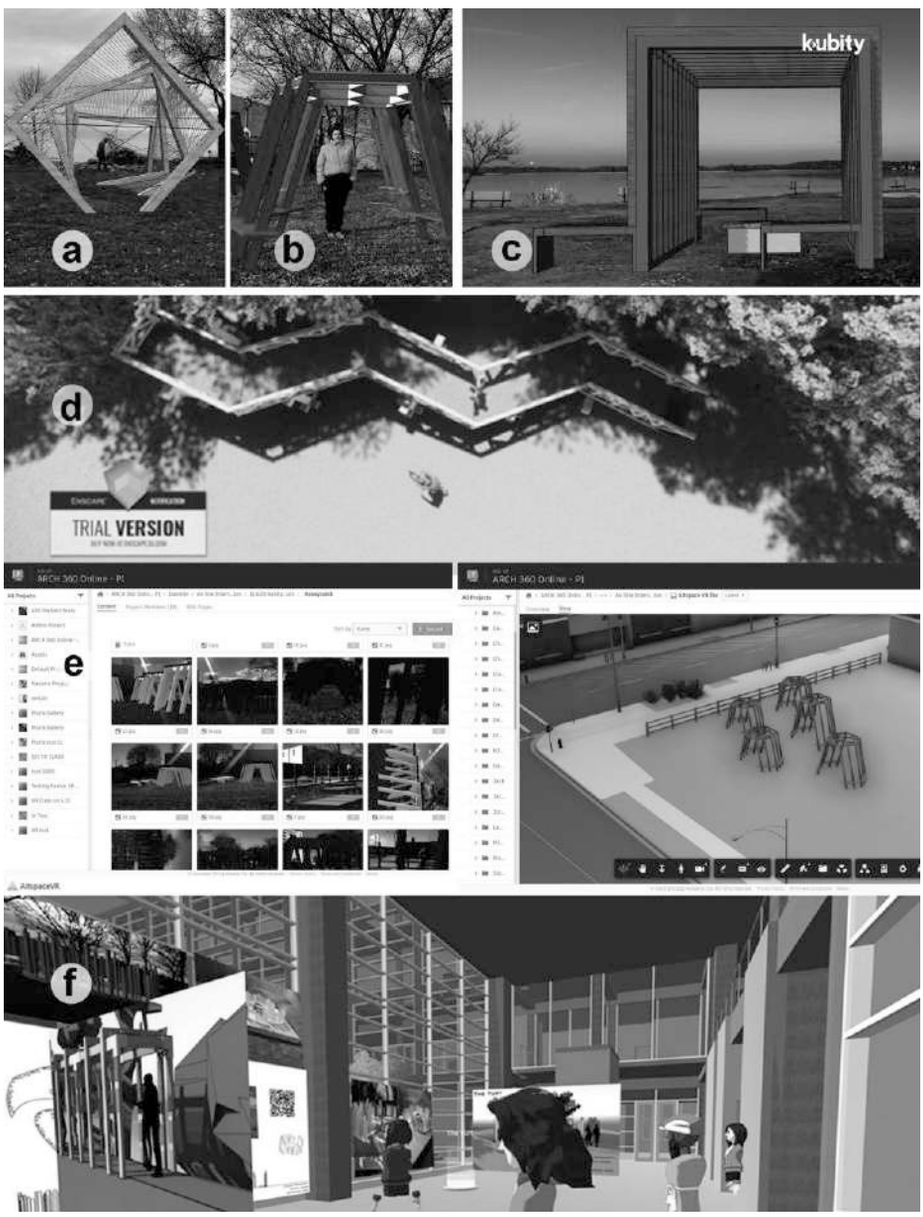

Figura 4. Uso de XR en Fase 4 UX-XR. a) “Frames of Michigan”, estudiantes Clare Masterson y Abigail Haseley, b) “The Hive”, estudiantes Danielle Frank y Craig Merten, c) “In the Park”, estudiantes Landen Cowell y Camryn Giles. Las imágenes a, b y c usando Kubity Go, con Realidad Aumentada (AR). d) “Trajectory”, estudiantes Amya Dorsey, Drew Running y Michaela Moore usando Enscape. e) Clase en Fusion y A360. f) Campus Virtual SARUP en Altspace VR. SARUP, Taller Experimental Virtual (TEV) ARCH310 F-2020. Fuente: Propia, 2020

3 Resultados

La calidad de diseño y gráfica de los proyectos del taller virtual fue extraordinaria. En la presentación final, revisores internacionales, arquitectos y una asociación de arte local de adolescentes y niños pudieron ingresar al campus virtual y revisar estos proyectos mientras estaban virtualmente inmersos en ellos. En la versión MUVE de los proyectos se incluyó animación, sonido y movimiento.

El uso de UX-XR como estrategia de revisión en diseño arquitectónico impactó positivamente la experiencia creativa tanto de estudiantes como de revisores ya que potenció las dinámicas de percepción de la tridimensionalidad del espacio y la experiencia del usuario, permitiendo experimentar la idea del diseñador de forma clara y consistente. Se generó un ambiente amigable, divertido y socialmente inclusivo para el aprendizaje de la arquitectura desde medios sintéticos y con el uso de MUVEs.

Los resultados arrojan relevancia y pertinencia en la implementación de la propuesta metodología UX-XR en experimentos pedagógicos, usando el metaverso como un lienzo para revisar, recrear, interactuar y evaluar los sistemas arquitectónicos.

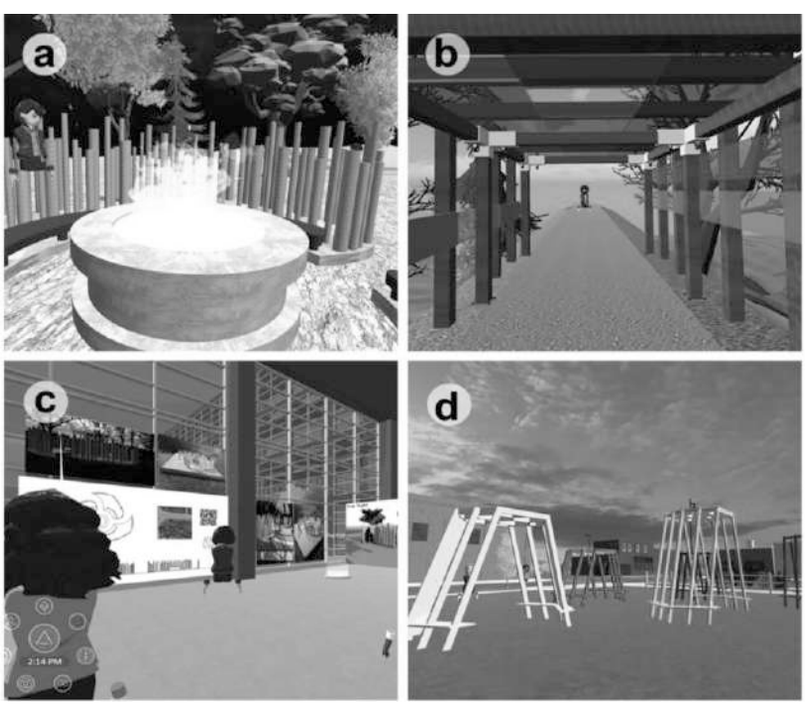

Figura 5. Presentación final MUVE. F-2020. a) “The Yurt” de Stefan Weber y Chase Opgenorthy, b) “Painting Nature” de Morgan Jurka y Jordyn Sufka, c) Virtual Campus SARUP-UWM, y d) “The Hive” de Danielle Frank y Craig Merten. Fuente: Propia 2020.

Está metodología UX-XR, permite generar soluciones de diseño de índole social, respondiendo a las esperanzas y necesidades planteadas en las primeras etapas de empatía, resolviendo propuestas arquitectónicas y transitando en el metaverso como medio que permite aprender haciendo.

4 Discusión

Actualmente se hacen más fuertes las comunicaciones desde los canales digitales, con el fin de construir comunidades, alianzas, investigaciones, y puentes que apoyen una eficiente UX, por lo que resulta necesario entrelazar equipos multidisciplinarios para gestionar proyectos de esta naturaleza, y que den respuesta a las expectativas de los usuarios. Las herramientas digitales exploradas indican que hay otras posibilidades para la educación contemporánea en arquitectura. XR no solo es una alternativa para el aprendizaje presencial o remoto (sincrónico o asincrónico), sino que es una herramienta sólida que ofrece muchos beneficios enmarcados en la inmediatez, visualización, interacción, colaboración, y la oportunidad de trabajar en equipo desde cualquier parte del mundo, construyendo conexiones que no pueden existir físicamente en algunas circunstancias.

La educación en arquitectura se vuelve cada vez más desafiante. Los diseños deben dar respuesta a necesidades de los usuarios dentro de una realidad compleja, de dimensiones múltiples y plurales, de allí la relevancia de investigaciones que involucren los principios de la metodología del diseño UX, como puente que se extiende a la enseñanza de los futuros profesionales de la arquitectura y diseño.

El proceso de la enseñanza del diseño arquitectónico en pandemia se convirtió en un reto que debía ir más allá del uso de videollamadas. Frente a esta crisis, el desarrollo e implementación de la estrategia UX-XR y el Campus Virtual SARUP, generó innovación en la implementación de la tecnología gratuita disponible y facilitó un entorno digital para crear comunidad dentro de la población académica para servir como plataforma operativa remota y sincrónica con niveles destacados de interactividad e inmersión.

Reconocimientos. A los académicos involucrados en TEV-ARCH 310 F20, de la Facultad de Arquitectura y Urbanismo de la Universidad de Wisconsin Milwaukee, en especial a Nancy Frank (Decano), Robert Moy, Mo Zell (Directora de Departamento de Arquitectura), Sarah Aziz (Coordinadora de ARCH310), Lisa Sun, Kurt R Meingast; y los estudiantes Danielle Frank, Craig Merten, Morgan Jurka, Jordyn Sufka, Stefan Weber, Chase Opgenorth, Landen Cowell, Camryn Giles, Amya Dorsey, Clare Masterson, Abigail Haseley, Drew Running y Michaela Moore. Al equipo multidisciplinario de colaboradores de Pluris XR: Caue Costa, Jack Glavin, Preston Pape, Gabrielle Norton y de Findorff, Sauron Sánchez.

Referencias

Aguirre, E., Ferrer, M., y Rojas, C. (2021). *La esquematización como estrategia de comunicación visual para una grata experiencia de usuario: un análisis de las aplicaciones educativas virtuales.* Revista KEPES 18(23), 219-242. http://vip.ucaldas.edu.co/kepes/downloads/Revista23_8.pdf

Aguirre, E., Ferrer, M., Bustos, B, & Méndez, R. (2020). *UX Design: una metodología para el diseño de proyectos digitales eficientes centrados en los usuarios.* Revista Espacios, Vol. 41 (Nº 05). Pág. 9-40. https://www.revistaespacios.com/a20v41n05/20410509.html (Consultado el 03 de julio de 2021)

Bustos, G. (2009). *Epistemología Compleja del Diseño Arquitectónico con Tecnología Digital: ASMI en los Talleres de Diseño Arquitectónico.* Doctor of Architecture. Honorable and publishing mention Dissertation - Doctoral Thesis Publication: October 30, 2009 – Maracaibo, Venezuela. Universidad del Zulia.

Bustos, G. (2021). *VR Elective: Visualization, Interaction and Collaboration.* Master Class: Introduction to XR– UWM. October 2021.

Dede, C., Nelson, B., Ketelhut, D., Clarke, J., & Bowman, C. (2004). *Design-based research strategies for studying situated learning in a multi-user virtual environment.* Paper presented at the 2004 International Conference on Learning Sciences, Mahweh, NJ

Design Thinking España. s/f. https://xn--designthinkingespaa-d4b.com/ (Consultado el 3-6-2021).

Dubs de Moya, Renie, and Sapiens. *"El Proyecto Factible: una modalidad de investigación."* Revista Universitaria de Investigación 3, no. 2 (2002):0. Redalyc, https://www.redalyc.org/articulo.oa?id=41030203

Ferrer, M., Aguirre, E., Méndez, R. (2020). *UX Una metodología de Diseño Eficiente.* EE. UU: Amazon

Garrett, J.J. (2011). *The elements of user experience: User-Centered Design for the web and beyond.* New Riders.

Hillmann, C. (2021). *UX FOR XR: user experience design and strategies for immersive technologies.* [S.l.]: APRESS.

Mootee, I. (2013). *Design thinking for strategic innovation: what they cannot teach you at business or design school.* Hoboken: John Wiley & Sons.

Nielsen, J. (2001). *Usabilidad, diseños de sitios web.* Prentice Hall PTR.

Osterwalder, A., Pigneur, Y., & Clark, T. (2013). *Generación de modelos de negocio: Un manual para visionarios, revolucionarios y retadores.* Barcelona: Centro Libros PAPF/Deusto.

Sun L., Bustos G., Sánchez S., Meingast K. (2021). *VR Campus: A Multi-User Virtual Reality Academic Experience.* The National Conference on the Beginning Design Student (NCBDS). Texas A&M.

Interactions & Collaborations: Mixed Realities

Augmented Bricklayer: an augmented human-robot collaboration method for the robotic assembly of masonry structures

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Abstract. The *Augmented Bricklayer* research project proposes a new augmented human-robot collaboration method for the robotic assembly of masonry structures. It aims to resolve the conventional limitations of the robotic bricklaying process by incorporating object recognition and Augmented Reality (AR) technologies. Towards this aim, we present a human-robot collaboration method consisting of two phases: a) the object recognition phase, in which bricks are recognized by a point cloud scanning sensor and analyzed by our calibration system as a feeding object for the robotic gripper to pick; b) the augmented human-robot collaboration phase, in which the masonry adhesive is being applied manually assisted by AR holographic guidance and gets assembled by an AR-assisted robotic operation method. The validation of our method is achieved with the robotic assembly of two real-scale building elements, a masonry column and a wall. Our findings highlight a more flexible, efficient, and convenient AR-assisted human-robot collaboration bricklaying method capable of dealing with complex on-site construction requirements.

Keywords: Mixed Realities (Augmented Reality), Object Recognition, Human-robot Collaboration, Robotic Assembly, Masonry Structures

1 Introduction

Recent approaches to digital fabrication, combing methods of computer-aid design (CAD) and robotic fabrication, have shown great potential for integrating architecture design and engineering practices to establish a highly effective interplay between digital design and conventional construction process (Dörfler et al., 2016). Additionally, CAD computational tools such as *Grasshopper* expand access and exploration of nonlinear parametric design solutions for architects, which means the complex design-oriented shapes require the assistance of industrial robotic fabrication methods to achieve precise

construction (Adam et al., 2019). Over the past decade, many digital fabrication applications have proved that the architectural industry stands to benefit tremendously from increased digitization and automation (Carra et al., 2018).

Bricks are standardized, prefabricated building components, which have been used in architecture since the ancient times of building construction history. Over time, the evolution of their design and construction methods never ceased to stimulate architects to explore their aesthetic potential (Kahn and Twombly, 2003). Brick masonry structures are ideal candidates for automated assembly, as they remain a complex and dexterous construction craft, traditionally performed by trade specialists. Bricklaying is fundamentally a repetitive process and is therefore well suited for robotic fabrication, which could increase its efficiency and assure complex traditional or novel brick constructions in a moment of scarce skilled labour (Oliveira and Sousa, 2016). Moreover, CAD computational design tools can support architects in the tectonic exploration of parametric and nonlinear brick structures. These CAD-designed parametric brick structures surely need the precise and efficient help of the automated bricklaying process.

Robotic automation displays advanced potential, but its application in real construction projects is still limited (Dawod and Hanna, 2019). The robotic automated bricklaying process currently lacks practical and flexible on-site construction solutions, regarding brick feeding systems, and spatial operation freedom, or includes messy usage of automatic mortar adhesive application on-site (Mitterberger et al., 2020). Mitterberger et al. proposed the AR guidance for manual bricklaying, but the AR-assisted manual bricklaying system lacks the accuracy of robotic operations. Additionally, there is a shortage of end-to-end solutions between architects and automated construction methods. The data is not shared in real-time, which means architects and engineers cannot operate or deal with each other's errors during the automation process because of different knowledge backgrounds.

The upper-named limitations may be eliminated by applying object recognition and AR technologies and setting up a human-robot collaborative bricklaying process. As Papazov et al. (2012) presented, using point cloud data generated by computer vision cameras provides robots with the ability to reference objects. Moreover, human builders are more flexible than programmed robots in dealing with on-site uncertainties, while robots are more efficient than human builders by keeping their accumulative error at an acceptable level (Sun et al., 2018). Digital fabrication tools can never fully replace the role of humans in construction processes, which means human-robot collaboration can flexibly solve unanticipated difficulties that cannot be solved by pure automation (Yoshida et al., 2015). Additionally, AR technology provides non-professionals with the possibility of visual programming robots with its object-attached holograms and convenient interactive input functions, which could bridge the gap between humans and robots (Song et al., 2021).

This paper proposes an augmented human-robot collaboration method by combining the above unique characteristics and functions of object recognition

and AR to discover how these technologies are changing and evolving the current shortcomings of the automated bricklaying process in architectural construction.

2 Research Methodology

The *Augmented Bricklayer* research project proposes an augmented human-robot collaboration method for the robotic assembly of parametric masonry structures. The method consists of two phases: a) the object recognition phase and b) the augmented human-robot collaboration phase (Fig. 1). To validate this method, we conduct an assembly experiment, which includes the object recognition and augmented human-robot collaboration for assembling an architectural scale masonry column and a wall, to evaluate our proposed method as well as evaluate the advantages and disadvantages of each phase. The prototype structures were assembled with the Class B red engineering bricks (215*103*65mm with 2.33kg each), which are suitable for sensors to recognize, and able to be picked and placed by the robotic gripper. Considering the laboratory environment, we adopt the hybrid polymer adhesive as the brick mortar, which is fast curing with high strength and easy to apply with a standard mastic sealant gun.

The software includes *Rhinoceros/Grasshopper*, the *Xbox Kinect* sensor toolkit *Tarsier* and the AR toolkit *Fologram* plugin for object recognition and calibration, as well as the *Robots* and *Fologram* plugin for the augmented human-robot collaboration. We use *Tarsier* to connect and get the point cloud data, RGB and depth data from *Kinect* sensor in *Grasshopper* for further analysis by our calibration system; *Fologram* to scan *ArUco* Marker (AM) for alignments and provide AR holographic guidance for manual fabrication and identify interactions for operating robots in the human-robot collaboration process; and *Robots* to develop and operate the robotic trajectory and gripper commands.

The hardware includes a *Kinect* sensor for point cloud scanning, a head-mounted device (HMD) – *Microsoft HoloLens 1* for augmented human-robot collaboration, and a *Universal Robots 10*e robotic arm with *Robotiq 2F-140* grippers for the robotic equipment. We fix the Kinect sensor to the top of the gripper by designing and 3D printing the connecting joint structures. Additionally, we use a laptop for back-end program running and debugging. All the devices are connected to a wireless WIFI router (data transfer rate - 50MBps) in the same IP address network environment for transforming the data from different stages, and live streaming commends on software and plugins to visualize and output response ports.

Our original contribution is to integrate and combine the different functions from various plugin applications into one augmented human-robot collaboration workflow for the robotic assembly of masonry structures.

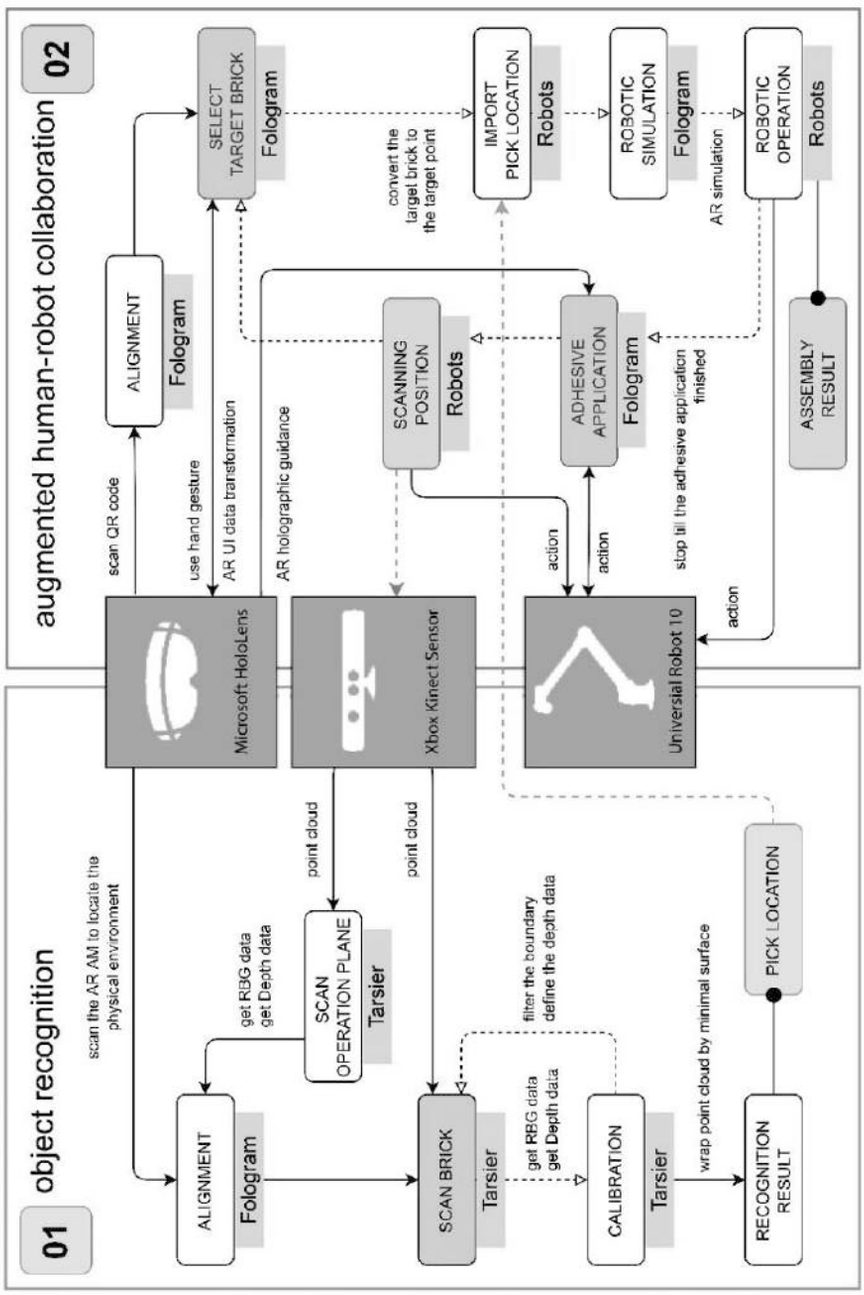

Figure 1. The *Augmented Bricklayer* project flowchart. The framework is divided into two phases: a) a robotic object recognition phase and b) the AR-assisted human-robot collaboration phase. (The connected device is coloured in grey, and the related software in each step is coloured in red above). Source: Yang Song, 2022.

3 The *Augmented Bricklayer* Experiment and Findings

3.1 Phase A: the Object Recognition

Object recognition is the first phase of the *Augmented Bricklayer* experiment, which contains the point cloud scanning method and analysis calibration system. The idea of proposing the object recognition method is to evolve the conventional fixed brick feeding installations by translating the point cloud data from RGB-D sensors to the robotic operation plugin for the robot to recognize, analyze, locate, pick and place the bricks flexibly.

At the recognition stage, we get the scene point cloud data from the *Kinect* sensor. The process starts by segmenting and extracting the scene. First, the end effector tool will be lifted to 80mm higher (the scanning position) from the operation plane to give *Kinect* sensor a more comprehensive scanning field version. The full-scale point cloud scanning results will be sent as meshes in *Grasshopper*. Second, the user needs to scan the AMs through the *HoloLens* from serial 1 to 4 to locate the boundary of our operation plane. Since the *Kinect* sensor is an external device, it is not easy to ensure the complete horizontal alignment physically of the camera. Therefore, the obtained scanning results must be further corrected for the alignments. To solve this issue, we combine the depth data from the *Kinect* sensor with the AR AM localization anchors to align the horizontal plane of the point cloud results and correct the mesh distortion in *Tarsier*. Last, we extract the RGB data from the *Kinect* sensor and use the RGB difference filter function to get the boundary of the operation plane with the synergistic correction from the AR AM (Fig. 2). In this way, the user can separate the operation plane mesh from the entire surrounding point cloud mesh and align the digital data with the physical environment.

At the analysis stage, the robot will remain at the scanning position. After the user places one brick on the operation plane, the *Kinect* sensor will be activated to scan. First, we analyze the RGB data to get the brick boundary point cloud. Second, we combine the depth data from the *Kinect* sensor with the thickness of the brick to determine the height and the brick top surface boundary from the scanned mesh in *Tarsier*. Next, we need to analyze the boundary results from both RGB and depth data to calibrate the tolerance, and determine the final digital corresponding minimum boundary of the top brick surface (Fig. 3). Last, the central point with related orientation for the top surface boundary will be uploaded to the robotic operation system as the picking point. In this way, the robot can recognize the centre point of the scanned brick as a picking point for the gripper in the following pick and place operation process.

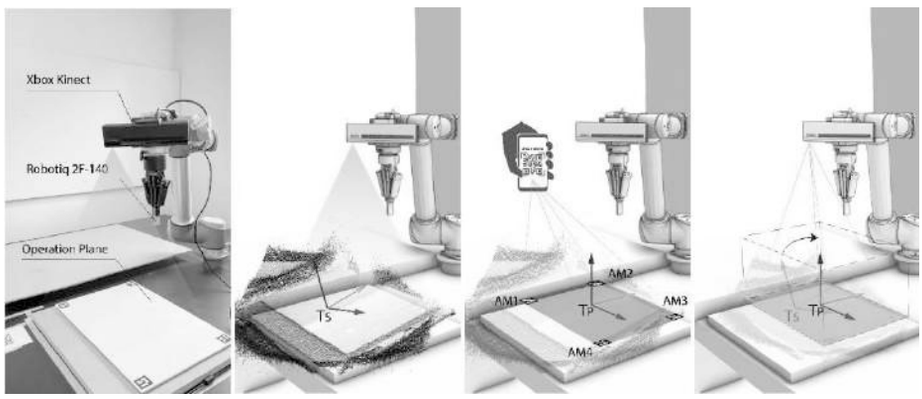

Figure 2. The figures from left to right are: a) the operation plane and device setting of the robotic object recognition phase, including a UR 10 robotic arm with *Robotiq* 2F-140 gripper and *Xbox Kinect* sensor; b) the point cloud meshes directly from the Kinect sensor, which is defined as plane TS and needs to be corrected horizontally and vertically; c) scan the AR AM in order (AM1 to AM4) from AR deceive to define the physical environment as plane TP and prepare to align the digital scanning results to the physical environment; d) rotate the plane TS to match with the plane TP in our calibration system to avoid problems such as inaccurate point cloud positioning and wide-angle sensor distortion. Source: Yang Song, 2022**.**

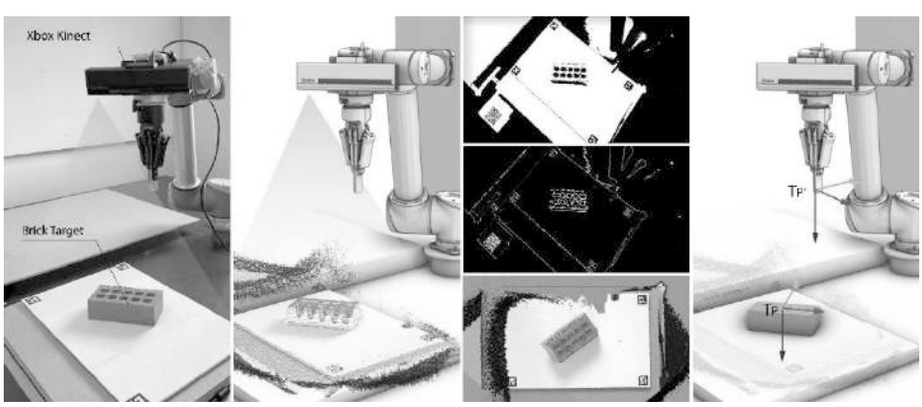

Figure 3. The figures from left to right are: a) put a brick in the operation plane for the *Kinect* sensor to scan and recognize; b) the point cloud mesh result from the *Kinect* sensor with RGB and depth data attached; c) using the RGB data to filter the boundary point cloud, using the depth data to remove other interference information and combine the boundary result to get the point cloud of the brick; d) using the minimum plane function in our calibration system to wrap the obtained brick point cloud to calculate the precise brick coordinate for the robotic gripper to pick. Source: Yang Song, 2022**.**

Phase A Findings. In summary, the object recognition method does fulfil our pre-determined assumptions. We successfully recognized and grabbed 400 bricks for the masonry column and wall, and each brick was placed freely at

random angles and locations on the operation plane, waiting for the *Kinect* sensor to scan and the gripper to pick. Although not every grip is very accurate, and there is a tolerance of about 5mm relative to the brick's physical centre, compared to the length of the brick, the ±5mm tolerance is almost negligible. As a result, the robotic object recognition phase achieves accurate robotic object recognizing and grasping by the point cloud scanning method. This method frees the automated bricklaying from the fixed brick feeding position and cumbersome feeding installations and provides a more flexible on-site brick feeding method. Although the professional robotic camera can also provide corresponding functions, the high cost of the equipment and the complex computer science development environment are not familiar and friendly to architects. Our experiment achieved the same effect through an affordable device - *Xbox Kinect* and *Rhino/Grasshopper* & the *Tarsier* plugin, an architectural-friendly visual scripting environment, which saves the cost and allows users to manipulate object recognition by themselves.

However, the object recognition method still has some limitations. For example, the position of the *Kinect* sensor will shift after multiple physical robotic operations, which causes tolerance issues. Therefore, the user needs to repeatedly correct the physics environment with scanned mesh by AR AM. Moreover, due to the use of RGB data filtering, it is required that the identified brick and operation plane should be objects of different colours, and the greater the colour difference, the more accurate the result. Additionally, the size and shape of the scanned objects are also limited due to the tolerance. Therefore, extra sensors will be introduced into our system to improve the accuracy of utilizing multi-angle depth data detection from sensors, instead of RGB data, for the calibration system to reduce the tolerance and achieve the recognition of complex geometric shapes.

3.2 Phase B: the Augmented Human-robot Collaboration

The augmented human-robot collaboration is the second phase of the *Augmented Bricklayer* experiment, which contains an AR holographic guidance and an AR-assisted robotic operation method. The idea of proposing the augmented human-robot collaboration method is to utilize the advantage of human labour and robots respectively in the robotic fabrication process, and combine AR holographic guidance and AR-assisted interactive robotic manipulation to achieve a simple, efficient, flexible and low-threshold human-robot collaboration method for architects to control over the digital fabrication process.

In the AR holographic guidance stage, we use AR devices to align physical and virtual environments and enable data sharing for holographic adhesive application guidance. First, the user needs to scan the QR code with *HoloLens* to align the physical environment with virtual data. After that, the user can preview the robotic assembly process in real-time as the 3D holograms upon the site. The brick in the operation process will be shown in a white holographic

border to highlight. Next, in our system, the overlapping part of the upper and lower bricks is automatically calculated, which means the overlapping area is where the adhesive needs to be applied. Last, the calculated overlapping area will be highlighted in red as a hologram upon the bricks. The user needs to follow the red holographic guidance, hold the mastic sealant gun, and apply the hybrid polymer adhesive at a constant speed until the virtual red holographic area is filled by the adhesive (Fig. 4). In this way, the user can apply the adhesive manually under the AR guidance on-site, which is a flexible method to avoid excess material waste and mess in the automated mortar application process.

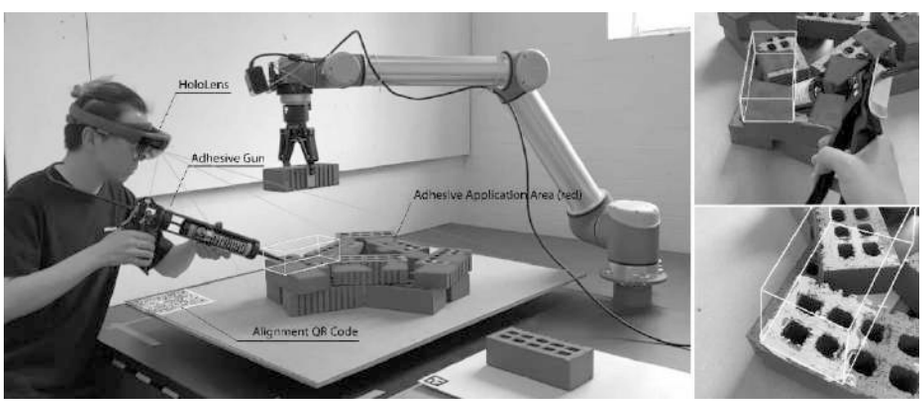

Figure 4. The AR holographic guidance stage in our augmented human-robot collaboration method. After scanning the alignment QR code through the *HoloLens* AR headset, the user needs to preview the adhesive application guidance upon the physical bricks through AR (red holograms in the picture above) and apply the adhesive through the mastic sealant gun to fill in the red holograms areas (left). The screenshots from *HoloLens* about the AR holographic adhesive application guidance upon the physical bricks and the bricks after applying adhesive (right). Source: Yang Song, 2022**.**

In the AR-assisted robotic operation stage, we use HMD (*HoloLens 1*) to achieve data interaction and send commands for robotic operation through gesture inputs. We have already pre-coded all robotic actions in *Grasshopper*, including choosing targets, setting trajectories, and gripper commands. We only use a few toggles in *Grasshopper* to control the entire coding system, and these toggles are mapped to our AR user interface (UI), which means the user only needs to point out the target and control the toggles in AR UI to send commands to the robotic arm (Fig. 5). First, the user needs to activate our AR UI, select the scanning position (details in phase A), operate the physical robotic arm there, and scan and get the position of the desired brick through AR UI. Second, the user can select the target in AR UI, preview the holographic trajectory simulation, and activate the physical robotic pick and place operation. After placing the brick to the target location, the robotic operation will be paused

automatically, so that the user will have enough time to apply the hybrid polymer adhesive under the AR holographic guidance. Last, the user can return the robotic arm to the scanning position through AR UI, and repeat the above assembly loops till the whole structure is finished (Fig. 6). In this way, the whole process of human-robot collaboration can be realized through the easy interactions in AR UI.

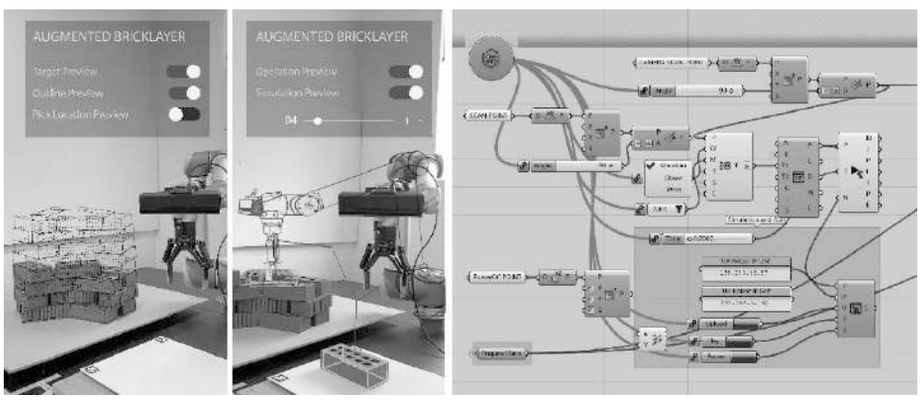

Figure 5. The toggles and the sliders in AR UI are mapped with the corresponding parameter settings in *Grasshopper,* which are colored and lined in purple in the *Grasshopper* processing file (right). The AR UI can achieve real-time visual programming modification for the robotic operation through the AR environment. Source: Yang Song, 2022**.**

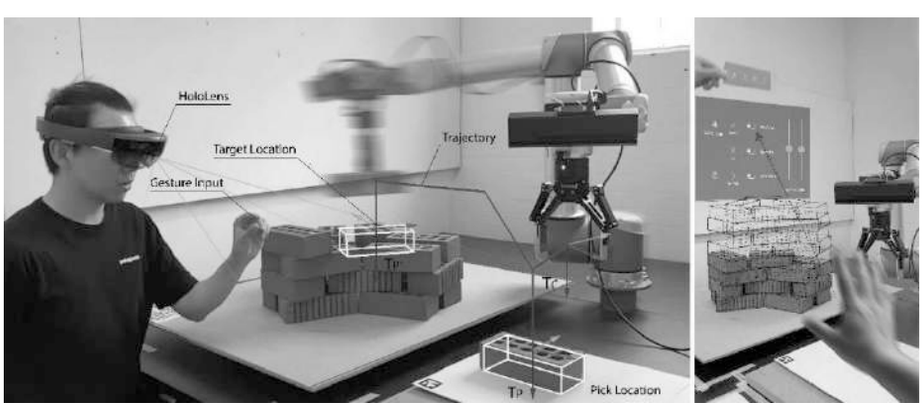

Figure 6. The AR-assisted robotic operation stage in our augmented human-robot collaboration method. The user can select the holographic targets in the AR environment through *HoloLens* through hand gestures, preview the robotic pick and place operation and trajectory as 3D AR animation, and operate the physical robot for the assembly process (left). The screenshot of our AR UI in HoloLens allows users to interact within the augmented human-robot collaboration process (right). Source: Yang Song, 2022**.**

Phase B Findings. In summary, augmented human-robot collaboration indeed achieves a more straightforward and accessible method for architects based on our pre-determined assumptions. We assembled 400 bricks for the masonry column and wall efficiently and precisely with the help of manual adhesive application in the AR environment (Fig. 7). As a result, the labour with considerable flexibility has an advantage over automated mortar applications when dealing with applying adhesive on-site, especially under the guidance of AR holographic instructions to improve the accuracy. Additionally, as a bridge between humans and robots, AR helped us to get rid of the constraints of coding skills successfully and control the robotic arm interactively in AR UI to realize the recognition, grasping and precise placement of 400 bricks. Moreover, we use HMD (*HoloLens 1*) as the AR device instead of smart devices (smartphones or tablets) because it can liberate the labourist hands for a more flexible operation.

Figure 7. The validation of our augmented human-robot collaboration method for the robotic assembly of parametric masonry structures is achieved with the robotic assembly of two real-scale building elements, a parametric masonry column (left) and a wall (right). Source: Yang Song, 2022.

However, this method still has some limitations. Due to the interference of ambient light, AR holograms often drift throughout our assembly process. The user needs to scan the QR code repeatedly to align the physical environment. Therefore, more sensors or QR code grid networks should be added to our alignment system to reduce the interference of surrounding environments. Moreover, all the interactive information data and the display of 3D holographic animations are connected through one WIFI router with the same IP address. Therefore, the network speed and the wireless router data transfer rate directly affect the smoothness of information exchange. We use the 50MBpas transfer

rate router, which causes the real-time preview intermittently to freeze or drop frames according to the size of our model or the data transmissions. To solve this problem, we need a good network connection with a high-speed router to ensure data transformation and holographic preview coherence during the augmented human-robot collaboration.

4 Conclusion and Discussion

The *Augmented Bricklayer* project developed and verified an augmented human-robot collaboration method for the robotic assembly of parametric masonry structures. This method takes advantage of the flexibility of humans and the accuracy of robotics. We assign each step of the robotic assembly process reasonably to humans and robots, including adhesive application, pick and place operation, and on-site error solutions, to maximize the use of their respective advantages. Moreover, the AR-assisted human-robot interaction and collaboration free architects from the need for cumbersome coding skills, and let architects control the robotic assembly of complex parametric masonry structures by themselves.

However, there are limitations and space for further improvement. The pros and cons of each phase have been summarized in the funding section above. In addition to these findings, there are future research goals for the overall macro augmented human-robot collaboration. This method has only been proven feasible in laboratory-based on-site environments with relatively low surrounding disturbances. For further research, we aim to repeat the experiment by mounting the robotic arm on the *MiR* mobile robotic platform, which would be better to test and validate our method in uncertain surroundings and natural on-site construction environments with movable robots. Moreover, during the AR-assisted manual adhesive application process, the pauses and restarts of the robotic arm make the entire workflow unsmooth and cause much wasted time. Suppose more sensors are added on-site, and the human body recognition function of *Kinect* is activated to realize the autonomous pause and restart of the robotic operation when it tests to detect if the user is in the operation area. In that case, it will significantly improve the user experience and workflow efficiency.

In conclusion, the *Augmented Bricklayer* project offers a more flexible, efficient, and controllable human-robot collaboration method, which gives a valid alternative to messy on-site adhesive applications and the limitations of non-professionals operating industrial robots, for improving the existing deficiencies in the conventional automated bricklaying process. This approach maximizes the strengths of human labour and robots through human-robot collaboration, and places high-tech manufacturing back into the hands of architects with the help of AR technology. Our final goal is to achieve the

augmented human-robot collaboration method for robotic assembly in more architectural scale applications.

References

Dörfler K, Sandy T, Giftthaler M, Gramazio F, Kohler M, Buchli J. (2016): Mobile Robotic Brickwork - Automation of a Discrete Robotic Fabrication Process Using an Autonomous Mobile Robot. In: Reinhardt D, Saunders R, Burry J (eds) Robotic Fabrication in Architecture, Art and Design 2016, Springer, pp 205-215.

Adam F, Kristof C and DARWIN L. (2019): Automation Complexity – Brick by Brick. Proceedings of CAADRIA 2019, Volume 1, 93-102, Hong Kong.

Carra G, Argiolas A, Bellissima A, Niccolini M and Ragaglia M. (2018): Robotics in the Construction Industry: state of the art and future opportunities. Proceedings of the 35th ISARC, Berlin, Germany, pp 866-873.

Kahn, L. and Twombly, R.C: Louis Kahn. (2003): Essential Texts, W.W. Norton & Company.

Oliveira R and Sousa JP. (2016): Building Traditions with Digital Research – reviewing the brick architecture of Raul Hestnes Ferreira through robotic fabrication. Proceedings of the eCAADe 2016, pp. 123-131, Oulu, Finland.

Mitterberger D, Dörfler K, Sandy T, Salveridou F, Hutter M, Gramazio F and Kohler M. (2020): Augmented Bricklaying – Human-machine interaction for in situ assembly of complex brickwork using object-aware augmented reality. Construction Robotics, Volume 4, pp. 151-161.

Dawod M and Hanna S. (2019): BIM-assisted object recognition for the on-site autonomous robotic assembly of discrete structures. Construction Robotics, Volume 3, pp. 69-8.

Papazov C, Haddadin S, Parusel S, Krieger K, Burschka D. (2012): Rigid 3d geometry matching for grasping of known objects in cluttered scenes. Int J Robot Res 31(4), pp. 538–553.

Sun CY, Zheng ZH, Wang YZ and Sun TY. (2018): Hybrid Fabrication – a freeform building process with high on-site flexibility and acceptable accumulative error. Proceedings of the ACADIA 2018, pp 82-87, Mexico City.

Yoshida H, Igarashi T, Obuchi Y, Takami Y, Sato J, Araki M, Miki M, Ngata K, Sakai K and Igarashi S. (2015): Architecture-scale human-assisted additive manufacturing. ACM Transactions on Graphics, Vol. 34, No. 4, Article 88.

Song Y, Koeck R and Luo S. (2021): Review and Analysis of Augmented Reality (AR) Literature for Digital Fabrication in Architecture. Automation in construction, 128-2021-103762.

Interactions & Collaborations: Virtual Reality

Appropriations and Extensions of Cultural Spaces in VR and the Metaverse

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Abstract. Digital virtual reality (VR) and the metaverse provide opportunities for the creation of cultural extensions that define our contemporary society. This has been the practice for millennia – using different technologies and media; humans have always attempted to convey experience through representational forms. The paper puts forward an initial theoretical examination of metaverse using theories on perception and subjectivity in psychology and philosophy and the implications of these in architecture and space creation, both physical and digital. It considers historical VR spaces to better understand the influence of culture and applies this to the contemporary social VR spheres. Though they offer novel opportunities, digital virtual realities and immersive spaces of today are no different than the lineage of spaces and representations that strove to do this throughout history (Grau, 2003). Using different mediums, they each provide an extension of culture that reflects society and becomes a record of their times and ideals.

Keywords: Virtual Reality, Metaverse, Digital Heritage, Mixed Realities, Identity and Subjectivity

1 Introduction

There is a long lineage of immersive representations that have been produced throughout history (Grau, 2003). Human cultures have used various mediums- whether in art, architecture, literature or otherwise- as a means to depict their society or its aspirations. These representations serve as a reflection of the values and social contexts. Many of them provided immersive encounters that, arguably, contributed to identity formation and subjectivity. The scope of this paper provides an initial application of theories around subjective experience in the context of virtual reality, using cases from history to better understand contemporary developments and their cultural implications.

Psychologists and philosophers like Lacan, Merleau-Ponty, Sartre and Schilder had theorized about subjectivity as it relates to perception and a yet unnamed idea of the virtuality of experience but they were working in a context that had not seen the likes of digital lives and the metaverse. They were however touching upon the fact that reality regularly coincides with virtual reality (a term that can be considered an oxymoron). Human subjectivity is dependent first on a virtual interaction- that is, the identification with the self through the mirror (Lacan, 1999). This was studied from the perspective of 'body image' in previous research, *The Dissolution of the Body Image* (Crossley, 2019) and is here expanded upon using the work of philosophers like Deleuze and Grosz who consider the architectural implications of space creation – the production of an "inside *of* the outside" (Deleuze, 1988), how that has applied to architecture and how that might be considered in a digital context respectively.

The following sections of this paper will draw upon understandings of perception and the sensorial to provide a reading on the 'virtual.' It will examine the involvement of these spaces, physical and digital, historic and contemporary, in shaping identity and subjectivity. And it will examine how culture extends itself into the virtual space providing a way to expose societal values.

The paper also references current movements in the production of digital assets and the metaverse, drawing from some of the recent literature on these subject matters (incl. NFT Plaza; Ordano et al., 2017; Shamash & Nordnes, 2022), to speculate the impact of new digital spaces and design methodologies on architecture and culture. These spaces, whether seen as Utopic, democratic systems or not, are a record of the respective time and ideals. They are not necessarily a carbon copy of any given reality but rather a reaction to or reflection of it. Therefore, applications of philosophy and theory are examined as they relate to the body in space in order to speculate the implications of contemporary VR and the metaverse on culture and the societal record left behind.

This examination will be carried out in three main parts throughout the paper. First, it will analyze media culture throughout history, focusing predominantly on the visual and the immersion, and how mediums of representation in art and architecture relate to subjectivity and society. Mediums from both history and the contemporary that have produced virtual spaces will be incorporated. It is not intended to be a comprehensive historical overview, as in Grau's *Virtual Art: From Illusion to Immersion*, but rather provide a sampling that places attention on illustrating modes and intentions. Second, philosophical and psychological literature will be reviewed and analyzed. This literature review will specifically focus on aspects of *the body* in space and subjectivity. It will go over crucial and foundational theories that connect the formation and evolution of the subject with perception and the sensorial. Finally, the result of the first two parts will be an application of the theories on media culture today. It will consider how humans develop and

accept new technologies (Mensvoort, n.d.). It will begin an investigation into how culture and societal ideology extends into the virtual space and ultimately acknowledge the impossibility of designing a VR in a vacuum- culture will always inevitably influence the design of space. This will be followed by a reflection on the contribution and relevancy of the work in discourse around the production of the metaverse and subsequent digital assets. The paper is meant to provide an initial reflection on the correlation between culture and virtual space to provoke further discourse and research on the subject.

2 Methodology

2.1 Inside the Outside

This research draws upon theoretical discourse on subjectivity in order to better understand the body in virtual space. Because of this theoretical nature, it makes practical and informed conjectures based on available knowledge.

The body and its biological processes allow for the sensation of experience. What one sees and experiences is as a result of what the brain believes is there (Smythies, 2009). What is perceived as the senses responding to external objects (whether 'natural' or synthetic) comes as a result of neurological processes (Aguilera, 2012). These processes can be set off by alternative stimuli and, in psychology, this is studied through cases of psychosis. Paul Schilder writes a text where he analyzes this in relation to perception. However, it is a universal experience- human sense can be easily stimulated or 'tricked' which has become the motivation for many a successful illusion in architectural and art history. We can think of examples like Borromini's Palazzo Spada to find spaces that were designed to trick the senses and immerse their viewer into an alternate reality. Many philosophers and psychologists have explored issues of the sensorial, perception and the body and these theories serve to better understand the impact of space on the body.

So why apply these theories to virtual reality and architecture? Architecture has the power to shape space. It is a tool that produces a virtuality of experience that creates an inside and an outside. Examining this from a Deleuzian perspective, the inside- the architecture or VR- becomes a fold (figure 1) that is simply an extension of the outside. This means that they are inevitably connected, since they are created by the same line. Rather than the space being considered something 'other,' it is just "the inside *of* the outside" (Deleuze, 1988). It is a condition that arises from what is a relative understanding of space. Deleuze describes this using Foucault's *Order of Things*, specifically the main idea that all thoughts arise from an outside. Subjectivity is inherently linked to the environment. Virtual spaces can also be thought of like this, read in relation to what is referred to as 'real' space.

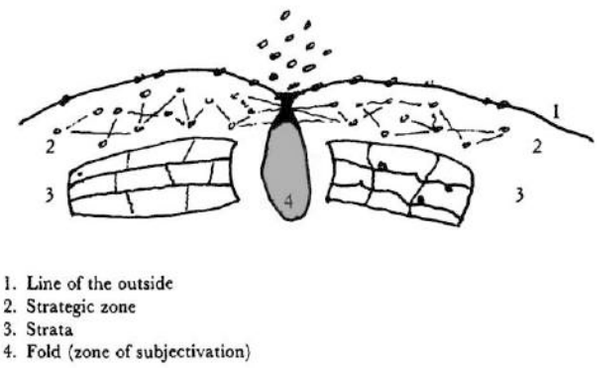

Figure 1. 'Fold' Diagram. Modified from Original Source: Deleuze, *Foucault*, 1988.

Arguably, architecture produces its own virtual spaces using a set of materials, which can be dissected, on two levels.

On the first level, architecture produces a set of environmental conditions that are presumably different from the outside. From a primitive perspective, it creates shelter from weather events and predators. From an architectural historic perspective, it creates private and public space and in doing so provides a manifestation of environments that act as an extension of identity (Popkin, 2016). In other words, whether public or private space, architectural aesthetic, detail and organization provide a means to understand the social and cultural values of any given society. This paper will use the example of Ancient Rome. The predominant feature of the urban plan in this context was the piazza, a public space intended to immerse its users into politics that were meant to be perceived as democratic (Russell, 2015). One of the most significant of these, the Roman Forum, is the site where the Triumphal marches would close after various military conquests. It was a space of power and, more importantly, shows of power, immersing people into the political apparatus (Popkin, 2016). The private space of the villa also served political purposes, producing a space for discourse, political debate, knowledge creation and serving in many cases as a memory palace (Bergmann, 1994). It is important to acknowledge that memory was an important tool in ancient times (Yates, 2014), since printed text was not available, and facilitated a unique relationship between virtual reality, the image, and narrative. This is where the second level comes in.

Grau argues that the pursuit of immersion and virtual reality can be traced back to cave paintings and that there is a long lineage of representational spaces in art and architectural history that constitute as predecessors to contemporary VR technology (Grau, 2003). Each of these historical precedents becomes a way to represent experience and a way of being. What distinguishes the various virtual realities as different from one another throughout history and the contemporary are the particular mediums utilized

and the ideology being represented. Architecture and the image become a means of representing narrative.

The representation of narrative is common throughout architectural history. In Ancient Rome, this was seen in both civic and private spaces. A significant space of visual representation was found in the Ancient Roman villa (figure 2) (Bergmann et al, 2010). The frescos that covered the walls of the villas served as memory palaces as described in Yate's *The Art of Memory* text. They contained frescos in a mixture of the four styles defined by August Mau and created a spatio-temporal way to remember narrative. Stories or memories could be associated with the images and these could be read in different ways depending on how the person navigated the physical space. This is significant since it offered a non-linear narrative model, something that is lost in written text. Additionally, the three-dimensional spaces depicted in the images produced a planar complexity that linked the virtual spaces of the frescos with the physical spaces of the villa (Plat and Squire, 2017). These frescos were intended to be immersive and many of them were meant to be viewed as virtual realities that expanded the space of the room and ultimately refocused attention to the center and onto its occupants. They used theatrical techniques that drew the gaze out and back into the space of the room (Dietrich, 2019). While the frescos provided virtual space, these rooms functioned in what would be termed today as a hybrid or augmented reality model allowing for the frescos to support the action within the space of the room.

Figure 2. Room 5 Ancient Roman Fresco at the Villa Dei Misteri, Pompeii. Source: Author, 2017.

The historical lineage of immersive spaces, which include examples like the ancient fresco rooms, the 18th and 19th century panorama rotundas and more contemporary pre-digital VR devices, provide two readings of architecture's role in producing virtual realities. One is based on the physical materiality of the architecture and its creation of an 'inside,' the other is based on the cultural signifiers and embedded narratives that architectural space

was used to represent. The next section will continue this discourse, examining representation from the perspective of the image and subjectivity.

2.2 What Comes First, Culture or Subjectivity? - Psychologizing the Subject

This section provides a reading of the psychological concept of the body image in immersive space. The body image is related to subjectivity and serves as a virtual double of the being, not in the physical sense but in the experiential sense. The body image arises as a result of the accumulated experiential history of the individual (Schilder, 2014). This section will examine several theories that surround subjectivity in order to provide a framework to understand the body image, drawing upon philosophy and psychology as it relates to perception of self, other and space.

The body image appears in tandem with subjectivity and this occurs through the identification of what constitutes the self and that which is outside of the self. From the beginning there is a notion of 'inside' and 'outside' and their relationship to each other. Jacques Lacan with his 'Mirror Stage Theory' describes this initial definition of the body image. The theory describes the moment of a (approximately) six-month-old infant finally recognizing itself as a subject. The infant, through the act of objectifying its own self-image reflection, gains subjectivity (Lacan, 1999). Subjectivity arises due to that which is virtual. Lacan's mirror provides the first virtual reality space from which identity manifests.

This process requires two modes of seeing: the scopic and the immersive. They are both present in 'mirror stage' and continue to work in tandem throughout the life of an individual. The scopic mode of visual perception relates to Freud's notions of the voyeur while the immersive relates to the narcissist (Lacan, 1953).

The development of the subject is interpreted in Sartre's ontological dimensions of the body: the body for self, the body for other, and the body for self as seen by the other (Sartre, 1969). The first- the body for self- can be equated to Freud's voyeur and the third- the body for self as seen by the other- can be equated to Freud's narcissist (Evans 1996). The third dimension works like the theory put forward by Lacan and can also be thought of in Deleuzian terms, the outside affects the inside. It provides the subject a way of objectifying the self as the other (outside) would in order to understand their own subjectivity. The two modes of seeing and the ontological dimensions of the body provide a way to understand the self in space. This is where architecture and the virtual space can provide an important role- they immerse the body within specific sensorial constructions which manipulate these modes and provide an opportunity to alter perception (Murray and Sixsmith, 1999).

Merleau-Ponty writes about the importance of perception on the body image. In *The Phenomenology of Perception* he asserts that every sensation

is charged with meaning. In other words, every perceptual experience has consequence and previous perceptual memory structures experience in the now. He calls this the 'association of ideas.' All experience of space is subjective, based on the previous experiences of the individual (Merleau-Ponty, 2002).

These philosophical theories are affirmed by work in psychology, specifically that of the psychologist Paul Schilder who first examined the body image disturbances in cases of patients with psychosis. He recognized the importance of sensory perception in its formation and evolution (Schilder, 2014).

The body image is a composite – it arises as an amalgam of its entire experiential history. As Merleau-Ponty and Schilder both assert, it adapts based on sensory perception but the body image also colors experience creating a subjective lens from which an individual experiences space. This body image, shaped by previous experience, is inherently shaped by culture and environment. In research conducted by Chiao et al., they recognized that culture plays an essential role in identity formation and how a person recognizes their self as compared with others and their environment. These scientific studies show how cultural values influence both psychological and neurobiological processes. Cultural beliefs influence perception, self-representation and self awareness (Chiao et al., 2008).

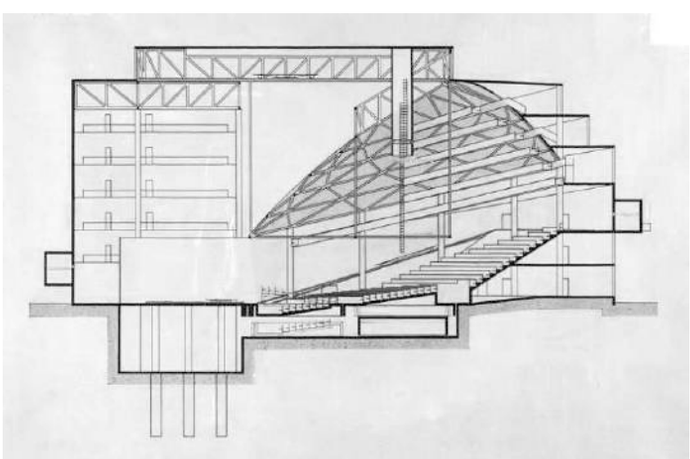

Figure 3. Gropius Total Theatre Section Drawing. Modified from Original Source: https://thecharnelhouse.org, 2014.

This paper supports the argument that architectural and art historical spaces like the Roman frescos (figure 2), panorama rotundas (figure 4), total theaters (figure 3), and cinema serve as precedent for today's digital VR's (Grau 2003).

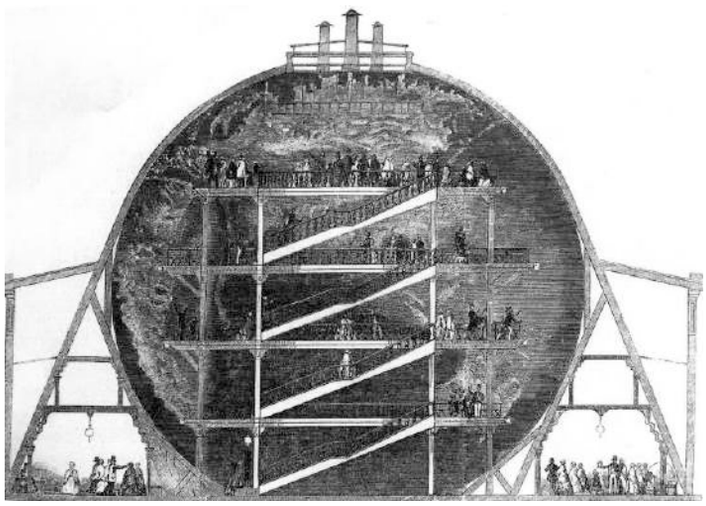

Figure 4. Panorama Rotunda Section Drawing. Modified from Original Source: Oetterman, *The Panorama: History of a Mass Medium*, 1997.

Panorama immersions, while seen as novel in each society's respective iteration, have been created using various technologies but ultimately produce the same result. They create a reflection of the society's values and a representation of the world as it was or idealized. Digital virtual realities today capitalize on current technologies to surround their audiences with a created environment. Examples such as Decentraland, Voxels (Cryptovoxels) and Sandbox define parameters that set up and perpetuate specific value systems (NFT Plazas, n.d.). These spaces, like those that came before, have consequences on the development of the body image.

3 Results

3.1 Our *New* Looking Glass

The metaverse provides a space for new representations. In some respects it functions like a panorama space using the technologies of today to immerse people into this digital realm. There are obvious differences from historical virtual spaces and from these differences come novel opportunities of creation and experience. However, from a psychological perspective, they do not produce such a schism from what our body image and subjectivity already negotiate. Humans already inhabit multiple personas (or avatars) dependent on their environments- we can think of personalities created for 'spaces' like social media vs. work vs. family vs. friends, etc.- and, using the argument that architecture and art has historically produced virtual realities, humans constantly negotiate virtual experience. (In fact, we could argue that

all experience is virtual and therefore all virtual realities are reality.) Therefore, psychologically and phenomenological speaking, the metaverse is simply another virtual space that the body adapts to. Neurologically speaking, the stimuli received from this virtual space is no different from that of 'reality.' However, important to acknowledge is that the design of the metaverse- its 'likeness' with reality and the transition- is another important factor to the success of these spaces. We can see comparisons with this in history. For example, with the early panorama rotundas (figure 4), people experienced 'panorama sickness' since the transition was dramatic (Grau 2003) and in the contemporary context, users unfamiliar with VR headsets experience disorientation when first trying them. As part of the design, designers will have to assign parameters and, at least for the immediate term, in order to have productive spaces of civic engagement, these parameters will need to include recognizable indicators from reality- for example, the use of gravity and mass. There needs to be a consistent 'language' or point of reference from which to understand the world. Looking at the example of Decentraland, we can see certain aspects that have been translated from reality. In this VR space, in order to create revenue and an economy, it uses a land ownership model that is reliant on a finite amount of allocated land space in the world (in order to produce land value). It also uses a planar methodology of understanding the relationship of one parcel to another- they need to be adjacent. This is an interesting design decision given that VR does not need to follow laws of physics, spaces could in theory be accessed by portals and exist together mapped in a much more 4-dimensional way. However, by making the world planar, it more closely resembles mapping techniques that humans have used for centuries, making it easier to understand. Our subjectivities and modes of perception have been defined by our external environment (one that has evolved over the centuries) so this needs to be considered. Perhaps future metaverses will slowly incorporate different dimensions of access, contributing to a type of evolution that takes us beyond recognizing planar mapping structures.

This also applies to the rules and value systems put in place. Many digital virtual spaces have the noble goal of creating an accessible democratic space for everyone. We can speculate that perhaps this desire to create democratic public space comes as a reaction to the social conditions of our times that has produced more fragmentation and given common people less agency over their politics with an increasing amount of control put in the hands of corporations and the one-percent. This illustrates a cultural dissatisfaction with the status quo that will now be preserved in these digital spaces for future generations to look back on and examine. However, though they may be made with good intentions, there are very real and non-virtual infrastructures that make these spaces possible. They require energy, data storage, physical space and money- there are limitations and ethical questions that must be considered. What communities/environments may be compromised to support this infrastructure? What consequences will be produced?

We already are seeing versions of governance forming within these spaces, many of which are community driven. Platforms like Mona aim to allow for any creator to develop their own world. On the other hand, there are also strong capitalist influences with many commercial industries buying land in the metaverse and selling NFT's of their products (Shamash & Nordnes, 2022). So we are at a pivotal moment in determining how we want these spaces to serve us and how they will be governed, supported, used, and funded- and who is making these decisions.

Human subjectivity is shaped by its entire history of experience, including the histories of the people that came before. It evolves rather than entirely breaking from the past. These social and cultural aspects become strong influences upon the design of new spaces, including virtual spaces. As can be seen from examples throughout history and today, aspects from the social and physical reality are directly translated or reacted to into the VR spaces.

From an architectural perspective, the metaverse provides a place to produce community spaces that can be accessed from all around the world, bringing together people from diverse backgrounds and perspectives in a way that could be radical and sets it apart from previous virtual realities. The question then for architects and designers is how can we shape these spaces and what will our role be potentially beyond the design process? What culture and societal ideology will we project into the space of the metaverse? Since, it is impossible to exist in a vacuum, without the influence of culture, it is inevitable that the history of architecture and society will be translated to the space of the digital, producing a new looking glass that reflects our social values and narratives.

4 Discussion

Humans have always in some capacity created virtual spaces and places for immersion through representation. Perhaps it could be argued that this is a consequence of subjectivity arising due to that first virtual encounter with the mirror. Digital virtual realities and the metaverse are simply an extension of these habits that use a different technology and medium. To refer back to Deleuze's notion of the fold, the metaverse or the various metaverses, then simply become another inside of the outside. Humans exist in a constant stream of virtual realities and go from one inside to another that all exist within a greater outside. Like architecture, they provide a means of projecting identity and encapsulating culture and history. The digital space is an extension of the physical space where a continuation of generated representations of identity occurs.

For those that believe this new virtual space of extension will provide a totally blank canvas for a completely new society, or conversely, that it will jeopardize human identities, these presumptions are naïve, since humans

have constantly negotiated virtuality and metaverses are no different with respect to this point, though they provide new and radical opportunities of interaction. Regarding the former aspiration, culture is embedded in subjectivity and being, so in order to produce an entirely different society, humans would need to entirely disengage with everything that has made us who we are- an impossibility. Regarding the latter belief, identity is largely informed by environment. As Sartre writes in *Being and Nothingness*, the being produces a version of itself that relates to the 'other'. A being exists with multiple 'avatars' already that do not jeopardize it but rather add new 'folds' (figure 1). The body creates new alignments, using its subjective knowledge, with virtual spaces just as it has done previously with others.

Reflecting on the lineage of representation and virtual reality allows for an interrogation of architectural practice and the role of this in producing new virtual realities. Incorporating psychology and philosophy provide a reading of the subject in space that can reflect upon the impact of culture and society and how this embeds itself in design. This paper begins to dissect this through the referenced literature with the aim of producing further dialogue around the implications of the metaverse and the production of new 'time capsules' and 'memory palaces' of the contemporary.

References

Aguilera, J. (2012). "A Categorization of Synthetic Experiences." *Technoetic Arts: A Journal of Speculative Research*. Volume 10. 255-260.

Bergmann, B. (1994). 'The Roman House as Memory Theater: The House of the Tragic Poet in Pompeii', *The Art Bulletin*, 76.2, 225–256.

Bergmann, B. et al. (2010). *Roman Frescoes from Boscoreale, The Villa of Publius Synistor in Reality and Virtual Reality*. The Metropolitan Museum of Art.

Chiao, J., Li, Z., Harada, T. (2008). "Cultural Neuroscience of Consciousness, From Visual Perception to Self Awareness," Journal of Consciousness Studies. Volume 15, issue 10-11. 58-69.

Crossley, T. (2019). *The Dissolution of the Body Image*. PhD Dissertation, Architectural Association, Open University.

Deleuze, G. (1988). *Foucault*. trans. Seán Hand. Minnesota: University of Minnesota Press.

Dietrich, N. (2019). "Spatial Dimensions in Roman Wall Painting and the Interplay of Enclosing and Enclosed Space: A New Perspective on Second Style." *Arts* Journal 8, no. 2. 68; https://doi.org/10.3390/arts8020068

Grau, O. (2003). *Virtual Art: From Illusion to Immersion*. MIT Press.

Grosz, E. (2001). “Cyberspace, Virtuality and the Real: Some Architectural Reflections.” *Architecture from the Outside Essays on Virtual and Real Space*. MIT Press. 89.

Lacan, J. (1953). “Some Reflections on the Ego.” *The International Journal of Psychoanalysis*. Volume 34. 11-17.

Lacan, J. (1999). ‘The Mirror Stage as Formative of the I Function as Revealed in Psychoanalytic Experience’, in *Ecrits*, trans. by Bruce Fink. New York, N.Y.: W.W. Norton & Company. Pg. 75–81.

Mensvoort, K. “Pyramid of Technology, How Technology Becomes Nature.” https://www.mensvoort.com/home/pyramid-of-technology

Merleau-Ponty, M. (2002). *Phenomenology of Perception.* Psychology Press.

Murray, C. D. & Sixsmith, J. (1999). “The Corporeal Body in Virtual Reality.” *Ethos*. 315-343.

Navarro de Zuvillaga, J. (2004). *Gropius. Teatro Total 1927*. Ministerio de Vivienda.

NFT Plazas. (n.d.) “Cryptovoxels Overview.” Retrieved July 8, 2022, from: https://nftplazas.com/cryptovoxels/

NFT Plazas. (n.d.) “Decentraland Overview.” Retrieved July 8, 2022, from: https://nftplazas.com/decentraland/

Ordano, E., Meilich, A., Yemel, J., & Araoz, M. (2017). *Decentraland Whitepaper*.

Oetterman, S. (1997). *The Panorama: History of a Mass Medium*. New York: Zone Books.

Pallasmaa, J. (2005). *The Eyes of the Skin; Architecture and the Senses*. Great Britain: John Wiley & Sons.

Plat, V & Squire, M. (2017). *The Frame in Classical Art, A Cultural History*. Cambridge: Cambridge University Press.

Popkin, M. L. (2016). *The Architecture of the Roman Triumph, Monuments, Memory and Identity*. Cambridge University Press.

Russell, A. (2015). *The Politics of Public Space in Republican Rome*. Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9781139629041

Sartre, J.-P. (1996). *Being and nothingness : an essay on phenomenological ontology / by Jean-Paul Sartre; translated by Hazel E. Barnes; introduction by Mary Warnock*. London: Routledge.

Schilder, P. (2014). *The Image and Appearance of the Human Body.* London: Routledge.

Shamash, D. & Nordnes, R. A. (2022). “State of the Open Metaverse 2021/22.” Outlier Ventures Operations.

Smythies, J. (2009). “’Reality’ and ‘Virtual Reality’ Mechanism in the Brain and their Significance.” *Journal of Consciousness Studies*. 69-80.

Yates, F. A. (2014). *The Art of Memory*. London: Routledge.

Evaluating Spatial Perception in Architectural Environments with Virtual Reality

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Abstract. This work compares empirically the dimensional perception of architectural spaces in virtual reality. Thirty volunteers estimated dimensions in virtual reality scenarios built with different 3D modeling methods and with 360 photography. The results show that dimensions are clearly underestimated in scenarios built with 3D modeling, which is consistent with the literature. However, the errors were significantly lower in the scenario built with 360 photography. The study suggests that using 360 photography for building virtual reality experiences could represent an interesting alternative to reduce perceptual dimensional distortions.

Keywords: spatial perception, virtual reality, architectural environments, 360 photography

1 Introducción

En los últimos años, la masificación de equipos de realidad virtual (RV) de bajo costo ha gatillado un crecimiento explosivo de su uso en visualización y simulación de proyectos de arquitectura (Delgado *et al*., 2020). El principal atractivo radica en la sensación de presencia inmersiva que los equipos tipo *head-mounted displays* (HMD) ofrecen para generar una experiencia espacial más natural y completa de la que se puede obtener con medios tradicionales como planimetrías e imágenes 2D o 3D (Jerald, 2016).

Sin embargo, la literatura muestra que, si bien las experiencias inmersivas son muy valiosas, no son completamente equivalentes a las experiencias físicas. Existen diferencias significativas en la percepción espacial entre entornos virtuales y físicos, siendo uno de los más evidentes la tendencia hacia la subestimación de dimensiones en los espacios virtuales. En otras palabras, en RV, las personas tienden a percibir los espacios más pequeños de lo que

realmente son (El-Jamiy & Marsh, 2019; Renner *et al*., 2013). Esta es una distorsión que puede parecer poco relevante en videojuegos y aplicaciones de entretenimiento, pero que es muy importante en aplicaciones de arquitectura. Por ejemplo, la percepción de distancias absolutas y relativas está íntimamente relacionada con la noción de escala, uno de los conceptos más trascendentales en el diseño de espacios arquitectónicos.

Existen antecedentes que sugieren que los entornos 3D construidos con bajo nivel de detalle y pistas visuales producen distorsiones mayores que los entornos modelados de modo realista (Madsen, 2022; Park *et al*., 2021; Loyola, 2018; Vaziri *et al*., 2017). Las pistas visuales (*visual cues*) son estímulos externos, percibidos a través de la vista, que nuestros cerebros interpretan y utilizan para proveer información sobre el entorno físico. Algunas pistas visuales son propias de los mecanismos físicos de percepción visual humana, como perspectiva y paralaje, pero otros son directamente modificables en el diseño del entorno RV, tales como el manejo de texturas o el uso de elementos referenciales de dimensión conocida. Así, se desprende que entornos de RV modelados con mejor calidad de pistas visuales de diseño deberían originar percepciones espaciales más precisas. Este estudio aborda esta pregunta comparando empíricamente la percepción de dimensiones y distancias en entornos de RV construidos con diferentes niveles de pistas visuales.

2 Métodos

La investigación tuvo un diseño cuasiexperimental. Treinta voluntarios sin experiencia previa con RV fueron expuestos de manera aleatoria a la visualización de tres entornos RV idénticos, pero modelados con diferente nivel de pistas visuales. El espacio de referencia fue el vestíbulo de una biblioteca universitaria; un espacio amplio, sin obstrucciones visuales y con variedad de texturas, colores, iluminación y elementos de mobiliario referenciales (figura 1). El primer escenario (E1) correspondió a una réplica digital del espacio, con el mayor nivel de fotorrealismo posible de obtener con las herramientas de modelado 3D (figura 2). El segundo escenario (E2) correspondió a una versión modificada con texturas simplificadas, colores planos, iluminación general y sin elementos de mobiliario (figura 3). El tercer escenario (E3) consistió en una fotografía 360° del espacio (figura 4, arriba). Se hipotetizó que la fotografía representaba el mejor medio disponible para la representación exacta del nivel de detalle visual del espacio físico. Adicionalmente, se consideró el espacio físico real como escenario de control (C). El orden de presentación de los escenarios fue aleatorizado entre los participantes.

Figura 1. Espacio real (físico) y escenario control

Figura 2. Escenario 1, réplica digital del espacio real

Figura 3. Escenario 2, con alteración de pistas visuales

Los escenarios digitales fueron modelados geométricamente con Rhinoceros 7 y, luego, exportados en formato Datasmith a Unreal Engine 4, donde fueron postprocesados con texturas e iluminación HDR. Los modelos fueron exportados como fotografía estereoscópica (figura 4, abajo). La fotografía 360° fue capturada con una cámara Samsung Gear 360 4K, en formato monoscópico. Se utilizó un equipo Intel Core i9-9900 K, 32 Gb RAM y tarjeta gráfica Nvidia GeForce RTX3070 para el desarrollo de los modelos. Para la visualización de los entornos RV, se utilizó un equipo HMD Oculus Quest 2.

Figura 4. Fotografía 360° (arriba) y escenario fotorrealista (abajo)

Los participantes, luego de un *screening* previo para descartar experiencia previa con realidad virtual, antecedentes de mareos o síntomas de COVID-19 y de aceptar el consentimiento informado, fueron expuestos a un escenario de *rapport* para que se familiarizaran con el equipo HMD y con la sensación de inmersión (figura 5).

Figura 5. Proceso experimental en terreno

Para la evaluación de la percepción de dimensiones, se utilizó un cuestionario de estimación verbal de dimensiones con cuatro distancias exocéntricas (i. e. distancias entre dos puntos determinados) y una distancia egocéntrica (i.e. distancia entre la persona y un punto externo). Se usó un listado de dimensiones distinto para cada escenario, pero todos con el mismo nivel de dificultad. Algunas dimensiones eran referidas al recinto (ej. alto y largo del espacio, distancia del participante al muro) y otras a objetos (ej. alto y ancho de una pieza de mobiliario).

Las respuestas de los participantes fueron registradas directamente y, luego, expresadas como errores normalizado; es decir, la diferencia entre la distancia percibida y la distancia real, dividida en la distancia real. Este valor normalizado y adimensional permite tener valores comparables entre diferentes preguntas y realizar análisis estadísticos. Adicionalmente, se registraron sus comentarios espontáneos y sus impresiones generales sobre la experiencia y la percepción espacial con el equipo de RV.

3 Resultados

Los resultados muestran, en general, una tendencia a la subestimación de distancias exocéntricas en todos los entornos RV modelados en 3D, lo cual es consistente con la literatura (figura 6).

En el escenario de control (C), correspondiente a la estimación de distancias en el espacio real, los errores normalizados de distancias exocéntricas variaron entre +0.031 y -0.130, con una desviación estándar (sd) entre 0.09 y 0.21, lo cual describe un grupo con habilidades moderadas promedio de estimación de distancias.

En los dos escenarios de modelos 3D los resultados fueron similares. En el escenario de réplica digital (E1), los errores normalizados de distancias exocéntricas variaron entre +0.009 y -0.235, con una desviación estándar entre 0.17 y 0.24. En el escenario de modelo alterado (E2), los errores normalizados de distancias exocéntricas variaron entre +0.064 y -0.135, con una desviación estándar entre 0.15 y 0.23. Ambos casos describen una tendencia hacia la subestimación de distancias. No se apreciaron diferencias estadísticamente significativas entre ambos casos.

En el escenario de fotografía 360 (E3), en cambio, los resultados muestran un comportamiento totalmente diferente. Los errores normalizados de distancias exocéntricas variaron entre +0.057 y +0.207, con una desviación estándar entre 0.39 y 0.21, lo cual describe una tendencia hacia la sobreestimación de distancias. Este es un resultado relevante, ya que representa un comportamiento significativamente diferente, incluso aparentemente opuesto, al de los entornos modelados en 3D.

En el análisis de estimaciones de distancias egocéntricas, se observa un fenómeno similar. En el escenario C, el error normalizado fue de -0.251 (sd = 0.16); en el escenario E1, el error fue de -0.288 (sd = 0.13); en el escenario E2, el error fue -0.201 (sd = 0.15); y, en el escenario E3, el error fue de -0.058 (sd = 0.28). El error de subestimación en E3 es significativamente menor que en los otros casos, incluyendo el escenario control, sugiriendo una tendencia en dirección a la sobrestimación.

El análisis cruzado por participante refuerza esta diferencia entre entornos modelados 3D y fotografía 360°. Los resultados muestran una correlación moderada entre los errores normalizados del caso control y los escenarios E1 y E2, con R = 0.45 y R = 0.55 para distancias egocéntricas, y R = 0.23 y R = 0.27 para distancias exocéntricas. Sin embargo, los coeficientes son significativamente más débiles en la comparación con el E3, R = 0,36 para distancias egocéntricas y R = 0.05 para distancias exocéntricas.

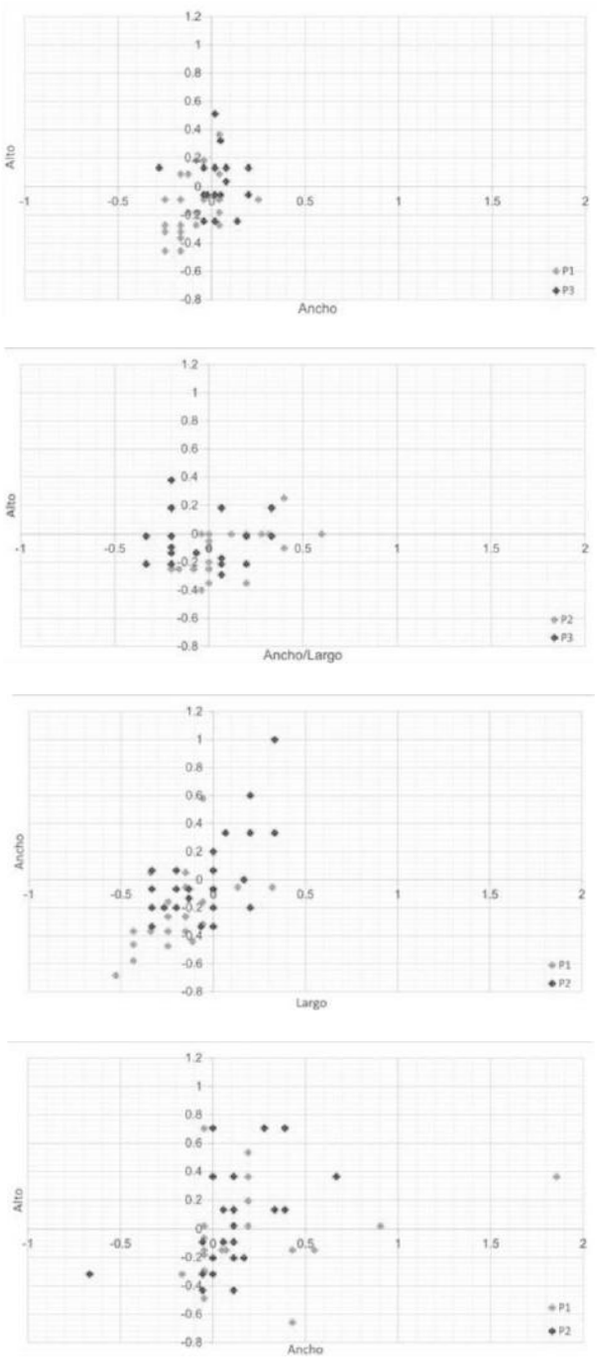

Figura 6. Error normalizado en distancias exocéntricas para los cuatro escenarios.
De arriba a abajo: escenario control, E1, E2 y E3.

En el análisis cualitativo de comentarios, se detecta que las distorsiones de percepción parecieron no ser detectadas por los participantes. Un 43% señaló que percibió el espacio virtual “del mismo tamaño” que el espacio real; un 37%, “más pequeño”; y un 20%, “mas grande”. No se observó ninguna relación entre las estimaciones efectivas de distancias y la percepción general.

4 Discusión

En general, los resultados generales confirman lo reportado en la literatura sobre la tendencia hacia la subestimación de distancias egocéntricas y exocéntricas en entornos de RV construidos con modelado 3D. Los resultados no permiten establecer un impacto significativo entre entornos modelados con más pistas visuales de texturas, colores y elementos de mobiliario referenciales.

El hallazgo más relevante de este trabajo, sin embargo, es la significativa diferencia que se observó entre los resultados de estimaciones en el escenario construido con fotografías 360° versus las estimaciones de los otros dos escenarios construidos con modelado 3D tradicional. No solo los errores de dimensiones fueron menores, sino que incluso fueron de tipo contrario (sobreestimación), tanto en distancias exocéntricas como egocéntricas. La mayor desviación estándar de los errores señala que existieron diferencias importantes entre participantes, lo que podría interpretarse como relacionado con factores humanos.

Un aspecto a considerar es que la fotografía 360° fue el único escenario monoscópico, lo que ciertamente podría ser un factor explicativo. La baja correlación entre el escenario control y el escenario de fotografía 360° también resulta llamativa, y refuerza la sospecha de que esta técnica de construcción de escenarios RV pareciera generar experiencias espaciales substancialmente distintas a las gatilladas por entornos RV modelados en 3D tradicionalmente y a la propia realidad. En cualquier caso, se recomienda continuar esta senda de investigación con nuevos experimentos relacionados específicamente con la percepción espacial con fotografía 360°.

Como en todo (cuasi)experimento, hay limitaciones. En primer lugar, el método de observación de la percepción de escala es, por definición, indirecto e imperfecto. La percepción espacial es un proceso psicológico y personal que no puede ser observado directamente. La estimación de dimensiones es una técnica *proxy* ampliamente utilizada, pero sujeta a sesgos cognitivos. En otras palabras, la dimensión reportada podría ser lo que el participante *piensa* o *calcula* que debería medir algo, en lugar de lo que *percibe* espacialmente. En este caso, además, los participantes conocían el lugar previamente, lo que

también introduce una variable no controlada al ejercicio. Otras limitaciones están relacionadas con el tamaño reducido de la muestra (N = 30) y con el hecho de que todos los escenarios de RV tenían una configuración estática, es decir, los participantes no podían desplazarse en el espacio virtual. Los resultados, por lo tanto, solo pueden ser interpretados para experiencias de RV estáticas.

En último término, este trabajo abre una veta prometedora dentro del nicho de investigación sobre percepción de espacios arquitectónicos en RV. Esto es importante porque el adecuado conocimiento de los mecanismos de percepción espacial y, por consiguiente, el dominio de técnicas de construcción de mejores entornos de RV son cruciales para que la tecnología pueda aplicarse en contextos donde se requieran experiencias espaciales precisas, predecibles y confiables.

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Referencias

Delgado, J. M. D., Oyedele, L., Demian, P. & Beach, T. (2020). A research agenda for augmented and virtual reality in architecture, engineering and construction. *Advanced Engineering Informatics*, *45*, 101122.

El-Jamiy, F. & Marsh, R. (2019). Distance estimation in virtual reality and augmented reality: A survey. En *2019 IEEE International Conference on Electro Information Technology (EIT)* (pp. 063-068). IEEE.

Interrante, V., Ries, B. & Anderson, L. (2006). Distance perception in immersive virtual environments, revisited. En *IEEE Virtual Reality Conference* (pp. 3-10). IEEE.

Jerald, J. (2016). *The VR Book: Human-Centered Design for Virtual Reality*. ACM & Claypool Publishers.

Loyola, M. (2018). The Influence of the Availability of Visual Cues on the Accurate Perception of Spatial Dimensions in Architectural Virtual Environments. *22*(3), 235-243.

Madsen, C. B. (2022). Influence of Texture Fidelity on Spatial Perception in Virtual Reality. En *17th Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications-GRAPP* (pp. 244-251). SCITEPRESS Digital Library.

Park, H., Faghihi, N., Dixit, M., Vaid, J. & McNamara, A. (2021). Judgments of object size and distance across different virtual reality environments: A preliminary study. *Applied Sciences*, *11*(23), 11510.

Renner, R. S., Velichkovsky, B. M. & Helmert, J. R. (2013). The perception of egocentric distances in virtual environments - A review. *ACM Computing Surveys*, *46*(2), 1-40.

Vaziri, K., Liu, P., Aseeri, S. & Interrante, V. (2017). Impact of Visual and Experiential Realism on Distance Perception in VR Using a Custom Video See-through System. En *Proceedings of the ACM Symposium on Applied Perception* (pp. 1-8).

Virtual reality and the familiarization of the University Campus space: USP São Carlos

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Abstract. Despite the multiple initiatives of extension activities currently implemented at USP São Carlos (SP - Brazil), the relationship between university and society can be strengthened in the context of a public presence in the physical spaces of the Campus, especially considering the majority of the city's population, which is not integrated in its academic community and doesn't use the same areas. This paper proposes that the products developed can encourage the neighboring communities of the Campus to enter its inner spaces, through a spatial familiarization in virtual environments. To achieve this, two distinct technologies were researched - virtual reality and virtual tour with 360° photography - evaluating their qualities and constraints. Finally, the main differences between the two processes were grouped in a comparative chart, as a result of this research.

Keywords: Virtual Reality, Immersive Environments, 360° Photography, Digital technology, Universidade de São Paulo.

1 Introdução

Este artigo está vinculado às atividades de pesquisa do grupo N.ELAC do Instituto de Arquitetura e Urbanismo da Universidade de São Paulo (IAU USP). O campo de estudo da realidade estendida (Chuah, 2019) tem ganhado relevância considerável na contemporaneidade, com destaque para a tecnologia de realidade virtual (RV), empregada em áreas diversas, que se estendem desde a construção civil até treinamentos militares e simulações de voo. Apesar disso, grande parte de seus usos ainda se encontram concentrados em alguns laboratórios acadêmicos e corporativos, com isso sendo mudado aos poucos a partir da recente disseminação dos HMDs voltados para o entretenimento, fomentando a expectativa de que os mercados

de outros setores invistam mais em técnicas de realidade virtual e realidade aumentada, de maneira gradual (Jerald, 2016).

Entre os diversos usos da RV, destaca-se nesta pesquisa a aplicação da tecnologia para a visualização de edifícios reconstruídos digitalmente, em que pode ser destacado, em específico, a possibilidade de engajamento do público com o objeto arquitetônico a partir de um ambiente imersivo (Mortara et al., 2014 apud Silcock et al., 2018). Sabe-se que o envolvimento e a interação de usuários com ambientes de realidade virtual de edifícios universitários podem trazer ganhos para a comunidade acadêmica, como demonstram Guida, Tian & Dong (2021), entretanto, a presente pesquisa busca investigar o desenvolvimento dessas experiências voltadas para um outro público: as comunidades que ainda não frequentam os espaços das universidades públicas.

Atualmente os Campi da USP possuem acesso controlado de pessoas e veículos nas portarias de suas principais entradas. Soma-se a isto, que no Campus de São Carlos, as Áreas 1 e 2 são totalmente muradas e cercadas com gradis. Diferentemente do Campus de São Paulo, maior em extensão e que possui ônibus público circular, a Área 2 do Campus de São Carlos não conta com linha pública de transporte, tendo duas portarias em suas extremidades, distantes entre si aproximadamente 1 km. Todos esses fatores não convidam os moradores do entorno, membros das comunidades locais, a conhecer os espaços internos do Campus.

1.1 Objetivo

O trabalho visa a elaboração de um tour virtual e uma experiência de realidade virtual dos espaços reconstruídos digitalmente de um edifício selecionado (Conjunto de Apoio Didático) da Área 2 do Campus da USP São Carlos. Pretende-se que esses ambientes virtuais sirvam como elementos de familiarização espacial para as comunidades vizinhas - principalmente entre os jovens das escolas públicas - e sejam também um convite a frequentar os espaços “intramuros” do campus. Para isso, além da tecnologia de RV, a fotografia 360° foi investigada como uma ferramenta para o levantamento dos espaços, auxiliando na percepção dos mesmos e complementando as informações técnicas obtidas a partir de desenhos técnicos, como plantas, cortes e fachadas.

1.2 Objeto de estudo

A Área 2 do Campus da USP São Carlos, escolhida para o estudo de caso deste projeto, iniciou sua implantação no ano de 2001, com o propósito de suprir as crescentes atividades universitárias. O território escolhido se insere nos bairros de Santa Felícia, Santa Angelina e Romeu Tortorelli.

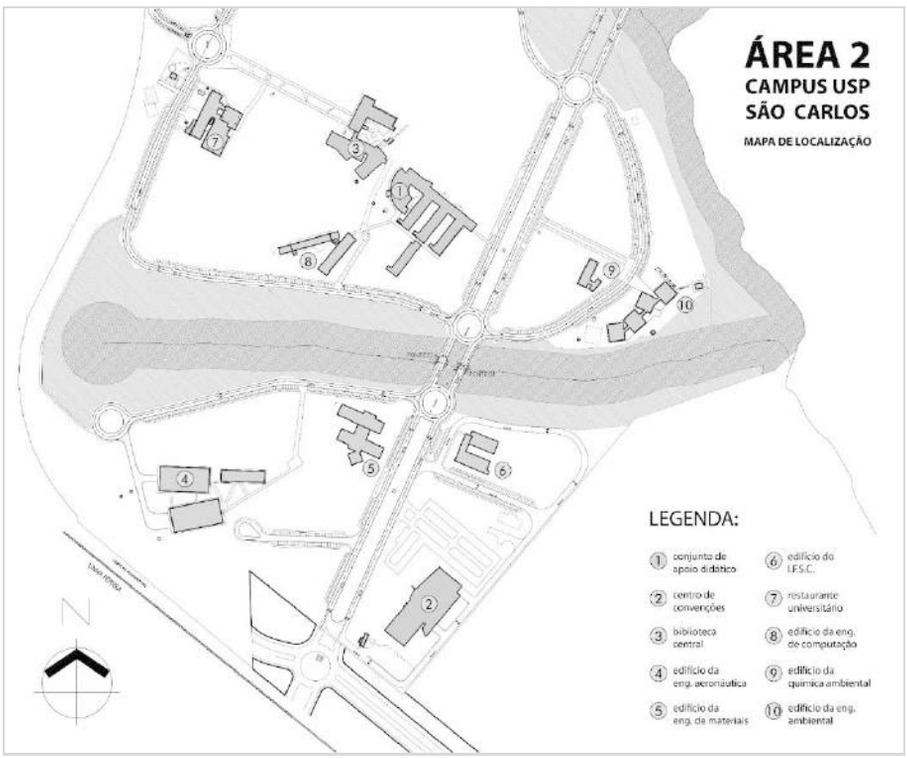

Figura 1. Mapa de localização da Área 2 do Campus da USP São Carlos, com destaque para o edifício CAD em rosa. Fonte: os autores, a partir de mapa da Área 2 do Campus USP São Carlos, 2022.

O impacto do campus universitário na região é notado em diversos setores, como a valorização imobiliária local, o maior número de veículos em circulação, além das diferentes relações de moradia e emprego acarretadas pela diversidade cultural e mudança na paisagem (Schenk et al., 2014).

Entre os diversos edifícios desta área, é possível destacar o Conjunto de Apoio Didático, costumeiramente referenciado apenas como CAD pela comunidade acadêmica local. A escolha deste edifício como objeto de estudo do trabalho foi motivada pelo seu intenso uso no Campus, devido a grande quantidade de salas de aula e laboratórios com atividades simultâneas, sendo um prédio já bastante integrado no cotidiano dos estudantes e professores universitários.

2 Metodologia

Esta pesquisa aplica parcialmente o Design Science Research (DSR), de acordo com as explicitações de Dresch, Lacerda & Antunes (2015), Peffers et al. (2007), e Voordijk (2009). Este método implica na criação de um experimento que busca solucionar um problema específico de um domínio. Nesse sentido, o conhecimento é gerado no momento de desenvolvimento prático de soluções que buscam melhorar sistemas existentes ou na criação de experiências que melhorem a performance humana.

A DSR foi explorada nesse trabalho no desenvolvimento de diferentes experiências de compreensão espacial de um edifício, geradas por meio de fotografias 360° ou realidade virtual, buscando entender como cada uma potencializa a familiarização com o prédio selecionado. Além disso, para esta última tecnologia foi necessária a aplicação parcial da Pesquisa de Simulação de Groat & Wang (2013), compreendendo o modelo tridimensional do Conjunto de Apoio Didático como a uma reprodução de um elemento da realidade, uma simulação do existente.

Para a elaboração de diferentes instrumentos de compreensão espacial do edifício selecionado - sejam estes no formato de tour virtual ou em realidade virtual - o trabalho foi dividido em três etapas principais, em que se distribuem as atividades realizadas: 1) Levantamento de Informações, 2) Desenvolvimento Prático e 3) Visualização e Percepção. Vale ressaltar que essas fases de estudo foram separadas para cada uma das tecnologias empregadas, como apresentado a seguir, buscando o melhor entendimento de seus processos e permitindo a posterior comparação dos resultados obtidos.

2.1 Etapa I - Levantamento de Informações

Em um primeiro momento, foi necessário extrair informações fundamentais para a elaboração dos produtos para o estudo. Nesse sentido, foi realizada uma visita técnica à Área II do Campus da USP São Carlos e ao Conjunto de Apoio Didático no dia 02 de janeiro de 2022, o que viabilizou a obtenção de registros no formato de fotografias panorâmicas 360° dos ambientes de interesse à pesquisa. Além disso, foi possível ter acesso digital aos desenhos técnicos do edifício trabalhado, possibilitando a elaboração de seu modelo na etapa seguinte.

Fotografias 360°

A visita técnica teve como objetivo a levantamento de materiais a partir de fontes primárias, na captura de fotografias 360° do edifício selecionado com a câmera Samsung Gear 360 (2017).

A câmera utilizada possui os seguintes dados técnicos: duas lentes do tipo olho de peixe, posicionadas em lados opostos, associadas a dois sensores CMOS com 8.4MP e abertura correspondente a f/2.2, além de uma saída padrão de pixels equivalente a 15.0 MP (5472 x 2736 pixels) nas fotografias e

vídeos de resolução de 4096 x 2048 pixels. Entre os diversos recursos da Gear 360, se destaca a possibilidade de realizar a conexão, via Bluetooth ou Wi-Fi, com determinados modelos de smartphones por meio de um aplicativo de celular exclusivo para a máquina, recebendo o mesmo nome da mesma. A partir dessa ferramenta, o trabalho com a câmera pode ser facilitado mediante funcionalidades como a visualização do campo de visão das lentes para o registro dos vídeos e fotografias, a captura dos mesmos remotamente, além de alguns recursos de edição. (Hiilesmaa, et al., 2021; Lima, et al., 2021). Durante o processo, no final, foram capturadas 95 imagens panorâmicas 360° do exterior e interior da construção no dia da visita, utilizadas como base para o tour virtual elaborado.

É importante mencionar que a Samsung Gear 360, lançada no ano de 2017 e utilizada durante os levantamentos da visita técnica, não é um equipamento de fácil acesso para compra atualmente. A multinacional Samsung desenvolveu essa câmera em período próximo ao que produzia o Gear VR - óculos de realidade virtual - e o Samsung XR - plataforma de compartilhamento de vídeos em 360° - formando um conjunto de equipamentos e plataforma voltados para RV, além da captura e visualização de imagens e vídeos panorâmicos 360°. No entanto, esses produtos foram deixando de ser fabricados pela empresa ao longo dos anos, perdendo também seu suporte oficial no ano de 2020. Como exemplo disso, no dia 11 de maio de 2020 foi publicada uma notificação no site da multinacional sobre o fim do serviço de assistência em relação ao Gear VR e ao Samsung XR, enquanto no dia 1 de agosto do mesmo ano, à Samsung Gear 360 (Samsung Eletronics Co.Ltd., 2020).

No caso da câmera 360° mencionada, além do fim do serviço de suporte, as atualizações de compatibilidade do equipamento com novos celulares lançados e as suas vendas em grande parte das lojas físicas oficiais da marca também foram descontinuadas, implicando em uma dificuldade de obter a câmera utilizada neste trabalho (Samsung Eletronics Co.Ltd., 2020)

Na figura 2 abaixo, é possível visualizar os dois equipamentos utilizados durante todos os dias da pesquisa - a Samsung Gear 360° e o tripé Bilora Action Line Eco 263 - além de observar como a câmera 360° era suportada e nivelada sobre o tripé profissional.

Figura 2. Câmera Samsung Gear 360 (2017) e acessórios da máquina (esquerda); câmera sobre o tripé Bilora Action Line Eco 263 (direita); vista dos equipamentos em frente a uma das fachadas do edifício CAD (abaixo). Fonte: os autores, 2022.

Realidade virtual

A etapa de levantamento de informações para a visualização espacial em realidade virtual envolveu a obtenção de desenhos técnicos do prédio do Conjunto de Apoio Didático. Foi possível obter arquivos no formato *.pdf* de algumas das pranchas do projeto executivo do edifício, auxiliando na compreensão das dimensões corretas dos espaços e sua recriação em um modelo digital na segunda etapa do processo.

Além das pranchas digitais do projeto inicial, foi possível obter arquivos referentes à expansão do edifício no ano de 2006, base de trabalho mais atualizada fornecida pela instituição, como recomendado por Agirachman, et al. (2017).

2.2 Etapa II - Desenvolvimento Prático

AA etapa intermediária envolveu o desenvolvimento e edição das bases utilizadas para a visualização final do edifício, sejam estas projeções equiretangulares de panoramas - no caso das fotografias 360° - ou um modelo revit - utilizado para a construção da ambiência de realidade virtual.

Fotografias 360°

Figura 3. Duas imagens tipo olho de peixe (esquerda) obtidas na visita e seus respectivos correspondentes em projeção equiretangular (direita). Fonte: os autores, a partir de fotos 360° registradas com a câmera Gear 360, 2022.

As fotografias panorâmicas 360° são registradas pela câmera Samsung Gear 360 no formato olho de peixe, como resposta automática à captura dos sensores internos do equipamento, associadas às suas duas lentes. Além dessa forma inicial de registro, é possível obter um segundo tipo de formato da imagem, a projeção equiretangular (Barazzetti, Previtali & Roncoroni (2017). Para essa segunda conformação, é necessário que a imagem do tipo olho de peixe passe por um processo de "costura" das partes correspondentes às capturas de cada sensor, o que pode ser realizado pelo aplicativo de celular da Samsung Gear 360 ou pelo software para desktop Gear 360 Action Director. (Lima et al., 2021; Hiilesmaa et al., 2021).

Para a elaboração do tour virtual, é necessário que as fotos 360° estejam no segundo formato, de projeção equiretangular. Nesse sentido, foi feita a seleção das imagens mais significativas para a compreensão espacial do edifício,obtendo um total de 46 imagens panorâmicas 360°, que, enfim, foram costuradas no software Gear 360 Action Director.

Realidade virtual

A partir das plantas, cortes e fachadas obtidas no processo de levantamento de informações técnicas, iniciou-se o desenvolvimento do modelo digital do edifício do Conjunto de Apoio Didático (CAD).

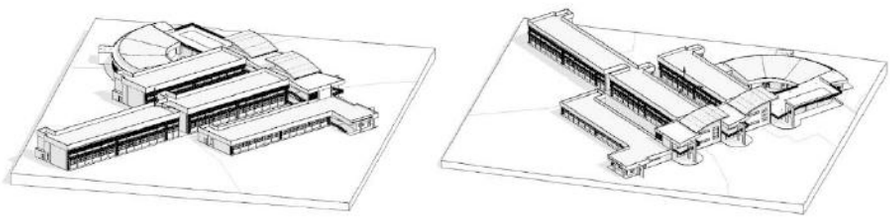

Figura 4. Perspectivas do modelo tridimensional realizado no software Revit. Fonte: os autores, a partir de capturas de tela do modelo criado no software Revit, 2022.

Objetivou-se uma visualização do modelo sem a adição de materiais texturizados, com o intuito de ressaltar apenas o caráter volumétrico e tridimensional de maneira objetiva, sem o risco de propor cores e texturas que não sejam condizentes com aquelas que são próprias do ambiente existente. Nesse processo, apenas houve a diferenciação de materiais transparentes como as esquadrias de vidro, já que as mesmas possuem grande influência na compreensão espacial, para a diferenciação de quais planos no modelo são verdadeiramente opacos.

2.3 Etapa III - Visualização e Percepção

Por fim, a terceira etapa representa a finalização dos processos de elaboração dos produtos para compreensão espacial do edifício selecionado. Além disso, objetivou-se nessa fase a análise de qualidades e limitantes dos dois experimentos realizados, como apresentado abaixo.

Fotografias 360°

Após a etapa de costura e seleção das fotografias 360° mais relevantes para o percurso no edifício, iniciou-se o processo de construção de um tour virtual interativo com as imagens. Para isso, foi realizado um levantamento das plataformas específicas de elaboração e edição de visitas virtuais a partir das imagens panorâmicas 360° em projeção equiretangular, como o Marzipano, Theasys, Kuula e Lapentor.

Essas plataformas, também denominadas de *Content Management Systems (CMS)* para tours virtuais, apresentam diferentes características e qualidades, envolvendo o número máximo de panoramas que podem ser enviados de uma vez só, a diversidade de opções para personalização da visita, entre outras (Hiilesmaa et al., 2021). A partir da análise dos pontos positivos e negativos de cada CMS, optou-se pelo uso da plataforma Marzipano, que é completamente gratuita e possui um processo de edição simples, rápido e eficiente para os propósitos deste estudo.

O tour virtual finalizado conta com as 46 vistas 360° do Conjunto de Apoio Didático, permitindo um um percurso pelo exterior e o interior do edifício. Ele

pode ser acessado gratuitamente por computador ou smartphone a partir do seguinte link: https://cad-conjunto-de-apoio-didatico-tour.netlify.app/. Para a locomoção entre imagens panorâmicas 360°, basta utilizar os elementos que aparecem sobre a imagem na forma de setas interativas, denominados *hotspots*.

Apesar do tour virtual contar com registros obtidos a partir de fontes primárias, por meio das fotografias 360° capturadas na visita ao edifício, a navegação pelo espaço não é livre. É possível visualizar o edifício apenas em pontos específicos, considerados mais relevantes para a apreensão da totalidade do prédio pelos autores, impossibilitando a exploração de outros espaços que não foram capturados por meio das imagens panorâmicas selecionadas. Vale ressaltar, no entanto, que essa possibilidade permite a visualização da ambiência existente de maneira mais próxima do real, com as texturas, cores e luminosidade do espaço existente no dia da visita técnica.

Realidade virtual

A última etapa da elaboração da experiência em realidade virtual teve início com a exportação do arquivo do modelo, elaborado no software Revit, no formato *.*fbx*. Esse arquivo foi então importado no programa Unity 3D, para uma fase de edição e visualização final em RV.

Soma-se a isso a inserção do elemento (ou *asset*) que permite que o usuário tenha uma perspectiva de câmera em primeira pessoa, denominado *First Person Shooter* (FPS). A partir dessa ferramenta, é possível visualizar os espaços virtuais com o campo de visão próximo ao de uma pessoa no local real existente, além de adicionar funcionalidades como caminhar, correr, saltar e olhar para os lados - o que enriquece a experiência de navegação pelo edifício. Vale ressaltar que houve atenção para a velocidade de deslocamento padrão durante a execução da experiência virtual, reajustada para um caminhar suave, mais próximo do real, evitando os efeitos de *cybersickness* (Fukuda, *et al.*, 2021; Agirachman, *et al.*, 2017; Firme, Andrade, 2017).

Figura 5. Perspectivas em primeira pessoa das ambiências em realidade virtual do edifício modelado. Fonte: os autores, a partir de capturas de tela da experiência em RV criada no software Unity, 2022.

A experiência de visualizar e percorrer o modelo do edifício em realidade virtual mostrou-se, portanto, capaz de fornecer uma exploração muito livre e fluida pelo local estudado. Diferentemente do tour virtual com as imagens 360°, o ambiente em RV possibilita o movimento de caminhar virtualmente pelo espaço, possibilitando a visualização de locais que não foram registrados em fotografias. Contudo, a visualização da ambiência é diferente da realidade, sem suas texturas e cores fidedignas, que são capturados, por outro lado, nas fotografias panorâmicas 360°.

3 Resultados

Embora o objetivo geral do trabalho seja voltado para a familiarização dos espaços do edifício selecionado, possibilitado pela criação de ambientes virtuais dos espaços do prédio situado no Campus da USP São Carlos, para este estudo foram testadas duas tecnologias digitais, o tour virtual e a realidade virtual. Abaixo, é possível verificar um quadro síntese com as qualidades e limitações de cada técnica, conforme notado durante a experiência prática dos autores.

Quadro 1. Quadro comparativo elaborado a partir das experiências realizadas nas etapas de desenvolvimento determinadas no trabalho. Fonte: os autores, 2022.

TECNOLOGIAS	TOUR VIRTUAL (FOTOGRAFIAS 360°)	REALIDADE VIRTUAL
QUALIDADES	Por ser baseado em registros fotográficos em 360°, o tour virtual realizado permitiu a visualização e representação de características físicas do espaço (como texturas e cores dos materiais) de forma mais próxima ao existente no mundo real/ /Quando comparado com a elaboração da experiência de realidade virtual, o tour virtual possuiu um processo mais veloz de edição, montagem e publicação dos produtos realizados.	Diferentemente do tour virtual, a realidade vitual permite o movimento completamente livre pelo espaço, permitindo interações diversas como caminhar, correr e saltar. A exploração, portanto, permite o contato com um maior número de espaços do edifício selecionado, por não se basear em pontos de visão pré-definidos.
LIMITAÇÕES	Para as fotografias 360°, utilizadas como base do tour virtual elaborado, é necessário estabelecer pontos específicos para executar os registros fotográficos. Nesse sentido, o tour virtual possui pontos de navegação pré-definidos e inflexíveis, que dependem exclusivamente do momento de levantamento de fotos *in loco*/ /Não há um grande grau de interação entre o usuário e o espaço, sendo limitado, no caso do tour realizado na plataforma Marzipano, à movimentação entre panoramas existentes.	No caso específico da experiência de realidade virtual realizada nessa pesquisa, o ambiente virtual não representa a realidade em sua totalidade, trata-se de um produto elaborado a partir de um modelo sem texturas e cores de materiais. É possível aproximar o modelo e sua aparência em relação ao real, mas é um processo prolongado e trabalhoso de edição dos elementos modelados/ /Processo prolongado de reconstrução digital do espaço selecionado, a partir do software Revit.

4 Discussão

A execução deste estudo fomenta o emprego de tecnologias como a realidade virtual para promover o acesso virtual a espaços universitários, por meio de uma familiarização dos locais “intramuros” do campus, incentivando os membros das comunidades vizinhas a desfrutar desse espaço público. Dessa forma, a partir dos espaços imersivos criados por meio da remodelagem interna e externa do edifício selecionado, acredita-se que será possível incentivar uma aproximação maior entre sociedade e universidade. Em um momento posterior, pretende-se apresentar esses ambientes virtuais às comunidades locais da cidade, principalmente aos jovens das escolas públicas, buscando convidá-los a frequentar esses espaços “intramuros” do campus a partir de uma familiarização espacial virtual.

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Referências

Agirachman, F., et al (2017). REIMAGINING BRAGA: Remodeling Bandung’s Historical Colonial Streetscape in Virtual Reality. In: THE ASSOCIATION FOR COMPUTER-AIDED ARCHITECTURAL DESIGN RESEARCH IN ASIA (CAADRIA), 22., Hong Kong. Proceedings [...]. Hong Kong: Blucher, 2017. p. 23-33

Barazzetti, L., Previtali, M., & Roncoroni, F. (2017). 3d Modelling With The Samsung Gear 360. Proceedings of the International Archives Of The Photogrammetry, Remote Sensing And Spatial Information Sciences, Xlii-2/W3., 2017, Nafplio. Creative Common Attribution 3.0, p. 85-90.

Chuah, Stephanie Hui-Wen (2019). Wearable XR-technology: literature review, conceptual framework and future research directions. International Journal of Technology Marketing, v. 13, n. 3-4, p. 205-259.

Dresch, A.; Lacerda, D. P., & Antunes Jr, J. A. V. (2015). Design Science Research: A Method for Science and Technology Advancement. Switzerland: Springer International Publishing.

Firme, E., Andrade, M. (2017) Projeto Colaborativo, Realidade Vitual e BIM: Uma experiência de participação dos clientes nas decisões dos projetos de arquitetura. In: CONFERENCE OF THE IBEROAMERICAN SOCIETY OF DIGITAL GRAPHICS, 21., 2017, Concepción. Proceedings [...]. São Paulo: Blucher. p. 603-609.

Fukuda, T. et al. (2021). A Motion Vector Visualization Method on a Virtual Reality Screen. In: CONFERENCE ON EDUCATION AND RESEARCH IN COMPUTER AIDED ARCHITECTURAL DESIGN IN EUROPE (eCAADe), 39., Vol.2, Novi Sad. Proceedings [...]. Novi Sad: Digital Design Center, University of Novi Sad. p. 513-520.

Groat, L., & Wang, D. (2013). Architectural research methods. Segunda Edição. [e-book]: New York: John Wiley & Sons, 2013.

Guida, G., Tian, R., Dong, Y. (2021). Multimodal Virtual Experience for Design Schools in the Immersive Web. In: CONFERENCE ON EDUCATION AND RESEARCH IN COMPUTER AIDED ARCHITECTURAL DESIGN IN EUROPE (eCAADe), 39., Vol.1, 2021, Novi Sad. Proceedings [...]. Novi Sad: Digital Design Center, University of Novi Sad, 2021. p. 415-424.

Hiilesmaa, L., et al. (2021). Heritage Education: Computational Design of the Virtual Exhibition at the Cultural and Scientific Divulgation Center of USP. In: International Conference of the Iberoamerican Society of Digital Graphics (SIGraDi), 25., 2021. Proceedings [...]. São Paulo: Blucher,, 2021. p. 605-616.

Jerald, J. (2016). The VR Book: Human-centered Design for Virtual Reality. 1. ed. The Association for Computing Machinery and Morgan & Claypool Publishers. p.1-43. ISBN:978-1-970001-12-9.

Lima, E., et al. (2021). Comparative Study between 2D and 3D Digital Freehand Drawing Applied to the Architectural Design Process. In: International Conference of the Iberoamerican Society of Digital Graphics (SIGraDi), 25., 2021. Proceedings [...]. São Paulo: Blucher,, 2021. p. 1065-2076.

Peffers, K. et al. (2007). A Design Science Research Methodology for Information Systems Research. Journal of Management Information Systems, v. 24(3), p. 45–77.

Schenk, L. et al. (2014) Integrando Campus e Bairro - Caracterização socioambiental do entorno da área 2 do Campus da USP São Carlos.

Samsung Eletronics Co.Ltd. (2020). End of service for Gear VR and Samsung XR. 2020. In: Samsung Support Troubleshooting. https://www.samsung.com/us/support/troubleshooting/TSG01111348/

Samsung Eletronics Co.Ltd. (2020) Gear 360 (2017). In: Samsung business wearabless - Gear 360 2017. https://www.samsung.com/pt/business/wearables/gear-360-2017/sm-r210nzwatph/

Schenk, L. et al. (2014) Integrando Campus e Bairro - Caracterização socioambiental do entorno da área 2 do Campus da USP São Carlos.

Silcock, D. et al. (2018). Tangible and Intangible Digital Heritage: Creating Virtual Environments to Engage Public Interpretation. In: CONFERENCE ON EDUCATION AND RESEARCH IN COMPUTER AIDED ARCHITECTURAL DESIGN IN EUROPE (eCAADe), 36., Vol.2, Lodz. Proceedings [...]. Łódź: Faculty of Civil Engineering, Architecture and Environmental Engineering, Lodz University of Technology, Poland, 2018. p. 225-232.

Voordijk, H. (2009). Construction management and economics: The epistemology of a multidisciplinary design science. Construction management and economics, 27. Taylor & Francis, p. 713-720, 2009.

Interactions & Collaborations: Codesign

Get Together: A digital platform for urban social participation

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Abstract. Citizens are the daily users of urban spaces and their facilities. It is important that they collaborate with local authorities for effective management, development, and maintenance of the cities they live in. Public participation although important is still developing in several European cities because its implementation poses difficulties. In this paper we argue that using digital technologies via a participatory digital tool, can empower citizens towards more engagement and collaboration on the city development. Despite the existence of several participation tools, we identified the lack of a tool that allows citizens to collaborate more actively in local development in a simple way. In this paper we introduce Get Together, a tool designed to improve collaboration between citizens and local authorities, that proposes a user experience that enables citizens to create design solutions, promote debate and perform a vote on the preferred solution, while having technical advice from municipal officials' specialists.

Keywords: Codesign, Digital technologies, User experience, Participation, Local development.

1 Introduction

Cities, more than a set of buildings and public spaces, are the result of social dynamics created by the lives of citizens that inhabit them. By having an active and participative role in the development of the spaces they inhabit, literature shows that citizens acquire a higher feeling of identity, ownership, and pride towards their living surroundings (Marschall, 1998; Sanoff, 2000, 2008).

There are several citizen participation initiatives and open urban data platforms that citizens can access, contribute with information, and discuss about their city, or even propose their own ideas for city development. Despite the existence of these participatory initiatives and platforms for web-based

data collection, the outcomes are not translated into architectural and urban planning design proposals (Nuojua et al., 2008).The problem identified is the lack of active collaboration of citizens on the design of the city in a simple and easy to use way. One way of acting on this problem is to develop a user-friendly and interactive digital platform to support co-design of local development projects that goes beyond the discussion and takes role in practice.

In this paper we introduce Get Together, a web tool intended to be a digital space in which citizens actively contribute by creating project proposals that reflect local requirements and are the basis for discussion among all stakeholders, to design a solution together. With Get Together, citizens participate in a transparent and collaborative way, in the creation, debate and voting of projects, while obtaining advice and feedback from experts in municipal authorities.

2 Participation and digital collaboration

2.1 Participatory and collaborative processes

Social participation in architectural design is a research topic that has been discussed since the 1960s by several authors such as Yona Friedman (1958), Sherry Arnstein (1969), John Carp (1986) and Fredrik Wulz (1986), and practiced in some project typologies and scales.

Relevant to the discussion is the distinction between what it means to participate and to collaborate, which gives rise to the distinction between participatory processes and co-design processes. Participatory processes are usually carried out with the participation of potential end users, who are invited to express their opinions and demands to be considered when the designers define the project proposals (Fröst & Warren, 2000). The inherent collaboration of co-design processes, implies more active involvement than the one observed within a participatory process, meaning that, in co-design, all participants contribute actively and in a balanced way to the proposal and presupposes that they contribute to the design definition (Stelzle & Noennig, 2019). In short, participation is related to approval of the designers' solutions and co-design is related to an active collaboration during the design phases.

Regarding the design process, participatory design encompasses tools and techniques that involve designers and non-designers in creating new future scenarios. Sanders and Stappers (2014) state that probes (e.g., questionnaires, surveys, and interviews) are used to gather information from users since they are designing for them, while toolkits (e.g., set of physical artefacts) are used to design with them, thus providing non-designers with means to generate the solutions themselves. Faliu et al. (2018) believe that these tools should help non-professionals to express their ideas through the

creation of proposals, otherwise their participation will be limited to the visualization of proposals made by the designers and final feedback. Accordingly, Brandt et al. (2012) refer that “making” activities allow externalizing thoughts and develop tactic knowledge, and toolkits help to create and visualize scenarios. To empower participation different toolkits can be used, like paper mockups, 2D images, stickers, and 3D objects. These authors argue that toolkits are adequate for non-designers since they provide users with graphic components to express their ideas.

However, technicians tend to take control because they are not receptive to proposals production by non-designers (Nuojua et al., 2008). In this line, for a more democratic process, Botero and Saad-Sulonnen (2010) argue that authorities need to reconsider the role of citizens and provide the necessary tools for them to actively contribute to the design process. Huybrechts et al. (2012) introduced Map-it, a toolkit for architectural and urban design, developed to promote discussion and encourage designers to release control over the process. Participants are asked to set up map-based design projects with cards and assign stickers that trigger the confrontation of different opinions

2.2 Digital technologies and collaboration

According to Kwiecinski et al. (2017), there is a lack of effective communication channels between the architect, the design’s final users, and other stakeholders. The authors state that the traditional process of direct discussion is limited by the number of possible participants in the same space, and that there is a need to explore alternative communication channels to reach a wider audience.

Furthermore, the visualization possibilities are critical, since they determine how understandable and clear the design proposal is to the user. Users must be able to understand what is presented, as they lack the skills to interpret technical drawings the same way as professionals. Fröst (2002) argues that a clear and simple visualization assists the understanding of the project by non-designers, avoiding inequalities and providing more information for decision making.

Digital technologies and tools play a crucial role when it comes to supporting collaboration, as they enable new communication channels and simple ways to understand and interact with a design.

Several authors have investigated the requirements for designing computational tools to allow both communication and collaboration during the architectural design process (Achten, 2002; Chiu, 2002), as well as learning through collaborative games (Antle et al., 2011; Collazos et al., 2007; Wendel et al., 2013). These authors highlighted that collaboration is highly dependent on the interaction between participants, and computational tools should include channels of communication and data exchange between them, as well as design-enabling features.

For creating design solutions, not only the visualization possibilities are critical but also the computational tools should provide easy interaction so that users focus their attention on the task, rather than on how to use the tool.

Münster et al. (2017) state that traditional participatory methods can be enhanced with the use of digital technologies. Nuojua et al. (2008) propose map-based participation methods to focus the communication between the citizens and other stakeholders on issues relevant to the planning process. The authors found that web-based mapping solutions support well the traditional methods used in the participatory urban planning process and can reach wider audiences. Draggable digital elements can simulate gestures performed in traditional processes, e.g., when assigning stickers to a printed map. However, besides the use of online maps, we believe that new digital versions of traditional participatory design methods, particularly for the visualization and understanding of the planning sketches, are needed.

2.3 Digital platforms for citizen participation

There are several platforms that accommodate in some extent the issues mentioned regarding participation. In this section, we present some examples of tools for information exchange through open data, citizen information reports and exchange of geolocated data, community discussion, and collaboration in activities.

Exemples of open data platforms are the Lisboa Aberta (Open Lisbon) portal (Câmara Municipal de Lisboa, 2018) and Lisboa Interativa (LXi) (Interactive Lisbon) (Câmara Municipal de Lisboa, 2021a). Lisboa Aberta is an open data platform about the city of Lisbon, constantly updated, with information on different sectors and services such as mobility, energy, and urban planning. The data is produced by the Lisbon City Council (CML) and by partner entities of the Lisboa Aberta program. The Lisboa Interativa (LXi) is a CML's web platform that provides georeferenced information about the city, as location of public services and facilities, urban furniture, bicycle circulation networks, urban management plans, among others. The open data is based in a geographic information system (GIS) and can be reused.

For the bidirectional exchange of information and geolocated data, other map-based platforms include Waze (Waze Mobile, 2021) and Na Minha Rua LX (Câmara Municipal de Lisboa, 2021b). Waze is a web tool and app that allows users to contribute with real-time information about traffic, such as accidents and slow points, while having access to warnings about road works, road traffic jams and lane interdictions. The platform promotes a participatory policy in the management of infrastructure in cities since this data informs authorities of necessary intervention points. Na Minha Rua LX is a platform where citizens can report incidents occurring in the maintenance of public spaces, municipal facilities, municipal housing, and urban hygiene, and are notified when the reported incident is solved.

Regarding the participation of citizens in the city development, manage and maintenance, Urban Mediator (Botero & Saad-Sulonen, 2008, 2010) and Web Map Media (Nuojua et al., 2008) platforms exist to enable discussion among users. Urban Mediator is a software tool that provides for communities the possibility to create, obtain, and share location-based information and engage in discussions. The system is envisioned as a mediator between city official systems and community-driven discussions. Also, Web Map Media was developed to collect local information from citizens for urban planning purposes and opens the resulting plan for public discussion.

Regarding collaboration in activities, the Lisbon City Council promotes a participatory budget (Câmara Municipal de Lisboa, 2021c) through a website that aims to gather ideas from citizens for local development. Proposals from different thematic areas are submitted and, after a voting period, a small number that ranked higher in the vote, are selected to be implemented, under the participatory budget. These proposals are submitted as text descriptions and photographs of the intervention place. Other examples include Futura: The Sustainable Futures Game (Antle et al., 2011). Futura is an educational game that promotes collaboration between players while managing themselves the use of the territory to minimize impacts on the environment. Also, Kwiecinski et al. (2017) conducted a collaborative design workshop to test a platform in which they proposed the use of augmented reality and parametric design as enabling technologies to support collaboration. The given task was for the participants to co-design a public equipment (multifunctional bench) using a tool that allowed them to explore multiple options in an automated way.

The U_CODE project (Stelzle & Noennig, 2019) includes a set of digital tools to help citizens collaborate in large design projects for public spaces and facilities. The goal is to enable citizens to create their own proposals, which are developed and debated by them in face-to-face sessions using advanced technologies, such as virtual reality and multi-touch table.

3 Get Together

As mentioned before, Get Together tool supports co-design by giving users a means to create their own design proposals, with the aim to improve collaboration between citizens and local authorities in local development. For that, the tool is designed to be linked to the city official website since, as Botero and Saad-Sulonen (2008, 2010) state, neither scattered community discussions nor top-down initiatives are fruitful if they do not involve both parties. The target audience are local authorities (as the ones implementing the tool for the city development) and citizens wanting to actively contribute to local development (as the end-users).

In Get together, the process of participation and collaboration, encompasses four phases (Figure 1) creation of proposals; 2) public debate; 3) voting; 4) and project follow-up.

During the first phase of creation of proposals, citizens will be able to participate individually, designing the projects according to what they identify as a need for a particular location. Proposals are georeferenced. Citizens, users of Get Together tool, can access all proposals unless some proposal is created with the aim of involving only the residents of a specific neighborhood.

In the second phase (debate phase), citizens can visualize proposals and debate with other users about them, particularly, on how to improve them according to everyone's opinion. The debates are accompanied by professionals, who act as mediators and provide expert technical advice.

When the deadline for discussion of proposals is reached, there is a voting period, the third phase, to elect the proposal that citizens would like most to see implemented and that will therefore be submitted for municipal approval and further execution.

Lastly in the follow-up phase, the proposals that have been selected by the citizens are announced. The local authorities' technicians work on the chosen proposals and produce the parts still necessary for the project's licensing, in accordance with all regulations and technical requirements. The entire process is therefore transparent and, as such, citizens can follow the progress and understand the different phases and requirements of such public development, including the design, licensing, and construction processes.

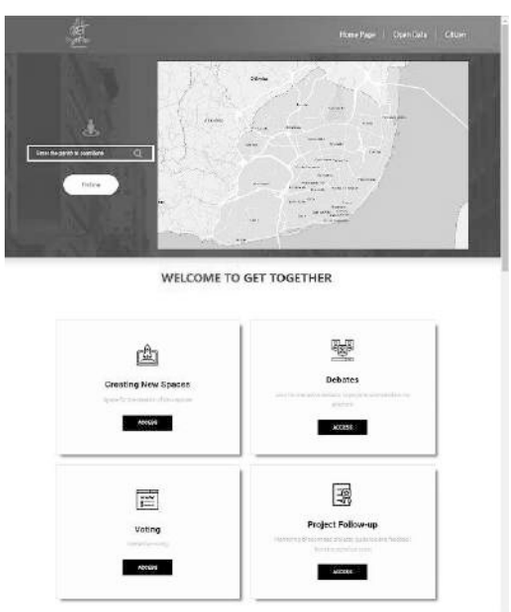

Figure 1: Home page of Get Together, by scrolling down the user can access to the four phases of Get Together process and decide to which phase he/she wants to go.

The tool is based on a map that is shared by all the participants and where they can simultaneously create projects, that are georeferenced and identified with a tag, once they are submitted. In the other phases (debate, vote and project follow-up) projects are accessed through these tags on the map. Get Together uses Lisboa Interativa map (LXi) since the tool was designed for working with Lisbon open data. Thus, the delimitation of the intervention area (Figure 2) is made with the LXi features. Nevertheless, if the tool would be applied to other cities, the map origin would be replaced by Google maps (Google, 2022), Open Street Map (Contributors, 2022) or the GIS map of the specific city.

To create design proposals (Figure 3), the tool includes a library of image icons (side bar), organized into categories (horizontal menu), available for users to drag onto the design (main screen). These icons are adapted to the type of project that is being designed Project categories are: “Mobility”, “Accessibility”, “Health”, “Education and culture”, “Social life”, and “Leisure and sport”. The example of Figure 3 shows the categories (horizontal menu) for a “Leisure and sport” project. These include “Equipment”, “Public furniture”, “Vegetation”, and “Floors”. When dragged from the library (side bar), the image icons automatically adjust to the project’s type of representation (top view) and become georeferenced. This automatic fit allows them to be selected while they are represented in a more identifiable way by using a 3D representation and only when are dragged onto the map, they assume a 2D orthophoto map view form.

When proposals are submitted, they are added to the general map and located by a tag (Figure 4). In the debates, voting and project follow-up areas, access to the projects is done through these tags, identified with a name and the icon according to the category of project that was submitted in that location.

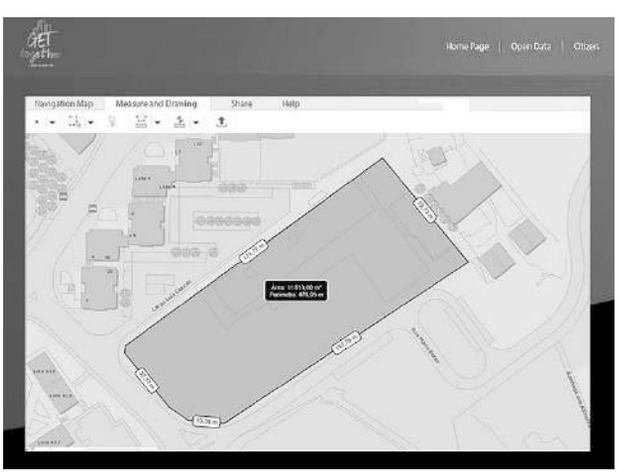

Figure 2: Delimitation of the intervention area on Get Together, using LXi features.

Figure 3: Create proposals interface for Leisure and Sport category. Public furniture is selected, and library items can be dragged. 1 - main screen, 2 – horizontal menu, 3 – sidebar.

To access the project proposals, users click on the respective project's tag and its information appears (Figure 5). This information includes the project's name, area, description, images, 3D models, audiovisual data, etc. The options for debating, voting, or obtaining more information about the project depend on the area in which it was accessed (debate, voting, or project follow-up). In the "Debate" area, participants can choose whether they want to leave a comment or enter a video call to debate with other users while viewing the project on the shared map. In the "Voting" area, participants can visualize the projects and the comments and cast their vote. In the project follow-up area, the user can visualize the information about the project and its status.

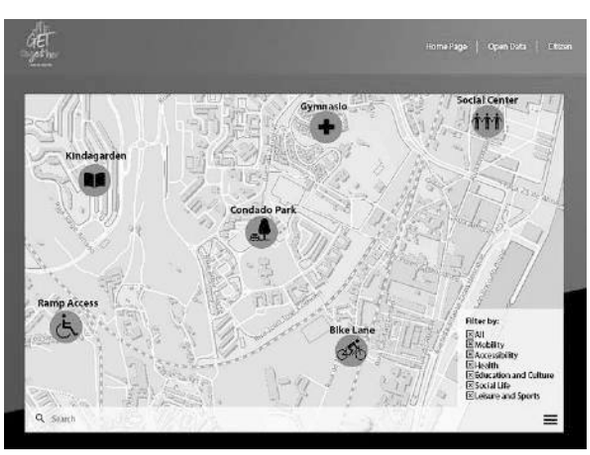

Figure 4: Visualization of a map showing submitted projects tagged with different category icons and filter option below right.

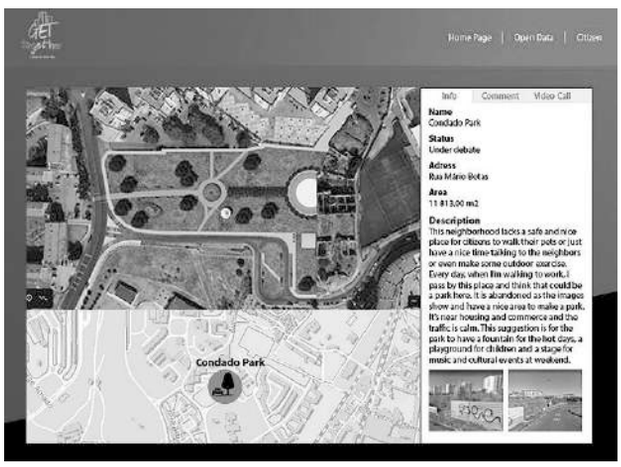

Figure 5: Visualization of a map with a design identified.

4 Discussion

Effective management, development, and maintenance of cities depends on social participation in urban and architectural projects, since citizens (final users) are the ones who have the experience of using spaces. Local authorities need this social knowledge for the solutions implemented to be accepted by citizens, who feel more empathy for the places if they have contributed to its creation (Sanoff, 2008). Despite this, social participation in architectural and urban design still lacks effective communication channels and easy to use design tools.

Some of the platforms mentioned on this paper aim to contribute to cities' management and maintenance as well as to the collaboration of citizens by contributing with their own ideas. However, these tools do not allow the creation of design solutions. City officials are not receptive about letting non-designers to produce design solutions, and the lack of skills to understand technical drawings experienced by most citizens, poses some barriers in the collaboration.

In this paper we argued how digital tools can improve collaboration between citizens and local authorities, by introducing a tool that aims to allow citizens to actively contribute with the creation of their own design proposals. The fact that Get Together provides easy-to-use tools and interactive ways of visualizing allows users to have a deeper understanding of the design solution. This is relevant since users are people without architectural and design skills. Therefore, the tool favors the quality of projects allowing users to combine elements to create solutions in an informed way.

Additionally, our web-based solution allows to broaden the audience, encouraging communication and discussion through debates on the proposals

submitted. Also, the proposals created in Get Together are chosen by citizen voting, instead of being selected by designers, which gives them an opportunity to participate in decision-making. This democratic process empowers citizens and encourage them to further engage with urban development.

Get Together is a tool under development, and future work is needed. Also, testing and evaluation with potential end-users are required and foreseen as future work, to obtain more concrete results. We envision that Get Together can improve collaboration, by providing non-designers with the tools for “making”, using draggable library graphical elements that can be combined to create design proposals. Our tool brings traditional techniques to the digital realm, taking advantage of its automation and visualization capabilities, for better understanding and finding common ground between designers and non-designers.

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References

Achten, H. (2002). Requirements for Collaborative Design in Architecture. In H.J.P. Timmermans & B Vries de (Ed.), Proceedings of the 6th Design and Decision Support Systems in Architecture and Urban Planning- Part one: Architecture Proceedings Avegoor (pp. 1–13).

Antle, A., Bevans, A., Tanenbaum, J., Seaborn, K., & Wang, S. (2011). Futura : Design for Collaborative Learning and Game Play on a Multi-touch Digital Tabletop. Proceedings of the Fifth International Conference on Tangible, Embedded, and Embodied Interaction, 93–100. https://doi.org/https://doi.org/10.1145/567752.567774

Arnstein, S. R. (1969). A Ladder Of Citizen Participation. Journal of American Institute of Planners, 35(4), 216–224. https://doi.org/10.1080/01944366908977225

Botero, A., & Saad-Sulonen, J. (2008). Co-designing for new city-citizen interaction possibilities: weaving prototypes and interventions in the design and development of Urban Mediator. Proceedings of the Tenth Anniversary Conference on Participatory Design 2008 (PDC ’08), 266–269. http://portal.acm.org/citation.cfm?id=1795296

Botero, A., & Saad-Sulonen, J. (2010). Enhancing citizenship: The role of in-between infrastructures. Proceedings of the 11th Biennial Participatory Design Conference (PDC ’10), 81–90. https://doi.org/https://doi.org/10.1145/1900441.1900453

Brandt, E., Binder, T., & Sanders, E. B. N. (2012). Ways to engage telling, making and enacting. In Routledge International Handbook of Participatory Design (pp. 145–181). Routledge. https://doi.org/10.4324/9780203108543

Câmara Municipal de Lisboa. (2018). Lisboa Aberta - Catálogo de dados abertos. http://lisboaaberta.cm-lisboa.pt/index.php/pt/dados/catalogo-de-dados-abertos

Câmara Municipal de Lisboa. (2021a). LXi - Lisboa Interativa. https://websig.cm-lisboa.pt/MuniSIG/visualizador/index.html?viewer=LxInterativa.LXi

Câmara Municipal de Lisboa. (2021b). Na minha rua LX. https://naminharualx.cm-lisboa.pt

Câmara Municipal de Lisboa. (2021c). OP Lisboa. https://op.lisboaparticipa.pt/

Carp, J. C. (1986). Design participation: new roles, new tools. Design Studies, 7(3), 125–132. https://doi.org/10.1016/0142-694X(86)90048-7

Chiu, M.-L. (2002). An organizational view of design communication in design collaboration. Design Studies, 23(2), 187–210. https://doi.org/10.1016/S0142-694X(01)00019-9

Collazos, C., Guerrero, L., Pino, J., Ochoa, S., & Stahl, G. (2007). Designing Collaborative Learning Environments Using Digital Games. Journal of Universal Computer Science, 13(7), 1022–1032.

Contributors, © OpenStreetMap. (2022). OpenStreetMap. www.openstreetmap.org

Faliu, B., Siarheyeva, A., Lou, R., & Merienne, F. (2018). Design and Prototyping of an Interactive Virtual Environment to Foster Citizen Participation and Creativity in Urban Design. Proceedings of 27th International Conference on Information Systems Development, Sweden, 1–13. https://doi.org/10.1007/978-3-030-22993-1_4

Friedman, Y. (1958). Manifesto Architecture Mobile. http://www.yonafriedman.nl/?page_id=225

Fröst, P. (2002). Interactive Tools for Collaborative Architectural Design. Proceedings of the 6th International Conference on Design and Decision Support Systems in Architecture, 134–147.

Fröst, P., & Warren, P. (2000). Virtual reality used in a collaborative architectural design process. Proceedings of IEEE Conference on Information Visualization. An International Conference on Computer Visualization and Graphics, 568–573. https://doi.org/10.1109/iv.2000.859814

Google. (2022). Google Maps. https://www.google.pt/maps/

Huybrechts, L., Dreessen, K., & Schepers, S. (2012). Mapping design practicess: on risk, hybridity and participation. Proceedings of the 12th Participatory Design Conference: Exploratory Papers, Workshop Descriptions, Industry Cases - Volume 2 (PDC ’12), 29–32. https://doi.org/https://doi.org/10.1145/2348144.2348155

Kwiecinski, K., Markusiewicz, J., & Pasternak, A. (2017). Participatory Design Supported with Design System and Augmented Reality. Proceedings of the 35th ECAADe Conference- Shock! Sharing of Computable Knowledge, 2, 745–754.

Marschall, S. (1998). Architecture as Empowerment: The Participatory Approach in Contemporary Architecture in South Africa. Transformation: Critical Perspectives on Southern Africa, 35, 103–123.

Münster, S., Georgi, C., Heijne, K., Klamert, K., Noennig, J. R., Pump, M., Stelzle, B., & van der Meer, H. (2017). How to involve inhabitants in urban design planning by using digital tools? An overview on a state of the art, key challenges and promising approaches. Procedia Computer Science, 112, 2391–2405. https://doi.org/10.1016/j.procs.2017.08.102

Nuojua, J., Juustila, A., Räisänen, T., Kuutti, K., & Soudunsaari, L. (2008). Exploring Web-based Participation Methods for Urban Planning. Proceedings of the Tenth Anniversary Conference on Participatory Design 2008 (PDC '08), 274–277. https://doi.org/10.1145/1795234.1795298

Sanders, E. B. N., & Stappers, P. J. (2014). Probes, toolkits and prototypes: Three approaches to making in codesigning. CoDesign, 10(1), 5–14. https://doi.org/10.1080/15710882.2014.888183

Sanoff, H. (2000). Community Participation Methods in Design and Planning. In Landscape and Urban Planning. https://doi.org/10.1016/s0169-2046(00)00063-3

Sanoff, H. (2008). Multiple Views of Participatory Design. International Journal of Architectural Research, 2(1), 57–69.

Stelzle, B., & Noennig, J. R. (2019). A method for the assessment of public participation in urban development. Urban Development Issues, 61(1), 33–40. https://doi.org/10.2478/udi-2019-0005

Waze Mobile. (2021). Waze. https://www.waze.com/

Wendel, V., Gutjahr, M., Gobel, S., & Steinmetz, R. (2013). Designing collaborative multiplayer serious games. Escape from Wilson Island — A multiplayer 3D serious game for collaborative learning in teams. Education and Information Technologies, 18, 287–308. https://doi.org/10.1007/s10639-012-9244-6

Wulz, F. (1986). The concept of participation. Design Studies, 7(3), 153–162. https://doi.org/10.1016/0142-694X(86)90052-9

Interactions & Collaborations: BIM Adoption

The development of a BIM Execution Plan for contracting public work projects

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Abstract. Building Information Modeling (BIM) is the current expression of innovation in the construction industry, a set of technologies, processes and policies that affect the deliveries, the relationships, and the roles of the civil construction industry. In Brazil, BIM is still scarce, especially in the public sector. Due to this problem, this study aims to elaborate a BIM Execution Plan for public works project contracts. The focus of this study is a public institution in the state of Ceará. For the development of this study, we adopted the Design Science Research method. As a result, we obtained a BIM Execution Plan that served as a foundation for the elaboration of BIM projects in the public institution in question. Therefore, this study contributes to the reduction of the main errors in BIM project contracting and, as a result, to the dissemination of BIM in the state of Ceará.

Keywords: BIM, BIM Execution Plan, BIM Implementation, Public Sector, ISO 19650.

1 Introduction

In Brazil, the implementation of BIM is still in its early stages. Its standardization, through the efforts of the Ministry of Development, Industry and Foreign Commerce and the Brazilian Association of Technical Standards (ABNT), is still recent. Currently, there are ABNT standards that cover information modeling: ABNT NBR ISO 12006 (Building construction — Organization of information about construction works); ABNT NBR 15965 Construction information classification system); NBR ISO 19650 (Organization of information about construction works information management using building information modeling).

From a legal point of view, there are a series of authors whose efforts focused on describing the most common problems related to contract topics (Arensman; Ozbek, 2013; Pandey; Shabodaghlou; Burger, 2016; Larson; Golden, 2017; Lowe; Muncey, 2009; Eadie; McLernon; Patton, 2015; Lip,

2012; Porwal; Hewage, 2013; Abdullah Habib, 2017; McAdam, 2010; Ashcraft, 2008). Through bibliographic research, the most common contractual problems were surveyed and categorized into 5 types: information responsibility; rights to intellectual property; project standard; data reliability; model status.

Due to the flow of information generated by the different types of professionals in BIM projects, conflicts can occur, caused by the loss of control over the responsibility of each information (Eadie; McLernon; Patton, 2015). Thus, the importance of a contractual definition for the correct assignment of the obligations of each party involved in the process is highlighted (Lip, 2012). One of the ways to achieve this is through the elaboration of a robust protocol model that eliminates any doubts, to provide the creation of a collaborative work model (Lip, 2012).

The BIM work environment is predominantly collaborative (Eadie; McLernon; Patton, 2015). This methodology aims to create a database that can be used by third parties for different occasions, allowing these professionals to have access to all information in the model (Lip, 2012). In a certain way, this characteristic can influence the generation of problems involving copyright, going from the sharing of this information to the plagiarism of ideas and projects (Eadie; McLernon; Patton, 2015).

The contractual issue that is related to the project standard concerns the level of project detail that designers must have to meet customer expectations. The new design pattern introduced by BIM helps to reduce the number of errors and, gradually, makes customers have higher expectations regarding the deliverables (Arensman; Ozbek, 2013; Eadie; McLernon; Patton, 2015). Thus, the importance of a contractual definition for the level of acceptance of each project is highlighted, considering an established acceptance standard. In addition, this standard is defined as a way to guarantee the quality of the information contained in the model, since the level of information sharing made possible by BIM requires a high degree of reliability in order to avoid detailed verifications about errors and failures in later steps (Foster, 2008).

The contractual problem that involves the trust of the data concerns the level of credibility of the project. Issues caused by the occurrence of design errors must be formally considered as it is necessary for the correct attribution of responsibilities (Lip, 2012). It is worth mentioning that the occurrence of these errors can be caused by technical or software interoperability problems that, in some cases, are independent of the designers (Lip, 2012).

The contractual problem that involves the model status concerns the level of updating of the two-dimensional drawings that are extracted from the BIM model (Abdullah Habib, 2017). These drawings are subject to being outdated at the time of obtaining them, as the models undergo constant changes. In this way, the conflict arises that addresses the perspective of whether the BIM model should be part of the deliverables defined in the contract or not (Ashcraft, 2008; McAdam, 2010). Therefore, the need for a prior contractual

definition on the delivery of the model is emphasized so that more reliable and updated data are obtained from the project to be delivered.

The study was developed in a public institution, in the state of Ceará (Brazil), responsible for attending to demands of project development, construction planning and execution, and building and state highway maintenance. Considering the large demand for projects and construction, and the limitation of resources (financial, time and personnel), it is fundamental that the project process increases the aggregation of value and eliminates waste. In other words, the aim is to: improve the project quality, the information management for planning and control of constructions, and the operation and maintenance of buildings; reduce project development time, project errors, and contractual additives. Thus, the adoption of BIM technologies, processes and policies is fundamental. In this sense, the standardization of information and data development, management and usage during the project contracting phase becomes necessary.

The BIM Execution Plan (BEP) is the document that summarizes objectives, responsibilities, and products during the process of project planning and development (Amorim, 2020). The ISO Standard 19650:2017 standardizes the creation, management, and utilization of BIM information. However, it is still necessary to have a specific approach for the public sector. In the current construction business environment, it is imperative to denote that public and private projects have their own distinct features and characteristics. For instance, public infrastructure projects are deemed to be complex, require huge resources, and are typically financed by either government or international donors. Hence, implementing BIM in these projects is distinct from the technological and innovation point of view and requires careful adoption strategies (Belay; Goedert; Woldesenbet; Rokooei, 2021).The main different between a BEP for the private sector and one for the public is that the one used on private sector is normally only focused on the project phase and, at most during the construction. A BEP used in the public sector needs to contain information about the entire life cycle of the building, since they are responsible for the maintenance of the building. Therefore, a BEP for public works contracts needs to guarantee that all the necessary information for the life cycle of the building is properly described.

Taking this into consideration, a question is raised: how does one elaborate a BEP for the development of public works projects in BIM? This task stems from the hypothesis that the BEP must be adapted to the public works contract specificities in order to contribute to the definition of contractual models that are more coherent with the public sector's reality. The main objective is to elaborate a BEP for public works contracts. The specific objectives aim to: identify support tools for BEP elaboration; identify support tools for BIM project collaboration and coordination; and propose a workflow for the BIM project process.

2 Methodology

This study was developed through the Design Science Research (DSR) strategic methodology, which aims to produce innovative constructions with the intent of resolving real-world problems and, therefore, also contributing to the theory of the subject in which it is being applied (Lukka, 2003). The usual manner of doing DSR is to construct and evaluate (March; Smith, 1995). Thus follow the stages: diagnostic, proposition, and evaluation.

At the diagnostic stage, the description of the process for the contracting and development stage of the projects in the institution was made, the survey of literature works that propose methods and models of BEP elaboration and the survey of tools for the collaboration and coordination of BIM projects were done. For this stage, we developed documentary research, bibliography survey and interviews with architects and engineers. Based on this, we mapped the current workflow to identify how BIM could improve the design process.

At the proposition stage, based on diagnostics and tool survey, the project requisites that composed the BEP were defined and a workflow based on the defined requisites was developed. These propositions composed the BEP, which followed the standards of ISO 19650. At this stage, we also modeled a project to simulate the protocols established at the BEP and the application of the proposed tools.

At the evaluation stage, the results were discussed with the expert team of the public institution to evaluate the developed workflow and verify potential improvements in interoperability, collaboration and integration.

3 Results

As a result of the diagnostic stage, it was possible to identify the main problems of the actual contracting process in the institution. Among them are: difficulties of integration and collaboration between projects due to the sequential and linear project process; lack of project development standards; poor definition of project requirements and development level and lack of definition of responsibilities.

Through the tools surveyed for the development of the BEP, the online platform called Plannerly was chosen. It has, in its free version, the requirements necessary for the elaboration of a BIM Execution Plan structured scope based on the ISO 19650.

Figure 1 shows the main interface of the platform used for the development of the plan.

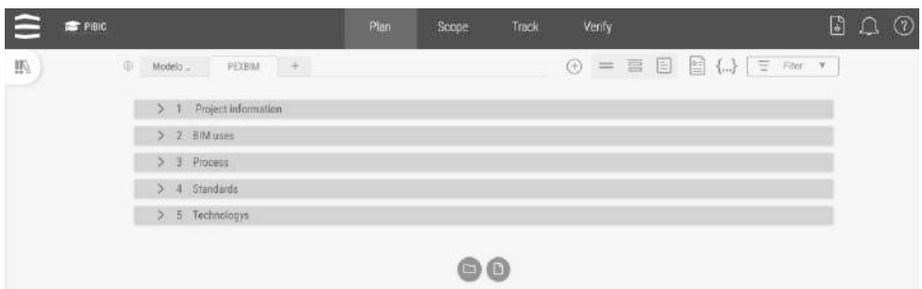

Figure 1. The platform's interface. Authors, 2022.

Through it, a document that contains two main parts for this study, the Plan, and the Scope, has been obtained as a result. The first is divided in 5 topics.

- Project information: in which the purposes and BIM uses in this BEP, and the basic information about the project is explained.
- BIM uses: the section that describes the roles and the responsibilities for each part;
- Process: this part of the plan contains the milestones and the level of development required for each one, what should be delivered at which point of the project process, when and where the meetings should happen, and where the files should go and in which format;
- Standards: this section explains every type of standard present in the project, from how the file should be named to where the project should be positioned in the software and;
- Technologies: this final section has information about the BIM software that can be used for each kind of project and the versions that are compatible. In general, it explains which information is needed, who is responsible to provide that information and how it should be structured. Providing the graphic value desired by the public institution.

The scope has all the objects that need to be contained in the project and how they should be represented depending on the phase (Preliminary study, Basic project, or Executive project). It also determines who is responsible for each representation (as show in Figure 2). In addition, it was also possible to create a scope with all the project phases, explaining which phases can happen simultaneously, and which should be completed prior to the rest.

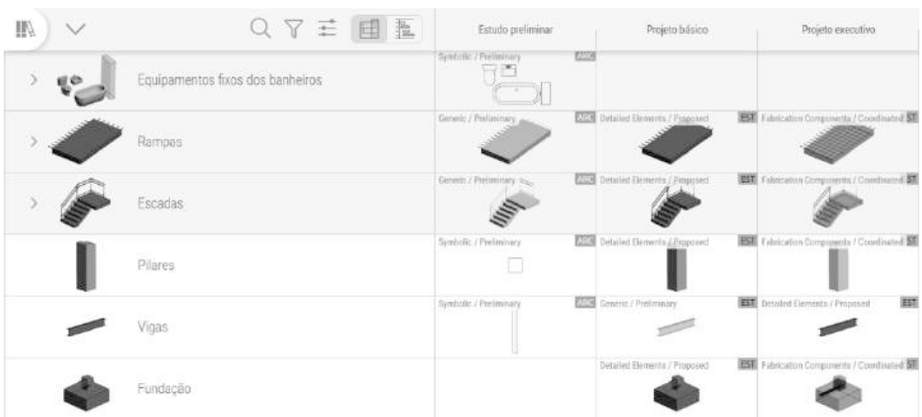

Figure 2. A part of the scope proposed to the public institution. Authors, 2022.

Figure 3. An example of delivery needed during the preliminary study. Authors, 2022.

The figure above (Figure 3) represents building components in the first column, with all subsequent columns representing the Level of Development of the object (LOD) in each project phase, each column representing a phase. At the top right corner of the cells that represent the LOD, is the name of the team responsible for the project. In this example, the architectural team (ARC) is responsible for the preliminary study. In the top left corner, it is informed at what LOD the building component is at, in its respective project phase. These can be: Symbolic/Preliminary, Generic/Preliminary, Detailed elements/Proposed, Fabrication components/Coordinated or Detailed elements/As built.

Besides that, the platform named BIM Collab was chosen for 3D visualization of the models to check possible clashes between the multidisciplinary projects. This verification is pre-established in the BEP through the project process, during the stage of basic project. The objective in this phase is to avoid design mistakes that in the traditional project process would only be identified later in the construction stage.

A new workflow was also proposed, that would be more adequate to the BEP and would allow collaborative work between the architectural team and the engineer team.

Figure 4 shows the actual workflow used at the institution. It is a process that tends to be slower because it requires some designs to be completed before others and there are no collaborations during the design process that are made simultaneously. This generates a longer interference correction phase.

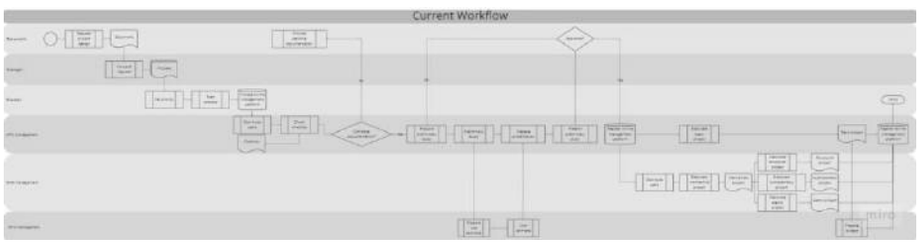

Figure 4. The current workflow at the public institution. Authors, 2022.

In the proposed workflow (Figure 5), the basic projects are developed simultaneously, creating a more collaborative process in which interferences can be checked and corrected during the process.

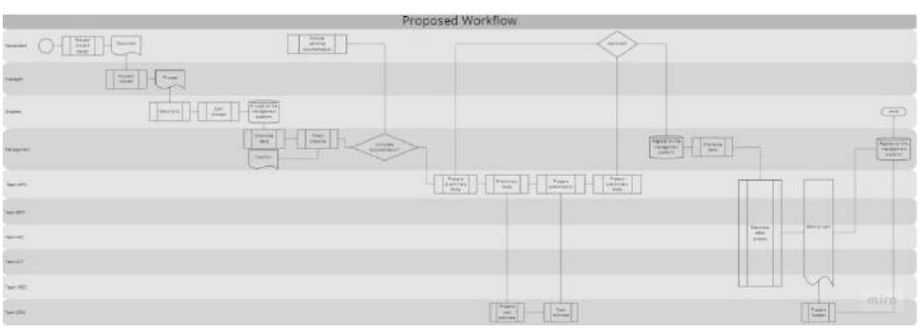

Figure 5. The proposed workflow. Authors, 2022.

Which these two platforms and the proposed workflow, it was possible to deal with the most frequent contractual problems. The responsibility of the information is determined by the team that produced it, whose responsible member is nominated at the beginning of the project. As for intellectual property rights, the verification of models takes place through a platform (BIM Collab) that makes it impossible to change the source file. This way, only members of the responsible team have access to that information, which also guarantees the intellectual property rights of the designers of that discipline and ensures confidence in the data. As for the project standard, this is

guaranteed by the BEP, which explains the LOD and the information that must be contained in each project and project object.

In addition, the BEP also establishes which software must be adopted by each team and which format must be adopted for deliverables. The model status should follow the weekly updates on the viewing platform to ensure that new interferences are not occurring. With this, the BEP created is suitable for public works contracts because it creates a way to verify and guarantee that all the information needed for the building life cycle is described, and in the case that it is not, who is responsible for the information can be easily identified. Another important characteristic is that the BEP describes the roles and the responsibility for each part, considering the particularities of public contracts.

4 Discussion

The evaluation of the results was done through discussion of the proposal with the expert team members of the institution. It was identified that the platform for BEP development facilitates the formalization of work protocol, which, in turn, favors the flow and the standardization of information and contributes to the reduction of errors and reworking. Other positive points are the identification of the LOD of the model via a visual scale, the detailing of the parameters of each object that should be informed, and the indication of how the information should be structured in each LOD.

In the studied case, the information should be structured in order to facilitate the extraction of quantitative data in the next stage, budgeting.

It is highlighted that the new workflow for the BIM project is potentially viable and optimizes resources and time. However, this hypothesis still needs to be validated through an application of the proposed flow in the development of a real-life project.

At the end of the study, the contribution of the developed BEP to the reduction of common contractual problems (information responsibility; intellectual property rights; project standard; data reliability; model status) is perceivable. Ultimately, the adoption of BIM by the public sector will result in encouraging the adoption of BIM in other sectors of the Architecture, Engineering and Construction industry.

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References

ABNT. NBR ISO 12006: Building construction — Organization of information about construction works, 2018.

ABNT. NBR 15965: Construction information classification system, 2022

ABNT. NBR ISO 19650: Organization of information about construction works information management using building information modeling, 2022.

Abdullah Habib, S. N. H. (2017) Critical success factors and contractual risks for Private Finance 2 (PF2) projects implementing Building Information Modelling (BIM). 2017. 351 f. Tese (PhD) - School of Built Environment, University of Salford.

Amorin, S. R. L. Gerenciamento e coordenação de Projetos BIM: um guia de ferramentas e boas práticas para o sucesso de empreendimentos. Rio de Janeiro: LTC, 2020.

Arensman, D. B.; Ozbek, M. E. (2012) Building information modeling and potential legal issues. International Journal of Construction Education and Research, v. 8, n. 2, p. 146-156.

Ashcraft, H. W. (2008) Building information modeling: A framework for collaboration. The Construction Lawyer, v. 28, n. 3, p. 1-14.

Belay, S., Goedert, J., Woldesenbet, A., & Rokooei, S. (2021). Comparison of BIM Adoption Models between Public and Private Sectors through Empirical Investigation. Hindawi, v. 2021, 5577654, 13 pages.

Eadie, R.; Mclernon, T.; Patton, A. (2015) An investigation into the legal issues relating to building information modelling (BIM). Proceedings of RICS COBRA AUBEA 2015.

Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2011). BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors. (Second ed.). John Wiley & Sons Inc.

Larson, D. A.; Golden, K. A. Entering the brave, new world: An introduction to contracting for building information modeling. Wm. Mitchell L. Rev., v. 34, p. 75, 2007.

Lip, E. (2012) Building Information Modelling-Key Contractual Perspectives. KPK Research.

Lowe, R. H.; Muncey, J. M. (2009) Consensus DOCS 301 BIM addendum. The Construction Lawyer, v. 29, p. 17.

Lukka, K. (2003) The constructive research approaches. In Ojala, L. & Hilmola, O-P. (eds.) Case study research in logistics. Publications of the Turku School of Economics and Business Administration, Series B1, p.83-101.

March, S. T.; Smith, G. F. (1995) Design, and natural science research on information technology. Decision support systems, v.15, n.4, p.251-266, 1995.

Mcadam, B. (2010) Building information modelling: The UK legal context. International Journal of Law in the Built Environment, v. 2, n. 3, p. 246-259.

Pandey, A.; Shahbodaghlou, F.; Burger, J. (2016) Legal and Contractual Challenges of Building Information Modeling - Designers Perspectives. In: Construction Research Congress 2016, 2016, San Juan. Anais [...] San Juan. p. 519- 527.

Porwal, A.; Hewage, K. N. (2013) Building Information Modeling (BIM) partnering framework for public construction projects. Automation in Construction, v. 31, p. 204-214.

Saltaren, S. A., Tienda, J. L. P., Bucheli, L. G., & Aparicio, M. S. (2018) Implementation of BIM in infrastructure: the need to address it from the public sector. Building & Management, v. 2, issue 3, 2530-8157, 11 pages.

Augmented Reality Assessment for the Production of a Virtual Design Construction Model With BIM

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Abstract. The use of BIM combined with Augmented Reality (AR) and Virtual Reality (VR) technologies allows the development of Virtual Design Construction (VDC). However, such application isn't widespread in construction sites, which have their management and control performed in a traditional way. With this research, 05 applications were mapped that allow the use of BIM in conjunction with AR, listing the main uses of each application, and finally, an experiment was carried out on the use of AR on a construction site. The integration of BIM with RA makes it possible for the project manager to have the project information in loco. This context allows to collect and share construction information at the site during the building process.

Keywords: BIM Adoption, Augmented Reality (AR), Virtual Design Constrution (VDC), Construction Industry.

1 Introdução

O *Building Information Modeling* (BIM), caracteriza-se por ser a representação digital das características físicas e funcionais de uma edificação, o qual fornece informações que dão suporte as atividades do ciclo de vida da edificação (Wu et al., 2019). A Indústria da Arquitetura, Engenharia, Construção e Operação (AECO), quando comparada a outros setores, enfrenta dificuldades para incorporar e implementar novas tecnologias (Wang et al., 2020). Processos baseados em BIM são uma importante ferramenta no processo de inserção de tecnologias da Indústria 4.0(I4) na construção civil (Maskuriy et al., 2019; Newman et al., 2021).

Apesar de possuir ferramentas que dão suporte ao ciclo de vida construção, o BIM tem sido utilizado frequentemente nas etapas de desenvolvimento de projeto, esta presença não ocorre na etapa de execução da obra (Hamledari et al., 2018). Portanto, um dos principais usos do BIM é a melhoria nos processos de visualização dos projetos (Wu et al., 2019).

A integração de tecnologias digitais como BIM, Realidade Vistual (RV) e Realidade Aumentada (RA) tem dado subsídio para a construção do Virtual Design Construction (VDC). O VDC é uma plataforma de compartilhamento de informações de projeto que permite a visualização e interação com artefatos de projeto, de forma a otimizar os processos de projeto, segurança e gerenciamento (Afzal et al., 2021; Rafsanjani & Nabizadeh, 2021).

A RA possibilita que o ambiente físico possa ser sobreposto com informações digitais e substituir o que está sendo visto por elementos gerados computacionalmente (Chi et al., 2013; Afzal et al., 2021). Para que esta sobreposição ocorra é necessário que as informações do mundo real possam ser rastreadas para que os elementos digitais possam ser devidamente posicionados (Arena et al., 2022).

A RA e a RV figuram entre as principais tecnologias da I4 e têm sido utilizadas na construção civil para otimizar os processos de visualização, produtividade e segurança (Sepasgozar et al., 2021). A indústria AECO, por meio de VDC's, pode substituir métodos convencionais de: visualização de projeto, monitoramento, controle de atividades de fiscalização, gestão da informação, acompanhamento da obra, produção e planejamento do canteiro, etc (Chi et al., 2013; X. Wang & Love, 2012).

O VDC, modelo produzido a partir de um modelo BIM, associado a RA permite que informações construtivas possam ser acessadas e compartilhadas *inloco*, o que otimiza atividades de execução de uma edificação. Além da visualização é possível acompanhar o cronograma de obra, acrescentar e compartilhar informações que foram registradas na construção (Rafsanjani & Nabizadeh, 2021).

Este trabalho avalia aplicativos que permitam a produção de um VDC que possa dar suporte a etapa de construção, com enfoque na visualização de projetos e no acompanhamento de obra. Nesta pesquisa são apresentadas as funcionalidades dos aplicativos necessárias para a integração entre informação BIM e RA, que resultam em um modelo de VDC, e um teste de uma das ferramentas in loco. A análise e o experimento deram origem a um fluxograma de integração entre a RA e o informações de modelo geradas em BIM.

Este artigo apresenta a seguinte estrutura: a) Metodologia, em que são descritos os processos e métodos utilizados durante a pesquisa; b) Resultados e Discussão, com os resultados e as análises desenvolvidas; c) Considerações Finais.

2 Metodologia

Metodologicamente este trabalho é classificado como *Design Science Research*, uma vez que faz a proposição de um conjunto de prescrições (Dresch, Aline; Lacerda, Daniel Pacheco; Júnior, 2015) para auxiliar e otimizar o processo de inserção de RA em canteiros de obra a partir de modelos BIM. A pesquisa foi realizada em três etapas, sendo elas: a) Avaliação dos aplicativos; b) Teste *inloco* com uma das ferramentas; c) Proposição de fluxograma de integração entre informação produzida a partir de um modelo BIM e RA.

A primeira etapa corresponde a avaliação dos aplicativos para a visualização de modelos de tridimensionais de projeto em RA. Para a escolha dos aplicativos foram estabelecidas as seguintes funções:

a. Visualização do modelo em dispositivos móveis;
b. Representação do modelo em escala natural (1:1);
c. Inserção de informações, como notas e fotografias;
d. Acompanhamento de atividades executivas;
e. Integração entre o modelo da edificação com o cronograma in loco.

Além das funções dos aplicativos, para a RA, é necessário que os dispositivos possuam uma *Inertial Measurement Unit* (IMU). Uma IMU corresponde ao conjunto constituído por um giroscópio, magnetômetro e acelerômetro que irá mapear os movimentos do dispositivo (Lavalle, 2020).

Os aplicativos foram avaliados em uma escala de 0 a 5, em que 0 corresponde a ausência da função analisada, 1 a 5 reflete a presença da função, sendo 1 a presença, com fortes limitações na utilização, e 5 a presença e utilização plena. Essa pontuação foi somada para determinar quais as ferramentas eram mais eficientes.

A segunda etapa consistiu na avalição do uso de RA no canteiro de obras produzida a partir de modelos BIM. A obra escolhida para a obtenção dos resultados foi uma edificação em que os projetos (arquitetura, estrutura elétrica, incêndio e hidrossanitário) foram desenvolvidos com metodologia BIM e que estivesse em construção. O edifício escolhido foi o prédio sede do Parque de Inovação e Sustentabilidade do Ambiente Construído – PISAC, que está localizado no campus Darcy Ribeiro da Universidade de Brasília-UnB. Por fim foi um proposto um fluxograma de integração resultante da avaliação e caracterização dos aplicativos e do teste *inloco*. As análises dos aplicativos e o teste realizado na obra gerou o fluxograma de produção de VDC's para canteiros de obra.

3 Resultados e Discussões

3.1 Análise e Avaliação dos Aplicativos

Durante a realização do levantamento dos aplicativos e das ferramentas a serem utilizadas para a produção de um VDC, chegou-se a cinco aplicativos que atendiam aos requisitos estipulados, sendo eles: BIMx®, Dalux Viewer, Augin®, Dalux Field e GammaAR®. Os requisitos operacionais considerados e as especificações dos aplicativos estão apresentados na Tabela 1.

Tabela 1. Requisitos Operacionais dos aplicativos.

Requisitos	BIMx®	Dalux Field®	Dalux Viewer®	Augin®	Gamma-AR®
Sistema Operacional	iOS 12+ Android 8.0+	iOS Android 7.0+	iOS Android 7.0+	iOS Android	iOS 13+ Android 7.0+
Hardware mínimo	Dispositivos intermediários com IMU	Dispositivo com IMU, câmera e GPS	Dispositivo com IMU	Dispositivo com IMU, câmera e GPS	Dispositivo com IMU, câmera e GPS
Conexão de Internet	Uso offline e armazenagem em nuvem	Uso offline e armazenagem nuvem	Uso offline e armazenagem em nuvem	Uso offline	Uso offline e armazenagem nuvem
Tipos de licença	Gratuito	Pago, com versão gratuita por 15 dias	Pago e Gratuito para teste.	Pago, com versão gratuita	Pago, com versão gratuita por 30 dias

Fonte: Veras & Alves-Silva, 2022

Na página do fornecedor do BIMX, é possível identificar quais os sistemas operacionais e as respectivas versões para a utilização do aplicativo. No aplicativo Augin® a informação aparece apenas na área de Central de Ajuda da página, que informa a necessidade de que o aparelho seja compatível com ARCore (para dispositivos Android) e ARKit (no caso dos dispositivos Apple), junto a esta informação estão os links das plataformas para que o usuário identifique o seu aparelho na lista. O Dalux Field® e o Dalux Viewer®, desenvolvidos pela mesma empresa, também não trazem quais as especificações necessárias ou recomendadas de sistema operacional para utilização dos aplicativos em suas páginas. Apesar destas informações nas páginas dos aplicativos, as especificações mínimas aparecem na plataforma de download nos dispositivos.

Outro ponto identificado no levantamento dos aplicativos foi a ausência de especificações técnicas sobre as características mínimas dos dispositivos necessárias para a utilização das ferramentas. Apenas a página do BIMX apresenta as configurações e mínimas e os dispositivos recomendados para a visualização adequada dos modelos.

Nos testes realizados foram utilizados iPad Air 2 (Ano de Fabricação 2014), não foi possível visualizar os projetos nos aplicativos Augin®, Dalux Field® e GammaAR®. Em testes com o smartphone, modelo M20, da Samsung (ano de fabricação 2019) Não foi possível visualizar os modelos de projeto nos aplicativos DaluxField® e GammaAR®.

Uma característica comum a todos os aplicativos foi a existência de versões para PC, a integração com softwares BIM e visualizadores de arquivos IFC's, formato universal para troca informações entre softwares distintos (Hamledari et al., 2018). A disponibilidade destes dados é fundamental para que a empresa (ou o projetista) possa avaliar a viabilidade da implementação de RA no canteiro e determinar quais as alterações necessárias para que seja possível a implementação de RA na gestão de obras. Após o levantamento das ferramentas, estes aplicativos foram avaliados e classificados de acordo com as funcionalidades desejadas (Tabela 2).

Tabela 2. Avaliação e classificação dos aplicativos.

Funções	BIMx®	Dalux Viewer®	Augin®	Dalux Field®	GammaAR®
Visualização do modelo 3D	5	5	5	5	3
Escala 1:1	0	0	5	5	5
Inserção de Informações	3	4	0	5	5
Acompanhamento de atividades	0	0	0	5	5
Cronograma	1	1	1	4	4
Total	**9**	**10**	**11**	**24**	**22**

Fonte: Veras & Alves-Silva, 2022

Em relação às funcionalidades apresentadas Tabela 2, todos os aplicativos apresentam a visualização do modelo em 3D, exceto o GammaAR®, que permite apenas a visualização da planta baixa durante a utilização da escala natural 1:1. Em relação a essa escala, o BIMx® e o Dalux Viewer® não permitem a sua utilização, pois são aplicativos voltados apenas para a visualização do modelo, o que os tornam ideais quando este é o objetivo da utilização da RA.

Apenas o aplicativo Augin® não permite a inserção de informações no modelo virtual visualizado em RA. Deste modo esta ferramenta não é adequada para a produção de VDC, já que não é possível inserir e compartilhar informações. A diferença entre o Dalux Viewer® e o BIMx®, nesse quesito, ocorre pois o primeiro permite a inserção de comentários a respeito dos ambientes, os quais podem ser visualizados no modelo ou agrupados por meio de uma planilha, o que otimiza a troca de informação.

No BIMx®, os comentários podem ser inseridos, porém, acessados apenas quando o ambiente que teve informações inseridas seja acessado, o que dificulta a gestão da informação. O Dalux Field® e o GammaAR®, além de comentários, permitem produzir relatórios associados a cada ambiente da edificação, que podem ser compartilhados por todos os membros do projeto.

Em relação ao acompanhamento de atividades desenvolvidas no canteiro de obra, essa funcionalidade está disponível apenas para o Dalux Field® e para o GammaAR®, deste modo são mais adequados para a produção de um VDC. Esta função permite que o responsável possa delegar serviços e que os operadores tenham condições de executar as atividades por meio de roteiros acessados pela plataforma e sejam capazes de relatar a execução da atividade para o gestor por meio do aplicativo.

Quanto a integração entre o modelo e o cronograma da obra, é possível realizá-lo no BIMx®, Dalux Viewer® e no Augin®, apenas se o modelo for adaptado com as informações de cada etapa construtiva. No Dalux Field® e no GammaAR® é possível monitorar o cronograma de execução por meio do acompanhamento de atividades, sendo possível monitorar as atividades que foram realizadas dentro do prazo e aquelas que se encontram em atraso.

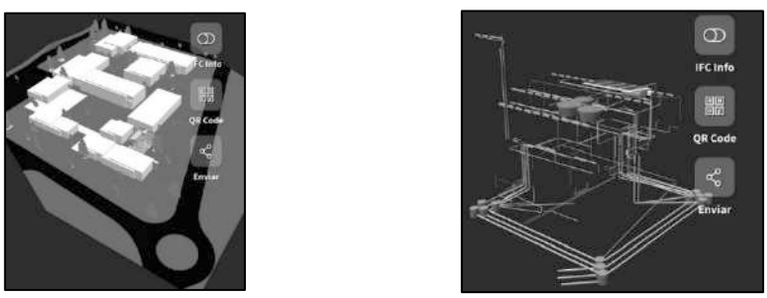
Dessa forma, os aplicativos Dalux Field® e GammaAR® são os mais adequados para a gestão de obra por meio da utilização da RA. Isso ocorre por ser possível coletar informações (sobre as etapas executadas, sobre o estado do cronograma, alterações realizadas no projeto) ao mesmo tempo que é possível associar e compartilhar estes dados ao modelo. Deste modo é possível afirmar que estas ferramentas são as mais adequadas para a produção de um VDC. Contudo, a depender dos objetivos e o nível de implantação da RA no canteiro, os aplicativos BIMx®, Dalux Viewer® e Augin® também se mostram adequados para auxiliar a construção.

3.2 Teste de Visualização no Canteiro de Obras com o Augin®

Após a análise dos aplicativos, o Augin® foi utilizado para a visualização dos projetos no canteiro, para isso foram selecionadas as seguintes disciplinas: arquitetura, estrutura metálica e hidrossanitário. Apesar deste aplicativo não ser o mais adequado para acompanhamento, ele o foi para testar a visualização de projeto em obra devido à compatibilidade com os dispositivos disponíveis para a pesquisa e pela sua versão gratuita disponibilizar as funções de visualização dos modelos. Outro aspecto foi o fato do Augin® permitir a visualização dos modelos de projeto do PISAC.

Para a utilização, foram gerados os modelos IFC dos projetos, exportados no formato IFC 2x3, compatível com o Augin®. Para otimizar a visualização dos modelos no Augin®, foi necessário passá-los por um programa otimizador de IFC. Foi utilizado o software Solibri, que simplificou a geometria dos elementos e produziu arquivos que necessitam de uma menor capacidade de processamento. Dessa forma, os modelos puderam ter sua visualização otimizada para os aparelhos disponíveis.

Após a otimização dos modelos no software, os arquivos foram carregados na plataforma Augin ® e depois abertos, pelo aplicativo nos dispositivos (Figura 1).

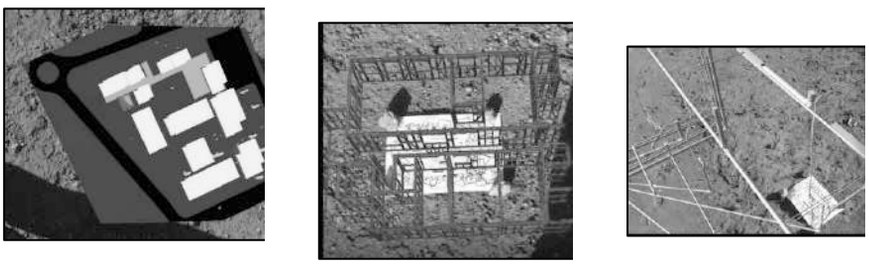


(a) (b)

Figura 1. Visualização do modelo volumétrico pelo aplicativo Augin®. (a) Implantação (b) Hidrossanitário. Fonte: Veras & Alves-Silva,2022.

Através desse experimento, foi possível constatar que a possibilidade de consultar a construção por meio de dispositivos móveis auxilia no entendimento completo da edificação e pode diminuir os erros na etapa construtiva. Na representação tridimensional, o usuário visualiza o projeto da maneira como ele será quando construído e não uma simplificação bidimensional por meio de plantas baixas e cortes.

Na visualização dos modelos em obra foram percebidas algumas dificuldades e limitações. Pelas características do terreno natural, ainda sem intervenções, o aplicativo não conseguiu determinar uma superfície plana o suficiente para posicionar os modelos. Dessa forma foi necessária a utilização de marcadores fixos no terreno para que o sistema pudesse locar os modelos (Figura 2).



(a) (b) (c)

Figura 2. Utilização da RA *in loco*. (a) Implantação, (b) Estrutura Metálica. (c) Hidrossanitário. Fonte: Veras & Alves-Silva, 2022

Os marcadores foram gerados pelo Augin®, impressos e posicionados na obra. O uso de um marcador torna necessário que esse esteja sempre visível na câmera do dispositivo, o que dificulta a utilização da escala 1:1 e a visualização do modelo.

Recomenda-se que para o uso dessa função em aplicativos similares, o modelo seja reduzido e represente apenas partes dos ambientes. Outra recomendação é a utilização de um número maior de marcadores no local da obra. Em aplicativos onde o modelo é locado por meio de pins definidos pelo usuário, essa dificuldade na escala 1:1 é suavizada e permite uma melhor experiência da RA, essa técnica de localização é utilizada em aplicativos como Dalux Field® e GammaAR®.

Uma outra dificuldade na visualização de modelos com RA na escala 1:1 é necessidade de maior da capacidade de processamento do dispositivo, o que impossibilita a utilização de forma fluída de RA em dispositivos com menor capacidade de processamento. Quanto a velocidade de banda de internet tem sido menos requerida, uma vez que a maioria dos aplicativos possibilitam o uso da RA de forma offline.

O ângulo de visão da câmera representa uma dificuldade para aplicativos que utilizam marcadores de posição fixos, sendo mais adequado o uso de aplicativos que permitam o posicionamento da RA por meio de pins, que mantém o modelo fixo no ponto desejado. Por fim, a oclusão pode ser obtida por meio do uso de aplicativos que permitem a aplicação de transparência à RA analisada, além de permitir ocultar elementos que não estão sendo analisados no momento pelo usuário, diminuindo as dificuldades para realizar a comparação entre o construído e o modelado.

O teste realizado com o Augin®, possibilitou a produção de um fluxograma de incorporação de tecnologias de RA no canteiro a partir de um modelo BIM, Figura 3.

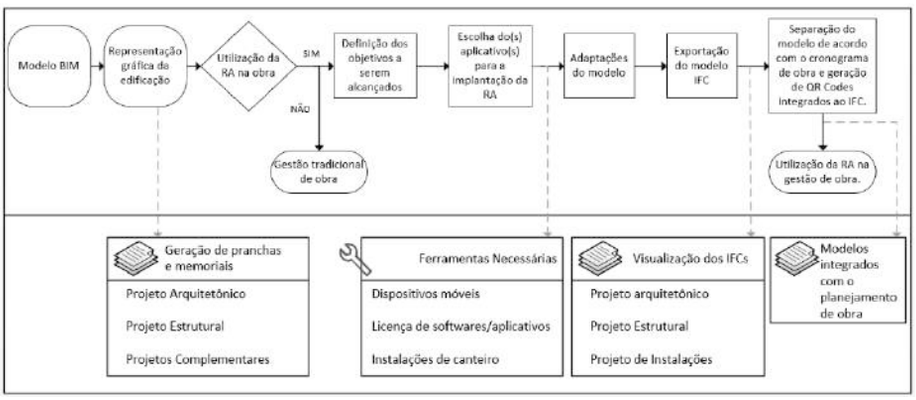


Figura 3. Fluxo para aplicação da RA no canteiro de obras. Fonte: Veras & Alves-Silva, 2022.

A primeira etapa corresponde a produção da representação gráfica dos projetos da edificação a partir dos modelos BIM. Após a elaboração destes modelos estabelecer quais os usos dados para a RA para que seja possível definir o aplicativo a ser utilizados. Com a escolha do aplicativo executar as adaptações necessárias ao modelo para que este possa ser visualizado no dispositivo e no aplicativo com as informações necessárias para os usos definidos no modelo.

4 Considerações Finais

Foi verificado que para utilizar a RA na gestão de obras é necessário definir os usos dados a tecnologia no canteiro, de forma a se levar as adaptações no canteiro, como a aquisição de dispositivos e aplicativos. Para auxiliar este processo o fluxograma proposto, junto com a análise feita com os aplicativos, se configura num instrumento para difundir o uso de RA no setor AECO.

Apesar das dificuldades encontradas na visualização *inloco*, os aplicativos avaliados, mesmo nas suas versões mais básicas, permitem a visualização dos modelos de projeto em RA fora da obra. O que auxilia a compreensão da informação construtiva produzida e na comunicação entre os agentes responsáveis pela construção da edificação. Outro aspecto observado é a importância do formato IFC para a integração entre BIM e RA.

No que diz respeito a produção de um VDC, as ferramentas avaliadas, Dalux Field® e Gamma®, parecem atender a produção de uma plataforma que integre visualização, avaliação, interação e análise das informações físicas e funcionais da obra. O que demonstra já ser possível lançar mão das vantagens proporcionadas pelo VDC, já que no Brasil tem sido crescente a utilização de ferramentas e processos BIM.

O uso de um VDC, permite ainda que os modelos possam ser atualizados já durante o processo construtivo. Dessa forma, após a construção, se obtenha um modelo preciso do edifício que pode ser utilizado em outras fases do ciclo de vida da edificação.

Os resultados apresentados devem ser complementados com pesquisas que visem testar o Gamma® e Dalux Field® na gestão de obras e, assim, identificar a eficiência das ferramentas para a produção de VDC. É importante ainda verificar como mitigar o problema relativo à locação da edificação, seja pela utilização de um maior número de marcadores, uso de dispositivos com telas maiores, ou o uso de óculos de Realidade Aumentada.

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Referências

Afzal, M., Shafiq, M. T., & al Jassmi, H. (2021). Improving construction safety with virtual-design construction technologies - A review. Journal of Information Technology in Construction, 26(May 2020), 319–340. https://doi.org/10.36680/j.itcon.2021.018

Arena, F., Collotta, M., Pau, G., & Termine, F. (2022). An Overview of Augmented Reality. Computers, 11(2). https://doi.org/10.3390/computers11020028

Chi, H. L., Kang, S. C., & Wang, X. (2013). Research trends and opportunities of augmented reality applications in architecture, engineering, and construction. Automation in Construction, 33, 116–122. https://doi.org/10.1016/j.autcon.2012.12.017

Dresch, Aline; Lacerda, Daniel Pacheco; Júnior, J. A. V. A. (2015). Design Science Research (1a). Bookman.

Hamledari, H., Rezazadeh Azar, E., & McCabe, B. (2018). IFC-Based Development of As-Built and As-Is BIMs Using Construction and Facility Inspection Data: Site-to-BIM Data Transfer Automation. Journal of Computing in Civil Engineering, 32(2), 1–15. https://doi.org/10.1061/(asce)cp.1943-5487.0000727

Lavalle, S. M. (2020). VIRTUAL REALITY. Cambridge University Press. http://lavalle.pl/vr/

Maskuriy, R., Selamat, A., Maresova, P., Krejcar, O., & David, O. O. (2019). Industry 4.0 for the construction industry: Review of management perspective. Economies, 7(3), 0–14. https://doi.org/10.3390/economies7030068

Newman, C., Edwards, D., Martek, I., Lai, J., Thwala, W. D., & Rillie, I. (2021). Industry 4.0 deployment in the construction industry: a bibliometric literature review and UK-based case study. Smart and Sustainable Built Environment, 10(4), 557–580. https://doi.org/10.1108/SASBE-02-2020-0016

Rafsanjani, H. N., & Nabizadeh, A. H. (2021). Towards digital architecture, engineering, and construction (AEC) industry through virtual design and construction (VDC) and digital twin. Energy and Built Environment, October. https://doi.org/10.1016/j.enbenv.2021.10.004

Sepasgozar, S. M. E., Ghobadi, M., Shirowzhan, S., Edwards, D. J., & Delzendeh, E. (2021). Metrics development and modelling the mixed reality and digital twin adoption in the context of Industry 4.0. Engineering, Construction and Architectural Management, 28(5), 1355–1376. https://doi.org/10.1108/ECAM-10-2020-0880

Wang, X., & Love, P. E. D. (2012). BIM + AR: Onsite information sharing and communication via advanced visualization. Proceedings of the 2012 IEEE 16th International Conference on Computer Supported Cooperative Work in Design, CSCWD 2012, 850–855. https://doi.org/10.1109/CSCWD.2012.6221920

Wu, Z., Chen, C., Cai, Y., Lu, C., Wang, H., & Yu, T. (2019). BIM-based visualization research in the construction industry: A network analysis. International Journal of Environmental Research and Public Health, 16(18). https://doi.org/10.3390/ijerph16183473

Yap, J. B. H., Lam, C. G. Y., Skitmore, M., & Talebian, N. (2022). Barriers To the Adoption of New Safety Technologies in Construction: a Developing Country Context. Journal of Civil Engineering and Management, 28(2), 120–133. https://doi.org/10.3846/jcem.2022.16014.

BIM Adoption in an Architecture and Urbanism course: analysis of the degree of maturity

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Abstract. This article aims to assess the degree of maturity of Building Information Modeling (BIM) in an Architecture and Urbanism course, identifying points of improvement and benefits, directing actions for a potential BIM implementation. The evaluation methodology investigates about Policies, Processes and Technologies of the architectural graduation course. The collection of information was done through questionnaires applied to the teaching staff. As results, it shows that BIM maturity,s level of the Institution in this course is in the 'Defined' level, however there are heterogeneous performances in relation to the evaluated points. It is also noticed that this result is due to the actions of a minority of teachers, not reflecting the institutionalized maturity of the entire course. On the other hand, this result indicates that efforts towards BIM adoption will start from initiatives already underway, in an environment relatively prepared for a planned insertion.

Keywords: BIM Adoption, BIM Teaching, BIM Maturity, BIM Execution Plan, Architecture and Urbanism Course

1 Introdução

Em 2019, o Ministério da Economia lançou um edital que tem por objetivo a "concessão de apoio da administração pública federal para a execução de projetos com vistas ao ganho de produtividade e competitividade do setor de Construção Civil" (Brasil. Ministério da Economia, 2019). A submeta 7.2 desse edital apresenta como objetivo a "Proposta e instalação de Célula BIM em Instituição de Ensino Superior (IES) visando estimular o desenvolvimento e aplicação de novas tecnologias relacionadas ao *Building Information Modeling* (BIM)", principalmente nos cursos de Arquitetura Urbanismo e Engenharia Civil.

Segundo Sacks et al (2018, p. 21), o BIM, é “uma tecnologia de modelagem e um conjunto associado de processos que visam produzir, comunicar e analisar a informação da construção”, ao longo do seu ciclo de vida. Para esses cursos de graduação a adoção do BIM é de fundamental importância para a ampliação das competências BIM no setor da Construção Civil (Delatori, 2014).

Todavia, o processo de implementação do BIM não acontece de maneira uniforme entre diferentes Instituições de Ensino Superior (IES). Enquanto algumas não apresentam nenhuma menção ao conteúdo, outras já apresentam ações mais avançadas. Assim, cada universidade que pretende adotar o BIM define seu objetivo principal em função do perfil do curso e das capacidades do corpo docente e discente. No caso da Universidade Federal de Pernambuco (UFPE), a formação do aluno de arquitetura e urbanismo passa por uma profunda discussão teórica, com uma abordagem voltada para as questões urbanas, arquitetônicas e paisagísticas. Neste contexto, a adoção de tecnologias ao longo do curso não é igualitária nem institucionalizada. Sendo assim, um dos objetivos da Célula BIM UFPE envolve mitigar as barreiras existentes para a difusão do conhecimento do BIM que está associado a uma visão mais técnica do ato de projetar. Para esse caso, a estratégia de adoção do BIM na estrutura curricular passa pela adoção do conhecimento em disciplinas que sejam encadeadas e coordenadas.

Contudo, para que a adoção do conteúdo BIM em cursos de graduação seja mais eficaz, e vá além da capacitação instrumental, é preciso fazer uma série de ações preliminares, sendo uma delas, a avaliação da maturidade BIM do curso. O termo maturidade pode ser entendido como a extensão, a profundidade, a qualidade, a previsibilidade e a repetitividade de uma habilidade na realização de uma tarefa ou entrega de um serviço ou produto. Para Succar (2009), o grau de maturidade BIM objetiva identificar um conjunto de melhorias que permitam alcançar benefícios específicos, proporcionando uma melhor percepção do crescimento e diversidade da aplicação do BIM, direcionando as ações da implementação. Ou seja, a identificação do grau de maturidade BIM revela como a organização compreende e usa o BIM nas suas ações educacionais, direcionando a tomada de decisões e servindo de guia para a definição das ações de implementação desse conteúdo no ensino.

Embora existam diversos métodos aplicados para a avaliação do grau de maturidade, eles têm como foco as empresas de projeto e construção principalmente (Liang, C. et al, 2016; Sebastian, R. & Berlo, L., 2010). Poucos são os exemplos de aplicação feitos para IES (BÖES, BARROS NETO E LIMA, 2021). E mesmo assim, alguns desses são adaptações de métodos desenvolvidos para empresas de projeto e construção. Mesmo com todas essas limitações, este artigo apresenta o resultado de uma ação prévia para implementação do BIM no ensino, cujo objetivo é avaliar o grau de maturidade

de BIM do curso de Arquitetura e Urbanismo da Universidade Federal de Pernambuco. Essa avaliação toma como base o método proposto por Böes, Barros Neto e Lima (2021), que, por sua vez, foi adaptado do método proposto por Succar (2010). Mesmo sabendo das limitações da adoção desse método na medição do grau de maturidade em uma instituição de ensino, a adoção dele dá uma noção básica de como a instituição tem trabalhado com o BIM, considerando os aspectos de processos, políticas e tecnologias.

2 Metodologia

Como já dito, a metodologia de avaliação da maturidade BIM segue a matriz estabelecida por Böes, Barros Neto, e Lima (2021), que, por sua vez, teve como base a The BIM Maturity Matrix (BIM3), desenvolvida por Succar, B. (2010). Nela, os autores descrevem o processo de investigação dividido em três campos: Políticas, Processos e Tecnologias, onde cada um deles apresenta seus requisitos (conforme tabelas 1, 2 e 3).

O campo de Políticas compreende as iniciativas, ações e visões institucionais sobre BIM. O foco desse campo está nas pessoas, na capacitação dos professores, no incentivo à pesquisa e nas ações de extensão acadêmica relacionadas ao tema. Já em relação ao campo de Processos, o foco é avaliar o desempenho do ensino, da pesquisa e da extensão em BIM, de maneira a abarcar a maior quantidade de Usos BIM, tanto nas disciplinas da grade curricular, quanto nas pesquisas e atividades de extensão, alcançando, assim, um maior número de alunos capacitados. E, por fim, o campo das Tecnologias compreende o conjunto de toda a infraestrutura tecnológica (softwares, hardwares e sistemas necessários para a utilização do BIM) e física (espaço adequado para receber os equipamentos), para o desenvolvimento das atividades de Ensino, Pesquisa e Extensão.

Esses três campos englobam 16 capacidades, descritos na Matriz de Maturidade BIM (ver tabelas 1, 2 e 3). A verificação da existência dessas capacidades determina o grau de maturidade BIM do curso em cinco níveis progressivos, que vai desde a inexistência do conteúdo BIM no ambiente acadêmico, até o nível máximo de maturidade. São estes: Pré-BIM, Inicial, Definido, Integrado e Otimizado. A ideia é que o nível de maturidade seja avaliado ao longo dos anos. Assim, à medida em que o curso faz melhorias nos três campos, o nível de maturidade BIM vai avançando.

Para que o preenchimento da matriz fosse o mais assertivo possível, foram elaborados questionários para coletar informações diretamente com as fontes desejadas: (a) o corpo docente; (b) os professores que formam o NDE (Núcleo Docente Estruturador); (c) o coordenador do curso; e (d) os coordenadores dos

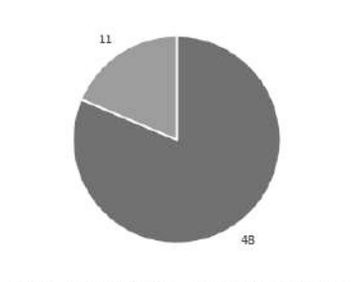
laboratórios de tecnologia que os estudantes do curso têm acesso. Para cada um desses grupos foi elaborado um questionário específico que captasse informações acerca das políticas, processos e tecnologias que envolvem o ensino e disseminação do conhecimento BIM para o curso de Arquitetura e Urbanismo.

3 Resultados e Discussão

3.1 Sobre o corpo docente do curso

Antes de apresentar o Grau de maturidade, vale destacar alguns resultados sobre as respostas dos questionários para melhor entender o grupo de docentes e suas apreensões sobre o curso de Arquitetura e Urbanismo da UFPE. Esse curso conta com professores de diferentes departamentos, sendo a maioria deles (81,35%) do Departamento de Arquitetura e Urbanismo (DAU) e os demais são de outros departamentos (Departamento de Expressão Gráfica, de Engenharia Civil, de Engenharia Cartográfica, etc.).

Entretanto, mesmo que o Departamento de Arquitetura e Urbanismo apresente a maioria de professores, as respostas ao questionário que basearam o resultado do Grau de Maturidade BIM foram majoritariamente de professores lotados em outros departamentos (Figura 1). Sendo assim, uma vez que o critério que leva a definição do Grau de Maturidade BIM do curso se baseia nas ações do corpo docente, essas ações são feitas por professores de outros departamentos. Esse fato fica visível quando se analisa as respostas da questão sobre o nível de conhecimento em BIM (Figura 2) onde nenhum docente declarou ter alto nível de conhecimento no assunto. Dentre aqueles que declararam médio nível de conhecimento, a maioria é de outros departamentos. Porém, mesmo apresentando um baixo conhecimento, a grande maioria dos docentes, de todos os departamentos, reconhece a importância do conhecimento do BIM no ambiente acadêmico (Figura 3).



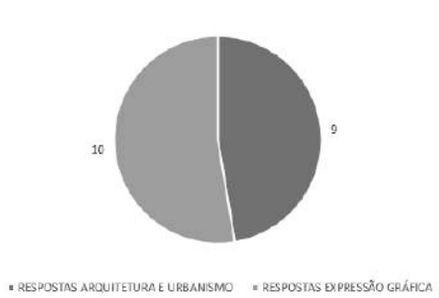


Figura 1. (A esquerda) Origem dos professores que ministram aulas no curso de Arquitetura e Urbanismo. (A direita) Participação dos professores na pesquisa desenvolvida. Fonte: Autoral, 2021**.**

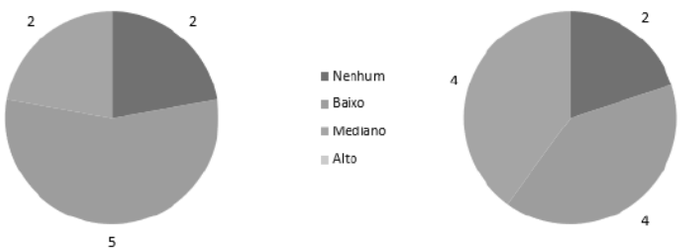


Figura 2. (A esquerda) Nível de Conhecimento BIM dos professores do departamento de Arquitetura. (A direita) Nível de Conhecimento BIM dos professores do departamento de Expressão Gráfica. Fonte: Autoral, 2021.

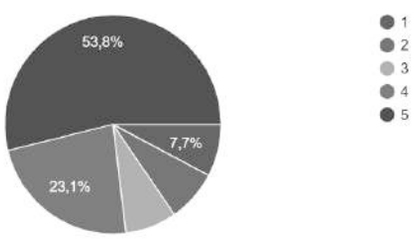


Figura 3. Respostas dos avaliados sobre Importância do conhecimento do BIM no ambiente acadêmico, em uma escala de 1 a 5. Fonte: Autoral, 2021

3.2 Sobre o grau de maturidade do curso

A avaliação do grau de maturidade BIM mostra que o curso de arquitetura e urbanismo da UFPE está no nível DEFINIDO de adoção do BIM com MÉDIA maturidade (Figura 4). Isso é positivo para a implantação da Célula BIM, uma vez que os esforços não partem do zero e encontram um ambiente relativamente preparado para uma inserção maior e mais bem planejada e, futuramente, para uma definitiva consolidação do tema.

Analisando a matriz mais detalhadamente, percebe-se a necessidade de ressaltar dois pontos. Primeiro, são verificados desempenhos distintos em relação aos três eixos apresentados na matriz de maturidade no curso. Enquanto as ações verificadas nos eixos de políticas e processos estão mais bem desenvolvidas, o eixo de tecnologias é o que precisa de um incentivo maior para que o curso seja classificado com o grau Integrado de Maturidade. Segundo, esse resultado se deve a ações realizadas por menos de 10% dos professores, conforme destacado anteriormente. Isso significa que o grau

“Definido” não reflete a maturidade da plenitude do corpo docente do curso, e sim, de um grande esforço de uma pequena parte de professores.

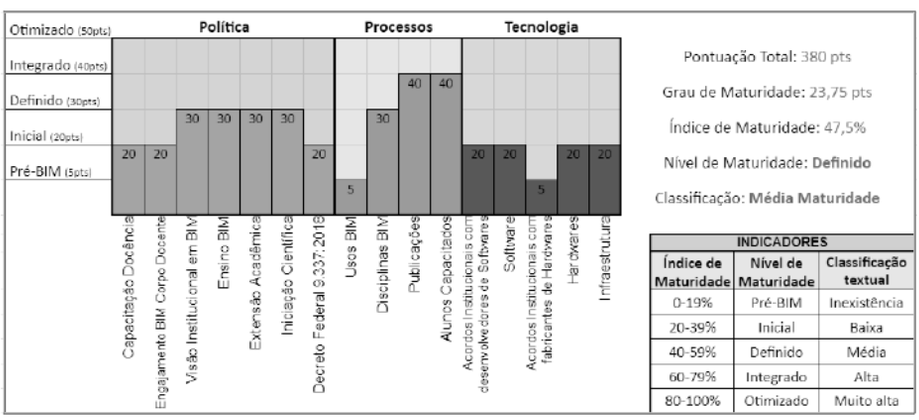


Figura 4. Pontuação da maturidade BIM na IES, para o curso de Arquitetura e Urbanismo, pelo método de Böes, J. S., Barros Neto, J. de P., & Lima, M. M. X. de. (2021). Fonte: Autoral, 2021.

O resultado da Matriz de Maturidade (Figura 4) é detalhado a seguir separadamente por Eixos: Políticas, Processos e Tecnologias. Essa ação se justifica pela análise e os resultados de maturidade de cada uma das 16 capacidades analisadas pelo método aqui apresentado.

Políticas

Em relação ao eixo de Políticas, o desempenho do curso de Arquitetura e Urbanismo oscila entre inicial e definido (Tabela 1). A classificação inicial foi verificada em relação a dois critérios. O Primeiro diz respeito ao conhecimento sobre o Decreto Federal 9.377:2018 (Brasil, 2018), que Institui a Estratégia Nacional de Disseminação do BIM (Estratégia BIMBR). Conforme verificado na Figura 5, a grande maioria dos docentes diz conhecer, mesmo que alguns não saibam do que o Decreto trata. Porém, mais uma vez, esse resultado é devido a um maior conhecimento por parte dos professores de outros departamentos.

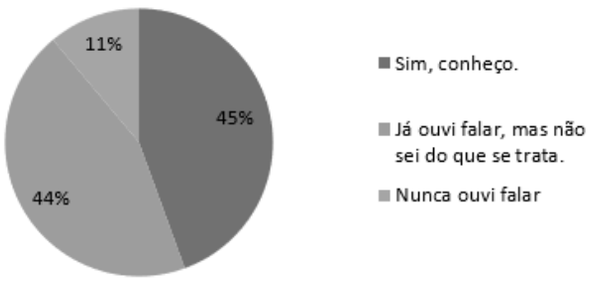


Figura 5. Nível de conhecimento dos docentes do curso de Arquitetura e Urbanismo em relação ao Decreto nº 9.377:2018. Fonte: Autoral, 2021.

O segundo critério classificado como inicial foi o relativo à capacitação e ao engajamento BIM pelo corpo docente. Além de não haver incentivo formal por parte da coordenação do curso, menos de 10% do corpo docente domina alguma tecnologia relacionada ao BIM.

Tabela 1. Maturidade BIM da IES para o curso de Arquitetura e Urbanismo - Políticas.

Capacidade	Eixo	Maturidade	Estado
CAPACITAÇÃO DA DOCÊNCIA	POL. 1	Inicial	Incentivo informal para capacitação BIM ao corpo docente. Não ocorre de forma institucionalizada e formalizada [Fonte: Respostas do formulário formatado para (a) o corpo docente; (b) coordenador]
ENGAJAMENTO BIM DO CORPO DOCENTE	POL. 2	Inicial	Até 10% do corpo docente domina a metodologia e software BIM. Não há nenhum tipo de engajamento. [Fonte: Respostas do formulário formatado para (a) o corpo docente]
VISÃO INSTITUCIONAL BIM	POL. 3	Definido	O BIM é enxergado como importante, mas não como prioridade ou como metodologia no processo de ensino-aprendizagem para os alunos. [Fonte: Respostas do formulário formatado para (a) o corpo docente; (b) NDE]
ENSINO BIM	POL. 4	Definido	O BIM é enxergado como importante, mas não como prioridade ou como metodologia no processo de ensino-aprendizagem para os alunos.

			[Fonte: Respostas do formulário formatado para (a) o corpo docente; (b) NDE; (c) coordenador]
EXTENSÃO ACADÊMICA / EMPRESA JR.	POL. 5	Definido	Não há nenhuma iniciativa BIM formalizada na extensão acadêmica. Há ações individuais de professores ou discentes, porém com conhecimento formalizado junto à IES. [Fonte: Respostas do formulário formatado para (a) o corpo docente]
INICIAÇÃO CIENTÍFICA	POL. 6	Definido	Não há Iniciação Científica formalizada, apenas ações individualizadas entre professores e alunos na produção de pesquisas. [Fonte: Respostas do formulário formatado para (a) o corpo docente]
DECRETO FEDERAL 9.337:2018	POL. 7	Inicial	A IES possui ciência do conteúdo. Não há plano/estratégia para atendimento dos requisitos e não vem desenvolvendo nenhuma ação. [Fonte: Respostas do formulário formatado para (a) o corpo docente; (b) NDE; (c) coordenador]

Fonte: Autoral, 2021

Ainda sobre o Eixo de políticas, nos critérios sobre ensino BIM, extensão acadêmica e iniciação científica, o curso se encontra no nível “DEFINIDO” de maturidade BIM. Isso se justifica porque existem disciplinas ministradas semestralmente onde é visto o conteúdo de Introdução ao BIM e, pelo menos, o uso de uma Plataforma BIM, além de eventuais workshops (formalizados juntos à IES como atividade de extensão). Além disso, há um número significativo de Trabalhos de Conclusão de Curso (TCC) que abordam o tema.

Processos

O eixo de processos também não apresentou uma uniformidade em relação ao grau de maturidade BIM. Apesar da classificação Definida em relação aos critérios ensino, extensão e pesquisa, os usos BIM verificados nestas atividades não ultrapassaram de cinco, definindo o estágio “pré-BIM” neste critério.

Tabela 2. Maturidade BIM da IES para o curso de Arquitetura e Urbanismo - Processos

Capacidade	Eixo	Maturidade	Estado
USOS BIM	PRO. 1	Inicial	Até 5 usos BIM. [Fonte: Pesquisas sem TCCs, Iniciação Científica, artigos acadêmicos e disciplinas] Usos BIM: Gerenciamento de Projetos, Projetos Arquitetônicos e Estruturais]
DISCIPLINAS BIM	PRO. 2	Definido	Existência de até 5 disciplinas que envolvam o BIM. [Fonte: Respostas do formulário formatado para (a) o corpo docente] Consideradas três disciplinas]
PUBLICAÇÕES	PRO. 3	Integrado	Publicações planejadas, com alcance em congressos regionais e nacionais, e periódicos nacionais. [Fonte: Respostas do formulário formatado para (a) o corpo docente]
ALUNOS CAPACITADOS	PRO. 4	Integrado	Até 500 alunos capacitados. [Considerando que as disciplinas listadas são ministradas semestralmente desde 2012, além de workshops eventuais]

Fonte: Autoral, 2021

Sobre as disciplinas BIM, a classificação se encontra ‘Definida”, uma vez que são ministradas semestralmente quatro disciplinas, sendo que apenas uma delas é ministrada por um docente do Departamento de Arquitetura e Urbanismo (DAU). Entretanto, o que mais elevou o grau de Maturidade BIM foram os dados referentes às publicações e ao número de alunos capacitados. Sobre o primeiro, foi verificada uma constância anual de publicações em um congresso internacional da área desde 2014 – o que demonstra certo planejamento desse grupo de professores. Além disso, existem publicações eventuais realizadas em revistas e outros congressos internacionais. O número aproximado de alunos capacitados em BIM se deve, principalmente, à disciplina Introdução ao BIM, que é ministrada semestralmente desde 2012 com uma média de 20 alunos. Soma-se a isso aos eventuais cursos de extensão universitária, que capacitaram aproximadamente 500 alunos.

Tecnologia

Por fim, o eixo de tecnologia é o que apresenta uma maior uniformidade de pontuação. Com exceção do quesito sobre os “acordos institucionais com fabricantes de hardware”, que é praticamente inexistente, todos os outros apresentam um estado Inicial de Maturidade BIM. Isso significa que, em relação à disponibilidade de hardware, software e infraestrutura para o desenvolvimento satisfatório do conhecimento e ensino BIM, o curso ainda precisa de muito incentivo e organização.

Tabela 3. Maturidade BIM da IES para o curso de Arquitetura e Urbanismo-Tecnologias

Capacidade	Eixo	Maturidade	Estado
ACORDOS INSTITUCIONAIS COM DESENVOLVEDORES DE SOFTWARES	TEC. 1	Inicial	Há acordos institucionais com um desenvolvedor de software (atendendo apenas 1 item dos 4 propostos do método: “Fornecimento de software para acesso na IES”; [Fonte: Respostas do formulário formatado para (a) o coordenador; (b) os coordenadores de laboratórios do Centro de Artes e Comunicação (que são usados pelos alunos do curso)]
SOFTWARE	TEC. 2	Definido	Software instalados em apenas alguns computadores. Controle institucional simples, com a instalação e licenças. [Fonte: Respostas do formulário formatado para (a) os coordenadores de laboratórios do Centro de Artes e Comunicação (que são usados pelos alunos do curso)]
ACORDOS INSTITUCIONAIS COM FABRICANTES DE HARDWARE	TEC. 3	Pré-BIM	Não há nenhum acordo institucional com desenvolvedores de hardware. [Fonte: Respostas do formulário formatado para (a) os coordenadores de laboratórios do Centro de Artes e Comunicação (que são usados pelos alunos do curso)]
HARDWARE	TEC. 4	Inicial	Hardware adequado em apenas algumas estações de trabalho em um laboratório de informática destinado aos alunos. Aquisição de hardware ocorre sem nenhum planejamento de acordo com os usos e software BIM pretendidos. [Fonte: Respostas do formulário formatado para

			(a) os coordenadores de laboratórios do Centro de Artes e Comunicação (que são usados pelos alunos do curso)]
INFRAESTRUTURA	TEC. 5	Inicial	Laboratórios de Informática com estações de trabalho com hardware e software BIM. O objetivo final do espaço físico não é o ensino BIM, sendo compartilhado com outros usos e ensinos. [Fonte: Respostas do formulário formatado para (a) os coordenadores de laboratórios do Centro de Artes e Comunicação (que são usados pelos alunos do curso)]

Fonte: Autoral, 2021

4 Conclusões

Este artigo apresenta parte dos resultados de uma das ações preliminares desenvolvidas por uma Célula BIM, cujo objetivo é medir o grau de maturidade BIM de um curso de Arquitetura e Urbanismo de uma Instituição de Ensino Superior (IES). Conforme comentado, essa identificação é uma importante ação preliminar e seus resultados servem para guiar os passos de uma adequada implantação do conteúdo BIM no curso. Sendo assim, apresentar estágio definido de incorporação BIM com médio grau de maturidade é muito positivo, mostrando que o curso, de maneira geral, apresenta interfaces capazes de facilitar a inserção mais planejada do conteúdo.

Entretanto, o engajamento e disseminação desse conhecimento para um maior número de professores alocados no departamento de Arquitetura e Urbanismo é apontada como um grande desafio. Dessa maneira, o grau de maturidade desta instituição reflete o esforço de pequena parte dos docentes. Assim, percebe-se que, assim como verificado por Böes, Barros Neto, e Lima, (2021), a maior barreira para a implantação BIM é o capital humano, seja por falta de capacitação, seja por falta de interesse.

Outrossim, deve-se ressaltar que as atividades de ensino, pesquisa e extensão BIM, apesar de serem desenvolvidas por minoria dos professores, ganham um grau de destaque na avaliação da instituição, uma vez que são ações constantes para a disseminação dos conteúdos BIM, servindo como base para o planejamento de uma potencial Implementação mais elaborada no curso de Arquitetura e Urbanismo em questão

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References

Böes, J. S., Barros Neto, J. de P., & Lima, M. M. X. de. (2021). BIM maturity model for higher education institutions. Ambiente Construído [online]. 2021, v. 21, n. 2 , pp. 131-150. https://doi.org/10.1590/s1678-86212021000200518.

Brasil. (2018). DECRETO Nº 9.377 DE 17 DE MAIO DE 2018: Institui a Estratégia Nacional de Disseminação de Building Information Modelling. Brasília. https://legislacao.presidencia.gov.br/atos/?tipo=DEC&numero=9377&ano=2018&ato=3bck3Z65UeZpWT387.

Brasil. Ministério da Economia. (2019). EDITAL Nº 3/2019: Termo de Colaboração para execução de ações para promover ganho de produtividade e competitividade do setor de Construção Civil. Brasília. https://www.gov.br/economia/pt-br/acesso-a-informacao/licitacoes-e-contratos/doacoes/chamamentos-publicos/2019/construcao-civil/edital

Delatorre, V. (2014). Potencialidades e limites do BIM no ensino de arquitetura: uma proposta de implementação. Florianópolis: [s/n], 2014, 293p.

Liang, C. et al. (2016). Development of a Multifunctional BIM Maturity Model. Journal of Construction Engineering and Management, [S. l.], v. 142, n. 11, p. 1-11.

Sebastian, R., & Berlo, L. V. (2010). Tool for benchmarking BIM performance of design, engineering and construction firms in the Netherlands. Architectural engineering and design management, [S. l.], v. 6, p. 254–263.

Succar B. (2009). Building information modelling framework: A research and delivery foundation for industry stakeholders.Automation in Construction, 18(3), 357–375. 10.1016/j.autcon.2008.10.003.

Succar, B. (2010). Building information modelling maturity matrix. In: UNDERWOOD, J.; ISIKDAG, U. (ed.). Handbook of research on building information modeling and construction informatics: concepts and technologies. Hershey, PA: Information Science Reference, 2010. p. 65-103. https://doi.org/10.4018/978-1-60566-928-1.ch004.

BIM implementation on the public sector of State of Pernambuco: a comparative study between State enterprises of PET-GOV extension project.

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Abstract. One of the greatest challenges in the BIM dissemination is the consolidation of its use by the public authorities. In Brazil, a series of actions have been taken, such as the National Strategy for the BIM Dissemination. These actions have intensified the pressure for the implementation of BIM in public authorities at the federal, state and municipal levels. In the State of Pernambuco a partnership between the Federal University of Pernambuco and the State Government led to the creation of a strategy to encourage innovation in the public sector. Among the projects is the creation of BIM Implementation Plans in the public sector. This paper presents the first steps of implementation, which consist of formulating a diagnosis of the public sector. The results, still preliminary, show the importance of understanding the organization before proposing any action in favor of BIM implementation.

Keywords: BIM Adoption, BIM Execution Plan, BIM Implementation Plan and BIM Diagnostic.

1 Introdução

Como forma de incentivar a implementação do BIM, vários esforços têm sido feitos em empresas privadas e públicas. Esses esforços vão desde a criação de guias até as regras e licitações que exigem o uso do BIM. Estados Unidos, Reino Unido, Finlândia, Singapura, Noruega e Hong Kong são países pioneiros na publicação de guias com diretrizes para a implementação do BIM. Estes guias incluem: Introdução ao BIM (NATSPEC, 2014); Building Information Modeling Roadmap (USACE e ERDC, 2006); National Building Information Modeling Standard (NIBS, 2007); National Building Information

Modeling Guide 01-07 (GSA, 2006-2015); BIM Guide for Germany (Federal Office for Building and Regional planning, 2013); CIC Building Information Modeling Standards (Construction Industry Council, Hong Kong, 2015); BIM Guideline Standard (Public Works Department, Malaysia, 2016); Statsbygg Building Information Modeling Manual Version 1. 2.1 (Statsbygg, 2017); Método de trabalho 3D (Agency for Enterprise and Construction, Dinamarca, 2006) entre outros (tradução de Rodrigues e Andrande, 2021).

No âmbito nacional, em 2018 o Governo Federal publicou o Decreto No. 9.377, posteriormente substituído pelos Decretos no 9.983 de 22 de agosto de 2019 e no 10.306 de 2 de abril de 2020, que oficializa a criação da Estratégia Nacional para a Disseminação do BIM, visando promover um ambiente adequado ao investimento e capacitação em BIM e na sua difusão no Brasil. Na esfera estadual, no ano de 2019 foi assinado um Acordo de Cooperação Técnica entre os estados participantes do Consórcio de Integração Sul e Sudeste (Cosud) para a criação da Câmara Temática da Estratégia do BIM (CT BIM Cosud). Entre os objetivos desta Câmara estão o de definir e gerenciar as ações necessárias para que as estratégias estaduais e federais de implementação do BIM sejam harmonizadas entre as iniciativas de órgãos e de entidades públicas estaduais que avaliam, desenvolvem e contratam obras públicas. A implementação do BIM em órgãos estaduais que lidam com a concepção, desenvolvimento, aprovação/avaliação, contratação, execução, manutenção ou operação de obras públicas, trará maior produtividade, previsibilidade e transparência no uso de recursos públicos. Isso porque, como sugere Leusin (2018), o BIM representa a expressão da inovação na indústria da AECO.

É dentro desse contexto que o presente artigo se situa. A ideia passa pelo estudo comparativo da implementação do BIM entre Secretarias do Estado de Pernambuco selecionadas para o projeto de extensão PET-GOV proposto pela Universidade Federal de Pernambuco, em parceria com a Universidade Estadual de Pernambuco, em prol da inovação tecnológica, voltados para servidores estaduais que avaliam, desenvolvem e contratam obras públicas.

Esse projeto de extensão se iniciou com a capacitação de algumas equipes ligadas à algumas secretarias do poder público estadual e de municípios do Estado. Esse foi um curso de 180 horas, com duração de 2 meses. Após essa primeira etapa as equipes iniciaram o desenvolvimento de um Plano de Implementação BIM em cada um dos setores. O ponto de partida foi a realização do diagnóstico do problema dentro de cada uma das secretarias a serem trabalhadas, identificando as barreiras e os meios de superação, com a introdução da inovação no setor público por meio do uso do BIM.

Após a realização do diagnóstico, está sendo desenvolvido a etapa seguinte do Plano de Implementação BIM (BIP) baseado nas estratégias BIM nacionais

e internacionais, que constitui-se de ações estratégicas de implementação BIM no setor público. O passo seguinte será de experimentação com o desenvolvimento de um projeto piloto que será apoiado em um Plano de Execução BIM (BEP) nos setores aos quais os recursos humanos a serem qualificados estão vinculados.

Para este artigo serão analisados os problemas identificados por duas das secretarias trabalhadas e como o BIP, em andamento, tem criado estratégias para auxiliar na resolução desses problemas. Embora o primeiro contato que um desses dois órgãos teve com o BIM aconteceu durante o curso de formação e apesar das limitações temporais, haja vista que são apenas 4 meses para a criação do Plano de Implementação BIM, acrescido por 1 primeiro projeto piloto vinculado a um Plano de Execução BIM esse processo de implementação tem permitido capacitar as equipes sobre como implementar e melhorar um BIP, identificando os principais desafios, limitações e ações necessárias para superação em termos de tecnologias, processos e políticas ligadas à adoção BIM.

2 Metodologia

O método proposto constituiu-se em quatro macro etapas: (i) Formação da equipe, considerando o perfil e a área de atuação dos servidores públicos; (ii) Estruturação dos trabalhos e planejamento das principais ações; (iii) Realização de projetos de integração de conhecimento, apoiados no uso das Tecnologias inovadoras relacionados ao BIM; (iv) Experimentação das Capacidades BIM adquiridas no curso de extensão e do conhecimento dos problemas relacionados à prática profissional pelo corpo técnico. Essas quatro macro etapas estão seguindo os ciclos de planejamento, ação, monitoramento e avaliação. Os pacotes de trabalho, dentro das macro etapas, são as ações desenvolvidas como sprints na metodologia Ágil. Para isso, são adotados os três papéis principais: dono do produto, time e scrummaster. O dono do produto é o gestor da atividade de extensão. O scrummaster é o líder do grupo de trabalho. O time é composto pelos professores, alunos de pós-graduação da UFPE e os funcionários públicos estaduais envolvidos na ação. Os times são elencados nas reuniões de planejamento dos pacotes de trabalho. O scrummaster, então, cuida da gestão dos pacotes de trabalho. O dono do produto é responsável pela gestão das macro etapas e participa das reuniões de demonstração/apresentação dos seus produtos e de retrospectiva do conjunto de sprints de uma macro etapa. Os produtos gerados em cada ação (sprint) são produtos parciais que orientam a formação de um BIP/BEP.

Nas reuniões semanais de monitoramento dos sprints são avaliados: (i) O que já foi realizado para ajudar a concluir as sprints; (ii) O que falta ser feito para as equipes concluírem as sprints; (iii) Quais obstáculos estão dificultando a realização das sprints por parte das equipes. Para o acompanhamento do projeto pelo dono do produto são elaborados relatórios mensais sobre informações das reuniões de monitoramento e dos produtos parciais realizados. Para manter as equipes em sintonia, são realizadas reuniões gerais no planejamento da macro etapa, onde é estabelecido os sprints de pacotes de trabalho. O início de cada sprint de pacote de trabalho também é marcado por uma reunião para definição do backlog do sprint, restrita à equipe do pacote de trabalho. São realizadas reuniões de scrum quinzenais para o monitoramento da sprint de um pacote de trabalho. Finalizada a sprint, tem-se uma reunião para demonstrar a funcionalidade do produto. Ao final de todas as sprints de uma macro etapa do projeto será realizada uma reunião geral de retrospectiva para registro das lições aprendidas, que é gerida pelo scrummaster geral.

3 Resultados

Duas secretarias do Estado de Pernambuco foram selecionadas para participar deste projeto de extensão: COMPESA e SEPLAG-SEDUH. Abaixo tem-se a descrição do campo de atuação e das atividades realizadas por essas secretarias.

A COMPESA atua nos setores de abastecimento de água e coleta e tratamento de esgotos sanitários. As atividades desenvolvidas pela Gerência de Projetos de Engenharia envolvem a análise e elaboração de projetos e orçamentos. De forma mais específica, envolvem: (1) Elaboração de Projetos Hidromecânicos, Estruturais e Elétricos pela equipe própria; (2) Levantamentos de Quantitativos de Projeto; (3) Elaboração e atualização de orçamentos, inclusive realização de pesquisa de preços; (4) Contratação de Projetos, dos mais diversos tipos, inclusive gestão dos contratos e análise dos produtos; (5) Análise de projetos de empreendimentos que por ventura queiram se ligar aos sistemas da COMPESA;

A SEPLAG-SEDUH atua para melhorar a mobilidade urbana, a partir da gestão de resíduos sólidos e na ampliação ao acesso à moradia digna. A equipe do projeto de extensão está alocada em uma secretaria executiva e tem como foco o acompanhamento e elaboração de orçamentos de projetos, relacionados à mobilidade urbana.

As secretarias participaram de um cronograma de capacitações proporcionadas pelo corpo técnico do projeto, com a contribuição de diversos

palestrantes nacionais e internacionais, a fim de construir uma base teórica sobre o BIM para permitir que os participantes, ao final do projeto de extensão, tenham autonomia para prosseguir com o desenvolvimento do BIP/BEP nas suas respectivas organizações. As capacitações foram estruturadas em 6 macro etapas, variando entre aulas síncronas e assíncronas:

Tabela 1. Macros etapas das capacitações ofertadas pelo corpo técnico.

Macro etapas das capacitações

Etapas	Conteúdos abordados
Introdução do BIM	Principais definições e conceitos BIM, importância do BIM para AECO no setor público, exemplos da aplicação do BIM no setor público da AECO, usos e tecnologias BIM
Integração	Diretrizes e regras para colaboração BIM, interoperabilidade, softwares, análise de projetos de arquitetura e engenharia em BIM
Gerenciamento	Novas habilidades do gerenciamento BIM; ambientes BIM de gestão, fiscalização e operação de projetos; ambientes BIM de planejamento e orçamento de obras; fluxos BIM e contrato, metodologia ágil
Protocolos e Normas	Normas BIM no mundo e no Brasil; Guias nacionais e nova lei de Licitação, NBR 15965; ISO 19650; criação de Normas e protocolos no poder público; protocolos de implementação BIM
Usos do BIM	Compreender os usos BIM, principais tipos de Classificação de Usos BIM, Sistema de Classificação do BIM - Model Uses Table
PIB e BEP	O que é PIB/BEP; importância do BIP e BEP; procedimentos envolvidos; objetivos da empresa e do projeto; Diagnóstico de maturidade BIM

Fonte: Autores, 2022

Essas informações servem para construção de um diagnóstico inicial da organização que será utilizado como base para identificar o perfil da

organização (MESSNER et al., 2019). Durante os dois meses de capacitações, foram realizadas diversas atividades práticas para dar subsídio ao produto final: o Plano de Implementação BIM e o Plano de Execução BIM. As duas empresas desenvolveram, com o suporte do corpo técnico, uma matriz SWOT como atividade inicial do diagnóstico das empresas. A matriz SWOT busca ter uma visão clara e objetiva sobre quais as forças e fraquezas no ambiente interno, e suas oportunidades e ameaças no ambiente externo da organização, possibilitando a elaborar estratégias para obter melhor desempenho organizacional (SILVA et. al, 2011) conforme indicado nas tabelas 02 e 03.

Tabela 2. Matriz SWOT COMPESA.

Matriz SWOT COMPESA

	Fatores Positivos	**Fatores Negativos**
Análise Interna	**Forças**	**Fraquezas**
	Disponibilidade de softwares; Corpo técnico capacitado para análise e elaboração de projetos; Apoio da alta direção para implementação do BIM; Processos e fluxos mapeados, monitoramento de indicadores	Falta de treinamento da equipe nos softwares; Múltiplas demandas simultâneas, Falta de planejamento das atividades; Dificuldade de contratação; Burocracia
Análise Externa	**Oportunidades**	**Ameaças**
	Decreto BIM; Projeto para PIB e PEB (PET-GOV); Ata da deskgraphics; Marco legal do saneamento	Falta de critérios de análise BIM dos os órgãos de controle; Contratados podem não estar habilitados para atender especificações solicitadas; Mudanças políticas; Mudança de estratégia da Companhia

Fonte: Autores, 2022.

Tabela 3. Matriz SWOT SEPLAG-SEDUH.

Matriz SWOT SEPLAG-SEDUH

	Fatores Positivos	Fatores Negativos
Análise Interna	**Forças**	**Fraquezas**
	Equipe qualificada; Bom relacionamento entre as equipes internas da secretaria; Tentativa de padronização; Otimização dos processos de trabalho - implantação do SEI; Motivação de alguns membros na busca de qualificação; Oportunidade de contratar softwares com cursos de sistema BIM (carona em ATAS)	Ausência de equipe própria; Falta de avaliação de desempenho; Falta de interação entre os setores externos, secretarias e órgãos vinculados; Ausência de definição de responsabilidades e competências de cada setor; Estrutura física precária; Ausência de softwares para desenvolvimento do trabalho; Ausência de espaço para arquivo (físico e digital); Ausência de recursos financeiros e tecnológicos
Análise Externa	**Oportunidades**	**Ameaças**
	Capacitação da equipe técnica; Implantação da padronização de todas as atividades da gerência de projetos e orçamento; Revisão dos modelos dos produtos a serem contratados (estudo, projeto e orçamento); Trabalhar de forma integrada; Redução de prazos de execução contratual referente a elaboração de estudos, projetos e orçamentos	Falta de quadro efetivo de funcionários da Secretaria; Inexistência de concurso público para vagas efetivas; Mudança de getsão; Rotatividade da equipe técnica; Falta de recurso financeiro para atualização e implementação dos recursos tecnológicos, podendo ocorrer a perda dos arquivos; Mudança da estrutura organizacional

Fonte: Autores, 2022.

Após a construção da matriz SWOT, os participantes foram levados a afunilar os problemas, identificando as causas raízes das suas organizações, a partir do princípio de Pareto, que afirma que cerca de 80% dos resultados são gerados por 20% das causas (Entendendo…, 2021). Foram executadas etapas de brainstorm para conseguir identificar os problemas, após isso, seguiu-se para etapa de análise dos problemas levantados, observando quais deles poderiam ter o mesmo denominador comum e se, de fato, aqueles eram os problemas raízes. Esse movimento de "chuva" de ideias e posterior afunilamento se repetiu por algumas vezes dentro de um sprint até findar nos problemas escolhidos. Assim, as secretarias selecionaram os principais problemas a serem trabalhados com o BIM no projeto de extensão, conforme identificado na imagem 1.

Para COMPESA o problema selecionado em relação a análise de projetos foi: atrasos e falhas de qualidade na elaboração dos projetos e orçamentos pelos contratados e de terceiros (retrabalhos, projetos desatualizados, sem qualidade, falta de recursos); e em relação a elaboração de projetos foi: escassez de recursos (dados, pessoal, equipamentos) e falta de padronização e de controle de processos na gerência para elaboração dos projetos e orçamentos. Já para SEPLAG-SEDUH os problemas selecionados foram: (1) falta de amadurecimento dos processos operacionais padronizados e na sua atualização; (2) rotatividade de membros da equipe, perde de "expertise" e (3) falta de infraestrutura tecnológica, forçando utilização de equipamentos particulares ou de colegas de trabalho, provocando inclusive perdas de documentos físicos.

ANÁLISE DIAGNÓSTICA DAS EQUIPES			
EQUIPE	**PROBLEMA**	**GRAVIDADE**	**OBS.**
SEPLAG-SEDUH	Falta de amadurecimento dos processos operacionais padronizados e na sua atualização.	Muito Grave	
	Rotatividade de membros da equipe, perde de "expertise".	Muito Grave	
	Falta de infraestrutura tecnológica, forçando utilização de equipamentos particulares ou de colegas de trabalho. Ex: Em alguns casos, ocorre perda de documentos digitais. Falta de infraestrutura física, provocando inclusive perdas de documentos físicos.	Grave	
	Falta de incentivo a educação continuada nas tecnologias necessárias à execução dos trabalhos.	Grave	
	Dificuldades na gestão contratual com relação ao controle da execução; por exemplo multas por atraso. Obs: A qualificação é conseguida através de exigências de experiencias passadas (comprovações).	Muito Grave	Fora da capacidade da equipe
COMPESA	Análise de Projetos: Atrasos e falhas de qualidade na elaboração dos projetos e orçamentos pelos contratados e de terceiros (retrabalhos, projetos desatualizados, sem qualidade, falta de recursos);	Grave	
	Elaboração de Projetos: Escassez de recursos (dados, pessoal, equipamentos) e falta de padronização e de controle de processos na gerência para elaboração dos projetos e orçamentos;	Muito Grave	
	Áreas estranhas ao setor: Falta de planejamento e priorização das atividades devido a motivações diversas, além de atrasos entre a conclusão do projeto e orçamento e o e licitação das obras (desatualização de projetos, alterações, retrabalhos);	Grave	Questões organizacionais - equipe sem capacidade de influenciar
	Áreas diversas: Obras incompletas e licitações fracassadas geram necessidade de adequação de projeto e orçamento;	Grave	Questões externas à organização
	Legenda		Problemas escolhidos para serem trabalhados no PET-GOV

Imagem 1. Análise diagnóstica das equipes estudadas. Fonte: Autores, 2022.

4 Discussões

Os resultados preliminares mostram a importância em iniciar o processo de implementação BIM a partir de uma conceituação mais ampla do que vem a ser implantar o BIM em uma organização. Compreender a estrutura da organização, os seus principais problemas ligados às suas atividades principais, identificando gargalos e como o BIM pode empreender transformações nessa organização parece ser uma forma frutífera de introduzir o BIM dentro de uma organização.

O Diagnóstico da organização parece como o primeiro passo da criação de um Plano de Implementação BIM. A compreensão da organização pública envolve muito mais que a visão da alta gestão, mas também como os funcionários vêem a organização e como os seus parceiros podem trabalhar de forma mais integrada e produtiva. Ao se ter essa visão mais ampla da organização e das múltiplas possibilidades de implementar o BIM dentro da organização abre-se espaço para um processo de implementação muito mais duradouro e de longo prazo, tornando a implementação muito mais produtiva e com efeitos mais profundos (Leusin, 2018).

Entre as inúmeras dificuldades e desafios para o processo de implementação BIM, cabe destacar aqui o desafio ligado à pressão de empresas do mercado que muitas vezes vendem a falsa ilusão que a implementação do BIM está associado à aquisição de certos pacotes de ferramentas, sem um estudo mais aprofundado sobre as reais necessidades da organização. Por força e pressões dessas empresas o processo de implementação torna-se contraproducente, dificultando inclusive o empenho de funcionários da organização. Alguns desses terminam achando que o treinamento de uma ou outra ferramenta vai realmente resolver os seus problemas, quando muitos desses treinamentos, capacitações e aquisições de softwares não correspondem às reais demandas da organização.

Assim, o processo de implementação exige uma árdua tarefa de convencimento, aderência e participação dos diversos atores de uma organização pública. Mesmo sabendo dos desafios que é implementar o BIM neste setor, que pode de uma hora para outra, por mudanças da visão política de um governo, mudar completamente ou até mesmo cancelar a estratégia de implementação, convencer o corpo técnico concursado e mostrar os benefícios estratégicos para a organização pode ser uma tarefa mais bem estruturada em busca de um processo de implementação que seja capaz de perdurar por vários anos e diferentes Governos.

5 Considerações finais

Mesmo sabendo da importância que é desenvolver projetos pilotos, compreender como certas ferramentas e tecnologias associadas à Modelagem da Informação funcionam, é importante compreender que o processo de adoção BIM em uma empresa pública passa por mudanças profundas em seus processos e sua cultura de trabalho. Esse parece ser o grande desafio na implementação. E, para conhecer como essas mudanças podem e devem acontecer, é de fundamental importância conhecer de uma forma mais ampla a organização pública que se vai trabalhar.

Portanto, no processo de implementação numa empresa pública duas questões são fundamentais: conscientizar a organização sobre o que é o BIM, mostrando que é muito mais de que o uso de uma tecnologia de ferramentas e; compreender as reais demandas da organização e como a Gestão da Informação da Construção pode contribuir com a melhoria dos serviços oferecidos por essa organização e com o trabalho das pessoas que fazem parte dessa organização.

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Referências

BIM Forum Brasil. Estratégia BIM dos Governos do Sul-Sudeste é tema do próximo evento do BIM Fórum Brasil. 2021. Página Inicial. Disponível em: < https://tecnoblog.net/247956/referencia-site-abnt-artigos/ >. Acesso em 15 nov. de 2021.

buildingSMART. BuildingSMART International, 2021. Página Inicial. Disponível em: < https://www.buildingsmart.org/>. Acesso em 9 nov. de 2021.

Coutinho, T. Entenda as funções de um Scrum Master e sua importância em um Scrum Team. Voitto, 2020. Disponível em: < https://tecnoblog.net/247956/referencia-site-abnt-artigos/>. Acesso em: 10 de julho de 2021.

Eastman, C. et al. Manual de BIM: um guia de modelagem da informação da construção para arquitetos, engenheiros, gerentes, construtores e incorporadores. Tradução: Cervantes Gonçalves Ayres Filho et al. Porto Alegre: Bookman, 2014.

Entendendo o princípio de Pareto (a regra 80/20). 2021. Disponível em: https://asana.com/pt/resources/pareto-principle-80-20-rule. Acesso em: 15 mai 2022.

Hass, Wolfgang. OPENBIM FOR THE ENTIRE BUILDING LIFECYCLE. BuildingSMART. 2018. Disponível em: < https://www.buildingsmart.org/openbim-for-the-entire-building-lifecycle/>. Acesso em: 11 de julho de 2021.

Ingram, J. Understand BIM: The past, present and future. Ed. Routledge Taylor & Francis Group, London and New York, 2020.

Kalay, Y Architecture's new mediaç. Ed.The MIT Press, Cambridge, 2005.

Leusin, S. Gerenciamento e Coordenação de Projetos BIM: Um guia de ferramentas e boas práticas para o sucesso de empreendimentos. 1. ed. Rio de Janeiro: Elsevier, 2018.

MESSNER, J. et al. BIM Project Execution Planning Guide, Version 2.2. Computer Integrated Construction Research Program, The Pennsylvania State University,University Park, PA, USA, August, 2019. Disponível em: http://BIM.psu.edu, acesso em: 13 março de 2022.

Rodrigues, I; Andrade, M. BIM Execution Plan (BEP) to Infrastructure Superintendence of the Federal University of Pernambuco: A proposal to implement BEP in a Federal University in Brazil. ASCAAD, 2021.

Silva, A. A., Silva, N. S., Barbosa, V. A., Henrique, M. R., & Baptista, J. A. (2011). A Utilização da Matriz Swot como Ferramenta Estratégica – um Estudo de Caso em uma Escola de Idioma de São Paulo. SEGeT - VIII Simpósio de Excelência Em Gestão e Tecnologia, 11. Retrieved from http://eng.aedb.br/seget/artigos11/26714255.pdf%0Ahttp://www.aedb.br/seget/arquivos/artigos11/26714255.pdf%0Ahttp://www.economia.aedb.br/seget/artigos11/26714255.pdf

INTERCOM 2.0: A web-based platform for collaborative design processes

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Abstract. Next to the advantages of consistent 3D planning, the Building Information Modeling (BIM) method also places new demands on the actors and thus primarily causes a change in the way of working. Against this background the paper discusses the development of the web-based BIM platform INTERCOM for collaborative planning processes in academia and AEC that enables monitoring, processing and assessment in a location and time independent environment. In addition to the technical advantages, a deeper, active and flexible discussion is intended to be created, involving all project partners. As such, INTERCOM is based on the openBIM idea and provides open access for all participants with a high degree of networking for solving complex planning tasks. The research showcases a further development of a previously implemented prototype and discusses the findings from the first academic projects, focussing on the collaborative workflow and the decision making throughout the design process.

Keywords: Building Information Modeling (BIM), Collaborative Design Process, Common Data Environment (CDE), Architecture Curriculum, Open Educational Resource (OER)

1 Introduction

Building Information Modeling (BIM) is a method that integrates diverse aspects around the design, construction and operation of an architecture and is based on the idea of a continuous use of digital building data models over the entire life cycle of a project. In this sense, BIM stands for a strategic approach that describes a process. The entire planning information of a building is organized in a central data set, which is accessed by all project participants in order to enter their contributions and coordinate them among themselves. The use of a common data environment (CDE) that is constantly synchronized, as well as the immediate availability of all current and relevant data, leads to a significant improvement in the exchange of information and, in the best case, to all-round

coordinated and optimized planning before construction activities begin (Borrmann et al, 2018).
Most importantly, BIM causes a change in the way of working, especially in the cooperation with other project participants. With the increasing complexity of planning and construction processes, the creation of clear communication structures and joint exchange platforms between the various project participants (client, planners, construction companies, authorities) is becoming an increasingly important factor. Particularly in the context of growing spatially distributed collaboration, this aspect of interdisciplinary interaction and the integration of different planning contents is becoming the central point for the success of construction-related cooperation (Daniotti, 2020).

Even though the computer provides an effective interface for the collaboration of various participants involved in construction, the success of a project depends decisively on the socio-cultural imprints and disciplinary boundary conditions of the people acting. In addition to the technological challenges of digitization, the different working methods, requirements and objectives often represent an obstacle to the successful cooperation and execution of construction tasks. The purpose of BIM is therefore not primarily to introduce digital tools into one's own work process. For BIM to be successful, the way in which the players involved are organized on the one hand and the project structure on the other must adapt. This inevitably requires that the people involved get involved in this process and understand the associated "new culture of cooperation" as an added value.

Figure 1. Conceptual diagram of the INTERCOM platform

Against this background, the development of the INTERCOM platform aims to provide a web-based infrastructure that enables all those involved in the planning process to exchange information independently of time and location. The core of the web-based platform is an open source application consisting of a fully modular software architecture. This enables different expansion stages and a demand-oriented configuration of the collaboration platform. Interaction with the model and exchange with other project participants takes place via an avatar presence in real time. In addition to the real-time representation of the current planning status via an IFC model viewer, various communication tools such as a model-related live chat, screenshot and comment functions as well as eLearning formats are provided. The collaborative platform should enable monitoring, processing and assessment in an interdisciplinary learning environment that is equally available to all participants. In addition to the technical advantages, a deeper, active and flexible discussion is intended throughout the progress of the project.

2 Methodology

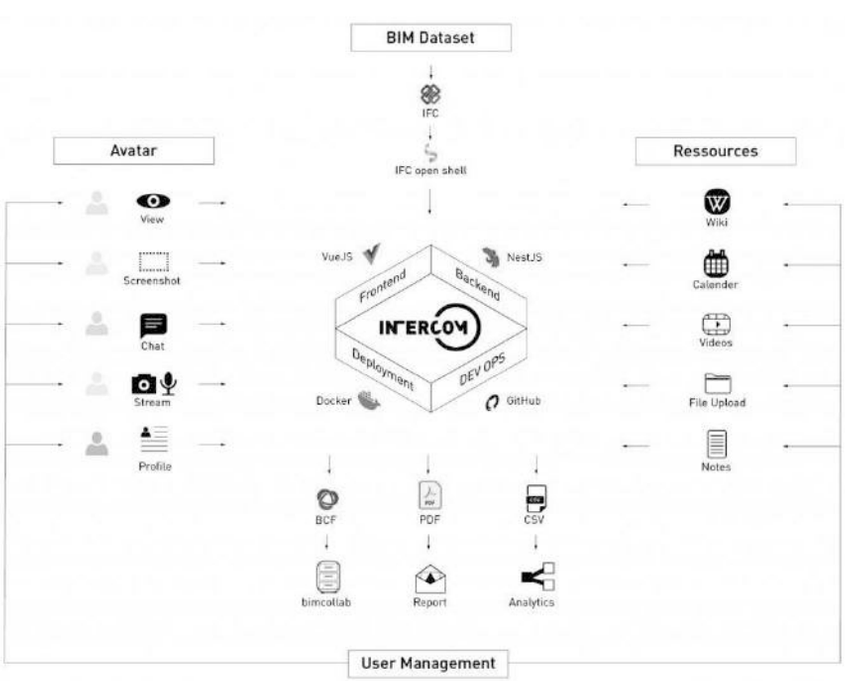

Figure 2. Technical architecture / system environment of the web-based platform.

The research showcases a further development of a previously implemented prototype that was realized based on the Unreal Engine (Edward, 2015). During the development of this first prototype it became apparent that the integration of communication technology (e.g. chat, tutorials, eLearning modules) had become increasingly difficult. Moreover, the scalability of the platform and modular extension had been quite limited (Hemmerling et.al, 2020). Since the communication and interlinking modules of the INTERCOM platform are essentially core web technologies, a move to an entirely web-based version form the starting point of the research presented in this paper.

The project is based on the openBIM idea and is intended to provide open access for all participants with a high degree of networking for solving complex planning tasks. The core of the web-based platform is an open source application consisting of a fully modular software architecture. This enables different expansion stages and a demand-oriented configuration of the platform. Interaction with the model and exchange with other project participants takes place via an avatar presence in real time – similar to a video game. In INTERCOM it is possible to meet with other project participants directly on the digital model. In this way, questions can be discussed very specifically and visually supported in real time and decisions can be made together. The option to take the point of view of other participants who are in the scene supports the interaction in the team and also promotes a common understanding of the project. A model-related chat with a screenshot and comment function supports direct exchange within the team. In addition, an integrated issue management, including BCF-interface (BIM Collaboration Format) and various eLearning modules complete the collaboration platform.

In architectural design we are dealing with a complexity, which can be characterized, according to Rittel and Webber (1973), as a series of wicked problems. The nature of these problems is based on a non-linear process, which is unique for each project and doesn't follow a well-described solution path. Hence, the decision-making process is hard to cope with, as there are multiple solutions, depending on the various interests and points of view of the stakeholders involved. In order to manage this kind of complexity collaborative approaches are key to arrive at a design solution, where the different perspectives are negotiated in open source and open-ended feedback loops where every output generates an input for the next step to improve, re-appropriate and reshape the design. A similar approach of iterative reflection has been proposed by Donald Schön (1983), focusing on a continuous conversation, confronting the designer's idea with others.

On this basis, a teaching format (Case Study – Borneo Sporenburg) was conceived that combines the development of an own design idea with a collaborative approach and requires as such an intensive exchange with other planning participants. The aim was to establish a working context that allows for the creation of collective knowledge in an environment of reciprocal support. In addition to the technological constraints (different proprietary software and CDEs) and the use of the newly developed INTERCOM platform, the focus was placed on the decision-making process and the associated design coordination

between the poles of "unity" and "difference". Or to put it another way: How much individuality can be mapped in a participatory and collaborative design process and vice versa? Referring to this question the following three operational levels were considered in parallel during the course of the project, evaluating their interdependencies:

- Individual design approach.
- Collaboration with direct neighbors and the overall urban context
- Decision making, communication and data exchange

3 Case Study - Borneo Sporenburg

The Borneo Sporenburg site, two peninsulas in the eastern part of the Amsterdam docks, served as an urban context to establish the desired collaborative design process. The masterplan tied together two seemingly opposing ideas. On the one hand the potential of the largescale dockland area was to be exploited for water-related activities, on the other hand the brief called for 2500 low-rise dwelling units, with a density of 100 units per hectare. Taking these points of departure presented a fascinating and unique opportunity for an urban experiment. West 8 sought the solution in developing a new typology of three-storey, ground-accessed houses deviating from the usual terraced house in being strongly oriented to the private realm, in this case by incorporating patios and roof gardens (Machado, 2006).

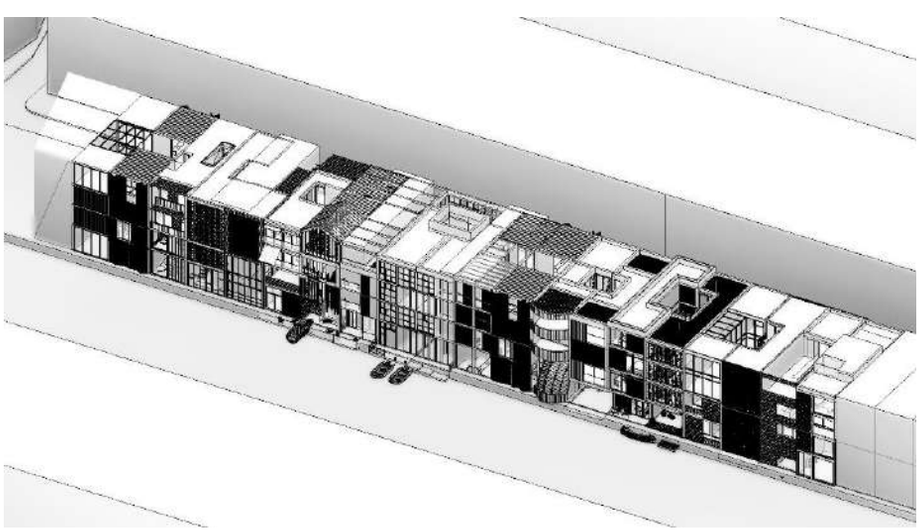

Figure 3. Collaborative design for the Borneo Sporenburg site (CDE).

The design task for the students demanded the development of individual houses for the peninsula within the pre-defined framework and design rules given by the West 8 masterplan. The participants of the course were supposed to carry out individual architectural designs for each single row house, as an integral part of the entire waterfront. An important aspect of the process was the coordination of each individual design with the adjacent canal houses and the urban context. The coordination and design decision making within the overall composition was organized via the INTERCOM platform.

At the beginning of the course, the participants' objectives and initial ideas were discussed in a design thinking workshop and agreed upon in the group. In addition, binding project goals (including a mix of functions, sustainability goals) and common planning principles (e.g. a uniform planning grid) were defined for further work. Throughout the course of the semester, meetings in presence alternated with video conferences and hybrid teaching formats, in which the design development was coordinated both in the entire group and in smaller teams. The INTERCOM platform was used in the process mainly to bring about and document the design decisions. It was essentially used outside the course itself to conduct asynchronous (time- and location-independent) coordination and to make the project evolution and outcomes visible to all participants in the planning process.

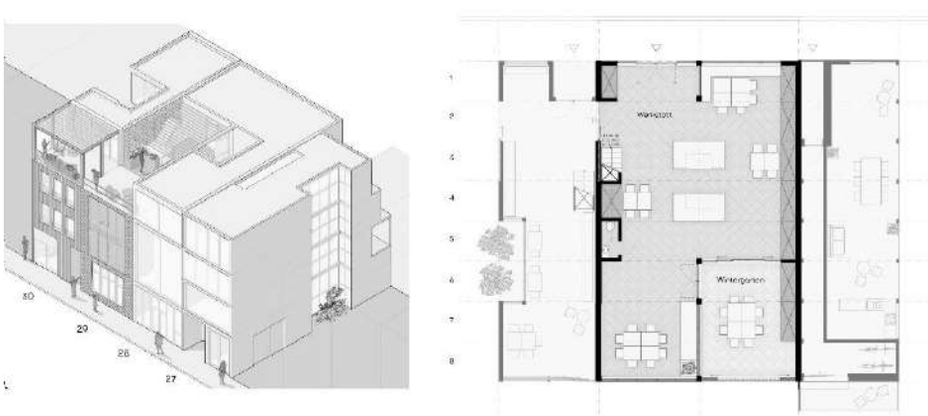

Figure 4. Example of adjacent houses with individual and common design features.

It should be noted that groups of two to three students formed quite quickly to move forward together on the design development. Coordination with the other adjacent properties then took place in a second planning step, so that there are stronger and weaker links within the overall urban design. This clustering can be clearly observed and is particularly prominent in the formation of atriums, programmatic definition of use, and façade design. Beyond that, however, there are design and content connections that establish a relationship between the designs across several plots. The resulting density of content and diversity of design within a common framework of action can be understood as a reflection

of the aforementioned complexity. In this respect, the process certainly represents the greater findings compared to the design results.

4 Results

Due to the fact that a large variety of authoring software was used for the planning of the respective houses, the challenge in the coordination, apart from the discussion of the design content, was mainly the data exchange and the synchronization of the individual models. Thus, bilateral interfaces between the programs were tested as well as the IFC interface in order to be able to view the individual buildings in entire and neighbouring context. The IFC export/import to the INTERCOM platform worked without any problems, only the positioning of the buildings in relation to each other had to be partially corrected due to the different positioning in the coordinate system of the authoring software. The majority of the students worked with Autodesk Revit and were able to use the CDE cloud service BIM360 for the synchronization of the models without any problems. Models created other programs (e.g. Archicad, Vectorworks, Rhinoceros, Nemetschek Allplan) were loaded into BIM360 via bilateral interfaces or IFC import. Although this worked in different ways for all models in the end, the BIM360 platform was hardly used for decision making and exchange in the group due to the lack of communication and interaction tools.

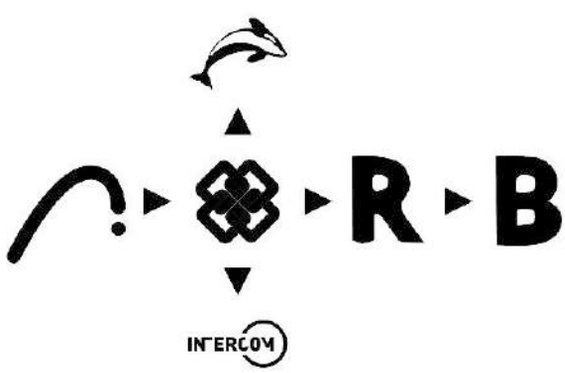

Figure 5. Work- and data flow example:
From Archicad via IFC to INTERCOM, Revit/BIM360 and Orca.

In addition to the INTERCOM platform, other media and formats were used for coordination in the process (messenger services, video conferences, break-out sessions, telephone). Direct exchange and face-to-face workshops at the university also contributed significantly to the success of the project. In this respect, the web-based collaboration platform is currently still to be seen as a supplement and not as a replacement for existing communication systems.

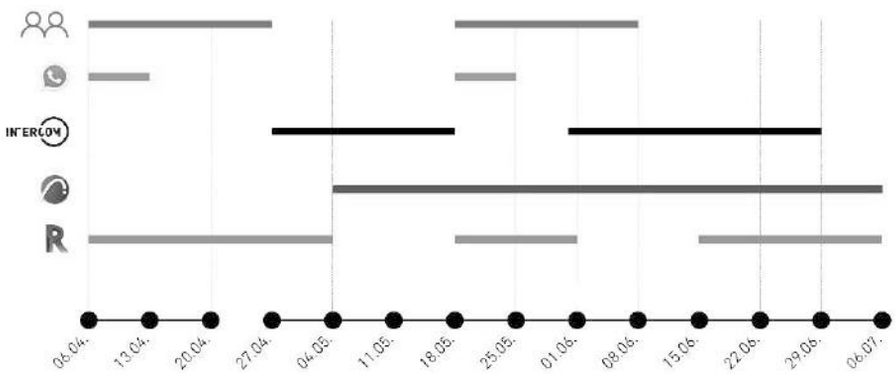

Figure 6. Example of a time-based use of communication and planning tools.

A Questionnaire that was conducted by the participants every week during the semester showed that the platform was appreciated as an added value for the collaboration and the design decision process from the beginning on. The basic modules of the platform that were used most included the IFC model navigation, the chat and screenshot function as well as the Avatar option. In INTERCOM it was made possible to meet with other project participants directly on the digital model. In this way, questions were discussed very specifically and visually supported in real time. As an avatar, one could explore the model, similar to a video game, and view it from different angles. The option to take the point of view of other participants who are in the scene supported the interaction in the team and also promoted a common understanding of the project.

Figure 7. Example of design coordination using chat, screenshot and file documentation within the INTERCOM platform.

So far, the platform was mainly perceived as a pinboard that documents design decisions and the project evolution. Amongst the desired functions a group chat, push messaging as well as an audio and video streaming were mentioned to improve the functionality and interactivity level of the platform. Extensions, such as the BCF interface, the issue management as well as the knowledge database and the extension towards eLearning modules (Tutorials, MOOCS etc.) are intended to be implement in the next development phase as well.

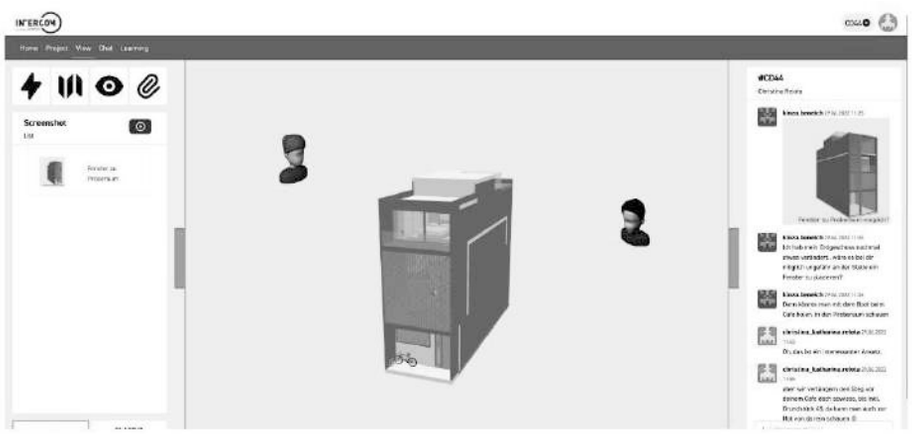

Figure 8. INTERCOM platform with IFC viewer, avatars, project chat and screenshot function.

5 Discussion

Professional orientation and motivating support form the basis for the students' learning success. Phases of trying out, repeating and practicing as well as reflecting, discussing and evaluating alternate in the learning process. Different methods of teaching and the use of various media modules enable broad access to the content and are intended to meet the needs of different learning types. The profile of this teaching innovation is therefore characterized by conveying a comprehensive approach to solving complex planning tasks with a high degree of networking.

An essential prerequisite for the success of the teaching innovation is the willingness of all participants to engage in a comprehensive process change. Working on a shared data set in the cloud requires not only technical training but also, indispensably, the teaching of a different social approach - from "I" to "We". The INTERCOM platform offers the appropriate learning space for this, which promotes exchange by defining a common action space for all participants from the very beginning. However, the success of the whole depends on the contribution of each individual. This applies to students as well as to lecturers. In the best case, this creates a conscious sense of community

and responsibility among all participants, which makes a decisive contribution to the success of the project and to learning success.

References

Borrmann, A, König, M, Koch, C and Beetz, J, eds. (2018), Building Information Modeling: Technology Foundations and Industry Practice, Springer International Publishing

Daniotti, B. et al. (2020), BIM-Based Collaborative Building Process Management, Springer International Publishing

Edward, G. et al. (2015), BIM based collaborative and interactive design process using computer game engine for general end-users, Visualization in Engineering, Springer Open Journal

Hemmerling, M., Maris S.., (2020) INTERCOM – A platform for collaborative design processes in: Proceedings of the 38th eCAADe Conference: Anthropologic – Architecture and Fabrication in the cognitive age, Berlin

Machado, R., ed. (2006) Residential Waterfront, Borneo Sporenburg, Amsterdam: Adriaan Geuze, West 8, Harvard Graduate School of Design

Rittel, H.W.J., Webber, M.M. (1973), Dilemmas in a general theory of planning, Policy Scieeces 4(2), pp 156-169

Schön, D. A. (1983), The reflective practitioner: how professionals think in action, Ashgate Publishing

BIM approaches in SIGraDi events: repercussions and scope

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Abstract. This article has as its theme the discussions on Building Information Modeling (BIM) within the scope of the research presented at the SIGraDi congresses. The main objective of this article is to present a mapping of the BIM approach by the SIGraDi community, showing how this technology has been appropriate, especially in Latin America. It was possible to understand, through the analysis of the occurrence of the BIM theme in article titles in the last 15 years, that there are four predominant approaches, namely: (1) BIM implementation processes, (2) impacts of BIM tools and their advent, (3) BIM teaching methodologies and (4) BIM uses. It is expected to contribute to the mapping of the main aspects and perspectives of how BIM has been incorporated in the research developed by the members of SIGraDi.

Keywords: BIM, SIGraDi, Systematic literature review, Approaches

1 Introdução

O BIM corresponde a uma mudança de paradigma da ideia da atividade do projetar como sendo “desenhar” para a ideia de “modelar” em um contexto colaborativo, ou seja, saindo de um formato de trabalho individual e linear para um trabalho colaborativo simultâneo, ressaltando seu caráter de “atividade” e não “objeto” de um desenvolvimento tecnológico somente (Eastman et al., 2014). Quase 40 anos depois de seu surgimento, o termo BIM vem ganhando força e sendo foco de diversos estudos (Mizumoto & Oliveira, 2020; Arrotéia et al., 2021; Batista, 2010), o que se justifica por uma conhecida defasagem entre criação de tecnologia, adoção e estudo no meio acadêmico (Álvarez et al., 2020).

Sendo a Sociedade Ibero-Americada de Gráfica Digital (SIGraDi) o principal fórum científico ibero-americano com foco no CAAD, reunindo, desde 1997, discussões-chave que refletem aspectos, de ordem local e internacional, da introdução das tecnologias digitais nos campos da arquitetura, urbanismo, artes e design, a questão discutida neste trabalho é a ocorrência e repercussão do tema BIM nesse congresso. De acordo com a publicação comemorativa de 25 anos da SIGraDi, o BIM apareceu entre as cinco palavras-chave dos artigos

mais citadas a partir da edição de 2010 e, novamente, nas edições de 2012, 2013, 2014, permanecendo no ranking de 2016 a 2020 (SIGraDi, 2021). O estudo específico da ocorrência do tema “BIM” neste congresso possibilita um retrato da dimensão que o tema tem tomado entre um grupo científico com alta participação de pesquisadores latino-americanos. Este artigo tem, assim, como objetivo principal compreender as abordagens dos estudos publicados sobre o BIM nas discussões da SIGraDi, no intuito de elucidar as vertentes do pensamento e categorizar os momentos da disseminação dessa tecnologia no âmbito ibero-americano.

O contexto do evento em que este artigo se insere, com tema “Apropriações críticas”, abre um espaço para diversas reflexões, “sobre a origem e o processo de um design transformador(...) a partir do papel da tecnologia e seus efeitos no contexto social, cultural, material e educacional” (SIGraDi, 2022). Através da evidenciação de como os pesquisadores que compõem a SIGraDi selecionam tópicos e enfoques para as pesquisas que versam sobre o BIM, consolida-se o pensamento, de quase duas décadas, sobre uso e apropriação da tecnologia BIM no cenário ibero-americano. Para este artigo, interessa o olhar sobre o BIM, quais são as suas aplicações mais frequentes, com quais temáticas ele se relaciona ou se funde. Dessa forma, espera-se evidenciar quais são as reflexões sobre o BIM que têm sido levadas a cabo na SIGraDi. Espera-se contribuir com um olhar crítico sobre a difusão dessa tecnologia através da análise temporal de um evento de grande repercussão e relevância, especialmente, para a América Latina.

2 Metodologia

Este artigo se baseou em um método de revisão sistemática de literatura, com ênfase exploratória e com abordagem predominantemente bibliométrica. Outras revisões da área já destacaram autores e os focos principais de discussão do BIM no Brasil (Carneiro et al., 2012; Checcucci et al., 2011; Sperling et al., 2019). Tais revisões contribuem para o estabelecimento de um panorama das discussões que se encontram dispersas ao longo de periódicos e eventos. Com uma revisão focada em um único evento, de abrangência territorial maior, pode-se ver o impacto dessas discussões ao longo dos anos, destacando-se as tendências de pesquisa.

Inicialmente, através de uma busca on-line no site oficial da SIGradi, extraiu-se o número de eventos já realizados e as suas temáticas, para uma análise temporal dos congressos (SIGraDi, 2021). Identificou-se a disponibilidade de acesso aos anais no site somente dos anos 2013 a 2020. Através da plataforma CuminCad, na busca avançada, entrou-se com o comando “Building Information Modeling {source} =~ m/SIGRADI/i”, para buscar todos os artigos que citavam o BIM, e que tinham como fonte somente os eventos da SIGraDi, o que resultou em 1097 artigos. No intuito de selecionar artigos com

ênfase específica em BIM, restringiu-se a amostra para artigos que continham as expressões “BIM” ou “Building Information Modeling” no título dos artigos, o que resultou em 74 resultados. Os anais do evento de 2021 foram encontrados especificamente na plataforma na editora Blucher, por ainda não estarem disponíveis no CuminCad. Na busca dos artigos do evento de 2021, encontrou-se manualmente quatro trabalhos com BIM no título. Os trabalhos selecionados foram sistematicamente classificados através de uma planilha eletrônica formada pelos seguintes campos: nome do artigo, autores, ano de publicação, país dos autores, instituição dos autores e metodologia utilizada. Uma linha do tempo sistematizou o início da ocorrência do tema BIM nos títulos dos artigos e sua distribuição ao longo dos anos. Através da leitura dos títulos e resumos, foram levantados quatro grupos temáticos de artigos que direcionaram a análise da abrangência do BIM nos artigos por grupo.

3 Resultados

Com a busca, reuniu-se um total de 78 artigos com o termo “BIM” no título. A primeira vez que um artigo apresentou a palavra BIM em seu título foi em 2007 (ver Sanguinetti, 2007). O ano com maior número de publicações com BIM foi 2013, com dez trabalhos. No Quadro 1, é possível observar a variedade de cidades sede do evento, assim como a concentração temporal dos artigos encontrados nos últimos 15 anos.

Quadro 1. Edições do SIGraDi presentes na amostra. Fonte: Autores, 2022.

Artigos Encontrados	Edição	Tema da Edição	País
1	2007	La Comunicaciónen la ComunidadVisual	México
2	2008	GráficaDigital eInformáticaAplicada:Cooperación,Integración yDesarrollo	Cuba
3	2009	Delo Moderno a lo Digital.Desafiosde una Transición	Brasil
2	2010	Disrupción, modelación y construcción: Diálogos cambiantes	Colombia
3	2011	CulturaAumentada	Argentina
6	2012	Forma (In) Formação	Brasil
10	2013	Knowledge-based Design	Chile
6	2014	Design in Freedom	Uruguay
2	2015	Informação de projeto para interação	Brasil
6	2016	Crowdthinking	Argentina
7	2017	Resilience Design	Chile
8	2018	Tecnopolíticas	Brasil
9	2019	ArchitectureintheAge ofthe4thIndustrialRevolution	Portugal
9	2020	Transformative Design	Colombia(on-line)
4	2021	Designing Possibilities	Ubíquo (on-line)

Com a classificação dos artigos por ano e tema do evento, pode-se lançar mão de uma análise de vinculação direta ou não do tema BIM ao tema de cada edição do evento. Interpretou-se que as edições de 2010, 2015, 2020 e 2021 possuem um tema com uma proximidade muito clara em relação ao BIM, e as edições 2013, 2014 e 2016 com uma proximidade média, com certa relação junto ao tema BIM.

Figura 1. Relação de artigos com BIM no título, por edição dos congressos da SIGraDi. Fonte: Autores, 2022

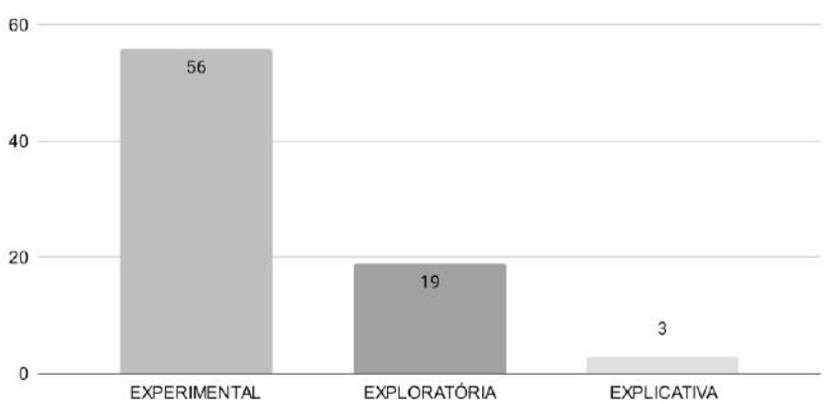

Figura 2. Metodologias dos artigos selecionados. Fonte: Autores, 2022

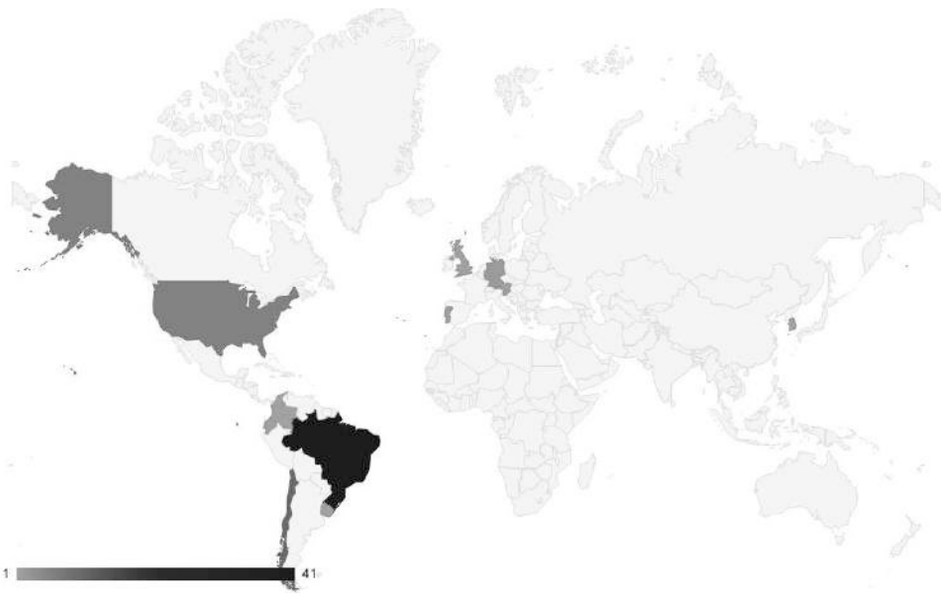

Figura 3. Países dos Primeiros Autores. Fonte: Autores, 2022

Observa-se, através da Figura 2, que 56 artigos se utilizaram de uma abordagem metodológica experimental, 19 de uma exploratória e três de uma abordagem explicativa. Sobre a localização das pesquisas, extraiu-se os países dos primeiros autores de cada artigo para uma observação das origens das discussões e pode-se observar que a grande maioria responsável por trazer o tema do BIM ao SIGraDi, um total de 41 artigos, é de pesquisadores brasileiros como demonstrado por contraste na Figura 3.

4 Discussão

Ao longo de 25 anos do evento, o foco na temática BIM, embora tenha sido ampliada, ainda é bastante enxuta, quando colocada em proporção com o volume de artigos das edições, como demonstrado na Figura 1, além de estar concentrada nos últimos 15 anos. No entanto, observa-se que a amostra analisada neste artigo não abarca os artigos que contemplam a temática do BIM de forma indireta, não explícita nos títulos, uma vez que somente foram incluídos os artigos que possuem o termo “BIM” ou “Building Information Modeling” no título.

Observou-se, através da montagem da tabela de análise dos artigos, e da leitura dos títulos e resumos, algumas tendências e grupos de discussão. Ao

todo, foram encontrados quatro grupos de temática de discussão principais: (1) Implantação do BIM; (2) Impacto do BIM; (3) Ensino; e (4) Uso do BIM.
De acordo com a listagem de Usos BIM divulgada pela BIM excellence.org, uma organização sem fins lucrativos que sistematizou 201 Usos BIM, conforme o conceito lançado por Succar et al. (2016), é que se pensou o grupo temático "Uso do BIM", no qual foram inseridos os artigos que trabalharam algum uso já classificado pela literatura.
Os artigos que exploraram a Implantação do BIM o fizeram através dos desafios e descrição do processo de adoção e difusão do BIM; artigos que exploraram o Impacto do BIM abordaram o viés de inovação e análise de suas capacidades; já os artigos que exploraram os desafios do ensino do BIM analisaram as contribuições da tecnologia no ensino de conhecimentos da construção civil e os desafios de ensinar o BIM; e artigos que relataram um ou mais de um uso do BIM o fizeram de forma tanto a expandir ou analisar estrategicamente o BIM em uma certa aplicação/uso.
Conforme Figura 4, 47,4% dos artigos foram enquadrados na abordagem "Uso do BIM", 26,9% na de "Ensino", 10,3% em "Implantação BIM" e 15,4% em "Impacto do BIM".

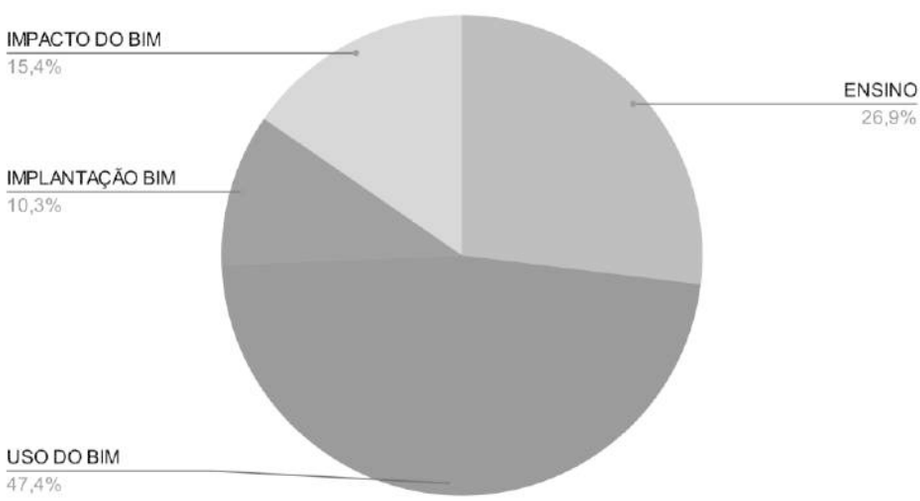

Figura 4. Percentual de grupos de abordagens do BIM na amostra.
Fonte: Autores, 2022

Sendo assim, há uma maior parcela de pesquisas voltadas para uma aplicação do BIM, e dentro dessa fatia maior, observou-se um variado espectro de aplicabilidades, desde um relato simples do uso de softwares BIM para uma abordagem voltada à solução de uma problemática específica, a explorações mais inovadoras envolvendo algoritmos e novas metodologias de cálculo, projeto e customização em ferramentas BIM.

Pode-se observar o foco maior nas abordagens experimentais com algum Uso do BIM, mas atenta-se para a segunda abordagem mais identificada, a de Ensino do BIM, demonstrando que o evento tem se configurado com um espaço para reflexões pedagógicas. Tais experiências abordam tanto experiências de métodos de ensino quanto à discussão sobre o BIM como paradigma, envolvendo hipóteses variadas da forma de abordagem deste em um ambiente de sala de aula e do primeiro contato de estudantes com a tecnologia.

4.1 Implantação BIM

Na observação de um grupo de artigos com foco no processo de advento do BIM, oito artigos foram enquadrados no que se denominou abordagem de Implantação do BIM. Dentre as metodologias encontradas entre os artigos desse grupo, 100% foi enquadrada como exploratória. Ao explorarem a implantação BIM, foram desenvolvidos e levantados aspectos do processo de aceitação da nova tecnologia de modelagem, assim como as dificuldades de compreensão do termo e os desafios de uma implantação adequada e completa, para além da tecnologia envolvendo o conjunto de processos BIM. Observou-se que, por parte dos autores destes artigos, há um grande benefício em uma difusão e implantação BIM, por vezes desconsiderado ou não reconhecido, e é colocado em pauta o desafio da falta de pessoal adequadamente capacitado em BIM. Entre os artigos que mapearam artigos e experiências sobre o BIM, com sua totalidade focada em métodos exploratórios, pode-se observar leituras focadas em classificar os assuntos mais frequentes relacionados ao BIM, abordagens com o objetivo de classificar o significado atribuído ao termo BIM, e de classificar os desafios de implantação através de categorias (humana, gestão, política, mercado e tecnologia). Por último, dois artigos se voltaram para um relato de implementação do BIM em instalações públicas, como por exemplo na Secretaria do Estado de Infraestrutura e Logística (SINFRA).

4.2 Impacto do BIM

Foi encontrado um total de 12 artigos que abordaram o Impacto do BIM, através de um desenvolvimento de novas metodologias em conjunto com a Tecnologia BIM e análises dos potenciais benefícios alcançados com ferramentas BIM. Pode-se ressaltar artigos neste grupo com objetivos de analisar ou criar um framework (estrutura de códigos) que categorize produtos BIM, assim como artigos que exploram novas formas de usar algumas ferramentas BIM ou padrões de extensão já existentes de maneira a alcançar novos resultados. Outros artigos focaram em explorar procedimentos de gestão que possibilitem a implantação eficiente do BIM ou explorar os impactos positivos e negativos da implantação BIM em empresas e projetos.

Ao todo, as abordagens metodológicas mais utilizadas foram as experimentais, correspondendo 66,7%, seguida das exploratórias e explicativas, 16, 7% cada. Os oito artigos que tiveram uma abordagem experimental consistiram em experiências situadas nas cidades de Salvador, Viçosa, Belo Horizonte e Recife, no Brasil, e Texas, Geórgia e Kansas, nos EUA. Entre os principais destaques, pode-se observar o estudo da utilização do Objeto Interaction Query (oIQ), que propõe uma nova forma de consultar modelos BIM, gerando um avanço no processo de avaliação de um modelo. Também é interessante destacar a utilização de método comparativo, para estudo do processo de especificação e extração do padrão Construction Operations Building Information Exchange - COBie, que é um padrão desenhado justamente para integrar dados entre as ferramentas BIM e os sistemas de Facility Management. No artigo enquadrado em uma metodologia de abordagem explicativa, encontrou-se a discussão do processo de concepção na chamada "arquitetura BIM" junto à semiótica peirceana. Nos três artigos enquadrados como exploratórios, houve a avaliação do estado da arte de técnicas de otimização e avaliação do projeto e, em seguida, a comparação com o impacto das ferramentas BIM; encontrou-se um levantamento das mudanças na gestão de obras com o BIM, e um artigo que examinou o impacto do BIM em projetos de pequena escala.

4.3 Ensino do BIM

No grupo identificado como de foco no ensino do BIM, foram enquadrados 21 artigos, por consistir em análises de metodologias pedagógicas que desenvolveram propostas de ensino do BIM ou desenvolveram o ensino de conteúdos da AECO através da tecnologia BIM. Dentre eles, destacam-se os 13 artigos enquadrados com uma metodologia experimental, os trabalhos que divulgaram suas experiências em estúdio de projeto com o BIM. No Quadro 2, estão elencadas oito principais contribuições desses experimentos.

Quadro 2. Resumo das contribuições das pesquisas experimentais sobre o Ensino BIM. Fonte: Autores, 2022

nº	Experiências no campo do Ensino BIM
1	Componentes paramétricos em disciplina voltada para tipologia habitacional
2	Studio de projeto propôs análises junto ao BIM que apoiam a solução do projeto final
3	Instrumentação no ensino de desenho com o BIM, apresentando solução em material multimídia
4	Introdução do BIM de forma a aumentar a compreensão da construção e facilitar documentação
5	Projeto de aula patrocinado pela indústria com objetivo de aprendizado do BIM
6	Método "Blended Learning" que propõe vídeo-aulas de modelagem BIM

7	Incorporação do BIM na inserção do campo técnico no estudo do ambiente formal e espacial de arquitetura (modelo educacional STEAM)
8	Processo de design e Software BIM são ensinados paralelamente

Nas oito pesquisas enquadradas como exploratórias, observou-se uma coleta de dados, tanto por revisões bibliométricas quanto por entrevistas, com objetivo de mapear pesquisadores e avanços nos métodos de ensino que incorporaram o BIM, e descobrir o impacto de certos métodos de aprendizagem na capacitação e ensino do BIM em empresas.

4.4 Uso do BIM

Através da classificação Usos do BIM, proposta inicialmente por Succar et al. (2016), foi possível agrupar 37 trabalhos que desenvolveram um relato ou experiência com, no mínimo, um uso BIM codificado de acordo com a publicação da BIM excellence.org. Como demonstrado no Quadro 3, foram enquadrados 20 dos 72 Usos BIM classificados como de domínio da construção civil (SUCCAR et al., 2016).

Quadro 3. Usos BIM trabalhados nos artigos da categoria Uso BIM. Fonte: Autores, 2022

Código	Uso BIM	Número de artigos em que o Uso BIM foi encontrado
3040	Design Authoring / Criação de design	6
2040	Generative Design / Design Generativo	5
2020	3D Detailing / Detalhamento 3D	3
2030	As-Constructed Representation	3
4050	Code-Checking Validation	2
4090	Energy Utilization	2
3060	Lean Process Analysis	2
4190	Solar Analysis	2
1310	Parametric Modeling	1

Dessa forma, algumas questões podem ser levantadas: em primeiro lugar, a concentração de ocorrências nos Usos 3040 e 2040, e, em segundo lugar, a concentração de usos BIM de modo geral relacionados às fases iniciais de projeto. Considera-se relevante ressaltar que segundo o BIM Dictionary, a definição do Uso BIM 3040 consiste em:

Um Uso do Modelo representando o processo de desenvolvimento de Modelos Generativos ou Modelos Paramétricos para propósitos relacionados à definição de projeto, à comunicação de projeto e a iterações de projeto. Autoria de Projeto é uma atividade chave do BIM conduzindo à Documentação 2D

baseada no modelo, Detalhamento 3D e outros entregáveis baseados no modelo (BIM Dictionary, 2020).

E a definição do Uso BIM 2040 em:

Um Uso do Modelo onde Aplicativos BIM e outras ferramentas especializadas são usadas para explorar algoritmicamente a forma ou a função do projeto (BIM Dictionary, 2020).

Dessa forma, ressalta-se o caráter múltiplo e interseccional de cada Uso BIM. Os artigos exploraram usos BIM na inovação, colaboração e processo de projeto auxiliado por ferramentas BIM. Sobre a metodologia, 31 dos 37 artigos foram enquadrados em abordagens metodológicas experimentais, o que demonstra uma tendência de divulgação científica das experiências ainda muito iniciais envolvendo os potenciais do BIM.

5 Considerações Finais

Este trabalho realizou uma revisão sistemática de literatura sobre os artigos que abordaram o BIM em todo o período das edições dos congressos da SIGraDi. Foram encontrados exemplares aplicáveis, com o tema já presente no título, somente nos últimos 15 anos do evento. Ao se realizar o mapeamento do foco de abordagem do BIM através de categorias que emergiram da leitura dos artigos encontrados, foi possível considerar quatro grupos de abordagens principais, sendo eles: (1) Implantação do BIM, (2) Impacto do BIM, (3) Ensino do BIM e (4) Uso do BIM. Com destaque para o último, em que se pode lançar mão da listagem de Usos BIM divulgada pela BIM excellence.org e, assim, mapear os usos de forma mais sistemática.
A respeito da localização das pesquisas, observou-se que os países latino-americanos, em especial o Brasil, foram os responsáveis pela condução das discussões com foco em BIM através da SIGraDi. Dos 78 artigos selecionados, 45 eram latino-americanos, onde 41 eram do Brasil, um da Colômbia, um do Equador, um do Chile e um do Uruguai.
Por fim, cabe ressaltar que, com este artigo, busca-se contribuir com o mapeamento das abordagens do BIM nos eventos da SIGraDi, suas repercussões e abrangências, e consequentemente evidenciar a efetiva contribuição dos pesquisadores da SIGraDi para as discussões sobre a tecnologia BIM levadas a cabo, sobretudo, na América Latina.

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Referências

Álvarez, N., Bernal, M., Cáceres, K. (2020) Evolution and Projection of Computational Design Theories: Generation, Analysis, Selection and Fabrication. In: Congresso SIGraDi 2020. (p. 120-127) São Paulo, Brasil.

Arrotéia, A. V., Freitas, R. C., Molhado, S. B. (2021). Barriers to BIM Adoption in Brazil. Frontiers in Built Environment, Systems for Construction Management v.7. p.1-12.

Batista, L.T. (2010) O Processo de Projeto na Era Digital: Um Novo Deslocamento da Prática Profissional. Dissertação de Mestrado, Curso de Mestrado da Escola de Arquitetura da Universidade Federal de Minas Gerais. Belo Horizonte, Brasil.

BIM Dictionary (2020), Autoria de Projeto, English, Version 1. Retrieved from https://bimdictionary.com/en/design-authoring/1

BIM Dictionary (2020), Design Generativo, English, Version 1. Retrieved from https://bimdictionary.com/en/generative-design/1

Carneiro, T.M., Lins, D.M.O., Barros Neto, J.P. (2012) Building information modeling: análise da produção científica nos anos de 2010 e 2011. In: Encontro Nacional de Tecnologia do Ambiente Construído (Eds.) XIV. Juiz de Fora, Brasil.

Checcucci,E.S., Pereira A. P. C., Amorim, A. L. (2011) A difusão das tecnologias BIM por pesquisadores do Brasil. In: Encontro de Tecnologia de Informação e Comunicação na Construção (Eds.) 5. (p.20) Salvador, Brasil.

Eastman, C., Teicholz, P., Sacks, R., Liston, K. (2014). *Manual de BIM: um guia de modelagem da informação da construção para arquitetos, engenheiros, gerentes, construtores e incorporadores* (C. G. A. Filho, Trad.). Porto Alegre: Bookman. (Trabalho original publicado em 2008)

Mizumoto, J., Oliveira, F. (2020) BIM educação, uma revisão bibliográfica estruturada. In: Congresso Português de Building Information Modelling, (Eds.) 3. Porto, Portugal.

Sanguinetti, P., (2007, october) Representing BIM-based design process. In: Sociedade Iberoamericana de Gráfica Digital. (p. 196-199). México D.F. – México SIGraDi. #25: Sociedad Iberoamericana de Gráfica Digital 1997-2021 / organización: Pablo C. Herrera... [et al]: edición: Gabriel B. Botasso -São Carlos: IAU/USP, 2021, (p.110) Disponível em: https://www.google.com/url?sa=t&source=web&rct=j&url=http://www.livrosabertos.sibi.usp.br/portaldelivrosUSP/catalog/book/

SIGraDi (2022). *Sociedade Iberoamericana de Gráfica Digital. Apropriações*

Críticas. Apresentação. Disponível em: https://www.sigradi.org/sigradi2022/apresentacao/.

SIGraDi (2021) [recurso eletrônico*]:#25 Sociedad Iberoamericana de Gráfica Digital 1997-2021* / organización: Pablo C. Herrera...[et al]: edición:Gabriel B.Botasso - São Carlos:IAU/USP, 110 p.

Sperling, D., Vizioli, S.H.T., Botasso, G.B., Tiberti, M.S., Santana E.F.Z., Sígolo, B.O.O. (2019). Crossing Timelines Main research topics in the histories of eCAADe and SIGraDi. p. 407-416. In: Proceedings of 37 eCAADe and XXIII SIGraDi Joint Conference, Architecture in the Age of the 4Th Industrial Revolution. Porto, Portugal.

Succar, B. Saleeb, N. Sher, W. (2016) Model Uses: Foundations for a Modular Requirements Clarification Language. In: Australasian Universities Building Education (AUBEA2016) (p.1-12) Cairns, Australia

Interactions & Collaborations: Interdisciplinary Design

Technological appropriations for socio-spatial transformation in São Gonçalo do Bação

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Abstract. Based on a university teaching-research-extension experience in São Gonçalo do Bação (Minas Gerais, Brazil), this article discusses the use of digital technology as a way to expand the virtual, understood as an event in latent state, as a process of problematization and not of problem solving. Three digital interfaces developed with the common goal of encouraging questioning and the exercise of autonomy from different approaches and themes are presented. The interfaces seek to articulate the Flusserian idea of 'responsibility', regarded as the act of responding to others in a way that promotes an opening for people to continue the design process dialogically. In short, the interfaces indicate possibilities provided by digital technologies and exemplify ways in which they might drive processes towards social-spatial transformation.

Keywords: Interactions, Technological appropriations, Sintegrity, Socio-spatial transformation, São Gonçalo do Bação.

1. Introdução

O artigo discute a importância das tecnologias digitais como elementos virtuais em processos coletivos que visam despertar postura crítica para viabilizar transformação sócio-espacial. Descreve experiências de ensino-pesquisa-extensão que tiveram início numa disciplina de projeto na Escola de Arquitetura da UFMG com desdobramentos em três Trabalhos de Conclusão de Curso, sempre em diálogo com integrantes do Grupo de Teatro de São Gonçalo do Bação, distrito de Itabirito em Minas Gerais.

São Gonçalo do Bação está inserido no coração da atividade minerária na bacia do Alto Rio das Velhas com impactos e ameaças históricos advindos da mineração (desde o ouro de aluvião no século XVIII, à construção de um muro de contenção devido à ameaça de rompimento de barragens em 2020–2021, e à atual ameaça da construção de um porto seco). As mineradoras (reconhecidas pelos moradores como sendo "a Vale") são obrigadas a mitigar

os impactos e por isso estão sempre presentes no território com processos pseudo-participativos e propostas de intervenção (na maioria das vezes) não demandadas nem desejadas pelos moradores. No intuito de informar a demanda de contrapartida da Vale pelos enormes danos ao distrito, o Grupo de Teatro se mobilizou para formular uma proposta de projeto para a reforma de sua sede e procurou o Professor José dos Santos Cabral que se mudou para o distrito no início da pandemia.

Dessa aproximação surgiu a proposta da disciplina Projetar o projeto, com 60 horas, oferecida no segundo semestre de 2020 por Ana Paula Baltazar e José dos Santos Cabral. A disciplina articulou a proposta de 'designing designing' — projetar o processo de projeto — de John Chris Jones (1991), com a ideia flusseriana de 'responsabilidade', entendida como o ato de responder ao outro promovendo abertura para que as pessoas deem continuidade ao projeto de forma dialógica (Flusser, [1988] 2007), e também com as ideias de 'value-free architecture' (Price, 2003) e 'enabling' (Price, 1966). A abertura do processo, tanto do ponto de vista pedagógico quanto da práxis extensionista foi fundamentada no conceito de virtual, entendido como evento em estado latente, processo de problematização e não de solução de problemas, considerando que o digital pode ampliar as possibilidades do virtual, mas não é seu sinônimo (Lévy, 1996; Baltazar, 2005).

Do ponto de vista organizacional, toda a comunicação durante a disciplina aconteceu de forma remota, com dinâmicas para mediar a relação dos alunos entre si, com os conteúdos teóricos e com os moradores. A principal dinâmica adotada foi a sintegração, uma estrutura formal de discussão em grupo, proposta pelo ciberneticista Stafford Beer (1994), que visa o desenvolvimento do conhecimento sobre um assunto complexo, mas que, seguindo um protocolo de interações específicas, busca evitar as disputas internas e as votações típicas de assembleias. Foram usadas salas digitais simultâneas onde alunos e moradores participavam ora como debatedores, ora como críticos e observadores, alternando os papéis e o grupo a cada rodada. A sintegração foi fundamental para organizar informações sobre o distrito de forma genuinamente virtual. Ou seja, o foco usual na solução imediata (e muitas vezes falsa) de problemas por meio de projetos de objetos e espaços prescritivos prontos foi abandonado. Voltou-se para a problematização de cada situação discutida, propondo interfaces para mediar as relações de diálogo contínuo entre as pessoas e das pessoas com objetos e espaços, tendo no horizonte o ideal de autonomia coletiva — dar a si mesmas as próprias regras (Souza, 2006) —, eventualmente levando à emancipação (Mészáros, 2005) e à transformação sócio-espacial (Baltazar et al., 2019).

A suposta demanda inicial do Grupo de Teatro pela reforma de sua sede deu lugar à problematização de diversas dinâmicas sócio-espaciais em que o grupo se insere. Assim, a disciplina concluiu com cinco propostas de interfaces

virtuais (físicas e digitais) que tiveram continuidade num segundo módulo, com metade dos alunos, num modelo autogestionário supervisionado pelos professores, assumindo um processo de extensão dialógica junto ao Grupo de Teatro (Freire, [1969] 1993).

O amadurecimento do processo de extensão possibilitou o levantamento de três temáticas para ampliar os trabalhos para a comunidade como um todo. A mineração foi identificada como tema que tangencia diversos aspectos, como vida cotidiana, meio ambiente, o Grupo de Teatro etc., mas cujos impactos não são claramente percebidos pelos moradores por não serem visíveis em sua totalidade (quando aparecem, é de forma fragmentada). Outro tema levantado foram as riquezas de São Gonçalo do Bação em relação ao passado, presente e possibilidades no futuro. O terceiro tema foi o legado de José Victor, um polímata que viveu em São Gonçalo do Bação, teve uma grande presença em sua época, mas não há registro sistemático de sua vida e sua produção. A partir daí, foram desenvolvidas, no período de um ano, três interfaces digitais e híbridas por Beatriz Bartholo, Gustavo Jun e Luísa Paiva em seus trabalhos de conclusão de curso que articulam a importância do digital em processos de abertura pela virtualidade.

2. Interfaces para São Gonçalo do Bação

2.1. Descaminhoss

A primeira interface, denominada Descaminhoss, consiste em um website que agrupa conteúdos em diversas camadas relativas à mineração em São Gonçalo do Bação e região, buscando evidenciar contradições e influências dos empreendimentos minerários nos processos de transformação do distrito. A intenção é a problematização e a conscientização sobre a relação deste setor com os modos de vida, as qualidades ambientais e a história local, aproximando questões culturais, históricas, geográficas, geológicas, biológicas, políticas, econômicas e do cotidiano, atuais e passadas. Para isso, foi desenvolvida uma plataforma on-line a fim de gerar o chamado “efeito OPA” (Arruda, 2021), que acontece quando dois ou mais aspectos, mesmo que conhecidos separadamente, são justapostos, incentivando o estabelecimento de paralelos e possíveis desdobramentos pelas pessoas.

Para tanto, há uma curadoria estratégica dos conteúdos — compostos por relatos, notícias, referências bibliográficas, mapas, imagens e vídeos — organizados em diferentes páginas do site. A partir das ferramentas disponíveis e da motivação da interface, foi criada uma rede de conexão entre os conteúdos que possibilita diversos caminhos de exploração sem impor um ponto de vista sobre o assunto. Em síntese, o funcionamento se baseia em um sistema de

input e output, de forma que palavras, imagens e ícones atuem como links para novas janelas, páginas e outros sites internos e externos à plataforma. Todos esses materiais se encontram categorizados em quatro grandes temas (empreendimentos minerários, história, modos de vida e qualidades ambientais) que podem ser acessados tanto pela exploração intuitiva da interface quanto de forma mais direta, por meio de buscas e links específicos.

A quantidade de conexões possíveis e a variedade do conteúdo utilizado neste trabalho somente foram viabilizadas pelo meio digital. O caráter público colaborativo deste universo possibilitou que os materiais fossem selecionados (por meio de blogs, canais do Youtube, páginas do Facebook, jornais, revistas e outros), abrangendo desde imagens profissionais de drone até vídeos caseiros de passarinhos ciscando no bar local. Como o trabalho foi desenvolvido no contexto de distanciamento social da pandemia, o ambiente tecnológico tornou possível também o diálogo com o Grupo de Teatro de São Gonçalo do Bação viabilizando a coleta de relatos e outras trocas fundamentais para o desenvolvimento da plataforma.

Figura 1. Imagem ilustrativa da interface digital e física de Descaminhoss.
Fonte: Beatriz Bartholo, 2022.

São também as tecnologias digitais que possibilitam o fácil acesso ao arcabouço de informações por meio de celulares, tablets ou computadores. A relação entre a interface digital e uma interface física, expande a plataforma para o modo híbrido, conectando as pessoas no espaço público de São Gonçalo do Bação com a plataforma on-line. As interfaces físicas consistem

em porta-retratos com colagens de imagens com QR Codes (como indicado na Fig. 1), escolhidas de acordo com o contexto em que estão localizados, que relacionam imagens de elementos da paisagem, ou de acontecimentos do lugar, a páginas específicas de entrada na interface digital do website. Essas páginas têm o papel de “ambientar” as pessoas, sendo um primeiro exercício para compreensão do funcionamento da plataforma e um possível ponto de partida para outros caminhos do site.

Esta plataforma aponta a potencialidade do meio digital como ferramenta nos processos de ampliação de diálogos problematizadores do contexto capitalista, especificamente associado à mineração, visando o exercício da autonomia na atualidade e, eventualmente, possíveis transformações sócio-espaciais no futuro.

O website da interface Descaminhoss pode ser acessado em <www.descaminhoss.wixsite.com/bacao>, e um vídeo de apresentação do projeto está disponível em <https://youtu.be/mxW_ZxdcNYE>.

2.2. As Riquezas do Bação

A segunda interface é denominada As Riquezas do Bação e parte dos questionamentos: "O que são essas riquezas de São Gonçalo do Bação? Seria a riqueza patrimonial? A riqueza cultural? A riqueza natural? Ou seriam os minérios abaixo disso tudo?" A partir dessas questões começa a se desvelar um contexto “baçônico”, cheio de contradições que contrapõe visões de futuro pautadas na preservação ou exploração. Assim, a dúvida que paira sobre o distrito é: "Qual o futuro de São Gonçalo do Bação?"

Para engajar as pessoas de forma aprofundada nessas reflexões uma possibilidade é provocá-las a pensar o futuro de São Gonçalo do Bação a partir de suas riquezas do passado e do presente, um processo inspirado no Princípio da Esperança de Ernst Bloch (1972) em que a história se torna uma biblioteca que fomenta o processo imaginativo de um futuro ideal e possível.

Para isso, foram reunidas as riquezas e as contradições de São Gonçalo do Bação em uma rede inspirada na Teoria Ator-Rede de Bruno Latour com o intuito de levantar os atores humanos e não humanos identificados no estudo, entender o que leva esses atores a agir, assim como os objetos empenhados em estabilizar grupos e agências, mapeando as controvérsias em torno das questões de interesse (Latour, 2012).

Tendo então a rede como base foi desenvolvida uma interface físico-digital para explorar a potencialidade do digital em ampliar o virtual. Tal interface híbrida trabalha também o potencial do meio físico, tendo em mente a importância dos espaços públicos em estabelecer diálogos mais ricos com problematizações de questões mais diversas e com pontos de vistas variados,

já que são neles onde as "bolhas sociais" se mostram menos presentes quando comparadas às redes sociais dos meios digitais (Arruda, 2021).

Assim sendo, como forma de diluir as barreiras entre meio físico e digital, a interface explora a Realidade Aumentada (RA), uma ferramenta que permite sobrepor elementos digitais no espaço físico. Os filtros do Instagram e o jogo de celular Pokémon Go são exemplos populares da RA, que usam a imagem capturada pela câmera do celular e a modifica digitalmente. O potencial explorado pela RA na interface é a alteração do espaço físico existente fomentando o imaginário do que poderia vir a ser pela elaboração de cenários possíveis e impossíveis, levando as pessoas a uma reflexão sobre o futuro desejado.

A interface consiste em totens posicionados diante de alguns pontos importantes do distrito, em locais públicos, trazendo informações sucintas das riquezas específicas do local. Por meio de um QR code as pessoas acessam uma seção de um website onde é acionada a RA própria daquele local. Além disso, há a possibilidade de continuar navegando pela interface em outra janela que mostra a rede de atores de São Gonçalo do Bação espacializada em um mapa, sendo possível explorar os outros pontos da rede e suas respectivas RAs. Em cada local há uma provocação específica para que os moradores pensem o futuro.

Figura 2. Telas do celular. À esquerda, a imagem com o totem capturada pela câmera do celular, ao centro, a imagem modificada pela RA e, à direita, a rede de atores espacializada em um mapa. Fonte: Gustavo Jun, 2022.

Um exemplo é a Igreja Matriz de São Gonçalo do Bação, um importante patrimônio local, que surge como consequência da atividade minerária colonial

e hoje se insere no centro de um distrito ameaçado por essa mesma atividade. Assim, o totem instalado no local traz de forma sucinta a história do patrimônio e também um questionamento: “O surgimento da Igreja está atrelado à atividade minerária, até que ponto essa atividade determinará sua história?” e o QR Code do totem leva a uma seção de RA no website, onde as pessoas podem visualizar, pelo celular, ambos os cenários contraditórios com elementos digitais inseridos no espaço da Igreja. A Fig. 2 mostra algumas das telas do celular que as pessoas veem ao navegar pela Interface.

Deste modo, a interface ilumina as contradições do passado e do presente e paralelamente levanta questionamentos que provocam imaginar um futuro ideal possível, buscando catalisar um processo de emancipação dos moradores engajando-os em uma práxis libertadora.

O projeto da interface As Riquezas do Bação pode ser acessado em <https://riquezasdobacao.editorx.io/asriquezasdobacao>, e um vídeo de apresentação do projeto está disponível em <https://youtu.be/pzr6JR2l6LY>.

2.3. O que Permanece Sobre o José Victor?

A terceira interface propõe um registro alimentado por multimídia (Baltazar, 1998) — um hipertexto que reúne fragmentos das histórias contadas sobre o polímata José Victor, bem como o contexto em que ele estava inserido, e possibilita que o usuário combine esses fragmentos a partir de sua curiosidade. O que permanece de José Victor é assim potencializado por cada pessoa que navega pela rede e cria sua própria percepção, relacionando José Victor com sua produção, com atores que o conheceram ou que contam histórias sobre ele, com o contexto histórico da época e eventos locais que influenciaram o cenário em que o polímata estava inserido.

Para fazer o registro da história de José Victor, havia algumas limitações práticas: grande parte de sua história é transmitida a partir da oralidade dos moradores do Bação, mas existem poucas pessoas que ainda vivem no distrito e conheceram o polímata. Além disso, com o tempo, os outros documentos que existiam sobre o polímata foram se perdendo, bem como algumas de suas produções e até sua casa, que atualmente se encontra em ruínas. Por isso, a pesquisa sobre a vida do polímata foi realizada por meio de entrevistas e dinâmicas com o Grupo de Teatro do Bação e alguns moradores que se lembravam das histórias de José Victor. Assim, o trabalho reúne várias perspectivas e fragmentos, evitando um texto linear, o que foi mantido na produção da interface, desenhada como um grafo em rede.

Com isso, foram reunidos setenta fragmentos da história de José Victor que se tornaram pontos coloridos no grafo em rede (Fig. 3). Esses pontos são hyperlinks conectados entre si por meio de linhas predeterminadas a partir de vestígios das relações históricas do polímata. Para essa organização, o digital

foi essencial por possibilitar a utilização do Highcharts (biblioteca em Javascript e Typescript) utilizada para construção da visualização de dados. Entre outras funcionalidades, a biblioteca disponibiliza API com alto poder de configuração sobre comportamento de suas visualizações, possibilitando flexibilidade sobre a usabilidade e desenvolvimento gráfico na aplicação final. Os fragmentos são dados armazenados estaticamente no mesmo ambiente que a aplicação e são buscados e formatados no padrão requerido pela biblioteca supracitada. A partir daí, constrói-se a rede de fragmentos centralizados em uma única tela, proporcionando que as pessoas definam a sua própria navegação por diferentes partes da história. Essa biblioteca também permitiu atribuir cores aos pontos, representando as seguintes categorias: documento, evento, local, instituição, ator que se relacionou com José Victor, ator que conheceu José Victor e ator que escutou histórias sobre José Victor.

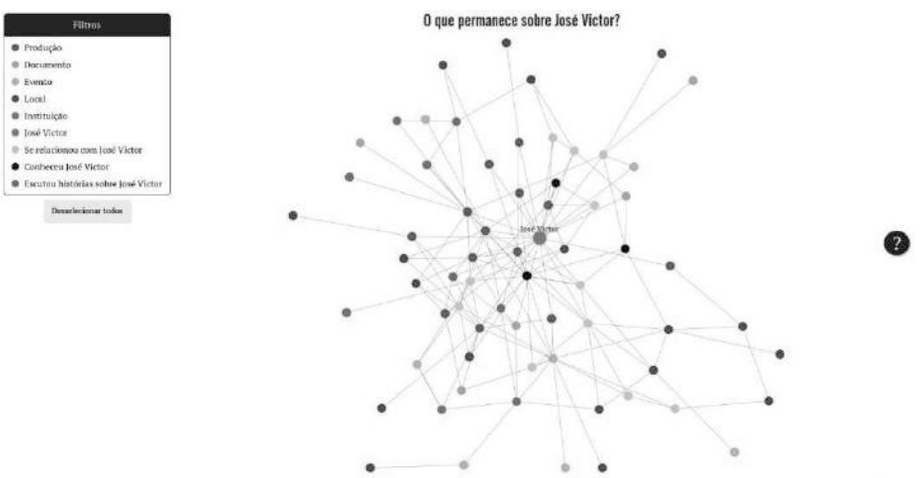

Figura 3. Tela com página inicial “O que permanece sobre José Victor?” com grafo em rede, à esquerda, e legendas, à direita. Fonte: Luísa Paiva, 2022.

Sendo assim, na interface os fragmentos da história aparecem em pop-ups que podem ser lidos quando clicados, expandidos, combinados e explorados conforme o interesse do usuário. Há também a possibilidade de filtragem dos pontos pelas categorias citadas anteriormente. Para interagir com a visualização dos fragmentos multimidiais, o framework chamado Angular viabiliza que o usuário consiga organizar os pop-ups de cada fragmento na tela conforme sua vontade. É a partir da possibilidade de utilização de multimídia que o digital potencializa a percepção do usuário: além de textos de cerca de 150 palavras, os pop-ups reúnem fotos, vídeos e áudios. Isso possibilita o trabalho com outros sentidos, sendo possível, por exemplo, perceber a

cadência da fala das pessoas ao falar de José Victor, os momentos de hesitação e de emoção, bem como exibir fotos de documentos, de jornais antigos e da produção de José Victor.

Por fim, o digital é o meio que traz flexibilidade nessa interface para que a história de José Victor seja construída de maneira mais rica do que um simples encadeamento linear dos poucos registros existentes. Também traz a riqueza de uma história contada a partir da oralidade, contendo, às vezes, discrepâncias e contradições por se pautar pela memória das pessoas e também pela percepção que tinham do polímata. Outra possibilidade do digital está na dupla faceta da interface: através dos hyperlinks é possível perceber as conexões feitas previamente, durante a concepção da interface, e também desviar dessas conexões, criando outros caminhos e possibilidades para a história de José Victor a cada acesso. Assim, o virtual cria uma abertura para imaginação, em uma história em que não se determina começo nem fim.

O website da interface O que Permanece Sobre o José Victor? está disponível em <https://victorlbitten.github.io/jv-network/networkgraph>, e um vídeo de apresentação do projeto pode ser acessado em <https://www.youtube.com/watch?v=p3_APYr0sdI>.

3. Considerações Finais

Os três casos acima apontam diferentes formas de uso do digital como ferramenta para ampliar a virtualidade das interfaces buscando a abertura dos processos para que as pessoas deem continuidade à sua problematização. Foram testados protótipos em diferentes estágios de produção, sempre adotando ferramentas digitais presentes no cotidiano dos moradores, como computador e Smartphone, priorizando a facilidade de acesso por todos. Ainda que trazendo tecnologias pouco conhecidas, como a realidade aumentada, por exemplo, a navegação intuitiva proposta nas interfaces viabilizou o engajamento dos moradores com o desconhecido. Vale ressaltar que depois que os trabalhos foram finalizados e apresentados para o grupo de moradores não foi feita ainda uma análise da interação das pessoas com as interfaces sem a presença de quem as produziu.

Em todos os casos, em maior grau nas duas primeiras interfaces e menor grau na terceira, há também a tentativa explícita de experimentar a produção de interface como uma espécie de "centelha" que pode eventualmente culminar em autonomia, emancipação e transformação sócio-espacial. Ainda que os resultados dos moradores usando as interfaces não tenham sido analisados até o momento, do ponto de vista pedagógico, é notável o processo de sensibilização destes e dos futuros arquitetos urbanistas com as temáticas desenvolvidas. Apesar de incipientes, as provocações propostas pelas

interfaces seguramente iniciaram um processo de conscientização dos envolvidos ao longo do percurso da disciplina e dos trabalhos apresentados e repercutem na construção de outras atividades adiante.

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4. Referências

Arruda, G. (2021). Pedagogia sócio-espacial para democracia radical: uma experiência mediada por interfaces em Glaura. Tese de doutorado. Programa de Pós-Graduação em Arquitetura e Urbanismo, Universidade Federal de Minas.

Baltazar, A. P., van Stralen, M., Melgaço, L., Arruda, G. & Milagres, L. (2019). Ituita: An Interface for Playful Interaction and Socio-Spatial Transformation. Built Environment, 45(2), 212–229.

Baltazar, A. P. (2005). Por uma arquitetura virtual: uma crítica das tecnologias digitais. Revista AU, Arquitetura e Urbanismo, 131, 57–60.

Baltazar, A. P. (1988). Multimídia interativa e registro de arquitetura: a imagem da arquitetura além da representação. Dissertação de mestrado. Programa de Pós-Graduação em Arquitetura e Urbanismo, Universidade Federal de Minas.

Beer, S. (1994). Beyond dispute: the invention of team syntegrity. Salisbury: Bookcraft.

Bloch, E. (1988). Ideas as transformed material in human minds, or problems of an ideological superstructure (Cultural Heritage) [1972]. In The Utopian Function of Art and Literature: Selected Essays. Studies in contemporary German social thought (pp. 18–71). MIT Press.

Flusser, V. (1988). Design: obstáculo para remoção de obstáculos?. In O mundo codificado (pp. 193–98). Cosac Naify.

Freire, P. (1969). Extensão ou comunicação?. Paz e Terra.

Jones, J. C. (1991). Part 2 Opus one, number two. In Designing designing (pp. 58-166). Architecture design and technology press.

Latour, B. (2012). Reagregando o social: uma introdução à teoria do Ator-Rede. EDUFBA; EDUSC.

Lévy, P. (1996). O que é o virtual?. Editora 34.

Mészáros, I. (2005). Educação para além do Capital. Boitempo.

Price, C. (2003). The square book. Wiley.

Price, C. (1966). Life-conditioning. Architectural Design, 36, 483. Academy Editions.

Souza, M. (2006). Poder e liberdade: da democracia à autonomia. In A prisão e a ágora: reflexões em torno da democratização do planejamento e da gestão das cidades (pp. 33–94). Bertrand Brasil.

Promoting Experimentation and Integrated Design Process through the Exploration of the Steam Bending Technique in Wood: Essay F8 Challenging Orthogonality

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Abstract. Due to the lack of experimentation with wood on a real scale, which is needed to generate design proposals and discuss aesthetic, spatial, and structural alternatives in a multidisciplinary way. An experimental workshop for architecture and engineering students was developed. To integrate design modeling, and fabrication, using the wood steam bending technique. It was explored following a collaborative methodology. The main results obtained included conceptualization sessions, prototyping, physical and digital modeling, and development of work strategies (base plan, scaffolding, production, assembly, iteration, adjustments, and detailing) until the proposal scope met the expectations. From this workshop, remains the challenge of converting empirical knowledge into more precise work parameters. The need to complement the design phases with parametric software modeling, structural analysis, and fabrication methods to open new teaching possibilities was identified.

Keywords: interdisciplinary design, construction experience, steam wood bending.

1 Introducción

La presente experiencia aborda la exposición de estudiantes de arquitectura e ingeniería al trabajo colaborativo y el desarrollo de un diseño integral utilizando la técnica tradicional de curveado de madera con vapor, que permite plantear cuestionamientos acerca de las tendencias actuales de la arquitectura en la práctica y en la academia. Desafiando la tendencia de la disciplina de ignorar métodos históricos artesanales (Benson, 2009), de aceptar el diseño digital sin considerar experimentaciones con los materiales o de complementar los procesos tradicionales con las tecnologías emergentes.

Con esta experiencia, el proceso convencional de diseño “se liberó” hacia el juego intuitivo con piezas curvas, a escala real, para descubrir e inventar configuraciones únicas del material. La relevancia de esta experimentación radica en que la técnica empleada busca utilizar de manera eficiente el material, complejizar la geometría y la estética, al asumir el reto de negar la ortogonalidad.

La propuesta se desarrolló realizando pruebas de la técnica y propiedades del material, a menudo llevándolo al límite o punto de falla (Schulte *et al*., 2011). Estas experimentaciones actúan como un complemento de los procesos de diseño actuales y permiten repensar la construcción rumbo a incorporar la fabricación digital.

1.1 La experiencia interdisciplinaria y colaborativa como aproximación en la enseñanza

Si bien es sabido que los estudiantes de arquitectura necesitan interactuar, comunicarse y debatir sus diseños con compañeros y profesores para formar destrezas, conocimientos, la sensibilidad de su pensamiento, y mejorar sus habilidades para resolver problemas, a la vez, deben aprender a cooperar para lograr un objetivo en conjunto (Priya *et al.*, 2020). De esta manera, estarán preparados para la naturaleza altamente colaborativa de la práctica arquitectónica a la que ingresarán.

Esto lleva a preguntarse ¿cómo se pueden abordar las técnicas colaborativas en el estudio de diseño para mejorar las habilidades de los estudiantes y prepararlos para los desafíos profesionales? A partir de esta interrogante, Emam *et al*. (2019) realizaron un estudio piloto empleando una metodología que utiliza informes de análisis cuantitativo y cualitativo de cuestionarios, en el cual las respuestas son analizadas para adoptar las herramientas y actividades que deberían ocurrir para hacer más eficiente el trabajo colaborativo. De esta forma, los estudiantes diseñan su propio proceso de aprendizaje, y proponen herramientas de programación de tiempo y tareas, que son evaluadas por pares. Así, los estudiantes cuestionan y evalúan su propia eficiencia y experiencias de aprendizaje.

Por otro lado, para (Biskjaer *et al*., 2019), es importante desarrollar valor en los procesos de diseño integrado, desde el diseño arquitectónico y el diseño en ingeniería, para que de los procesos de creación conjuntos emerjan valores que normalmente están ocultos o subexpuestos. Para esto, es común emplear el modelo de las cuatro “P” fundamentales de la investigación de la creatividad: persona, proceso, producto y prensa.

Dichos autores aportaron un modelo de trébol de cuatro hojas con posibles puntos ciegos en la creación de valor en el diseño colaborativo. Estos puntos son el valor de (1) la exploración, (2) la negociación, (3) la formulación y (4) la manifestación de valor en sí mismo. Este modelo se puede usar como un andamiaje para desarrollar la teoría del valor del diseño y para que los profesionales relacionados con el diseño puedan emplearlo como un

instrumento para “conducirse” mejor en los procesos colaborativos con múltiples partes interesadas, cuyos conjuntos de valores individuales pueden no estar siempre claramente articulados y, por lo tanto, a veces pueden no solo no coincidir, sino chocar.

Si se considera la colaboración interdisciplinaria, Erkan (2013) la define como un enfoque de conocimiento y currículo que aplica conscientemente la metodología y el lenguaje de más de una disciplina para examinar un tema central, cuestión, problema o experiencia. En este caso particular, interesa un primer acercamiento que permita a los estudiantes comprender el lenguaje y las prácticas comunes en sus disciplinas para que los alumnos de otras áreas entiendan cómo y con qué propósito se realizan, y a partir de ahí incluso surjan nuevas estrategias conjuntas, “híbridas”, etc. Esto es requerido porque idealmente un proceso de diseño integrado implica una estrecha coordinación entre los profesionales que diseñan sistemas arquitectónicos, estructurales y mecánicos con el equipo de construcción y los fabricantes de productos de construcción. Sin embargo, este proceso no se sigue universalmente en la práctica, ni es un modelo común para la educación en diseño ni en arquitectura ni en ingeniería según lo expuesto por Sheine *et al*. (2019)..

Específicamente, sobre experimentaciones con madera, llama la atención un curso universitario interdisciplinario planteado para alumnos de arquitectura, ciencias de la madera e ingeniería, que estudia cómo su capacidad para dominar los flujos de trabajo digitales influye en su éxito en el aprendizaje de habilidades de diseño colaborativo. Se destacan destacando los desafíos y las oportunidades potenciales que plantea la introducción de nuevas herramientas digitales para apoyar el diseño de edificios integrados emergentes tanto en la educación como en la práctica profesional (Riggio & Cheng, 2021). Para el presente taller experimental, los intereses temáticos surgieron a partir de la iniciativa conjunta de profesores y estudiantes que contaban con experiencias previas de experimentación con estructuras colaborativas y que estaban interesados en el diseño multidisciplinario, la experimentación de estructuras con madera, la promoción del uso de este material. Esto anteriormente había sido realizado por medio de talleres libres de verano que plantean concursos de diseño, cuyas propuestas electas, posteriormente, se detallan, optimizan y construyen entre los participantes.

En esta ocasión, plantearon la necesidad de promover la experimentación y el proceso de diseño integral a través de la exploración de la técnica de curveado de madera con vapor. El interés en dicha técnica surgió por una gira técnica al astillero verde, un barco carguero de gran envergadura que se está construyendo en el país, retomando técnicas tradicionales milenarias de construcción con este material. Sin embargo, se planteó el desafío de repensar dicha técnica a partir de las posibilidades que ofrecen los *softwares* de diseño paramétrico, las alternativas de fabricación digital, la necesidad de complementar conocimientos artesanales y tecnológicos, empíricos e ingenieriles para efectuar iteraciones que permitan evolucionar los

planteamientos de diseño, que en los procesos académicos de diseño arquitectónico no se abordan, discuten ni se profundizan de forma rigurosa.

En cuanto a la escala del proyecto inicialmente se planteó que fuera un pabellón experimental “de pequeña huella y alto impacto estético”, y de ahí surgió la posibilidad de que, además, fuera una envolvente escultórica. Para el emplazamiento, se eligió un sitio estratégico en la universidad que permitiera tanto la exposición del producto logrado como realizar una crítica a la escala y materialidad de los edificios de la Facultad de Ingeniería, los cuales están conformados por grandes volúmenes en concreto masivo. Por esta razón, la intervención de su patio central con una estructura orgánica y en madera busca evidenciar la necesidad de reflexión sobre el tema propuesto.

2 Metodología

La propuesta de trabajo está enmarcada en un taller experimental de estructuras en madera, cuya modalidad es de curso libre de verano, dirigido a estudiantes de pregrado interesados en el desarrollo y en la experimentación con estructuras en madera. Dicho taller es coordinado por un equipo de profesoras dentro de un proyecto de extensión docente y acción social. Incluye fases de ideación, prototipado y construcción a escala 1:1, complementadas con charlas, sesiones de discusión y de aprendizaje de técnicas y uso de equipo especializado.

2.1 Definición de la técnica aplicada

La principal técnica elegida para esta experiencia práctica fue el *curveado de madera con vapor*, en la cual las piezas secas de madera sólida de pino y ciprés de 1 x 2” 12 ft ≈ aproximadamente 25 x 50 mm y 3.6 m de longitud se someten al calor, al vapor y a la humedad en una caldera de fabricación artesanal diseñada y fabricada por un grupo de estudiantes. Este proceso “flexibiliza momentáneamente” las fibras de la madera y permite que se puedan curvear en múltiples direcciones, las cuales no son posibles con el material seco o en estado convencional.

La técnica se desarrolla comprendiendo el comportamiento viscoelástico de la madera mediante la aplicación de calor y humedad a través de vapor de agua, lo cual modifica los enlaces de los polímeros que conforman el material y la rigidez característica que posee la madera cuando se cambian los enlaces de la lignina. Una explicación muy simplificada del fenómeno es que es más maleable gracias a la disminución de la zona de tracción y al aumento de la compresión en el elemento de madera (figura 1). Al enfriarse, los enlaces de la lignina se vuelven a modificar y la madera retiene la mayor

parte de dicha deformación. Este proceso se desarrolla utilizando una caldera artesanal (figura 2) que utilizaba combustible a base de madera de desecho (leña), con una capacidad de 15 litros y un tiempo aproximado de 45 minutos para alcanzar los 100 °C.

Una vez alcanzada esta temperatura, el vapor es dirigido a un envoltorio hermético de polietileno en donde se encontraban las piezas de madera (un máximo de seis piezas). Después de un periodo aproximado de 80 minutos, con una temperatura constante no menor de 100°C, la madera está lista para ser manipulada mediante guantes y con un tiempo máximo de dos minutos aproximadamente para su flexión definitiva. Este proceso es realizado enteramente por los estudiantes que conforman el taller, e implica un proceso de planeación y diseño para su ejecución.

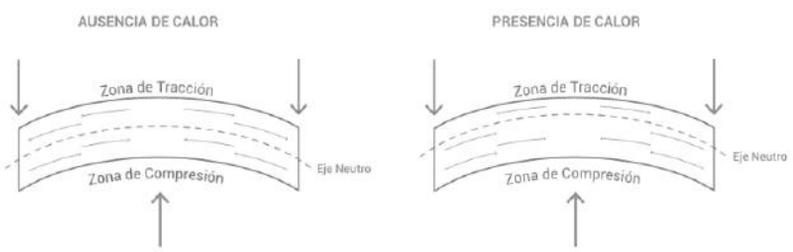

Figura 1. Comportamiento en sección, variación de fuerzas en presencia de calor al momento de la flexión.

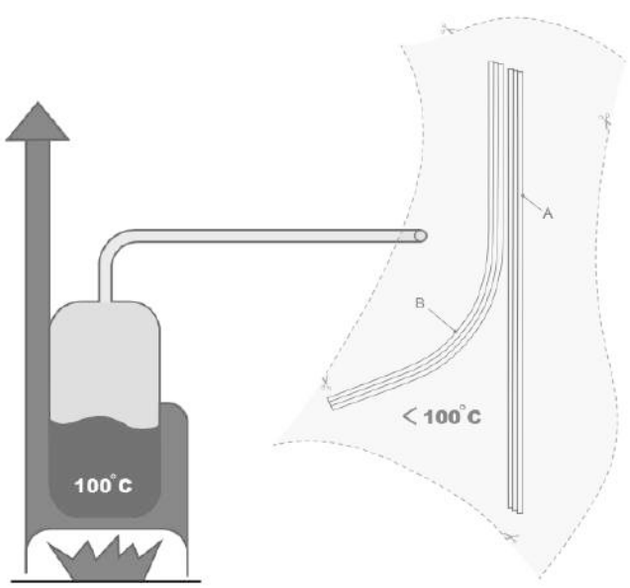

Figura 2. Diagrama de funcionamiento de la caldera artesanal para doblado de madera al vapor.

Se realiza un análisis previo de cada una de las piezas para definir su desempeño estructural en la estructura o el elemento a formar, ya que cada pieza de madera presenta cualidades estructurales en sus fibras y tipo de corte que van a determinar algunas limitaciones de deformación. Estas, si no son tomadas en cuenta, pueden finalizar con reventaduras, principalmente en nudos. La madera que se utilizó y se recomienda para el curveado en vapor en este caso es industrializada, de corte radial y sin defectos (nudos e inclinación en el canto de las fibras no mayor de 3° en 500 mm).

Para las definiciones morfológicas del proyecto, se consideraron los datos previamente obtenidos mediante ensayos realizados por estudiantes en investigaciones individuales referentes a las curvaturas máximas permitidas en las secciones en madera de pino radiata de 9 mm x 65 mm x 3600 mm con un porcentaje de humedad del 14.5%. Estos ensayos indican que las curvaturas deberían tener un radio no menor a 200 mm.

Una de las principales motivaciones para curvear la madera es mantener la integridad de la pieza en su eje más fuerte, en sentido longitudinal, paralelo a las fibras. De este modo, cuando la madera se dobla se somete a esfuerzos de compresión y la orientación de su grano se ajusta en función del eje de curvatura para obtener mejores propiedades de resistencia, ya que las fuerzas de tensión y compresión se desarrollan a lo largo de la curvatura. Una vez que estas fuerzas se equilibran sin aplicar demasiada fuerza, la madera se puede doblar con éxito sin roturas ni rajaduras (Hiziroglu, 2011). Las piezas curvas, a su vez, ofrecen la posibilidad de explorar diversas formas de continuidad, ramificaciones, ondulaciones irregulares y en distintos sentidos formando trazados sinuosos.

2.2 Proceso de ideación y diseño

Para la fase práctica del taller, se planteó una metodología de diseño y construcción participativa, colaborativa e intuitiva por parte del equipo de estudiantes. Para el diseño, se procedió a generar esquemas de ideación a partir de experimentos constructivos a baja escala desarrollados en modelos tridimensionales y, posteriormente, construidos. Se realizaron pruebas que incluyeron eficiencia del diseño y desempeño del material que permitió tomar decisiones sobre la implementación de las técnicas a trabajar con la madera.

El esquema de planificación surge a partir de exploraciones tridimensionales digitales y físicas que se fusionan durante el proceso de construcción colaborativa. Los estudiantes desarrollaron sus exploraciones individuales y colectivas utilizando habilidades propias del nivel de avance en la carrera y del área a las que pertenecen. De ahí que se formaran equipos de construcción y puesta en operación de maquinaria, equipos de diseño y equipo de modelado.

El diseño a partir de la técnica elegida se centró en una propuesta exploratoria del material con carácter escultórico a colocar dentro de un espacio del campus universitario como una pausa y llamada de atención desde el material y la forma hacia el carácter ortogonal y el uso excesivo del concreto en los edificios universitarios. Posterior al entendimiento de la técnica de curveado en madera se migró a desarrollar la técnica de acoplado. Para ello, las piezas curvas se ensamblaron con sujetadores provisionales (sujetadores ajustables comerciales y otros de elaboración propia), y se exploró la bifurcación, el laminado (reforzamiento con múltiples capas o piezas de madera en los componentes principales) y diversas posibilidades de estabilización de los cuatro puntos de apoyo de la estructura propuesta.

Es importante aclarar que la estructura se desarrolló con un andamiaje provisional que jugó un papel clave, ya que permitió tanto el control de la escala de la experimentación como el manejo dentro de las condiciones del sitio propuesto para su emplazamiento, como se muestra en la figura 3. Este, además, sirvió para su refuerzo y transporte de segmentos que permitieron desensamblar la estructura y reensamblarla primero en un emplazamiento provisional para su exposición temporal y posteriormente para el emplazamiento definitivo. En síntesis, el andamiaje y estructura primaria, conformada por las curvas generatrices de mayor longitud, posibilitaron la agregación “mutable y compleja” de componentes secundarios que se observan en las elevaciones de la figura 4. Se puede afirmar que la naturaleza del proceso fue de coordinación y reconocimiento constante de las tendencias estructurales y la resiliencia de la estructura incompleta.

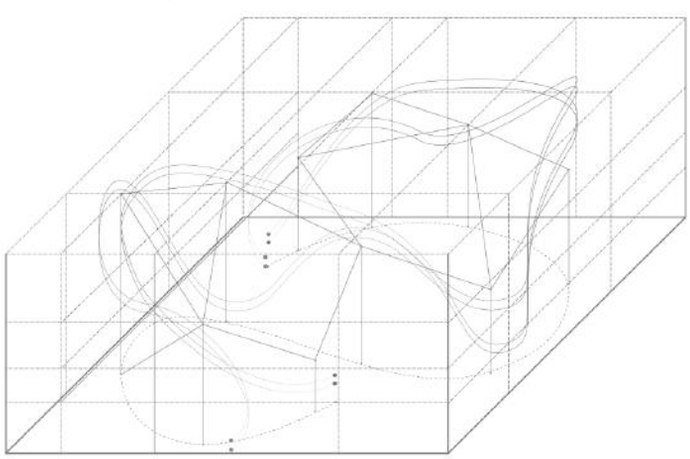

Figura 3. Diagrama de proceso de ensamblaje, andamio ortogonal con puntos de referencia.

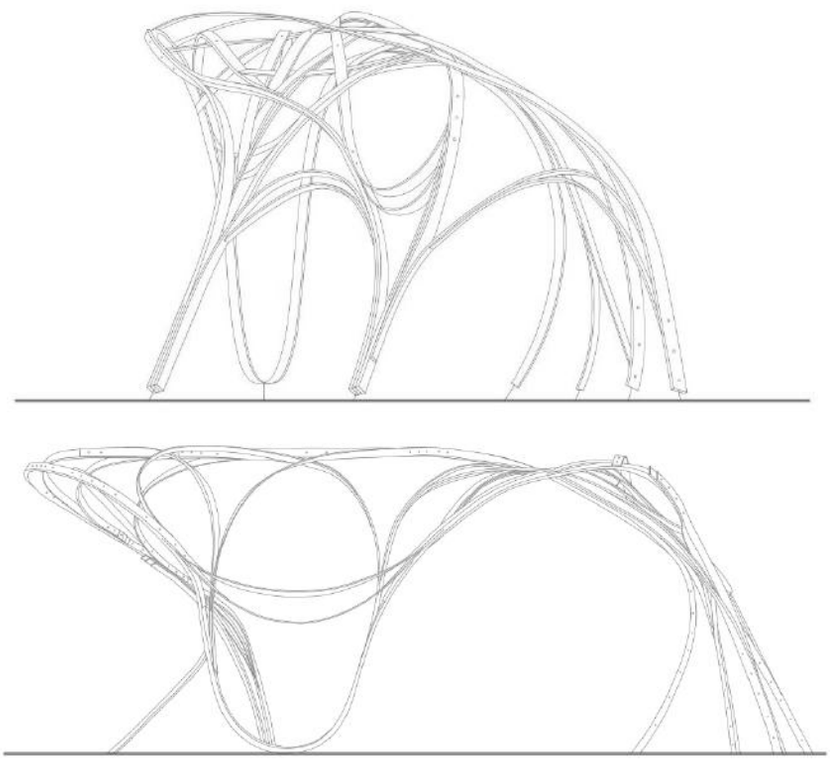

Figura 4. Elevación lateral y posterior de la propuesta.

3 Resultados

Con el proceso de experimentación se demostró que los procesos integrales de diseño de espacios y estructuras implican una coordinación estrecha entre diversos “actores” de las áreas de diseño, ingeniería y construcción, y sus correspondientes áreas de interés y experiencia. Por ello, al tener participantes de distintos niveles de la carrera de arquitectura y diferentes ingenierías, hizo que este proceso no siguiera una metodología típica o universal de diseño de anteproyectos colectivos, con participantes de una única disciplina, y dado que este tipo de ejercicios es común en la enseñanza del diseño del espacio. Se desarrolló desde el empirismo y la validación de posibilidades de éxito valoradas sobre la marcha. Sin embargo, se han identificado procesos y experiencias universitarias con didácticas similares (Grau *et al.*, 2017; Nelson *et al.*, 2010; Leung *et al.*, 2019) que, demuestran la necesidad de procesos para responder y formular nuevas

temáticas de reflexión sobre el espacio, los materiales y las formas en que se aborda la formación académica.

Por ello, se considera que la obra resultante del proceso de experimentación es “descendiente de su tiempo”, en este caso es una estructura orientada al reto del material y al abandono de la ortogonalidad.

A medida que los estudiantes exploran esta forma de trabajo, descubren que para comprender las posibilidades y las limitaciones de los materiales requieren la interacción con estos, para que de forma consciente puedan optimizar sus ventajas y controlar sus límites o vulnerabilidades. Además, se identifica que con la técnica de curveado con vapor se pueden lograr estructuras con características complejas, en las cuales la iteración permite derivar posibles medios de conexión tectónica, ensamblajes y desarrollo de la forma general confluyendo en estructuras espaciales a escala real que abren otras posibilidades y reflexiones sobre el uso del material y las técnicas constructivas.

La experimentación sobre la técnica de “curvado de la madera con vapor” históricamente se ha utilizado para diversos propósitos como la construcción de barcos y muebles; en este caso, se empleó para el diseño y experimentación de estructuras arquitectónicas concebidas como “envolventes escultóricas”, que permitan reflexiones sobre el diseño y diversas posibilidades de fabricación asociadas a la madera.

Sobre el concepto desarrollado, según los participantes, este se refiere a la estructura como un ensayo. Alude particularmente al concepto japonés del valor de ensayar, *zuihitsu*, que acorde a la obra “*Un tratado de estética japonesa*” (Richie, 2021) implica la idea de seguir el trazo del pincel, entendido en este caso el del material, y dejar que este encabece el lenguaje. La estructura es la multiplicidad de trazos que compone la cualidad estética, quien construye la deja implícita y quien la lee la infiere. Estos trazos, al haber desactivado la ortogonalidad, de ahí la analogía al F8 en el uso del *software* de diseño, atiende al mayor reto posible del material y de la imaginación.

El taller estuvo conformado por estudiantes de diversos niveles de arquitectura, ingeniería mecánica e ingeniería en biosistemas y múltiples colaboradores que se unieron a lo largo del desarrollo del taller, de quienes emerge la estructura a partir del diseño colaborativo y por ende con autoría colectiva, como se muestra en la figura 5. Cada pieza fue colocada y ajustada bajo el criterio de quienes la manipulan durante los aproximadamente cinco minutos de flexibilidad del material, otorgados por cada hora en la caldera. Si bien la experimentación fue intuitiva, surge del análisis del trabajo realizado a cada paso y se basó en la plasticidad del material que se logra con un proceso de modificación que lo torna flexible y trabajable.

Figura 5. Fotografías del proceso de diseño colaborativo (izquierda) y transporte de la estructura, apoyada sobre su andamiaje provisional (derecha).

4 Discusión

La contribución de esta experiencia en la arquitectura radica en valorar la importancia de involucrar métodos alternativos de pensamiento, y la reflexión de diseño y de trabajo colaborativo a través de un diálogo abierto entre material, la búsqueda formal y espacial y la definición del sistema estructural en un taller donde converjan diversos actos arquitectónicos, los cuales son valorados durante los procesos por parte de todos los participantes. Con este taller experimental, se muestra la importancia de incorporar actividades que permitan entender la lógica de los materiales y las técnicas de construcción en modelos (prototipos) digitales y físicos (maquetas) que actualmente raras veces convergen en la mayoría de las escuelas de arquitectura. Su importancia radica en que permiten atravesar el umbral entre “lo posible y lo imposible ahora posible” para cuestionar este límite imaginario y enfrentar los desafíos que se derivan al intentar asimilar nuevos conocimientos y destrezas en la construcción a escala real. Esto se ejemplifica en la figura 6, que muestra el contraste entre la realidad habitual y la ahora propuesta.

A partir de la realización del taller, quedó pendiente el reto de traducir los conocimientos y las formas de medición del mundo empírico en estrategias de diseño por medio de parámetros digitales más sofisticados y robustos que permitan explorar más allá de los procesos lineales de enseñanza digital y teórica convencional. Se entiende que cuando los medios y las posibilidades

de fabricación están divorciados del proceso de diseño, lo cual es característico en los sistemas digitales cerrados, se pone en riesgo olvidar o bien no contemplar algunos aspectos de los procesos reales de construcción, prefabricación y montaje que pueden comprometer la integridad de una estructura o la intención del diseño.

Por último, se reflexiona sobre la importancia de complementar la técnica integral de diseño con un modelado de *software* paramétrico avanzado, análisis estructural y métodos de fabricación Computer Numerical Control (CNC), entre otras técnicas, para reinventar los procesos de diseño; ya que, como lo propone Schulte *et al.* (2011), los modelos deben ser capaces de tratar con características tradicionalmente difíciles de visualizar como la elasticidad y la recuperación elástica de un material, manteniendo un seguimiento preciso del conjunto detallado de instrucciones que se pueden comunicar con elementos de desarrollo digital.

Todo lo anterior se concibe como la fase inicial de un proceso de reflexiones y exploraciones que deben continuar y evolucionar para aprovechar las posibilidades que ofrece la multidisciplinariedad, la necesidad de adaptación tecnológica y el rescate de los conocimientos que conforman la cultura, la identidad y coexisten con procesos en constante evolución.

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Figura 6. Fotografía de la estructura experimental.

5 Referencias

Benson, J. (2009). *Woodworker's Guide to Bending Wood: Techniques, Projects, and Expert Advice for Fine Woodworking.* Fox Chapel Publishing.

Biskjaer, M. M., Kamari, A., Jensen, S. R. & Kirkegaard, P. H. (2019). Exploring blind spots in collaborative value creation in building design: a creativity perspective. *CoDesign*, *17*(4), 374-391. https://doi.org/10.1080/15710882.2019.1654521

Emam, M., Taha, D. & ElSayad, Z. (2019). Collaborative Pedagogy in Architectural Design Studio: A Case Study in Applying Collaborative Design. *Alexandria Engineering Journal, 58*(1), 163-170. https://doi.org/10.1016/j.aej.2018.03.005

Erkan, Ö. (2013). Interdisciplinary Collaboration Between Interior Architecture and Industrial Product Design Programs in Turkey. *Procedia-Social and Behavioral Sciences, 106,* 1540-1547. https://doi.org/10.1016/j.sbspro.2013.12.174

Grau, G. R., Bruneau, D., Lagiere, P., Rouault, F., Rodriguez, G. & Bodennec, J. (2017). Interdisciplinay Design for the Development of a Wood House with Positive Energy. *World Conference on Timber Engineering WCTE, 2016*.

Hiziroglu, S. (2011). Bending Wood for Hobbyists. *Oklahoma State University. Division of Agricultural Sciences and Natural Resources. Cooperative Extension Service.*

Leung, Y. S., Kwok, T. H., Li, X., Yang, Y., Wang, C. C. & Chen, Y. (2019). Challenges and Status on Design and Computation for Emerging Additive Manufacturing Technologies. *Journal of Computing and Information Science in Engineering*, *19*(2). https://doi.org/10.1115/1.4041913

Nelson, J., Nuttall, B. & Estes, A. (2010). Interdisciplinary Design: The Good, the Bad, and the Ugly. En *2010 Annual Conference & Exposition Proceedings*, 15-791.

Priya, R. S., Shabitha, P. & Radhakrishnan, S. (2020). Collaborative and participatory design approach in architectural design studios. *Social Sciences & Humanities Open, 2*(1). https://doi.org/10.1016/j.ssaho.2020.100033

Richie, D. (2021). *Un tratado de estética japonesa*. Alpha Decay.

Riggio, M. & Cheng, N. Y. W. (2021). Computation and Learning Partnerships: Lessons from Wood Architecture, Engineering, and Construction Integration. *Education Sciences, 11*(3), 124. https://doi.org/10.3390/educsci11030124

Schulte, M., Mankouche, S., Bard, J. & Ng, T. Y. (2011). Digital Steam Bending: Recasting Historical Craft Through Digital Techniques. En *Considering Research: Reflecting upon Current Themes in Architecture Research.*

Sheine, J., Donofrio, M. & Gershfeld, M. (2019). Promoting Interdisciplinary Integrated Design Education Through Mass Timber. *Reynolds Symposium: Education by Design*.

Mental Breadcrumbs: Developing biometric methods to understand how emotions and sensory cues affect wayfinding

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Abstract. How do one's emotions, mental state, and the spatial environment interact? Interdisciplinary research methods in architecture and neuroscience can be used to examine the interrelated factors of mental load, sensory cues, emotions, and memory in wayfinding. The objective is to propose a biometric methodology for quantifying the emotional and cognitive experience of wayfinding, and to present a pilot experiment on the impact of mental load on wayfinding. The methodology collected biometric (electrodermal activity, electroencephalogram, heart rate, accelerometer), visuospatial (GPS, camera), and interview data. The pilot study revealed a new category of sensory cues used by individuals to wayfind. Identified as "breadcrumbs" and associated with subjective emotions, researchers propose an addition to Kevin Lynch's elements of the built environment that contribute to cognitive mapping. The aim is to invite a rethinking of the typically precedent-based nature of spatial design, bolstering the discussion with individual experience data to encourage evidence-based design.

Keywords: Interdisciplinary Design, Biometric, Wayfinding, Sensory Cues, Mental Load

1 Introduction

How do one's emotions, mental state, and the spatial environment interact? Why are some built environments easier to navigate than others? What spatial cues do people use in wayfinding, and how are they impacted by one's cognitive load?

Emerging interdisciplinary research methods drawn from collaborations between architecture and neuroscience have allowed spatial design researchers to expand beyond a predominant reliance on observational studies (ESUM, 2017; Werner et al., 2019). Biometric wearable technologies can augment our understanding of the human spatial experience by giving researchers quantitative insights into the real-time physiological changes

experienced by people in the field. Specific physiological metrics have been shown to be correlated with emotion, stress, memory, and attention, providing a wealth of information for experience analysis (Antonenko et al., 2010; Kyriakou et al., 2019). The presented work is part of this new frontier in architectural research that quantifies the human experience with biometric sensor technologies (Karakas & Yildiz, 2020).

The objective of this paper is a) to propose a biometric methodology for quantifying spatial experience, which examines the interrelated factors that contribute to the wayfinding experience - mental load, sensory cues, emotions, and memory - and b) to present a pilot experiment using this methodology to explore the impact of mental load on pedestrian wayfinding. The researchers organized volunteers to take two urban walks, the first of which was designed to impose a low mental load and the second, a high mental load. The pilot study revealed a new category of sensory cues used by individuals to wayfind. Identified as “breadcrumbs” and associated with subjective emotions, researchers propose an addition to Kevin Lynch’s elements of the built environment that contribute to cognitive mapping.

This paper is the second in a series that aims to better understand the human experience of built environments. It builds upon prior work by the researchers that examined air travel passenger experience in airports (Song et al., 2022). Observations from the prior work indicated a possible relationship between an individual's mental load and spatial stress. Drawing from those findings, this paper presents a refined biometric methodology that can be deployed in a wider range of built environment contexts. The methodology collects biometric data (Electrodermal Activity (EDA), Electroencephalogram (EEG), Heart Rate, Accelerometer), visuospatial data (GPS, Body camera), and qualitative data (interviews, drawings). It is then analyzed through a dashboard designed by the research team. The dashboard facilitates visual cross-referencing to glean possible relationships among the different data streams.

The methodology is designed to be replicable with substitute technologies as available to other researchers around the world. Ultimately, the researchers hope to encourage a rethinking and redesigning of the typically precedent-based nature of spatial design, by bolstering the discussion with individual experience data to encourage evidence-based design.

1.1 Literature Review

Measuring the human experience of the built environment has posed an enduring challenge to architects, urban planners, and designers. The foundational research investigating this include Kevin Lynch’s work on people's urban cognitive maps, which identified five elements of the built environment that contribute to mental mapping (Lynch, 1960) and William Whyte’s work on human behavior at public spaces (Whyte, 1980). Researchers today have built upon these by incorporating novel technologies from eye-trackers (Sayegh et al., 2015), biometric sensors (Poh et al., 2010, Sagl et al., 2019), camera analysis (Schlickman & Domlesky, 2019), to AI/machine learning (ESUM, 2017). Using these tools, experience research has been conducted in a variety

of physical settings, from within passenger automobiles (Healey & Picard, 2005) to city centers (Andreani & Sayegh, 2017).

The commercialization of wearable health products has made these tools more readily accessible than before. Additionally, technological advances have eased the transition from conducting research indoors to outdoors in the field (Poh et al., 2010). The field has also benefited from the rise in “hacking culture” within digital Do-it-yourself (DIY) subcultures (Bechthold & Sayegh, 2015), which promotes the creation of new combinations of tools that subvert the existing conventions of the original technology and generate unexpected outcomes.

The topic of interest in this research work is “wayfinding”, defined as the purposive and motivated process of finding a path from an origin to a destination, that involves deciding on a sequence of turns and continuation of travel path (Golledge, 1999). Of the variety of research experiment setups for investigating wayfinding, this research uses Golledge’s description of *Explore and Retrace,* where people explore an unfamiliar environment and then attempt to retrace their path back to starting point. The goal is to understand how people acquire new primary information about their environment in their “explore” phase, and how that information gets used in the “retrace” phase. The act of retracing one’s steps relies heavily on one’s memory and attention (Nori et al., 2009; Pazzaglia et al., 2018). This research is interested in investigating the ways that emotion and attention interact with memory and affect one’s ability to retrace one’s steps.

2 Methodology

This research proposes a biometric methodology for quantifying the experience of wayfinding, examining the interrelated factors that contribute to it such as mental load, sensory cues, emotions, and memory. To demonstrate this methodology setup, the researchers present a pilot experiment of urban walks that investigate the impact of mental load on wayfinding.

2.1 Data Type & Wearables Technology Selection

The researchers used an equipment setup that combines biometric wearables, body cameras, and interviews. The specific data types collected are enumerated in Table 1, followed by a description of their relevance to quantifying experience of the built environment. The methodology was intentionally designed to be applicable in a variety of settings and replicable by researchers with varying available technology. The researchers chose technologies which balance reliability and availability. The following table lists the researchers’ choices of biometric products and associated validation studies, so that others may make informed decisions for possible substitutions.

Table 1. Quantitative data types collected by the methodology and their relevance.

Data Type	Wearable Product Used	Relevance to research topics
Electrodermal Activity (EDA)	Empatica E4	Used as a strong indicator of heightened physiological activity correlated with heightened emotional states (Kyriakou et al., 2019; Poh et al., 2010).
Electroencephalogram (EEG)	OpenBCI Electrode Cap	Used as a strong indicator of cognitive load, focus and attention, and confidence level in decision making (Antonenko et al., 2010).
Heart Rate (HR)	Garmin	Used as a weak indicator of stress and heightened emotional states, and a weak indicator of amount of bodily movement. (Kyriakou et al., 2019)
Accelerometer	Empatica E4	Shows the amount and speed of bodily movement
Global Positioning System (GPS)	Garmin	Shows exact geographical location which can be overlaid on maps and plans.
Body camera		Shows first-person perspective view of what was visible to the individual

2.2 "Explore & Retrace" Urban Walks Experiments

To develop the methodology, a pilot experiment was conducted with volunteers. Eight participants were outfitted with the equipment setup, and took two urban walks, one designed for low mental load, and another for high mental load.

Walk 1 (Low mental load): Participants explore an unfamiliar neighborhood.

- Step 1: Participants are instructed to wander in a predetermined unfamiliar neighborhood for 20 minutes, with the intent of getting lost. Participants were advised to not consult a map, to avoid walking continuously straight, and to take multiple turns. They are equipped with the aforementioned wearables and given a rule stating:
    - Do not listen to audio, or wear headphones
- Step 2: After 20 minutes, participants are instructed to call researchers who now instruct them to retrace their steps and return to their starting point using the same exact path.

Walk 2 (High mental load): The same set of participants explores a different unfamiliar neighborhood, replicating the conditions of Walk 1, but given a different rule stating:

- Listen to music during the walk
- Mentally count the number of people and animals encountered

2.3 Qualitative Data Collection: Interviews & Drawings

The researchers supplemented the quantitative data with qualitative data collection to better understand the individual experience (Mauss & Robinson, 2009). First, upon their return from each walk, the participants were given a blank piece of paper and asked to draw from memory the route that they took (Figure 1). Secondly, the researchers conducted a conversational interview guided by a questionnaire. The answers were recorded verbatim and then

categorized through a qualitative data coding process. The questionnaire was worded to help elucidate 1) what environmental elements people used for retracing, 2) the moments people felt uncertain, and 3) the moments people felt changes in emotion, and 4) the moments people experienced changes in mental load. Thirdly, the researchers presented the participants with the satellite map of the GPS tracked route to record their reaction. Lastly, the participants were asked to annotate the map with self-reported moments of elevated emotions, marking discrete moments as dots, continuous moments as lines, labeling their annotations with one word and noting whether it was a positive (+) or negative (-) emotion.

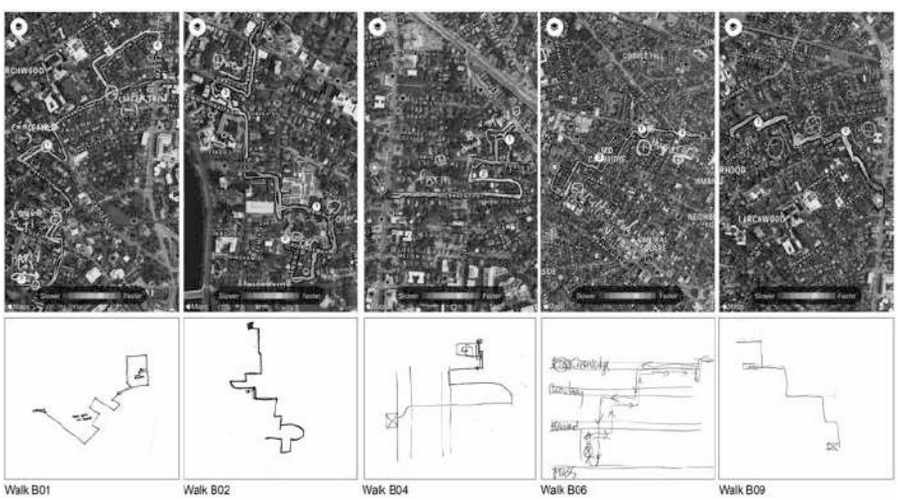

Figure 1. GPS maps of the participants' urban walks (explore + retrace), annotated by the participants with self-reported moments of elevated emotions. Bottom drawings show cognitive maps drawn by the participants.

2.4 Dashboard

To facilitate analysis of the collected data, the researchers designed a dashboard which allows concurrent visualization of the various data streams. The dashboard contains three main types of information, 1) Route data: the path taken by the participant, 2) Subjective data: self-reported sensory environmental elements and emotions, and 3) Biometric Data: EDA, EEG, HR, and ACC. The dashboard unrolls the walking path into segments from *Explore + Retrace*. The simultaneous visualizations assist researchers in understanding the relationships among different data streams, changes in emotion, and wayfinding decisions.

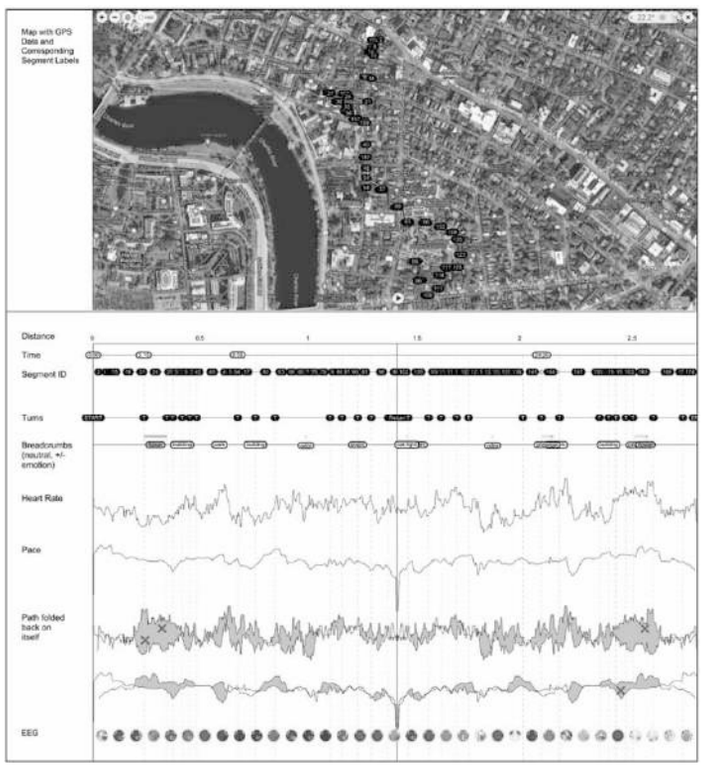

Figure 2. Dashboard for concurrent analysis of 1) route data, 2) self-reported data, and 3) biometric data, which are mapped onto an unrolled walking path identified as discrete segments.

3 Findings & Discussions

As part of developing this methodology, a pilot study was conducted to better understand the types of findings and analysis that are possible with this type of research. Using the proposed methodology, the pilot experiment resulted in three main types of findings. First is a catalog of sensory cues acquired by participants from the environment that aid in wayfinding. Second is a relationship between high mental load and one's decreased ability to wayfind and remember their spatial experience. Third is an observation that emotion plays an outsized role in spatial memory, and that a higher mental load increases perceptual distortions during wayfinding. Altogether, these findings function as proof-of-concept for the proposed methodology's particular combination of biometric, visuospatial, and qualitative data collection.

3.1 The Breadcrumbs Catalog

In the seminal work, *The Image of the City*, Kevin Lynch introduces five elements of the built environment that give shape to one's "cognitive map" of the city (Lynch, 1960). These elements are identified as nodes, paths, edges, districts, and landmarks. The researchers propose an additional element, identified as "breadcrumbs", referencing the story of Hansel and Gretel. In the story, breadcrumbs were hints left on a trail to help the children find their way back home. In this paper, the researchers use the term "breadcrumbs" to refer to sensory cues from the environment that aid in the process of wayfinding.

Breadcrumbs are distinct from Lynch's landmarks in that landmarks are identified through spatial prominence, size, and "figure background contrast" (Lynch, 1960). In contrast, breadcrumbs are smaller and individually determined pieces of sensory information gathered from the immediate environment. The researchers established this new category after noticing participants repeatedly mentioning a type of environmental sensory cue that did not fit in Lynch's identified elements (Table 2).

Self-reported breadcrumbs can be cataloged as subjective or objective information (Table 3). For example, an interview participant who recalled an objective breadcrumb reported, "the house was blue," whereas another participant's subjective breadcrumb was, "the color of the house was very ugly." Researchers found that participants logged more subjective breadcrumbs than objective ones. The memories of breadcrumbs were often associated with personal perception of the environment and indicated individual preference such as, the place "seemed like a nice place to live," or "it smelled very fishy."

Table 2. The number of times a type of breadcrumb was mentioned following Walk #1.

Environmental Breadcrumb Types	Participants ID								Total
	A01	A02	A03	A04	A05	A06	A07	A08	
Architectural elements	2	5	6	2	2	2	2	2	**23**
Programmatic elements (e.g school, bakery, construction zone)	2	5	4	1	1	3	1	2	**19**
Urban Built environment (with text, e.g. street signs)	0	2	1	2	0	2	2	2	**11**
Urban Built environment (without text)	3	1	1	2	2	1	1	1	**12**
Urban Furniture, Cars, etc. (objects occupying the sidewalk and street)	1	2	1	4	0	2	3	2	**15**
Nature and Animals	2	5	2	3	0	2	2	2	**18**
Human	4	1	1	0	3	3	0	2	**14**
Topography (Elevation changes)	0	0	0	0	0	0	1	0	**1**

Table 3. Catalog of Reported Breadcrumb

Subjective Breadcrumbs	Objective Breadcrumbs
Feeling tired from incline Feeling happy from someones smile Inspired by abundance of greenery and beautiful yards Frightened by dog barks Feeling uninspired by monotonous residential styles, Hungry from smell of indian food. Overwhelmed by construction noise Feeling safer with stop signs	Topography and elevation changes Human, Nature and Animals Urban Built Environment Programmatic Elements (eg School, Bakery) Urban Built Environment (w/text, eg. street names, dead end, building signs,slow down) Architectural Elements Urban Furniture, Cars, Objects, (objects encountered along the way)
Examples from Participants: • *"Excited by old green car and I took a picture"* • *"Noticed surprisingly spacious garden"* • *"saw construction workers who were doing exciting things"* • *"surprised by how beautiful the neighborhood was"* • *"seemed like a nice place to live"* • *"the color of the house was either very bright or very ugly"* • *"street that was so idyllic"* • *"attic window - and wondered how I could live there"* • *"giant consturction machine looked like giant spider robot"* • *"felt it was an out of ordinary sculpture"* • *"house that was painted blue/green/purple - it was odd"* • *"the corners were very annoying"* • *"Beach smell, very fishy"*	Examples from Participants: • *"There were two chairs on the road"* • *"Noticed a guy and a girl gardening"* • *"Then I saw the pole with Loki the missing cat"* • *"3 painter vans along the same street"* • *"weathered wood shingle"* • *"None of the houses here have awning"* • *"Noticed street signs"* • *"All the streets were very narrow."* • *"parking lot $240/mo"* • *"side walk was very bumpy"* • *"saw a hanging bed sheet"* • *"wooden pathway"* • *"there was a church bell"*

In addition, the researchers frequently observed a strong relationship between the presence of a breadcrumb (as reported during interviews) and a corresponding change in physiological data and self-reported emotions. Often, the breadcrumb was identified as the reason for the change in emotion. Figure 3 shows one such example of a participant's growing uncertainty and anxiety about correctly retracing the path (as reported during interview and corresponding increase in heart rate). The subsequent recognition of a visual breadcrumb confirmed the accuracy of the path taken, resulting in the subsequent drastic lowering and stabilization of heart rate. The same sequence of events is repeated later in Figure 3. The events diagrammed in Figure 3 were not an isolated case; participants reported heightened navigational certainty after encountering breadcrumbs.

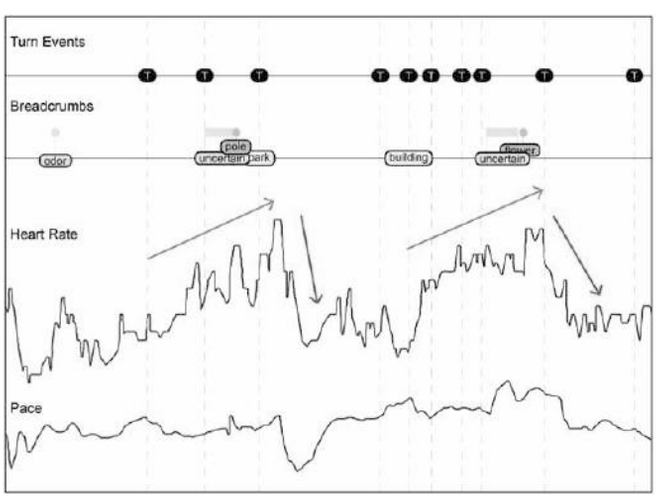

Figure 3. A zoomed in portion of the dashboard shows an example where the recognition of a breadcrumb triggers a significant change in physiological response.

3.2 The Impact of Mental Load on Wayfinding

Wayfinding requires the cognitive learning of an environment. Cognitive learning is the acquisition of this knowledge of one's environment is a dynamic process of continuous updates affected by a person's emotion, memory, and attention (Golledge, 1999). To better understand this process, the researchers analyzed the effects of increased mental load on wayfinding abilities, as it relates to sensory cues, emotion, and memory.

The experiment revealed that changes in mental load impacted the participants' experience and accuracy of wayfinding. A greater number of volunteers correctly retraced their route during the lower mental load walk than the higher mental load walk. Higher mental load seemed to negatively affect the acquisition of new environmental information and "breadcrumbs." Participants mentioned fewer specific breadcrumbs during interviews following the second walk. This decrease in information acquisition also seemed to lower a person's ability to recognize and use previously encountered sensory inputs as wayfinding cues.

Not only does high cognitive load affect one's ability to acquire new environmental information, but it also affects one's ability to encode experience into memory (Yegiyan & Yonelinas, 2011). The experiment showed that the mental logging of breadcrumbs was highly correlated to self-reported emotion. Higher cognitive load lowered the number of self-reported discrete positive emotional moments during their walk.

3.3 Perception vs. Reality

This research is particularly interested in the effect of emotion and mental load on distorting one's perception of wayfinding. The researchers used the techniques of mental map drawings and EEG Signal-to-Image to externally visualize the participants' internal perceptions. The mental maps illustrate how the participants remembered their route, allowing researchers to better understand how their spatial memory and perception is affected by emotions and mental load. The EEG Signal-to-Image produces a visualization of how the participant's brain is processing what the participant sees, through distorting one's visual experience with the recorded EEG signals.

Comparing the mental maps drawn by the participants to the GPS data allows researchers to identify patterns among the distortions between one's perception and reality (Figure 1). Most participants overestimated the number of turns taken during their walks and expressed surprise when shown the GPS map afterwards. Event perception plays a fundamental role in the memory of human experience (Zacks et al., 2007), and self-produced events, such as deciding to take a turn, are perceived more significantly in one's memory. Every "event" looms disproportionally large in one's memory, and active decisions are given priority in memory.

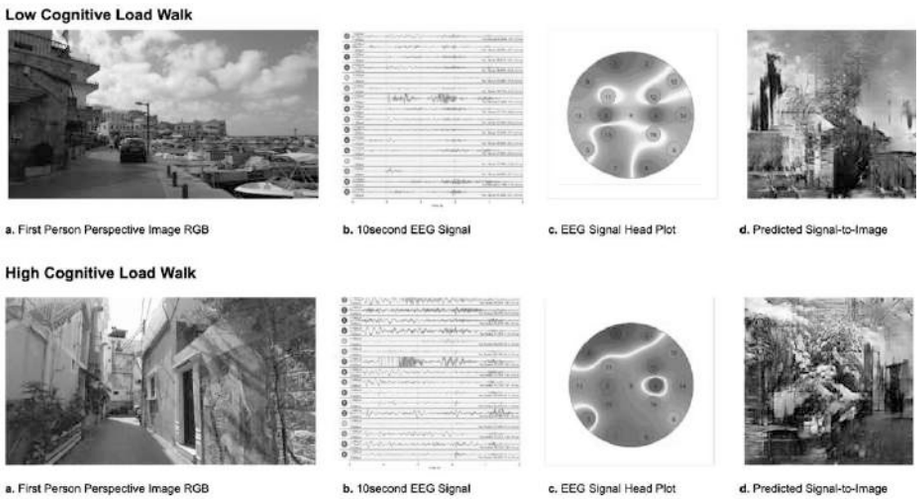

Figure 4. Shows the relationship between video footage, EEG brain signals, and predicted Signal-to-Image, and the comparison between Signal to Image prediction during low cognitive load and high cognitive load.

To further explore the effects of mental load on one's perception of reality, the researchers used the EEG Signal-to-Image technique as part of the methodology (Figure 4). The EEG Signal-to-Image technique provides insight into the hidden effect of cognitive load on the processing of sensory cues. During walks of low cognitive load, the brain more accurately processed the visual information that the eyes saw from the immediate physical environment. Thus, the resulting Signal-to-Image output had a visual similarity the environment as documented by the body camera worn by the participant. During walks with high cognitive load, the cognitive processing of immediate visual information is clouded by other mental processes, and the resulting Signal-to-Image output shows an image that is more greatly distorted by cognitive interference.

4 Conclusion

The above findings serve as proof-of-concept for the proposed methodology of combining biometric, visuospatial, and qualitative data collection. It also demonstrates the potential of the dashboard as a versatile analysis tool for researching the topics of sensory cues, cognitive mapping, memory, emotion, and wayfinding. The main strength of the methodology is that it provides an alternative to the typically precedent-based nature of architecture and urban design and facilitates evidence-based experiential design through the addition of quantitative individual experience data.

The most obvious application of this research method and dashboard would be in post-occupancy evaluations of architecture and public spaces. The initial

findings from the pilot study begin to suggest recommendations for the urban design of neighborhoods. Since breadcrumbs associated with spikes in emotion are more readily encoded into memory, urban designers should consider increasing sensory variety when designing neighborhoods to improve an individual's cognitive map and lower one's spatial anxiety.

We hope that the presented research methodology allows researchers around the world to conduct experiments in a variety of built environment settings, and that this type of research will facilitate speculations on alternative scenarios for designing public spaces, architecture, and urban neighborhoods. This collection of interdisciplinary knowledge on individual experiences can empower and enable better design within the built environment.

References

Andreani, S., & Sayegh, A. (2017). *Technologically Enhanced Design Research Methods for Revealing Hidden Qualities of the Built Environment*. 10.

Antonenko, P., Paas, F., Grabner, R., & van Gog, T. (2010). Using Electroencephalography to Measure Cognitive Load. *Educational Psychology Review*, *22*(4), 425–438. https://doi.org/10.1007/s10648-010-9130-y

Bechthold, M., & Sayegh, A. (2015). Hacking Science: The ALivE Group's Material Design Methods for Interdisciplinary Environments. *Architectural Design*, *85*. https://doi.org/10.1002/ad.1962

Bradley, M. M., Sabatinelli, D., & Lang, P. J. (2014). Emotion and Motivation in the Perceptual Processing of Natural Scenes. In K. Kveraga & M. Bar (Eds.), *Scene Vision* (pp. 273–290). The MIT Press. https://doi.org/10.7551/mitpress/9780262027854.003.0013

ESUM. (2017). *Human perception of urban environment*. www.esum.arch.ethz.ch/

Golledge, R. G. (1999). *Wayfinding behavior: Cognitive mapping and other spatial processes*. Johns Hopkins University Press.

Healey, J. A., & Picard, R. W. (2005). Detecting stress during real-world driving tasks using physiological sensors. *IEEE Transactions on Intelligent Transportation Systems*, *6*(2), 156–166. https://doi.org/10.1109/TITS.2005.848368

Karakas, T., & Yildiz, D. (2020). Exploring the influence of the built environment on human experience through a neuroscience approach: A systematic review. *Frontiers of Architectural Research*, *9*(1), 236–247. https://doi.org/10.1016/j.foar.2019.10.005

Kyriakou, K., Resch, B., Sagl, G., Petutschnig, A., Werner, C., Niederseer, D., Liedlgruber, M., Wilhelm, F., Osborne, T., & Pykett, J. (2019). Detecting Moments of Stress from Measurements of Wearable Physiological Sensors. *Sensors (Basel, Switzerland)*, *19*(17), 3805-. https://doi.org/10.3390/s19173805

Lynch, K. (1960). *The image of the city*. Technology Press.

Mauss, I. B., & Robinson, M. D. (2009). Measures of emotion: A review. *Cognition & Emotion*, *23*(2), 209–237. https://doi.org/10.1080/02699930802204677

Nori, R., Grandicelli, S., & Giusberti, F. (2009). Individual Differences in Visuo-Spatial Working Memory and Real-World Wayfinding. *Swiss Journal of Psychology/Schweizerische Zeitschrift Für Psychologie/Revue Suisse de Psychologie*, *68*, 7–16. https://doi.org/10.1024/1421-0185.68.1.7

Pazzaglia, F., Meneghetti, C., & Ronconi, L. (2018). Tracing a Route and Finding a Shortcut: The Working Memory, Motivational, and Personality Factors Involved. *Frontiers in Human Neuroscience*, *12*. https://www.frontiersin.org/article/10.3389/fnhum.2018.00225

Poh, M.-Z., Swenson, N., & Picard, R. (2010). A Wearable Sensor for Unobstrusive, Long-Term Assessment of Electrodermal Activity. *IEEE Transaction On Biomedical*, *57*(No. 5), 1243–1252.

Sagl, G., Resch, B., Petutschnig, A., Kyriakou, K., Liedlgruber, M., & Wilhelm, F. (2019). Wearables and the Quantified Self: Systematic Benchmarking of Physiological Sensors. *Sensors (Basel)*, *19*(20), 4448-. https://doi.org/10.3390/s19204448

Sayegh, A., Andreani, S., Li, L., Rudin, J., & Yan, X. (2015). A New Method for Urban Spatial Analysis: Measuring Gaze, Attention, and Memory in the Built Environment. *Proceedings of the 1st International ACM SIGSPATIAL Workshop on Smart Cities and Urban Analytics*, 42–46. https://doi.org/10.1145/2835022.2835030

Schlickman, E., & Domlesky, A. (2019). *Field Guide to Life in Urban Plazas: A study in New York City*. SWA. https://live-swa-2019.pantheonsite.io/wp-content/uploads/2019/08/Field-Guide-to-Life-in-Urban-Plazas_digital1.pdf

Song, H., He, I., Seibold, Z., & Sayegh, A. (2022, July). *A Biometric Method for Spatial Experience Analysis: A Case Study of Airport Design and Traveler Stress*. The European Conference on Arts, Design & Education (ECADE), Porto, Portgual.

Werner, C., Resch, B., & Loidl, M. (2019). Evaluating Urban Bicycle Infrastructures through Intersubjectivity of Stress Sensations Derived from Physiological Measurements. *International Journal of Geo-Information*, *8*(6), 265. https://doi.org/10.3390/ijgi8060265

Whyte, W. (1980). *The social life of small urban spaces*. Conservation Foundation. http://id.lib.harvard.edu/alma/990008811700203941/catalog

Yegiyan, N. S., & Yonelinas, A. P. (2011). Encoding details: Positive emotion leads to memory broadening. *Cognition and Emotion*, *25*(7), 1255–1262. https://doi.org/10.1080/02699931.2010.540821

Zacks, J. M., Speer, N. K., Swallow, K. M., Braver, T. S., & Reynolds, J. R. (2007). Event perception: A mind-brain perspective. *Psychological Bulletin*, *133*(2), 273–293. https://doi.org/10.1037/0033-2909.133.2.273

Special Topics: Digital Heritage

The remains of Morro do Castelo: locative gaming and digital heritage in Rio de Janeiro

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Abstract. This paper describes a research studying the tactical appropriation of location-based informational media in urban space. More specifically, we are concerned with using these techniques as a ludic tool to shed light in the processes of urban transformations and preservation of heritage in the city of Rio de Janeiro, using Morro do Castelo as a case study. This research is divided in three parts: the first comprises a historical review of the demolition of Morro do Castelo; the second consists in the elaboration of a set of points of interest related to the theme downtown Rio; the third involves the creation of a proof-of-concept prototype using the Actionbound platform, conducting a few field tests to evaluate the consistency of the itinerary. The results indicate the potential of location-based games as a tool for cultural heritage education, as well as the inherent difficulties in designing such experiences.

Keywords: Digital Heritage, Location-based games, Morro do Castelo, 20th century Rio de Janeiro

1 Introduction

This research was developed as a graduation project in Architecture and Urbanism, in the larger context of a research project on augmented urban spaces in the city of Rio de Janeiro, conducted in LAURD – Laboratory of Urban Analysis and Digital Representation – Graduate Program in Urbanism PROURB – Faculty of Architecture and Urbanism – Federal University of Rio de Janeiro. It seeks to study ways of tactical appropriation of location-based informational media in urban space. More specifically, we are concerned with using these techniques as a ludic tool for reflection on the processes of urban transformations and preservation of heritage in the city of Rio de Janeiro in Brazil, using Morro do Castelo as a case study.

In this paper, we describe the conception of a location-based game prototype that invites the players to discover the processes that led to the demolition of Morro do Castelo and its remains in the today city. Location-

based games use urban space as a space of play, merging digital mobile technologies and geo-locating systems (Lemos, 2010).

The methodology used is divided into three stages. The first stage comprises a historical review of Morro do Castelo and the processes related to its demolition, such as the construction of the Avenida Central and the urban reforms for the celebrations of the centenary of independence of Brazil. This review was supplemented by chronicles of authors like João do Rio and Machado de Assis and newspaper and magazine articles dating from the beginning of the 20th century. The second stage consists in the elaboration of a set of points of interest in the Castelo region in downtown Rio de Janeiro, based on the historical review. We then created location-based challenges for each point, therefore forcing users to actually be there to solve them. They were organized into a three-act itinerary (three linked itineraries of approximately seven points of interest each), according to different themes and proximity, so each one would not be a too long distance to walk.The third stage involves the creation of a proof of concept prototype.

Our technical tools review pointed to the Actionbound platform in order to achieve that, which we then used to conduct the experiment. It consisted, therefore, mostly of multiple choice and full text questions, using photos and sounds as part of the questions. The game prototype was then published on the platform so we could conduct a few field tests in order to evaluate the consistency of the itinerary, the difficulty of the questions, the overall length and duration of the walk and the general impression of the surroundings while performing the activity.

2 Morro do Castelo

“Morro do Castelo” (Castle Hill) was a hill in downtown Rio de Janeiro directly related to the foundation of the city in 1567 by Portuguese colonizers. It was the first colonial urban centrality, at first occupied by government buildings, the Jesuitic building complex and residences of the colonial elite (Sisson, 2008; Vilas Boas, 2007). In the beginning of the 17th century, urban activities extended into the plains, which provided an easier access to the littoral of the city. However, the residential use remained on the hill until the beginning of the 20th century, but now most of its inhabitants were low income tenants (Paixão, 2008).

In the beginning of the 20th century, the city of Rio de Janeiro was the capital of the recently proclaimed Republic, and there was the urge to build a new public image apart from its colonial past (Abreu, 1987). The mayor Francisco Pereira Passos undertook a series of large urban reforms, the largest being the construction of Avenida Central (Central Avenue, today Rio Branco Avenue) in 1905. To accomplish this, circa 2.000 popular residences

were demolished, old streets were significantly reduced or completely eliminated, and part of the land of Morro do Castelo was extracted.

The presence of the hill (and its poorer inhabitants) right next to the new avenue brought discontentment to many. Newspapers depicted the hill as an obstruction to the city progress, referring to it as an urban "cyst" that should be removed entirely, even if that represented a sacrifice of memory for the city. The definitive dismantling of Morro do Castelo took place during the 1920s, as part of the works for the Brazilian Independence Centennial Exhibition. The inhabitants of the hill were displaced to other parts of the city, and the land extracted was used as landfill for the creation of new areas for the Exhibition and other modernizing urban developments.

In spite of its historical importance, there were public outcries in favor of the hill's demolition from as early as the 17th century, mostly alleging that it obstructed the circulation of air within the city. During the 18th century, with the expulsion of the Jesuitic order from Brazil (and consequently from their buildings in the hill), a rumor started to spread among the townspeople that the religious order left behind a hidden treasure (Kessel, 2008). As the demolition started, in the beginning of the 20th century, there was great excitement whether the legendary treasure would finally appear (Lima Barreto, 1905/1997).

The only physical remnant of Morro do Castelo today is the beginning of Ladeira da Misericórdia (Misericórdia Slope), one of the old accesses to the hill (Figure 1). In addition to the slope, some fragments of important buildings such as the Jesuit Church were rescued from the demolition and moved to different parts of the city. Although the presence of Morro do Castelo is no longer part of the landscape, it remained as a flickering part of the image of the city, as noted in popular culture and even in the use of the toponym "Castelo" as a reference for the area it once stood.

Figure 1. Misericórdia Slope and the Nossa Senhora de Bonsucesso Church.
Source: Google Street View.

3 Location based games

As pointed out by Zeffiro (2012), the term “locative media” was coined by Karlis Kalnins in the context of the Art+Communication Festival in Riga, and it encompassed a set of emergent artistic practices based on mobile and location-aware technologies (Leorke & Wood, 2019). Location based games are therefore gaming experiences that profit from those practices and technologies to use diverse daily spaces as playful spaces. According to Lange (2009, p. 56), location-based mobile games are *games whose outcome depends not only on the events on the screen but also on the player's positions in the physical world*, involving *the player’s interactions with particular locations as part of the game*.

In this paper, playful spaces refers to spaces where play takes place, using Huizinga’s (1938/2007) concept of “play” as an activity apart from daily activities, within its own limited time and space. This means that a user/player is from the start in a state of mind that considers his or her current space as a place where new representations can be enacted. This work considers the premise that the player is therefore open to new interpretations of space.

It is quite clear that some games, and entire game types, as pervasive games, ARGs (alternate reality games), LARPs (live-action role playing games) and location based games - and perhaps it is no coincidence that these concepts that tend to overlap -, tend to challenge or actively blur such boundaries of time and space, especially when it comes to the actual playing field as distinct from the non-playing space surroundings. As Ejsing-Duun puts it:

Location based games affects players perception of and behavior in everyday spaces, as the games reside on the boundaries between the continuums of play and ordinary, authentic and fictional, and as they merge physical and digital media, and the intention of the player [from the very decision to play, we could add] *has a key role in this process of spatial reinterpretation.* (2011, i)

We consider that these games can be an important tool in creating awareness and fostering the creation of new meanings for urban heritage places. In fact, when it comes to how location based games deal with space, it is possible to identify their different approaches with general spatial categories of territory and place, respectively dealing with the control of space and the association of narratives (fictional and non-fictional) to space. From

“ARQuake” (Thomas et al., 2000) to “Wizards Unite” (Niantic, 2019), those two aspects coexist in different proportions across these games.

Games based on place exploration include “WHAVSM?” (Budziski & Isermann, 2005) - German acronym for “Who Is Afraid of The Man in Black”, a reference to architects’ usual choice of color for their clothes -, a QR code based game developed by the Stuttgart School of Architecture to help new students get acquainted with the school’s premises and the surrounding city. Another example is “Frequency 1550” (Waag Society, 2005), where young students in Amsterdam play around the city center to learn about its medieval history.

Using a device to uncover stories or see what is hidden or invisible in a given space is a physical enactment of the attribution of meaning to a place, helping the player to visualize different narrative layers related to a given space. It induces, therefore, the reinterpretation of ordinary spaces, as they are transformed - and ressignified - by the act of playing. The use of location based games, therefore, helps anchor narratives to the ordinary spaces of the city.

4 Game structure

The research aims to give users a sense of the original presence of the hill and its inhabitants by means of a location based game that also helps users to map those spaces in the current city. While playing, the user will be conducted around the original site of the hill while solving riddles that depict the importance of this original space and of those who lived there.

The game invites the players to discover why Morro do Castelo is no longer physically present. In order to achieve this, they must find the “pieces of the treasure” of Morro do Castelo, in a reference to the popular legend about the Jesuit treasure. In our case, the pieces of treasure are fragments of the hill and its buildings that are still present in the city. The structure of the game follows a three-act itinerary (Figure 2). Each act covers a different theme and has a set of location-based challenges that the players must solve in order to progress to the next challenge. At the end of each act, players are rewarded with information about the remnants of the hill.

Figure 2. Itineraries of the three main acts of the game in the Castelo region downtown Rio de Janeiro. Source: Author's production.

The first act covers the construction of Central Avenue, introducing players to the political and social context of the beginning of the 20th century Rio de Janeiro, as well as drawing attention to the architectural and urban models fostered by the republican society of that time. The itinerary starts at Almirante Barroso Avenue, where once stood the entrance to the hill's popular village called Chácara da Floresta, and ends next to the building of the National Library, where was found during the demolition of the hill what many believed to be an entrance to a subterranean gallery. When the players complete each challenge, they receive excerpts of local newspapers from the beginning of the 20th century debating the proximity of Morro do Castelo to the recently built Avenue. Upon completing the itinerary, the players receive the first fragment of the treasure, a drawing of the altarpieces and the pulpit of the Jesuit Church of Morro do Castelo.

The second act covers the celebrations of the centenary of the Independence of Brazil, and invites the players to visit the pavilions' locations of the Centennial Exhibition and observe the urban transformations that took place after it. The itinerary starts at Mahatma Gandhi Plaza, where Monroe Palace once stood, and ends in front of the building of the Brazilian Academy of Letters, originally the French Pavilion of the Exhibition. When the players complete each challenge, they receive pictures of the demolition of the hill, reinforcing that this process and the Centennial Exhibition happened simultaneously. Upon completing the itinerary, the players receive the second

fragment of the treasure, a drawing of the pediment of the Jesuit Church of Morro do Castelo.

The third act invites the players to discover current urban fragments of the city that were contemporary to the hill. The itinerary starts at Santa Luzia Church, and ends at Ladeira da Misericórdia, which was part of the Hill and is the final reward, the last piece of Morro do Castelo's treasure. As players solve each challenge, they receive pictures and excerpts of narratives written by chronists like Machado de Assis, João do Rio and Luis Edmundo, describing their memories of how the city and Morro do Castelo were like at the beginning of 20th century. We chose to use chronicles and memorial narratives over more academic texts from historians or urbanists in order to give players the chance to be in touch with first-hand, subjective and emotional accounts of the city and its processes. Based on them, players might become witnesses themselves as they add their own interpretation of these events and their perceptions about the city as it came to be in the present.

The epilogue works as a conclusion whose objective is to lead the players to the current locations of the fragments of Morro do Castelo, gathered along the past acts. The itinerary starts at the Misericórdia Slope, goes through Nossa Senhora de Bonsucesso Church (the current location of the altarpieces and the pulpit), and ends at the Museu Histórico Nacional (where the pediment is currently exhibited). Upon completing the challenges related to each fragment, players receive more information about them, such as pictures of its original state and location.

5 Assembling the game

Based on the historical review, we conducted a curatorial process of photographs, testimonials, chronicles and newspaper articles related to the themes of the acts and its objectives. In addition, based on photographs and maps from imagineRio (El-Dahdah & Metcalf, 2016), we were able to compare the present city with its historical layers and evaluate how these urban processes of the past present themselves nowadays - buildings, monuments, streets, and so on. We then established a set of points of interest, with an average of seven points per act.

To create the script structure of the narrative, we used Twine (Klimas, 2009), an open source online tool for creating interactive stories. In spite of the game having a linear structure, the map-like visualization of the interactions provided by the software (Figure 3) helped build the relationships between the interactions and the media featured in the game, giving a clearer view of the narrative as a whole.

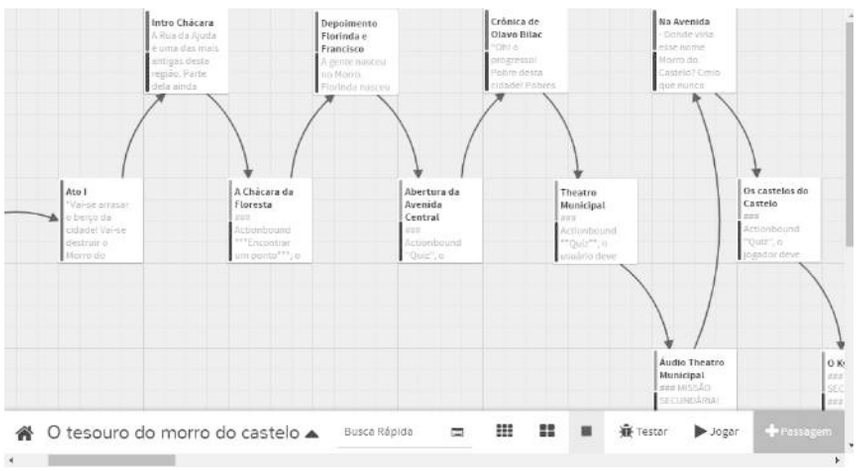

Figure 3. Visualization from the narrative creation interface of Twine. Source: Twine, screen capture

The gameplay follows as such: players receive a question involving a location. To answer it, they must move towards the location and search for the solution in the surroundings: it can be in a street sign, pavement pattern, in a detail on a building facade or even in a specific view from a given coordinate. When they successfully answer the question, they receive another one and repeat the process. Questions are intercalated with pictures and texts, which are related to the themes of the respective act they are inserted in.

In order to build a proof of concept prototype and conduct a few field tests, we used the Actionbound application. Actionbound (Actionbound, 2012) is a platform for creation and distribution of personalized treasure hunting games and interactive guides (called “bounds”). It is a freemium service: the free version allows for most of the features, with a non-customizable interface. It provides a series of elements, such as quizzes (multiple choice or full texts questions where answers are automatically checked by the system), missions (which support media input from the user, and do not count with an automated correction system), information screens (that only display additional information but have no quest attached) and “Find a Spot” (where users must find a specific coordinate). There is also an “if-else” structure named Switch, used to show specific screens or quests when certain conditions are met. All of these elements were used in the prototype. It allows the users to explore a certain territory through a descriptive and illustrated path, encouraging observation of the surroundings and comparison. The game is built in the desktop management version of the platform, and is played on smartphones (Figure 4). We used the free version of the platform, in which it is not possible to customize the interface of the bound.

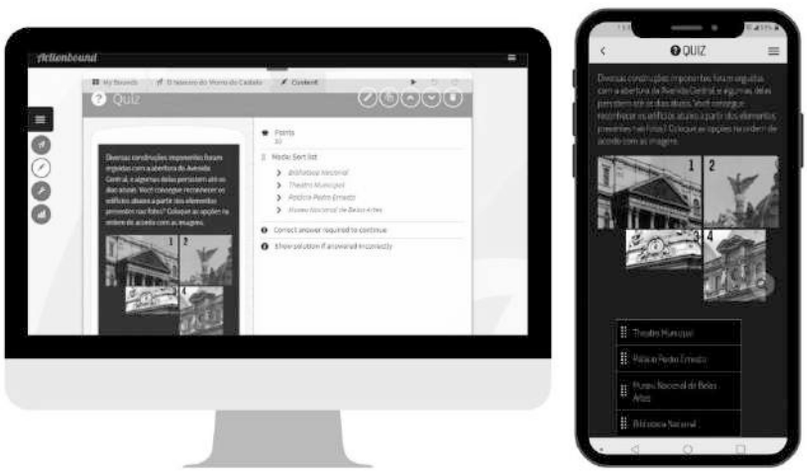

Figure 4. Screens from the bound creation desktop interface and the playable smartphone version. Source: Actionbound, screen capture

Questions involve searching for a reference in urban space, comparing elements of the present city with the past, taking a photo based on an angle of a 20th century picture and recording an audio based on a description from the past. At this point, the game has a total of 26 quests (most of them multiple choice or text-based questions). We used quizzes for the main activites, as they have a correction system. We also experimented with creating side questions, using elements that do not require a correction, such as missions. They promote small deviations from the main path, delving deeper into the subjects addressed within the acts of the game.

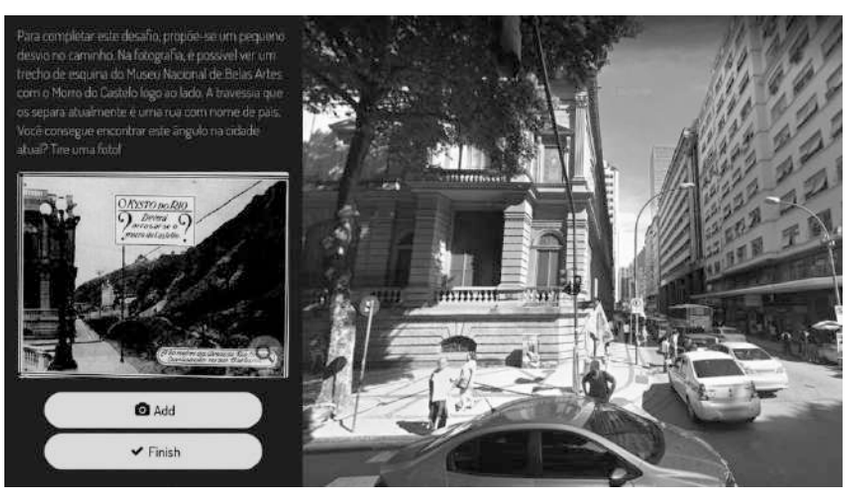

Figure 5. An example of a “take a picture” quest and the approximate solution location at México Street. Source: Actionbound, screen capture; Google Street View

However, there are some limitations. Quizzes that require full text input need to have a precise match to the registered answer in order to be considered, meaning that typos or missing and extra words are deemed wrong by the software. As mentioned before, the system also does not check media uploaded by the user, like pictures or audios. Actionbound also works with a ranking scoring system and the definition of a score for the activities is mandatory. Because of this, even if the experience intended by the game does not focus on player scores, we attributed points for the questions.

6 Results

Beta field tests done by our research team showed that the three-act itinerary structure was significantly easier to complete by walking than a single itinerary format, taking approximately 30 to 45 minutes to complete each act. It also provided greater clarity to the themes addressed in the game, focusing users’ attention to the subjects in each challenge.

The overall difficulty of the quests was considered average. Quests that required taking a photo mimicking an early 20th century picture were considered quite challenging to solve, as the city has heavily changed. GPS signal worked fine for “Find a Spot” activities as expected, since downtown Rio is well covered by mobile phone networks. However, our researchers experienced some difficulties with the full text questions, most of them being related to the correction system of the application. Scores helped motivating them to complete challenges, in spite of it not being the main focus of the experience.

We observed that the users experienced increased attention to aspects of the city, like buildings, street signs and landmarks. This was achieved due to the game format which helps create a detachment from the daily use of urban space (Huizinga, 1938/2007). Based on the photos and chronicles depicted in the game, users should be able to reflect on the transformations that took place, its influence on the present-day city and the processes behind them.

7 Discussion

The research experiments with digital devices as auxiliary instruments in navigating the historical layers of the city. Mobile phones are already widely used for spatial navigation, reconfiguring our perception of the city and its territoriality (Souza e Silva, 2013). We propose its use to navigate in time; anchoring in present space to perceive its symbolic layers and the physical

remains of historical processes, raising awareness about the changes that take place in the city and how they affect its inhabitants.

The decision of using a game to convey this subject was to create a detachment from the daily use of urban space (Huizinga, 2007). The project therefore also discusses games as media in the context of urban heritage, that is, how game design - its materiality and its rules - can create engagement that equally fosters interest in historical knowledge and raises heritage awareness.

The use of Actionbound provided an efficient way to build a prototype and test some of our ideas. Apart from some improvements to Actionbound itself, such as a better text interpreter to correct full text answers, it would be interesting to develop our own version with other layout options and research the possibilities of image recognition for pictures and visualization of 3D objects in Augmented Reality, for example.

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References

Abreu, M. de. (1987). *A Evolução Urbana do Rio de Janeiro*. Iplanrio; Zahar.

Actionbound. (2012). *Actionbound* [Website]. Actionbound. Retrieved from http://actionbound.com/

Budzinski, M., & Isermann, H. (2007). WHAVSM? A pervasive role-playing game. Em F. von Borries, S. P. Walz, & M. Böttger (Orgs.), *Space time play computer games, architecture and urbanism: The next level* (p. 286–287). Birkhauser.

Ejsing-Duun, S. (2011). *Location-based games: From screen to street* [Doctoral dissertation, The Danish School of Education, Aarhus University]. https://vbn.aau.dk/en/publications/location-based-games-from-screen-to-street

el-Dahdah, F., & Metcalf, A. C. (2016). *ImagineRio*. ImagineRio. Retrieved from http://imaginerio.org/

Huizinga, J. (2007). *Homo ludens: O jogo como elemento da cultura* (ed. 5). Perspectiva. Originally published in 1938.

Kessel, C. (2008). *Tesouros do Morro do Castelo: Mistério e história nos subterrâneos do Rio de Janeiro*. Rio de Janeiro: Zahar.

Lange, M. de. (2009). From always-on to always-there: Locative media as playful technologies. Em A. de S. e Silva & D. M. Sutko (Orgs.), *Digital Cityscapes: Merging Digital and Urban Playspaces* (First printing edition, p. 55–70). Peter Lang International Academic Publishers.

Lemos, A. (2010). Jogos móveis locativos: Cibercultura, espaço urbano e mídia locativa. *Revista USP*, 86, 54–65. https://doi.org/10.11606/issn.2316-9036.v0i86p54-65

Leorke, D., & Wood, C. (2019). 'Alternative Ways of Being': Reimagining Locative Media Materiality through Speculative Fiction and Design. *Media Theory*, 3(2), 63–102.

Lima Barreto, A. H. de. (1997). *O Subterrâneo do Morro do Castelo.* Dantes. Originally published in newspapers in 1905.

Paixão, C. M. Q. (2008) *O Rio de Janeiro e o morro do Castelo: populares, estratégias de vida e hierarquias sociais (1904-1922).* [Master's Thesis, Instituto de Ciências Humanas e Filosofia, Universidade Federal Fluminense]. https://www.historia.uff.br/stricto/teses/Dissert-2008_PAIXAO_Claudia_Miriam_Quelhas-S.pdf

Sisson, R. E. F. (2008) *Espaço e Poder: os três centros do Rio de Janeiro e a chegada da Corte Portuguesa*. Rio de Janeiro: Arco

Souza e Silva, A. de. (2013). Location-aware mobile technologies: Historical, social and spatial approaches. *Mobile Media & Communication*, 1(1), 116–121. https://doi.org/10.1177/2050157912459492

Thomas, B., Piekarski, W., & Gunther, B. (1999). Using Augmented Reality to Visualise Architecture Designs in an Outdoor Enviroment. *International Journal of Design Computing*, 2.

Klimas, C. (2009) *Twine / An open-source tool for telling interactive, nonlinear stories*. ([s.d.]). Retrieved from http://twinery.org/

Vilas Boas, N. B. (2007). *A Esplanada do Castelo: Fragmentos de uma História Urbana* [Doctoral dissertation, Faculdade de Arquitetura e Urbanismo, Universidade Federal do Rio de Janeiro]. http://www.dominiopublico.gov.br/pesquisa/DetalheObraForm.do?select_action=&co_obra=128595

WAAG SOCIETY. (2005). *Frequency 1550*. Locative game.

Zeffiro, A. (2012). A location of one's own: A genealogy of locative media. Convergence: *The International Journal of Research into New Media Technologies*, 18(3), 249–266. https://doi.org/10.1177/1354856512441148

Mapping of cultural heritage: the Palacete Bento Carlos, São Carlos - SP.

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Abstract. Documenting a historical heritage is always a complex process, especially in terms of data acquisition. However, the new technologies, in particular the scanning techniques with laser scanner and photogrammetry, allow a fast data acquisition. This research aims to carry out a scientifically based documentation of the Palacete Bento Carlos (1890), an example of the eclectic architecture of the interior of São Paulo, by applying a heritage documentation protocol as a way of standardizing the process and 3D mapping results, allowing access to information by different audiences.

Keywords: Photogrammetry, Laser Scanner; Protocol; Digital heritage; Cloud Point.

1 Introdução

Esta pesquisa integra as atividades do grupo de pesquisa N.ELAC do Instituto de Arquitetura e Urbanismo (IAU USP) que atualmente desenvolve pesquisas voltadas para o mapeamento digital 3D com objetivo de documentação e disseminação do patrimônio cultural.

Esta pesquisa insere-se nas atividades do Acordo de Cooperação Internacional entre o Instituto de Arquitetura e Urbanismo (IAU USP) e a Sapienza Università di Roma, no qual, as pesquisas em andamento tratam dos edifícios ecléticos de São Carlos, desde 2020.

Esta pesquisa tem por objetivo realizar uma documentação com base científica do Palacete Bento Carlos (1890), um exemplo da arquitetura eclética do interior paulista, por meio da aplicação de um protocolo de documentação patrimonial, como um modo de padronização do processo e resultados do

mapeamento digital de patrimônio históricos, permitindo o acesso às informações por diferentes públicos.

Documentar um patrimônio histórico é sempre um processo complexo, principalmente no levantamento de dados, que deve ser eficiente e completo. Tem-se tecnologias de levantamento direto, como o uso de estação total para medições in loco as quais possuem limitações. Outra alternativa que surgiu nos últimos anos, são as técnicas de levantamento indireto, como a fotogrametria de curta distância, aérea e o laser scanner que apresentam diversas vantagens para a documentação patrimonial. (Bastian, 2015).

1.1 Expansão Urbana de São Carlos

A cidade de São Carlos obteve avanços significativos ao longo do século XIX proveniente do plantio do café iniciado por volta da década de 1838/1840 e cultivado primeiramente na grande fazenda do Pinhal, alcançando um alto desenvolvimento da economia e o mais alto posto administrativo do império, foi elevado de vila para cidade em 1886.

Segundo Bortolucci (1991), em 1866 a Câmara aprovou a denominação das primeiras ruas, entre elas a Avenida São Carlos, que desde o princípio recebeu um destaque no processo de expansão urbana, pelas atividades instaladas e por seus moradores.

Os diversos investimentos provenientes do café trouxeram, em 1884, a ferrovia para a cidade de São Carlos pelo fazendeiro Antônio Carlos de Arruda Botelho, o Conde do Pinhal. A chegada da estrada de ferro deu origem a diversos bairros operários e de ex-escravos que se instalaram ao redor da estação ferroviária. A ocupação do território ao redor da estação conformou uma concentração de funcionários e do comércio na região, enquanto as classes mais abastadas se consolidaram na região central da cidade, próximo a catedral e as praças cercadas, como era de costume na época.

A instalação da ferrovia também acarretou em um significativo aumento da população, com a chegada de imigrantes alemães, em um primeiro momento. (Benincasa, 2008).

Desse modo, os primeiros imigrantes italianos chegaram à cidade em 1886. Logo depois, na primeira década do século XX, a cidade se tornou um dos pólos de destinos de imigrantes instigados pelo avanço ferroviário e pela oportunidade de trabalho nas lavouras de café ou nos comércios e, posteriormente, nas indústrias.

Esses imigrantes ao chegarem nas cidades não se depararam com uma sociedade paulistana urbana consolidada. Os modelos latifundiários não davam motivos para o investimento no comércio e na indústria, que ao

contrário de suas fazendas eram negócios incertos e arriscados. Dessa maneira, os imigrantes que se instalavam na cidade não enfrentavam grandes resistências de uma população urbana com habilidade técnica para a construção de um negócio.

O rápido processo de urbanização de São Carlos, atraiu muitos dos arquitetos e engenheiros imigrantes que chegavam no país, revelando o desejo da elite local em se parecer com a grande capital, em suas residências e edifícios públicos (Bortolucci 1991; Truzzi, 1986).

Um grande exemplo de engenheiro-arquiteto imigrante é David Pietro Cassinelli (1854 - 1898). O construtor chegou ao Brasil em 1882 e veio para a cidade de São Carlos com o trabalho de construir a Sede da Fazenda Santa Maria. Suas construções demonstram as influências do neoclassicismo, possibilitada na região por meio da chegada de materiais pela ferrovia e pelo capital da cafeicultura. Cassinelli foi responsável por diversas obras da região como o Palacete Bento Carlos e o Palacete Conde do Pinhal, ambos construídos no final do século XIX (Bortolucci, 1987).

1.1 O Palacete Bento Carlos

Um dos mais luxuosos palacetes ecléticos do século XIX, de tendência neoclássica, localizado em uma das praças mais importantes da época, o pátio da Matriz da cidade. O palacete foi construído na década de 1890 por Bento Carlos de Arruda Botelho (1841-1896), irmão mais novo do Conde do Pinhal, fazendeiro e político de destaque na região. (Pró-memória, 2013).

Em meados do século XX o prédio abrigou a Biblioteca Municipal, o Museu de São Carlos e o posto do Instituto Nacional de Previdência Social (INPS). Após alguns anos fechado, em 2005 foi concluído o restauro integral do imóvel, que é patrimônio cultural do Estado de São Paulo. (Pró-memória, 2013).

A antiga residência de Bento Carlos de Arruda Botelho é um exemplo da arquitetura eclética na cidade de São Carlos. Um dos grandes edifícios construídos ao redor da atual praça. O edifício conserva muito de suas características atuais, com exceção dos vitrôs do térreo. (Bortolucci, 1987).

Trata-se de uma construção de influências neoclássicas, como por exemplo o uso dos arcos das janelas da porta principal, no pavimento térreo, pelo frontão grego inserido na platibanda e nos ornamentos das janelas do pavimento superior. (Bortolucci, 1987).

Figura 1. Fachada do Palacete Bento Carlos. Fonte: Autores, 2022.

2 Metodologia

A pesquisa é pautada em uma metodologia híbrida: método histórico, no qual foi feito uma leitura sobre a história do edifício e de sua importância para a cidade desde o momento de construção e método experimental, no qual é realizado a aquisição de dados para a elaboração de modelos gráficos 2D e 3D (Groat & Wang, 2013). A pesquisa seguiu um protocolo para a documentação da fachada do edifício dividida em: pesquisa histórica do edifício; elaboração do eidotipo; aquisição de dados massivos e elaboração de desenhos geométricos e arquitetônicos da fachada e de detalhes do arco da entrada principal.

1.1 Eidotipo

Para compreensão do processo de documentação do patrimônio cultural, é fundamental que haja um entendimento dos termos e conceitos envolvidos neste desenvolvimento. Nesse sentido, um termo comumente utilizado é a palavra “Eidotipo”, cujo sinônimo não é encontrado na língua portuguesa, tendo estes pesquisadores, adotado o termo usado nas referências internacionais.

Eidotipo é proveniente da palavra grega *eidos*, que significa aspecto/forma. Segundo Kuhl (2019), o eidotipo é uma representação a mão livre do real, considerando as proporções e características formais do objeto de estudo. Para o início do levantamento, portanto, realizou-se um eidotipo da fachada (figura 2) e das plantas do palacete Bento Carlos. Para a fachada, o objetivo do desenho de levantamento foi entender as proporções entre as alturas e principalmente dos ornamentos que compõem sua fachada. O eidotipo das plantas foi utilizado para o planejamento do levantamento com o laser scanner,

prevendo os pontos de escaneamento e a sobreposição entre eles. Na prática, em posse da planta do edifício e da fachada, definiu-se 6 pontos de scans, considerando o seu raio de alcance de 6 metros , e uma sequência de escaneamento de modo em que a configuração das posições mantenham o laser scanner em um ponto onde tanto a localização anterior quanto a seguinte, estarão visíveis, garantindo a sobreposição das nuvens de pontos.

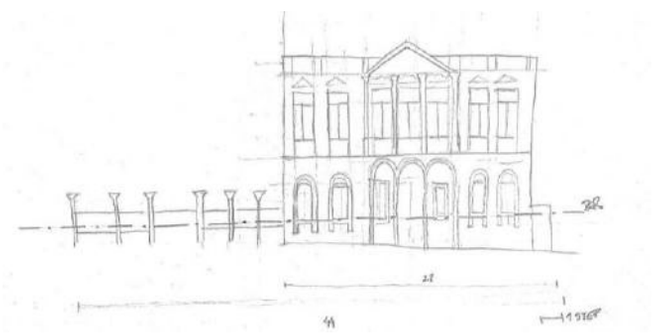

Figura 2. Eidotipo da fachada do Palacete Bento Carlos. Fonte: Autores, 2022

1.2 Aquisição de dados massivos

A grande evolução da fotogrametria se deu nos últimos 10 anos com a criação do método SfM (Structure from Motion ou também chamada de DSM, Dense Stereo Matching ou Dense Surface Modeling). A técnica se baseia na utilização de duas fotos do mesmo objeto. Possuem centros de perspectivas diferentes, de modo que os eixos ópticos sejam paralelos entre si. Neste método os pontos do objeto são determinados por meio da identificação de dois ou mais pontos homólogos nas áreas de sobreposição das imagens, considerando a convenção de no mínimo 60% de sobreposição na horizontal e 30% de sobreposição na vertical. (Tolentino, 2017) (Amorim e Groetelaars, 2004).

Segundo a definição de Shults (2017), dentro do campo da fotogrametria tem-se a de curta distância ou fotogrametria terrestre e a fotogrametria aérea. A primeira é a mais difundida na documentação patrimonial pela praticidade do equipamento, por modelos com alto nível de resolução e por seu baixo custo. A fotogrametria aérea com a utilização de RPAS (Remotely Piloted Aircraft Systems), ou convencionalmente denominados drones que permite fotografar em locais inacessíveis com segurança sem perda de qualidade das imagens obtidas. (Adami, Achille, Chiarini, Cremosi, Fassi, Fregonese e Taffurelli, 2015) (Campos, Cattani, da Silva, 2020).

Vale ressaltar que a fotogrametria aérea utilizando RPAS necessita de um eficiente plano de voo. O planejamento do ponto inicial e final de voo, altura e

sobreposição de imagens pode ser realizado manualmente ou por softwares de planejamento. Um dos softwares mais utilizados em missões é o Pix4D, que possibilita diversos tipos de levantamentos automatizados e configurações de sobreposição de acordo com o objetivo de cada usuário. (Gandor, F., Rehak, M., & Skaloud, J. 2015).

Outra técnica de levantamento indireto para documentação patrimonial é o 3D laser scanner. O equipamento permite a aquisição de muita informação com uma alta precisão dos dados em um curto espaço de tempo. (Remondino, 2006). Uma das muitas classificações de laser scanner é quanto à sua portabilidade, sendo classificado em dinâmico, quando o instrumento é móvel, ou estático quando não possui essa mobilidade, sendo este último dividido em curto alcance e longo alcance, usualmente utilizado para arquitetura.

O laser scanner trabalha com um laser que tem como origem o centro do instrumento e que atinge a superfície do objeto alvo, como a fachada de um edifício. A varredura do edifício é feita por meio de múltiplos *scans*, isto é, diversas estações de escaneamento para o levantamento de todo o objeto de estudo, que são unidos no *software* Autodesk Recap Pro. Como resultado tem-se uma composição de diversos pontos numéricos (nuvem de pontos) que possui informações quanto à aparência e cor dos elementos. Em suma, suas vantagens são superfícies extensas e complexas com alta precisão e em pouco tempo e aquisição de de cor e geometria que podem ser utilizados para desenhos e construção de modelos 3D. (Bianchini, Inglese, Ippolito, 2016) (Groetelaars, 2015)

Para a aquisição de dados da fachada do palacete realizou-se, primeiramente, um levantamento com o laser scanner FARO Focus M 70, com peso aproximado de 4,2Kg e precisão de 3mm. O processo de levantamento foi baseado no plano de disposição dos pontos e sequência de escaneamentos. Após a execução, obteve-se 6 scans da fachada, realizados em um tempo médio de 7 minutos por scan. A varredura foi facilitada devido a ausência de fluxo de veículos intenso e de fiação elétrica na frente da fachada permitindo uma aquisição de dados completa.

Realizou-se posteriormente o outro levantamento fotogramétrico foi feito, utilizando uma Câmera NIKON D500, capturando um total de 133 fotos com configurações ISO 100 e *Shutter speed* 1/1000, para o levantamento de detalhes da fachada a fim de integrá-las ao modelo gerado pelo laser scanner.

1.3 Elaboração de produtos gráficos

Com a aquisição dos dados, as diferentes nuvens de pontos obtidas a partir da varredura com o laser scanner foram unidas utilizando o software Autodesk Recap, que além de possibilitar a rápida edição de nuvem de pontos, permite

a visualização de outras informações adquiridas pelo laser scanner, como a cor RGB capturada do objeto e RGB de refletância dos materiais que constituem o objeto escaneado.

Como pode ser visto na figura 3, a nuvem de pontos da fachada foi gerada no Agisoft Metashape, com intuito de comparar com a nuvem de pontos geradas pelo laser scanner. Para a comparação adicionou-se anotações dos pontos de interesse na fachada (figura 4), para a referenciação no modelo fotogramétrico para a verificação da precisão dos modelos elaborados pelas duas técnicas. Foi gerado também nuvem de pontos de elementos da fachada como o arco da entrada principal do edifício, apresentando mais informações sobre os ornamentos, sua materialidade e estado de conservação atual.

Figura 3. Nuvem de pontos gerada por meio da fotogrametria da fachada do Palacete Bento Carlos. Fonte: Autores, 2022.

Figura 4. Nuvem de pontos gerada por meio do levantamento com laser scanner da fachada do Palacete Bento Carlos. Fonte: Autores, 2022

As nuvens de pontos foram utilizadas como base para a elaboração do desenho geométrico. Segundo Ching (2010), este tipo de desenho é uma representação simplificada, que pode ser descrita como projeções de um objeto tridimensional em uma superfície plana, de modo a ter suas proporções e relações reproduzidas. O desenho geométrico, segundo Bianchini, Inglese e Ippolito (2016), é de grande utilidade no estudo do volume e proporções na

compreensão da posição recíproca e das relações entre os elementos da composição arquitetônica.

A nuvem de pontos construída a partir da união dos levantamentos do laser scanner no software Recap Pro, foi exportada para o Autodesk AutoCAD e alinhada nos planos por meio do comando UCS, para a elaboração do desenho geométrico da elevação do edifício, tendo em vista a alta precisão das medidas do objeto que o scanner é capaz de extrair. A nuvem de pontos criada a partir do processo de fotogrametria, foram utilizadas para o desenho de detalhes da fachada, como o arco da entrada principal do edifício, pois a fotogrametria, além de adquirir informações de cores do objeto mais confiáveis do que o laser scanner, o ruído das nuvens de pontos é reduzido tendo em vista a área menor do objeto alvo.

Sempre deve-se considerar o ruído gerado pelas nuvens de pontos além do objeto alvo do mapeamento e que embora haja métodos automatizados de limpeza da nuvem de pontos, é necessário a limpeza manual e seleção dos dados segundo o objetivo do levantamento.

A fotogrametria permitiu também a construção de modelos mesh da fachada e dos detalhes dos ornamentos do edifício, adicionando novas informações acerca das cores reais dos elementos que compõem a fachada do palacete.

Desenvolveu-se um quadro comparativo em relação aos equipamentos utilizados e suas respectivas características e as configurações ideais de processamento para a realização do levantamento.

Quadro 1. Relação dos equipamentos utilizados nesta pesquisa para o mapeamento 3D do edifício e as suas respectivas características e custos médios.

Recurso	Características	Custo médio
Máquina Fotográfica	Nikon D500 12.9 megapixels	R$ 10.000,00
Laser Scanner	Laser Scanner FARO Focus M 70, com precisão de 3mm e Tripé de fibra de carbono	R$ 127.710,00
Drone	Mavic 2 Pro, DJI com câmera Hasselblad L1D-20c, distância focal 28mm	R$ 20.000,00
Software Recap Pro	8GB de RAM, CPU com 2,0 GHz, GPU com 1GB de memória de vídeo	R$ 1.489,00/ano
Software Metashape	Configuração Básica: Até 32GB de RAM. Processador Intel ou AMD com 4 ou 8 núcleos 2,0+ GHz. GPU com mais de 700 núcleos CUDA	R$ 399,00
Software Pix4D	Compatível com qualquer smartphone	Gratuito

AutoCAD	Processador entre 2,5 e 2,9 GHz, 8Gb de RAM	R$ 8.037,00/ano
Computador utilizado	Ideapad S145. 8GB de RAM. CPU Intel i7 8565U *quad-core*. GPU MX110.	R$ 3.600,00
Computador Ideal	Workstation com 64GB de RAM, GPU Nvidia Quadro P2000	R$ 17.000,00

Fonte. Autores, 2022.

3 Resultados

A pesquisa apresentada obteve como resultados, além da sistematização dos dados históricos sobre o edifício, a análise do contexto urbano no qual se insere, incluindo documentos textuais, cartografias da evolução urbana do município e a elaboração de desenhos científicos e modelos digitais.

O modelo mesh (figura 5), possível tanto pelo modo de levantamento com laser scanner ou por fotogrametria, permite a visualização do objeto com suas texturas e detalhes.

Figura 5. Mesh da fachada do Palacete Bento Carlos. Fonte: Autores, 2022.

Outro produto proveniente deste processo, consiste nos desenhos geométricos e arquitetônicos elaborados a partir dos dados extraídos da nuvem de pontos e das ortofotos. Estas representações bidimensionais são muito utilizadas nos projetos de restauro pois, como pode ser visto na figura 6 e 7, trata-se de um desenho chamado científico, um tipo de as built da realidade.

Figura 6.a. Desenho geométrico da fachada do Palacete Bento Carlos. **Figura 6.b.** Desenho geométrico do arco que compõe a porta de entrada do Palacete Bento Carlos. Fonte: Autores, 2022.

Figura 7. Desenho arquitetônico da fachada do palacete Bento Carlo, São Carlos - SP. Fonte: Autores, 2022.

4 Discussão

As peças gráficas elaboradas a partir da metodologia aplicada servem de base para outras áreas, entre elas a do Restauro. Profissionais da área podem consultar informações de medidas e propor intervenções a partir de um arquivo CAD, facilitando a utilização do levantamento pelos profissionais.

É evidenciado nesta pesquisa a necessidade de consolidação dos métodos e procedimentos do processo de documentação por meio do mapeamento digital com novas tecnologias, utilizando as nuvens de pontos como ferramenta para atingir objetivo de um mapeamento digital.

O objetivo deve ser estabelecido anteriormente, pois orientará todas as etapas do protocolo. O levantamento, a elaboração de desenhos científicos e a análise de dados devem ser guiados pelo objetivo do mapeamento digital. Esse objetivo determinará a aplicação final dos resultados, seja para a conservação e o restauro do patrimônio, seja para a divulgação da história da cidade e do edifício em museus, ou disponibilizados em sites como materiais de educação patrimonial, servindo assim a diferentes usos e públicos de acordo com o objetivo estabelecido.

O protocolo adotado nesta pesquisa possibilita a padronização do processo e dos resultados do mapeamento digital 3D. Partindo do contexto histórico do edifício, compreendendo o entorno do objeto e seus impactos nele, para então pesquisar sua lógica e características formais e depois realizar a aquisição de dados para o mapeamento digital, resultando em modelos mesh e desenhos geométricos e arquitetônicos, como desenhos científicos. Desta maneira, a aplicação do protocolo possibilita entender todas as diferentes camadas de informação que o patrimônio possui.

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Referências

Achille, C.; Adami, A.; Chiarini, S.; Cremonesi, S.; Fassi, F.; Fregonese, L.; Taffurelli, L. (2015). UAV-Based Photogrammetry and Integrated Technologies for Architectural Applications—Methodological Strategies for the After-Quake Survey of Vertical Structures in Mantua (Italy). Sensors 2015, 15, 15520-15539. https://doi.org/10.3390/s150715520.

Bastian, A. V. (2016). Fotogrametria esférica: uma técnica de baixo custo para documentação arquitetônica. In: SIGRADI, 2016, Florianópolis. Proceedings of SIGRADI 2016, 2016.

Benincasa, V. (2008). Fazendas paulistas: arquitetura rural no ciclo cafeeiro. Tese (Doutorado em Teoria e História da Arquitetura e do Urbanismo) - Escola de Engenharia de São Carlos, Universidade de São Paulo, São Carlos.

Bianchini, C.; Inglese, C.; Ippolito, A. (2016). I Teatri Antiche del Mediterraneo come esperienza di rilevamento integrato. Roma: Sapienza Università Editrice, 2016.

Bortolucci, M. A. P. C. S. (1991). Moradias urbanas construídas em São Carlos no período cafeeiro. Dissertação (Doutorado em Arquitetura e Urbanismo) - Faculdade de Arquitetura e Urbanismo da Universidade de São Paulo, São Paulo.

Bortolucci, M. A. P. C. S. (1987). O ecletismo em São Carlos. Jornal a Notícia, São Carlos, 20-26 nov. 26-03 dez. 04-10 dez. 11-17 dez.

Campos, S. B. C., Cattani, A., da Silva, F. (2020). Geração de conteúdo em realidade aumentada com o uso de drones na digitalização 3D por fotogrametria, caso da igreja do desterro em São Luís Maranhão. In Nunez, Gustavo Javier Zani; Oliveira, Geísa Gaiger de (Orgs.). Design em pesquisa: vol 3. Porto Alegre : Marcavisual, 2020. p. 534-545.

Ching, F. D. K. (2010) Dicionário visual de arquitetura. Tradução: Julio Fischer. 2. ed. São Paulo: Martins Fontes.

Fundação PRÓ-MEMÓRIA (2013). Exposição A presença italiana em São Carlos. São Paulo.. Disponível em: https://www.promemoria.saocarlos.sp.gov.br/index.php?option=com_content&view=article&id=169&Itemid=181

Gandor, F., Rehak, M., & Skaloud, J. (2015). Photogrammetric mission planner for RPAS. InInternational Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRSArchives (Vol. 40, pp. 61–65). International Society for Photogrammetry and Remote Sensing. Disponível em:https://doi.org/10.5194/isprsarchives-XL-1-W4-61-2015

Groat, L., Wang, D. (2013). Architectural research methods. 2 edition. Published by John Wiley & Sons, Inc., Hoboken, New Jersey Published simultaneously in Canada.

Groetelaars, N. J.; Amorim, A. L. (2004). Técnicas de restituição fotogramétricas digitais aplicadas à Arquitetura: um estudo de caso. In: COBRAC - CONGRESSO BRASILEIRO DE CADASTRO TÉCNICO MULTIFINALITÁRIO, 6., 2004, Florianópolis. Anais eletrônicos... Florianópolis: UFSC, 2004. CD-ROM. p. 1-12.

Groetelaars, N. J. (2015). Criação de modelos BIM a partir de “nuvem de pontos”: estudo de métodos e técnicas para documentação arquitetônica. 372 f. Dissertação (Doutorado em Arquitetura e Urbanismo) - Faculdade de Arquitetura da Universidade Federal da Bahia, Salvador, 2015. Disponível em: https://repositorio.ufba.br/bitstream/ri/20220/1/T_Natalie%20Groetelaars.pdf.

Kühl, B. M., Salvo, S. (2019). Levantamento Arquitetônico: experiência didática integrada na FAUUSP. Pós. Revista do Programa de Pós-Graduação em Arquitetura e Urbanismo da FAUUSP, v. 26, n. 48, p. e151042-e151042.

Remondino, F., Voltolini, F., Pontin, M., Girardi, S., Rizzi, A., Gonzo, L. (2006). Integrazione di fotogrammetria e laser scanner per la documentazione di beni culturali. In ASITA (Ed.) 10o Conferenza Nazionale Asita.

Shults, R. (2017). New opportunities of low-cost photogrammetry for culture heritage preservation, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLII-5/W1, p. 481-486, https://doi.org/10.5194/isprs-archives-XLII-5-W1-481-2017.

Truzzi, O. (1986). Café e indústria: São Carlos 1850 - 1950. São Carlos: Arquivo de história contemporânea: UFSCar.

Tolentino, M., Groetelaars, N. J. (2017). Levantamento da igreja de Nossa Senhora da Conceição do Boqueirão através das técnicas fotogrametria digital (stricto senso) e dense stereo matching (DSM). Simpósio científico 2017 - icomos brasil.

In the ACAIACA-Verse. Geometric Digitization, Cyberculture, Heritage and Musealization

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Abstract. This work first presents the Acaiaca building, recognizing its iconicity in the city of Belo Horizonte, and discussing aspects of patrimonialization. The building has two sculptures of indigenous faces on its facade, which contribute to the symbolic establishment in the city. Taking advantage of this characteristic of this element of cultural heritage, the research explores, from the photogrammetric digitization of the indigenous face, derivations or cultural products such as resources in mixed realities (augmented and virtual), three-dimensional printing and metal casting, graphic productions. The objective is to show ways for the penetration of representations of our culture in the increasingly digital daily life, illuminating processes that strengthens relationships between the physical world and cyberspace. Thus, the object contributes to museum cyberculture by providing resources for the digital musealization of cultural goods.

Keywords: Digital Heritage, Cyberculture, Structure from Motion, Musealization, Media Art

1 Introdução

As relações entre tecnologias digitais apresentam-se no campo da cultura contemporânea e do Patrimônio Cultural sob diversas formas e efeitos. No campo da cultura – ou, mais especificamente, da cibercultura (Lévy, 1997) –,

ainda não há fronteiras claras ou um universo totalitário, mas sim um campo que pouco se limita a funções computacionais, *gadgets*, mundos em 3D. Entendendo esse contexto, Laymert Garcia (2003) sugere um olhar estruturado para o campo, prevendo políticas e ações específicas. Merece destaque o fato de a Lei Nacional de Incentivo à Cultura (Lei nº 8.313, de 23 de dezembro de 1991) operar sob uma Instrução Normativa que traz os campos *Artes Digital, Eletrônica, Cibernética Games, e Apps culturais* como meios de manifestação de projetos culturais.

No campo do Patrimônio Cultural, as tecnologias digitais estão presentes em diversos momentos, desde os trabalhos de cadastramento e restauração dos bens até a apresentação desses bens em museus e sítios históricos, muitas vezes recriando-os e fazendo-os "presentes" pela realidade aumentada. Neste artigo, o aspecto que gostaríamos de abordar, no entanto, não é o material do bem, mas a imaterialidade que o circunda, os valores que fazem os bens serem considerados patrimônio de uma comunidade, e como a digitalização pode ser eficiente na criação de outras materialidades que não as do bem em si, mas que são importantes para a função social exercida por ele.

A história da patrimonialização de bens culturais nos mostra que eles se tornaram quase fetiches, presos na sua materialidade, elementos embalsamados para remeter a um passado como curiosidades aprisionadas em museus-acervos. Essa concepção de bem patrimonial distanciou os bens patrimoniais de sua razão de existir: sua função social de criar referências às comunidades a que servem, de gerar identidade e orientação, bem como senso de pertencimento.

Quanto mais o bem patrimonial se integrar à vida cotidiana, melhor exercerá seu papel de semióforo − termo cunhado por Krzyystof Pomian (1987) que pode ser entendido como "objetos visíveis investidos de significação", fortemente marcados tanto pela sua presença quanto pelo seu significado. O semióforo exerce poder não apenas a partir de seu objeto original (o bem em si), mas das reproduções que dele se fazem e que facilitam a reprodução de seu significado. Os *souvenirs* (como as miniaturas da Torre Eiffel) não seriam, portanto, lembranças frívolas de momentos pessoais, mas a divulgação de símbolos de identidade, portadores de significados individuais e coletivos.

Sendo o bem cultural um semióforo, ele cria uma dialética própria entre materialidade e imaterialidade que marcam o seu trato, com todos os paradoxos decorrentes dessa sua nova natureza revelados por uma série de práticas que passam, então, a se associarem ao bem – desde técnicas especiais para sua conservação (com suas diferentes especialidades em função da natureza física do bem) até aquelas associadas à proteção jurídica desse tipo de bem (Carsalade, 2015).

A reprodução e a divulgação do bem original parecem exercer uma tarefa de educação patrimonial, divulgando a sua importância e potência, tornando-o presente no cotidiano das pessoas. Os meios digitais, de ampla circulação na sociedade contemporânea, e até mesmo os desdobramentos materiais feitos a partir deles são importantes auxiliares nesse processo de educação

patrimonial. Apontamos, a seguir, dois fatos singelos para ilustrar ao que estamos aqui nos referindo.

Muitas vezes, a nossa própria sociedade não conhece os bens materiais tombados como seu patrimônio. Embora o processo de tombamento seja feito por conselhos nos quais a sociedade está representada, grande parte das vezes esses bens e essas proteções não chegam ao grande público, fragilizando sua presença. Em alguns casos, pela falta de identidade entre eles e uma parcela maior da população, eles são até mesmo rejeitados – como explicou um pichador da Igreja da Pampulha, que explicou seu vandalismo pelo não reconhecimento da Igreja como seu representante, mas sim de uma elite alheia à sua realidade. Falta divulgação, falta sensibilização social, faltam estratégias de incorporação dos bens patrimoniais ao grande público.

O segundo fato é também significativo. Em exposições e museus nos países de primeiro mundo, é comum que se façam miniaturas, canetas, blocos de notas, utensílios e outras peças de *design* que remetam ao museu ou à exposição. Além de sua função comercial, esses objetos ajudam a criar uma aura em relação a temas e referências que vão se incorporando ao imaginário coletivo e ensejam atitudes diferenciadas em relação aos bens culturais. Dar-se a conhecer e divulgar são duas estratégias fundamentais da educação patrimonial. Nesse contexto, Wen Xiao mostra as contribuições que as digitalizações geométricas podem desempenhar para o patrimônio cultural no âmbito dos objetivos de desenvolvimento sustentável da Organização das Nações Unidas – ONU (Xiao, 2018)

Em Belo Horizonte, como soa correr na tradição brasileira, tampouco há uma estratégia forte de reforçar a identidade fornecida pelos bens tombados para a população. Embora eles tenham uma função fática importante (como a Igreja da Pampulha) e sejam participantes da vida diária, a maioria deles não é apresentada como patrimônio coletivo, o que reduz seu significado e sua potência de semióforo. É o caso do Edifício Acaiaca, situado no ponto de maior circulação da capital mineira, bastante identificado pelos indígenas esculpidos em sua fachada. Embora seja uma das principais referências da cidade, ele é, surpreendemente, desconhecido e pouco associado à sua função patrimonial. Cabe entender um pouco os valores que se associam ao prédio e a estratégia possível da digitalização geométrica como auxiliar na educação patrimonial.

2 O Edifício Acaiaca

O Edifício Acaiaca é um ícone da Arquitetura *art déco* projetado por Luis Pinto Coelho e construído entre 1934 e 1947 (Guia do Bem, 2022). Seu projeto apresenta um rigor compositivo que o distingue como obra-prima, a começar pelo respeito ao lugar onde se instala: uma esquina em ângulo obtuso, tão característica da republicana Belo Horizonte. Essa situação faz a composição modular-se em três partes verticais, reservando os intervalos entre elas, nas

esquinas preciosas de Afonso Pena com Tamoios e Espírito Santo, para um trabalho de lapidação volumétrica de surpreendente e excepcional fatura (Miranda, 2017). A clássica tripartição em base, fuste e capitel com as quais a Arquitetura dialoga desde a invenção da coluna grega também se faz presente no Acaiaca de modo criativo e inusitado: a base é alta e propõe, com muita ênfase, a vida urbana, generosamente dedicando aos transeuntes interação entre prédio e rua e uma extensa marquise, linha delicada que corrige as proporções da base e costura as partes do edifício.

Quanto ao fuste, os volumes que faceiam as ruas exibem linhas horizontais retas e linhas verticais curvas, celebrando a sua imponente altura e criando ritmos ascendentes que se equilibram, evitando uma disputa de direções pelo habilidoso trabalho com as formas. Nas mudanças de direção, o volume vertical dos cantos reparte-se em três – divisão esta que não se contrapõe ao movimento ascendente, mas que cria um ritmo saboroso de percurso em direção ao céu. Na parte inferior, as carrancas indígenas, objetos deste estudo, marcam nossa identidade nacional – característica tão importante do *art déco* brasileiro – e geram uma empatia com o público, temperando a frieza da geometria tão abundante na selva de pedra. O intermédio cria a necessária pausa e a importante base para o lançamento das torres de vidro, menção ao futuro presente na parte superior, eternamente a se lançar ao espaço sideral. A sutil marcação do capitel sugere o tenso equilíbrio entre a continuidade infinita e o momento de se ater.

Figura 1. Edifício Acaiaca em Belo Horizonte, MG. Fonte: Leandro Magalhães, 2022.

O Edifício Acaiaca é um ícone da cidade de Belo Horizonte. Marca de pujança em um momento histórico de afirmação e explosão da metrópole, o multifuncional Acaiaca dialoga com a vida da cidade, seja diurna (com tanto comércio e serviço), seja noturna (com suas *boîtes* e o trabalho feérico de empresas notívagas). Nasceu no solo de uma antiga igreja e, até hoje, celebra essa sacralidade abrigando espaços de culto. Dialoga, também, com a temporalidade belo-horizontina, tendo sido universidade quando esta tinha o tamanho de uma cidade que crescia, e como arauto de novos tempos, no advento da televisão, com a TV Itacolomi ascendendo, como as torres de vidro, em direção ao futuro.

Ser ícone é ser imagem e ídolo. O Acaiaca traduz, em suas formas e presença, a cidade de Belo Horizonte e traz a seus moradores a segurança e o conforto da sólida eternidade de sua civilização.

3 Métodos

A característica de ícone belo-horizontino do Acaiaca, especificamente das faces indígenas em sua fachada, somada à sua volumetria de poucas reentrâncias e revestimento fosco, faz dele um elemento passível de captura digital para a exploração de formas de musealização de bens culturais (Maranda, 2009) no contexto digital.

A digitalização das faces indígenas do edifício Acaiaca ocorreu dentro do contexto de um projeto extensionista, mais amplo, que mirava a constituição de uma coleção de digitalizações geométricas de elementos em Belo Horizonte – tais como esculturas, bustos e outros marcos urbanos. O projeto original foi intitulado Monumento Digital 120, em comemoração ao centésimo vigésimo aniversário da cidade. Posteriormente, os avanços do projeto permitiram uma segunda versão, incorporando gestos de contornos museais – como curadoria, interface mais amigável e categorização sistemática do acervo. A viabilidade da segunda proposta, denominada Marcos Urbanos, ocorreu por meio da Lei de Incentivo à Cultura de Belo Horizonte (Magalhães, 2021). Este artigo explora derivações possíveis a partir do produto da digitalização. São experimentados recursos dentro do campo das realidades mistas (Milgram, 1994) de fabricação digital, levando à fundição em metais de réplicas reduzidas das faces, e demais produções gráficas estáticas ou em movimento.

3.1 Digitalização por Fotogrametria SfM

Apesar da busca pela execução dentro das recomendações inerentes ao método *Structure from Motion* - SfM (England, 2017), a digitalização de elementos na cidade impõe condicionantes imprevisíveis – como a luminosidade no momento das fotografias ou a presença de elementos em movimento ao redor do objeto, o que pode ser um empecilho para o algoritmo que gera a nuvem de pontos a partir da correspondência entre os mesmos pontos em fotos diferentes (Magalhães, 2017).

O equipamento disponível também foi determinante nos resultados obtidos. Uma câmera fotográfica não profissional, Canon Powershot SX520 HS, foi utilizada para a obtenção das fotografias. É um equipamento suficiente para a obtenção de bons resultados geométricos. No entanto, outros equipamentos – como um drone, ou mesmo um bastão para prolongar a distância entre a câmera e o objeto – permitiriam varreduras mais completas nos casos em que o objeto é muito alto ou está em local inacessível.

No caso do Acaiaca, a obtenção do acervo fotográfico posteriormente utilizado para a geração da nuvem de pontos ocorreu a partir do solo, distante cerca de 70 metros das faces indígenas. A distância foi compensada com utilização do recurso de *zoom* ótico da câmera (Figura 2).

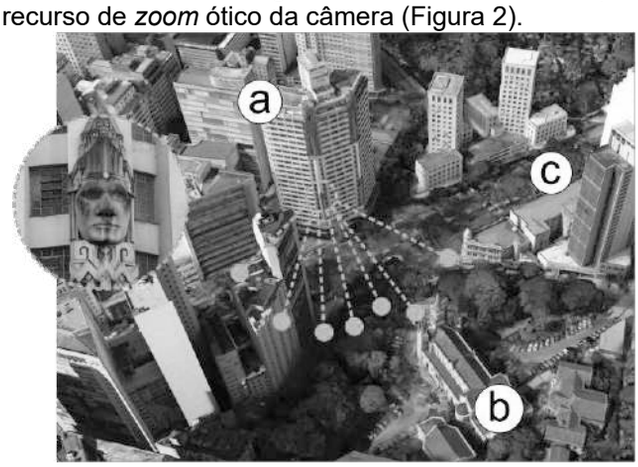

Figura 2. Mapa-chave: (a) Edifício Acaiaca; (b) Avenida Afonso Pena; (c) Igreja de São José. Circunferências tracejadas: face indígena no edifício, ampliação e posição, respectivamente. Linhas tracejadas: distâncias entre o objeto e o local de obtenção das fotografias. Circunferências preenchidas: regiões de onde foram obtidas fotografias. Fonte: montagem desenvolvida por Leandro Magalhães, sobre a base do Google Earth, 2022.

Como as faces de cerca de 7 metros de altura estão a aproximadamente 12 metros em relação ao nível da rua, na Avenida Afonso Pena, foi necessário percorrer mais de 100 metros para que fosse possível obter o conjunto de 112 fotografias. Apesar de não ter sido possível capturar imagens a partir de um ponto mais alto do que as próprias faces – o que poderia ser viabilizado por meio do uso de um drone –, pontos mais elevados no entorno (como o alto das escadarias da Igreja de São José) permitiram certa variabilidade altimétrica, fator positivo para o sucesso da digitalização geométrica. Conforme mencionado, o aspecto fosco e volumetria com pouca complexidade também favoreceram a obtenção de uma digitalização de qualidade suficiente para os experimentos propostos.

Do acervo fotográfico gerado, foram selecionadas 100 fotos – limite colocado pelo tipo de assinatura do *software* Autodesk Recap Pro.

O arquivo, gerado remotamente, apresentou-se conforme ilustrado pela Figura 3. Do arquivo original, foram exportados outros, nos formatos adequados para cada um dos produtos gerados. O software Tinkercad, da Autodesk, mostrou-se adequado para simplificações do modelo e geração dos arquivos para impressão 3D.

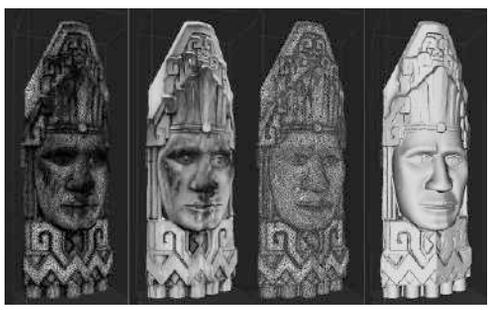

Figura 3. Visualizações do produto fotogramétrico. Fonte: Leandro Magalhães, 2022.

4 Resultados

São apresentados como resultados os produtos obtidos a partir do modelo geométrico digital da face indígena. Busca-se destacar as técnicas específicas para permitir sua apropriação em outros contextos de promoção de elementos da cultura, bem como fomentar discussões no campo.

4.1 Fundição

A técnica da joalheria chamada *fundição em cera perdida* é datada de aproximadamente 5500 AEC, quando a metalurgia do cobre teve início. A origem da técnica se dá quando é moldada a argila, imprimindo forma volumosa. Essa argila é queimada e, depois de endurecida, serve de molde (como um negativo) para que nele se deposite o metal líquido incandescente.

A técnica da fundição em cera perdida consiste em uma peça esculpida ou reproduzida em cera agrupada no que chamamos “árvore”, ou seja, um bastão central de cera (caule) ao qual se unem todas as peças, fixadas por meio de um gito (tronco). Essa “árvore” é colocada em um recipiente e envolta com gesso.

O gesso é endurecido e levado ao forno em alta temperatura. A cera derretida escorre para fora do gesso e tem-se um molde interno das peças. Atualmente, tem sido utilizada a fundição a vácuo, na qual a cera é também absorvida pelas paredes laterais do gesso. O metal líquido é injetado para dentro desse molde e o gesso é dissolvido em água – surgem as peças de metal.

O processo de fundição das réplicas reduzidas da face do Acaiaca foi um pouco diferente. A joia não precisou ser esculpida artesanal e manualmente em cera. A digitalização foi exportada e configurada no formato STL - *Standard Triangle Language* e, então, impressa em 3D com resina. Não há uma tradução manual, mas sim a própria representação do bem que está no edifício.

A partir desse molde impresso em resina, fez-se uma borracha que permite inúmeras repetições do processo para geração dos moldes em cera.

Figura 4. Processo para fundição em metais. O primeiro quadro exibe a impressão 3D em resina. Posteriormente, a árvore de cera. A terceira e a quarta imagens mostram a árvore após a injeção dos metais sendo uma liga simples e de baixo custo, denominada popularmente de moeda e prata respectivamente. Na linha inferior: a borracha, a peça fundida em prata antes do polimento, e, ao final, o par de peças limpas. Fonte: os autores, 2022.

Com a borracha, utilizamos uma máquina injetora de cera, em que uma cera específica para fundição de joias é inserida no molde. A partir dessa cera é feita a árvore de fundição. Por sua vez, com a árvore é gerado o molde de gesso, que, finalmente, é injetado com metal líquido.

4.2 Realidades mistas

A digitalização da face indígena do edifício Acaiaca foi primeiramente exportada como um modelo 3D para formatos pertinentes a dois fluxos de trabalho distintos: um arquivo em formato OBJ e outro em formato FBX. Em ambos os casos, optou-se por uma redução de polígonos – possibilidade oferecida pelo *software* de digitalização (Autodesk Recap Pro) antes da exportação. É importante destacar que os arquivos originais com altas resoluções são armazenados e, deles, exportados outros, simplificados, para diminuir o impacto nas capacidades de processamento do dispositivo que irá acessar a função de realidade aumentada ou virtual.

O arquivo OBJ foi submetido para uma plataforma privada e *online* denominada Sketchfab, que permite o armazenamento, a visualização, a manipulação e a comercialização de modelos 3D. A própria plataforma permite o ajuste de configurações com uma amplitude significativa de variáveis para

alterar os aspectos visuais do modelo submetido inclusive a configuração do recurso de realidade aumentada e realidade virtual.

O método para ajustes não requer escrever linhas de código, mas manipular uma interface gráfica simplificada. Isso encurta distâncias e permite criações de experiências no campo das realidades mistas por pessoas não especialistas. A própria equipe de um museu, ainda que pequena e com equipamentos escassos, poderia, por exemplo, engendrar em uma ação de digitalização e disponibilização de acervos.

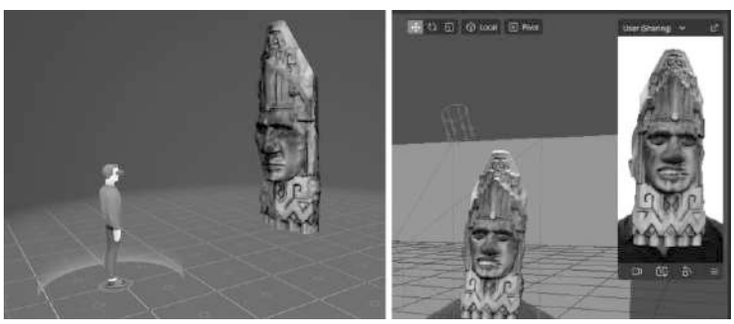

Figura5. Montagem com recortes de capturas de *softwares*. Primeiro a interface de configuração da visualização em realidade virtual na plataforma Sketchfab. A segunda imagem é um recorte da tela do *software* Spark AR Studio mostrando a aplicação de realidade aumentada. Fonte da montagem e imagens: os autores, 2022.

O *software* Spark AR Studio, por sua vez, foi utilizado na criação de um recurso de realidade aumentada que identifica a face do usuário e sobrepõe a ela o modelo 3D obtido na digitalização. O recurso encontra-se disponível para uso abertamente na internet e coloca um bem tombado dentro do contexto digital cotidiano. É possível a uma pessoa vestir-se com um bem cultural belo-horizontino e divulgar o resultado na sua rede.

4.3 Gráficos estáticos ou em movimento

O modelo 3D, quando utilizado em diferentes programas de computador, produz resultados estéticos variados. A Figura 6 demonstra resultados obtidos primeiramente da intercessão entre a malha 3D e múltiplos planos horizontais, paralelos, equidistantes e sobrepostos. O resultado é uma visualização topológica da face indígena. Já o segundo resultado é obtido da substituição da textura original do modelo 3D por um material reflexivo. Os dois últimos são quadros de uma animação na qual a face, fatiada, é partida e remontada.

Em um contexto de comunicação visual massiva, a digitalização e a disponibilização de acervos culturais para artistas podem permitir o surgimento de novas comunicações que, criativamente, promovem bens culturais em contextos digitais.

Assim, essas imagens podem servir simplesmente a funções estéticas, mas também podem compor materiais didáticos, infográficos e outras comunicações para museus ou para qualquer recurso educacional.

Figura 6. Montagem com produções gráficas a partir do modelo 3D. Fonte: Leandro Magalhães, 2022.

5 Discussão

Além das possibilidades exploradas neste trabalho, há outros processos digitais que também reforçam a iconicidade do Acaiaca. A Figura 7 ilustra o processo de digitalização CAD da face (Delaqua, 2016) até sua aplicação como tatuagem permanente.

Figura7. Montagem de uma etapa da produção e o desenho pronto do projeto Fachada Frontal. Por último, a mesma imagem tatuada na pele de um belo-horizontino. Fachada Frontal. Fonte: Os autores, 2022.

O universo das múltiplas representações da face do Acaiaca aqui é chamado de Acaiaca-verso. Talvez essa construção seja uma apropriação superficial dos conceitos que exploram a possibilidade da existência de múltiplos universos–iniciados na física com Erwin Schrödinger e atualizados por Stephen Hawking (2018). No entanto, o próprio termo multiverso parece ter sido assimilado em um contexto popular mais amplo, com a ação de agentes da cultura popular massiva – como estúdios de cinema que criam filmes sobre super-heróis e seus multiversos. Assim, a aplicação coloquial do sufixo "-verso", presente desde o título deste trabalho, vem exatamente como um

convite à ampla difusão e à participação dos elementos de nossa cultura no cotidiano popular, inclusive no contexto digital.

O conjunto de experimentos e de resultados obtidos aponta para uma vastidão de possibilidades: fundições para acessibilidade tátil; realidades mistas para experimentação corpórea; produções gráficas para material didático, para um pôster ou para uma camiseta. Mais do que isso, o trabalho revela a existência de uma série de ferramentas com pouca exigência de conhecimentos especializados para a geração de produtos altamente tecnológicos. Esse contexto conta com a simplificação tanto das técnicas de digitalização quanto da posterior manipulação dos resultados obtidos.

A emergência do ciberespaço – representado na atualidade pelo termo metaverso – depende desse tipo de ação que gera processos retroalimentados entre os mundos físico e digital. Contribui-se, assim, para o estabelecimento de uma cibercultura museal (Mello, 2018), na qual se exploram recursos da cibernética para a fruição de bens culturais e para a própria patrimonialização.

Referências

Autodesk (2022). *RecapPhoto Pro* (Versão 23.0.0.216) [Programa de computador]. https://www.autodesk.com/

Autodesk (2022b). Tinkercad [Programa de computador]. https://www.tinkercad.com/

Carsalade, F. *Bem*. In: Resende, M. B.; GRIECO, B.; Teixeira, L.; Thompson, A. (2014). *Dicionário IPHAN de Patrimônio Cultural*. Rio de Janeiro, Brasília: IPHAN/DAF/Copedoc. Em http://portal.iphan.gov.br/uploads/ckfinder/arquivos/Bem%20pdf.pdf

Delaqua, V. (2016, 25 de setembro). *Ilustrações feitas no AutoCAD*: Fachada Frontal. Arch Daily Brasil. Recuperado em 11 julho, 2022, de <https://www.archdaily.com.br/br/795929/ilustracoes-feitas-no-autocad-fachada-frontal> ISSN 0719-8906

England, H. (2017). *Photogram metric applications for cultural heritage*. Guidance for Good Practice. Swindon. Historic England.

Guia do bem – Edifício Acaiaca. Recuperado em setembro, 2022, de https://guiadobem.org/#12.

Hawking, S. W., & Hertog, T. (2018). *A smoothexitfrom eternal inflation? Journal of High Energy Physics*, *2018*(4), 1-14.

Politizar as novas tecnologias: impacto sócio-técnico da informação digital e genética, de Laymert Garcia dos Santos (2003). São Paulo: Editora 34, 319 p.

Lei Nº 8.313, de 23 de dezembro de 1991. (1991) Recuperado em 12 julho, 2022, em http://www.planalto.gov.br/ccivil_03/leis/L8313cons.htm

Lévy, P. (1997). *Cibercultura*. *São Paulo,* Editora 34.

Magalhães, L., Carvalho, J. (2017). *Digitalização Tridimensional de Elementos Escultóricos de Espaços Públicos de Belo Horizonte*. Anais do Encontro

Internacional Arquimemória 5 sobre Preservação do Patrimônio Edificado, Salvador.

Magalhães, L. dos S., & Souza, R. C. F. de. (2022). *Fotogrametria e catálogos digitais de esculturas e outros marcos urbanos*: recursos para cibercultura museal. [Versão eletrônica]. Gestão & Tecnologia de Projetos, 17(2), 113-126. https://doi.org/10.11606/gtp.v17i2.175164

Maranda, L. (2009). *Museology*: Back to the Basics. Musealization. *ICOFOM Study Series*, *38*, 251-258.

Mello, J. C. (2013). *Museus e ciberespaço*: novas linguagens da comunicação na era digital. *Cultura Histórica & Patrimônio*, *1*(2), 6-29.

Meta (2022). *Spark AR Studio* (Versão 141.0.0.21.233) [Programa de computador].

Milgram, P., & Kishino, F. (1994). *A taxonomyofmixed reality visual displays.* IEICE Transactions on Information and Systems, *77*(12), 1321-1329.

Miranda, A. R. (2017). Edifício Acaiaca, o colosso humano e concreto. Belo Horizonte.

Monumento Digital 120. Sketchfab**:** *Monumento Digital 120* [Internet]. Disponível em: <www.sketchfab.com/monumentodigital120>. Recuperado em 12 julho, 2022.

Pomian, K. (1987). *Collectionneurs, amateurs et curieux*. Paris, Venise, XVI-XVII siécle. Paris: Gallimard.

Secult (2022). *Instrução Normativa Secult/MTUR Nº 1*, de 4 de fevereiro de 2022. Recuperado em 12 julho, 2022.

Sketchfab (2022) [Programa de computador *online*]. Disponível em: <www.sketchfab.com >

Xiao, W., Mills, J. Guidi, G. Rodríguez-Gonzálvez, P., Gonizzi, S., Barsanti, González-Aguilera, D. *Geoinformatics for the conservation and promotion of cultural heritage in support of the UN Sustainable Development Goals*, ISPRS Journal of Photogrammetry and Remote Sensing, Volume 142, 2018, Pages 389-406,ISSN 0924-2716,https://doi.org/10.1016/j.isprsjprs.2018.01.001.

Form, Data, Matter: Photogrammetry and Digital Fabrication at the Service of Safeguarding the Built Cultural Heritage

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Abstract. Documentation of built cultural heritage is an important safeguarding strategy. However, the use of traditional documentation techniques, based on the direct acquisition of measurements with analog devices, makes the process time-consuming, inaccurate, and often inadequate for recording complex shapes, often found in the ornaments of certain architectural styles. This work explores the use of photogrammetry combined with digital fabrication in order to develop a methodology to document these elements of high geometric complexity, creating a workflow that connects digital techniques to traditional materialization techniques, exploring the potential of documentation to translate back into matter similar to that of the documented object. Seeking to validate these workflows, a series of prototypes are made in different materialities to evaluate the different techniques employed.

Keywords: Digital Heritage, Digital Fabrication, Built Cultural Heritage, Restoration, Photogrammetry

1 Introduction

When we talk about built cultural heritage, documentation emerges as an important safeguarding strategy, as it allows the reproduction of the information contained in the form and matter of buildings at other points in time and space. However, the use of traditional techniques, based on the direct acquisition of key measurements with analog tools to produce 2D drawings, makes the documentation process time-consuming, imprecise, and often inadequate for recording complex forms. Moreover, ambiguities and inconsistencies in

representations are common, since drawings are, as a rule, produced individually in conventional CAD tools (GROETELAARS, 2015). On the other hand, the growing scarcity in the availability of craftsmen specialized in interpreting and producing artifacts from these representations raises suspicions about the suitability of this type of record to allow future reconstitutions of damaged parts, an action common to restoration processes (NOGUEIRA et al., 2019). This is a crucial point, since the goal of the restoration process is to preserve and reveal the aesthetic and historical value of the monument and should be based on the original materiality and authentic documents. It must cease in the moment the conjecture begins (ICOMOS, 1964). In this context, Digital Information and Communication Technologies (DICTs), such as photogrammetry and digital fabrication, present the possibility of improving the way the documentation of cultural heritage is carried out, allowing the creation of methodologies based on non-intrusive techniques that do not damage the object to be documented (ICOMOS, 1996).

With these considerations in mind, technologies for digital capture and reconstruction of objects, such as photogrammetry and 3D scanning, have proven to be an effective tool for heritage documentation, providing another approach to the morphology of the object of study, allowing its storage, manipulation and fabrication, opening a series of possibilities for production methodologies and use of this type of record. This work focuses on the use of digital reconstructions using Dense Stereo Matching (DSM) photogrammetry as a capture method, selected for being the most accessible, having as a minimum requirement only the possession of a camera and a computer equipped with some softwares.

The objective of this work is the development of a methodology to operationalize the documentation of elements of high geometric complexity common to the stylistic groups of the built cultural heritage that permeate the context of Fortaleza, Ceará, Brazil. The design of such a methodology is sought so that it can be used in restoration processes.

2 Methodology

The development approach for this work was divided into two stages. The first stage of analysis and planning, starts from the identification of the problem in the present paradigm of documentation of the built heritage, expressed in the difficulty of transposing geometric information in the registration processes. For this, photogrammetric capture and digital fabrication processes are incorporated to complementary fabrication processes aiming at the reconstruction of distinct materialities. With a reasonable understanding of the problems, tools and processes, we seek to develop organized workflows, in which we can classify a series of processes that operationalize the production of models and prototypes in accordance with the materiality of the object of

study. The second stage seeks to validate the workflow propositions raised in the first, observing the feasibility of the application of these models in a local context, producing a series of prototypes in different materialities to evaluate different manufacturing techniques, observe the difficulties and potentialities of the processes, and record the results. Observing the particularities of the analyzed processes and the selected tooling, it was possible to outline a standard workflow for the production of physical reproductions of ornaments from digital models. The proposed workflow seeks, initially, to demonstrate the applicability in certain contexts and materialities. Besides obtaining the digital data, the process includes the reconstruction of the ornaments via digital fabrication, seeking to close a cycle of restoration steps for heritage assets so as to ensure a greater permanence for built cultural systems.

Observing the samples documented in the field, we sought to categorize them into common criteria related to the different materialities present in the ornaments of the included buildings. The categories that were considered as the focus of the scope of this work were: "cast metal", "wood carving", and "plaster". This classification has direct correlation to the manufacturing methods employed.

The techniques involved in the manufacturing processes most common to the different ornaments materialities observed are mapped in a flow chart where one can more clearly observe each step involved referring to each materiality.

To this flow chart is incorporated a device composed of a group of steps that range from the capture and digitization of the ornament's shape using photogrammetry techniques, to its rematerialization using digital fabrication techniques.

2.1 Capture and Fabrication Workflow

Photogrammetry using DSM was the primary technique used in the process of digitally capturing and reconstructing the artifacts. It operates by taking a collection of photographs taken from various angles of the target object as input and identifying correlations between groups of homologous pixels present in the provided photographs. The photos in different perspectives of the same object allow the comparative processing algorithm to spatialize the correlated pixels as points projected into Cartesian space. This aggregate of pixels is referred to as a "point cloud". According to Groetelaars (2015) The process of generating "point clouds" with the DSM technique can be divided into 5 main steps: (1) photo input; (2) automatic correlation of the photos; (3) reconstruction of the preliminary geometry of the object and camera; (4) dense association of homologous pixels; (5) creation of the geometric model as a " point cloud" and the Triangulated Irregular Network (TIN) mesh, which is a mesh of non-rectified triangles generated from the association of the vertices generated by the point cloud, which may be textured or not. As previously stated, the TIN mesh is generated by the associating vertices from the “point cloud” that are adjacent to each other to make faces. Given this process, the generated geometry is

often overdetailed, making its file size sometimes too large to be handled efficiently for its proposed uses (i. e. documentation and digital fabrication). When that's the case, the process of remeshing comes as an optional step, enabling the creation of a simplified version of the 3D model, reducing the number of faces of the mesh while retaining as much detail as possible.

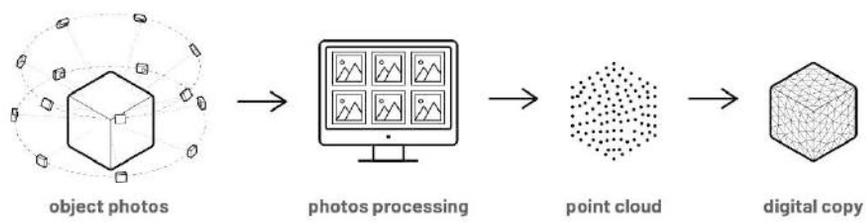

Figure 1. Diagram representing the main steps in a photogrammetry reconstruction. Source: Authors, 2022.

Acquiring a 3D model of the artifact allows for its use as a digital blueprint in processes of additive and subtractive manufacturing. Computer-Aided Design to Computer-Aided Manufacture software (CAD/CAM) can interpret the input geometry and output a series of machine-specific toolpath commands (this process is also known as "slicing"), these are known as G-code. Computer Numerical Control (CNC) machines such as CNC routers and 3D printers can receive G-code as input to produce physical prototypes of the original geometry.

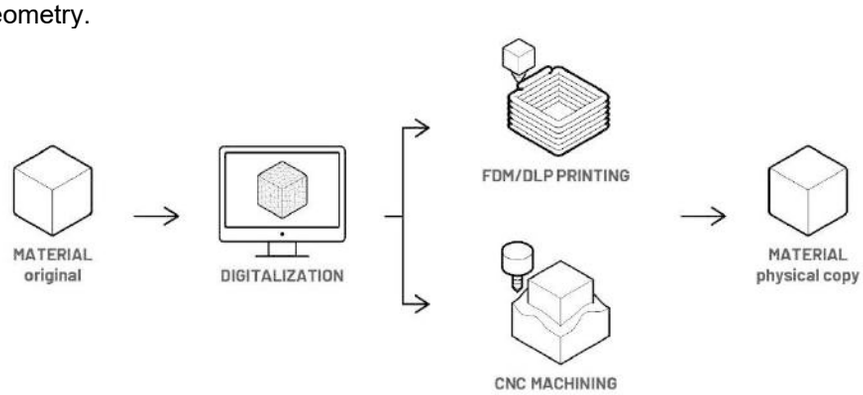

Figure 2. Diagram resuming the translation of a physical object's shape into a 3D model and rematerialization through digital fabrication. Source: Authors, 2022.

These digital processes were grouped and considered as a minor workflow path that allows for the translation of the artifact's shape through different materialities.

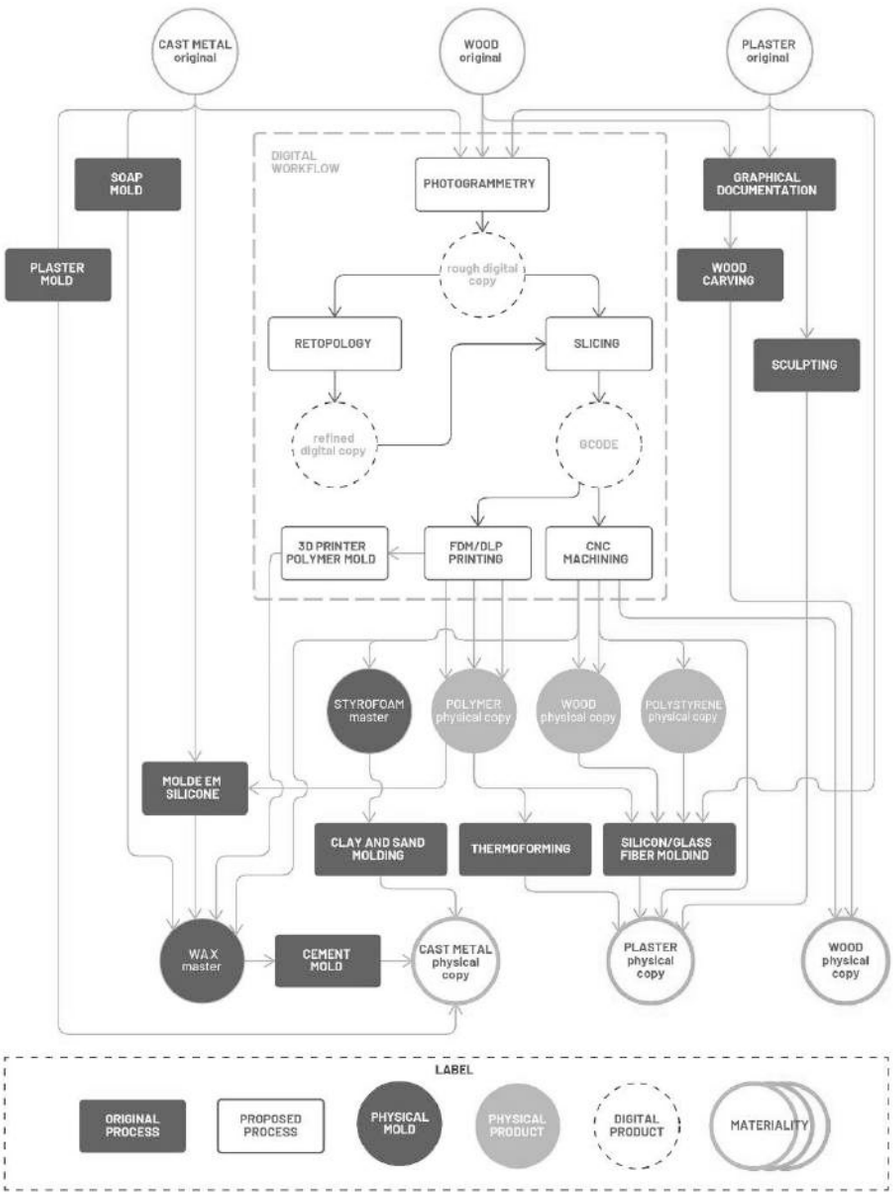

Figure 3. Flowchart mapping the possible pathways of processes involved in the translation of an artifact's shape from its original medium to a replica of the same materiality. Source: Authors, 2022.

Having all steps laid out (the digital processes together with the physical processes to produce replicas for the three materialities considered), possible

workflows were elaborated in which the end goal was taking advantage of the digital device in the process of translating the artifact's shape from its original medium to a replica of the same materiality.

To validate the device elaborated by the merging of those previous workflows, a number of case studies were elaborated where a chosen sample of each kind of materiality would be subject to a series of processes mapped on by this device, wherein the goal is that the workflow meets two conditions: (1) the artifact is documented and replicated by the digital processes; (2) the final replica reaches the same category of materiality as the original one.

Limitations on the methods of fabrication available restricted the digitally manufactured replicas to be made mainly of polymers, polystyrene and wood. This means that to reach the end product, additional processes (i.e. lost wax casting, silicon molding, thermoforming, etc.) would need to be included in order to transpose the artifact shape to its proper final materiality.

3 Results

These samples were ornaments chosen from three different buildings as case studies in the scope of this work: (1) *Theatro José de Alencar* (Wood); (2) *Mercado dos Pinhões* (Metal); (3) *Farmácia Oswaldo Cruz* (Plaster). The criteria for their selection accounted for: ease of access, graphical complexity and how likely its photo-capturing were to result in a good 3D model.

3.1 Wood (Theatro José de Alencar)

Figure 4. From left to right: Photo taken from the ornament on the Teatro José de Alencar's door; The ornament's photogrammetric reconstructed model; 3D model of the isolated ornament; 3D printed replica. Source: Authors, 2022.

The chosen ornament for this case study was carved on the main access wood door from the "Theatro José de Alencar", that leads to the metallic internal structure of the theater. It is situated in Fortaleza, the capital of the state of Ceará, in Brazil.

Remarkable example of European imported iron architecture, the Theatro José de Alencar was built with the Glasgow firm *Walter MacFarlane & Co.* metallic structures, in its entirety made out of iron, supported by columns in cast iron that featured special design.

The chosen building fulfills the type of garden theaters and portrays the eclecticism in Fortaleza's architecture, emphasizing the art nouveau features. Having its doors open by the time of 1910 and registered in 1964 by the national government, through Decree 25 of November 30, 1937, as a protected heritage. (BARROSO, 2002)

As the ornament, which was worked on this step, the last segment of the construction was the settlement of the carpentry and frames, by the end of 1909. Most of the details are still preserved as the building has gone through some restorations.

The photogrammetry process sampled 45 photographs taken by a 12 MP cellphone camera, given the occasional absence of a professional one, and models were generated using the Epic Games Reality Capture v1.2. The results turned out convincingly similar to other captures, with minimal artifacts, and model cleanup was done separately in Blender.

A physical prototype was fabricated using 3D printing (ABS polymer) at a 1:2,5 scale. So far, the wooden prototype has not been manufactured yet.

3.2 Metal (Mercado dos Pinhões)

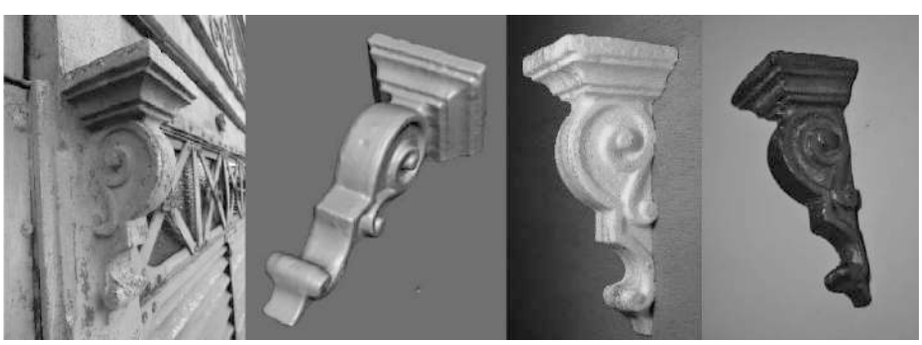

Figure 5. From left to right: Photo taken from the Mercado dos Pinhões ornament; The ornament's photogrammetric reconstructed model after cleanup; 3D printed replica; Lost wax cast metal replica. Source: Authors, 2022.

The Mercado dos Pinhões is a building registered as a Protected Cultural Heritage by the municipality of Fortaleza by Decree 12.368 of March 31, 2008. Originally, the metal structure was imported from France to be the first meat market in the city. It was made entirely of cast iron by the Guillot Pelletier workshop, which was also responsible for the structure of the Eiffel Tower. Inaugurated on April 18, 1897, it was one of several buildings built during the Belle Époque, a historical period marked by initiatives to "modernize" the

province. In its first form, the "Iron Market" consisted of two pavilions connected by a central avenue and was located downtown in Waldemar Falcão Square.

With the construction of a new and more modern municipal market in 1932, the old "Iron Market" lost its strength. In 1938, the structure was disassembled and divided. One of the pavilions was moved and rebuilt in Marquês de Pelotas Square (also located downtown, but closer to its borders), where it remains to this day, gaining the name Mercado dos Pinhões. Currently, in addition to commercial activities, it hosts an extensive cultural programme overseen by the Fortaleza City Hall. The other pavilion has been relocated and rebuilt twice and is now located in the Aerolândia neighborhood (Filho & Sarmiento, 2003; Leal & Seligman, 2011). After abandonment for decades, it has recently been restored to house similar activities as its twin.

The ornament chosen is on the facade of the Mercado dos Pinhões, on the top of the pillars outside the building.

The photogrammetry process sampled 37 6MP photographs and models were generated using three different software (Agisoft Photoscan, Autodesk ReCap, and Autodesk ReMake), all yielded similar results. Model cleanup was done separately in Autodesk Meshmixer.

Physical prototypes were fabricated using 3D printing (PLA polymer) and CNC milling (Styrofoam, Wax, MDF). The 3D printed prototype was later used to produce a silicone mold to make wax copies. The final metallic piece was produced using lost wax casting using a mold in 1:2 scale.

This case study is described in further detail in “Documentation and digital fabrication methods for restoration of eclectic metal ornaments” (MOREIRA et al. 2017).

3.3 Plaster (Farmácia Oswaldo Cruz)

Figure 6. From left to right: Photo taken from the Farmácia Oswaldo Cruz ornament; The ornament’s photogrammetric reconstructed model; 3D printed replica (top) and silicone molded plaster replica. Source: Authors, 2022.

The building is described on the institutional site of the Secretary of Culture of the State of Ceará (SECULT-CE) as follows:

The pharmacy was built in the eclectic style, in the first half of the 20th century, the pharmacy occupied a prominent position in the commercial area, located in the middle of Praça do Ferreira, a place of cultural and social

effervescence at that time. There, for a long time, until the 1970s, there was the custom of meetings on the sidewalks of the most varied groups, to discuss various topics, ranging from the trivial to the erudite, and where the famous "booing at the sun" took place, which is part of Ceará's anecdotes.

The building reflects, through its ornate facade and the mix of decorative elements, the restlessness of an architecture in search of a new language, which emerges in eclecticism as a way to revive the old architecture, but with the use of new technological advances of nineteenth-century engineering (FORTALEZA-CE, 2015).

The chosen ornament was the crowning of the facade, whose hard-to-reach position above the first floor presented a good testing opportunity for using drones as a photographic capture tool. The photogrammetry process sampled two sets of photographs (180 and 257 photos) sampled from 4k 60fps videos taken by a DJI Phantom 4 Pro drone equipped with a 20MP camera. The 3D model was generated using RealityCapture v1.2.

The original model captured most of the building facade and had approximately 26.3 million triangles, this model had some surface noise, and its size was unhandy, so it was cropped, smoothed and remeshed into four different versions (3M tris, 1M tris, 100K tris and 10K tris each). The 1M tris model was chosen for prototyping, since it was the one with less geometry that still maintained most detail. The ornament was isolated from the model using boolean operations in Blender and exported for slicing. Physical prototypes were fabricated using 3D printing (PLA and ABS polymers) and CNC milling (Styrofoam, XPS). The 3D printed ABS copy was later used to produce a silicone mold to make plaster copies.

The main issues found through this case study were:

- The photogrammetric reconstruction generated surface noises that affected the physical accuracy of the model, it’s unclear if the photo sampling hasn’t covered enough angles or if the photos taken by the drone while moving had motion artifacts.
- FDM printing generated stringing on the printed piece (this can happen especially when printing ABS and PETG), this can negatively affect molding processes and make clean-up time consuming.
- The silicon molding was inconsistent, which made artifacts that could affect the final piece.

4 Discussion

This study has allowed an exploration of the possibilities presented by the development of a methodology for documenting elements of high geometric complexity. Techniques such as photogrammetry and 3D scanning reveal complementary possibilities to these processes of documentation and registration, as the form of the registered object is transposed to digital media.

Higueras (2021) reinforces this by explaining that obtaining 3D virtual models with metric accuracy in relation to the original measurements has several applications in the field of cultural heritage. These applications range from documentation, research and promotion of cultural heritage to its reconstruction, virtual reintegration and 3D printing for its reproduction and physical reintegration.

4.1 Practical application possibilities

The main possibility explored with the incorporation of the processes in this research was the manipulation of obtained 3D models as visual aids or on the process of fabricating physical prosthesis to be used in restoration projects (NOGUEIRA et al., 2019; AMORIM, 2022).

Experiments in producing these prosthesis often rely on the presence of symmetry and repetition in the documented artifact. This way speculation on the original shape of the ornament is more easily avoided and a 3D model can be produced using a model of a damaged area and an undamaged one, this way a boolean difference operation could be performed, where a digital model acts as a geometric operator, detecting another model that intersects with its geometry. The operator is used as a reference to construct a solid model, which is composed of the junction of the faces of the geometry of the operated object that do not intersect with the operator, and the geometry of the operator that intersects with the operated object. This process generates a fragment based on the reference model, which fills the negative space of the model (HIGUERAS et al., 2021; HENRIQUES et al., 2020).

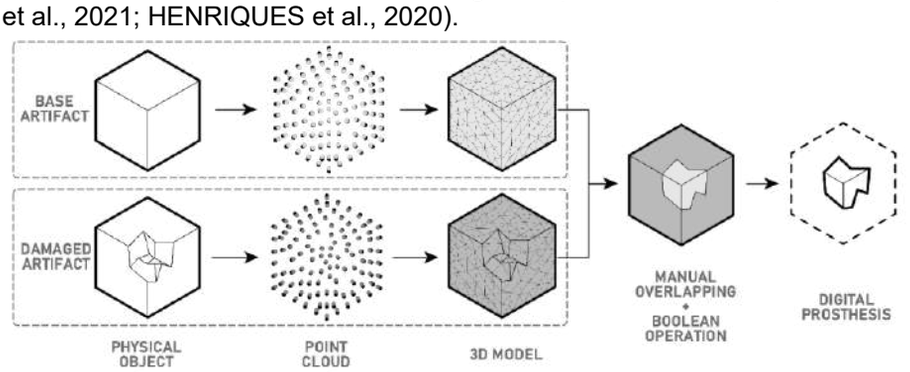

Figure 7. Diagram representing an artifact prosthesis produced through boolean subtraction using 3D models of a damaged artifact and a base that's symmetric to it. Source: Authors, 2022.

4.2 Quantitative Analysis

A workflow such as the one described in this work, encompassing many different processes and tools, is bound to have results of varying qualities, and serves mostly as a general guideline through the steps available. Its

exploration, however, opens a path to the qualitative evaluation of the techniques and tools available, as well as different workpaths, pertaining to the recording and replicating of built cultural heritage.

Scopigno et al. (2015) produces a survey which presents a summary table of fabrication techniques for cultural heritage, precision, and working size. Expanding this method of analysis to encompass different work paths might be an option when producing a more thorough workflow.

References

Amorim, L. E. (2022). Forma, dado e matéria: a incorporação de técnicas de fotogrametria e fabricação digital a estratégias de documentação patrimonial e restauro. http://www.repositorio.ufc.br/handle/riufc/66498.

Barroso, O. (2022). Theatro José de Alencar: O Teatro e a Cidade. Fortaleza: Luz Editorial.

Filho, J. C.; Sarmiento, L. Mercado de Ferro: notas sobre a restauração do Mercado dos Pinhões. Fortaleza, Ceará: Oficina de Projetos S/C Ltda, 2003.

Fortaleza-CE. André Quintino. Farmácia Oswaldo Cruz. (2015). Retrieved Feb 10, 2022, from https://mapacultural.secult.ce.gov.br/espaco/241/

Groetelaars, N. J. (2015). Criação de modelos BIM a partir de "nuvens de pontos": Estudo de métodos e técnicas para documentação arquitetônica. [Doctoral dissertation, Universidade Federal da Bahia] UFBA Repository. https://repositorio.ufba.br/handle/ri/20220

Henriques, F. (2020). Restoration of an 18th Century Frame: 3D Modelling, Printing and Matching Color of Decorative Flowers Elements. Ge-Conservacion 18, no 1 313–22. https://doi.org/10.37558/gec.v18i1.854.

Higueras, M. et al. (2021). Digital 3D modeling using photogrammetry and 3D printing applied to the restoration of a Hispano-Roman architectural ornament. Digital Applications in Archaeology and Cultural Heritage, v. 20, p. e00179, 2021.

ICOMOS. (1964). International Charter for The Conservation and Restoration of Monuments and Sites (The Venice Charter 1964). https://www.icomos.org/charters/venice_e.pdf

ICOMOS. (1996). Principles for the recording of monuments, groups of buildings and sites (1996). https://www.icomos.org/charters/archives-e.pdf

Leal, A. B. & Seligman, G. (2011). Mercado de ferro do Brasil: aromas e sabores. Brasília: ITS - Instituto Terceiro Setor.

Moreira, E. et al. (2017). Documentation and digital fabrication methods for restoration of eclectic metal ornaments. In: CELANI, Gabriela; KANOUN, Olfa (Orgs.). Frontiers of Science and Technology. Berlin, Boston: De Gruyter.

Nogueira, J. L. V. (2019). Fortaleza mestiça: aquém dos ideais, além das saudades. 2019. 184 f. Tese (Doutorado) - Curso de Comunicação e Semiótica, Pontifícia Universidade Católica de São Paulo, São Paulo. Cap. 1

Nogueira, J. L. V. et al. (2019). Uso da fabricação digital nos processos de restauração: o retábulo do altar da Igreja Matriz de Nossa Senhora do Rosário de Russas - CE. 3o Simpósio Científico do Icomos Brasil, Brasil. https://doi.org//10.29327/15175

Scopigno, R., Cignoni, P., Pietroni, N., Callieri, M., & Dellepiane, M. (2015, November). Digital Fabrication Techniques for Cultural Heritage: A Survey. In Computer Graphics Forum.

Special Topics: Inclusive Design

Design and Publication of Content as a Form of Sociotechnical Interaction. Case Study Practice of Social Appropriation of Internet

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Abstract. Digital social networks are an actor that mediates a big part of social interactions. Therefore, inclusive design should put the accent not on technology, if not, what people do with it. Under this purpose, through the ethnographic method, it characterized one of the practices of social appropriation of the internet for peace in Comuna 13 of Medellín, Colombia. As result, it is evident that the design and publication of content are a form of sociotechnical interaction that connect technology, people and social contexts, which expands the design/use relationship.

Keywords: inclusive design, social appropriation, sociotechnical interaction, social network, internet

1 Introducción

Las redes sociales digitales son un actor que media gran parte de las interacciones sociales contemporáneas. Desde la década de los noventa, cuando se diseña e implementa Sixdegrees, se inicia un entramado sociotécnico que crece exponencialmente. La plataforma es la primera en asemejarse al modelo mental y conceptual de red social en la actualidad: creación de perfil público o semippúblico que posibilita establecer conexiones con otras personas, con el propósito de articular y volver visible la red de relaciones de los usuarios (Albornoz, 2020). Además, según We Are Social y Hootsuite (2022), de los 4.95 billones de usuarios actuales de internet, 4.68 billones usan plataformas de redes sociales; por tanto, este espacio de interacción es un mediador que vincula a una gran cantidad de personas, pero también tecnologías e intereses sociopolíticos, económicos y culturales.

Por consiguiente, el diseño de estas plataformas establece los modelos para la interacción social en el entorno digital al vincular la tecnología informática (*hardware* y *software*) con las personas para constituir comunidades en línea. Este aspecto concuerda con los dos últimos niveles de la computación que conecta internet: el nivel de la interacción persona-computador y el nivel comunitario (Whitworth & Ahmad, 2014).

Por consiguiente, su creación debe orientarse desde el diseño inclusivo, el cual tiene como propósito que un producto sea usado por una gran cantidad de personas; o, como lo sugiere Gould-Stewart (2014), un diseño para la humanidad, que implica audacia y humildad al pensar que lo que se diseña les será útil a muchos y, por tanto, no solo es un asunto del diseñador y su portafolio. Esto implica dar cuenta de aspectos estéticos, comunicativos y funcionales para lograr una eficiente y eficaz experiencia de usuario, además de diseñar regulaciones y estrategias que modelan las relaciones que entreteje, como las políticas de privacidad, manejo y comercialización de datos, e incluso implementación de tecnologías de vigilancia para monitorear la actividad en línea (Orlowski, 2020). Como lo evidencia Albornoz (2020), “si la gente iba a participar en espacios virtuales comunes era necesario condicionar su comportamiento para que lo hicieran en función a su diseño” (p. 75).

Cada vez es más evidente que las interacciones en las redes sociales digitales no son naturales ni neutrales, por una parte, son una intrincada red de procesos semióticos y cognitivos que modelan las acciones mediante interfaces de usuario (Scolari, 2004), y, por otra, responden a intereses económicos y políticos que no obedecen al funcionamiento interno de la tecnología (Orlowski, 2020). Además, en las relaciones interpersonales, sean virtuales o no, entran en juego significados, interpretaciones y comprensiones no solo del otro, sino de sí mismo (Goffman, 1970), aspectos que demuestran la complejidad de este vínculo.

Comúnmente estas interacciones se estudian de forma independiente, lo que dificulta entender lo intrincado que se encuentra la tecnología con lo social, y viceversa. Esto lo enfatizan Thomas, Fressoli y Lalouf (2008) al reconocer que es inviable comprender la sociedad sin su entramado tecnológico e igualmente la tecnología sin la construcción social. En sintonía con esta reflexión, se destaca el aporte teórico y metodológico de la TAR (teoría del actor-red), que establece un punto de encuentro para comprender estas relaciones desde un contexto sociotécnico, lo que implica pensar en conexiones y no en la naturaleza de los actores.

La TAR es inicialmente una teoría propuesta por Bruno Latour, Michel Callon y Jhon Law, pero posteriormente direccionada por Latour (2008) hacia una sociología de las asociaciones, que busca comprender lo social no como una materia estable homogénea, sino como un entramado de relaciones entre actores heterogéneos que establecen interacciones que deben ser constantemente renegociadas y ensambladas, y donde el objeto técnico tiene un papel activo y capacidad de agencia. Por tanto, las interacciones sociales no se establecen solo entre los seres humanos sin ninguna otra dotación que permita la acción conjunta (Latour, 2008).

En concomitancia, para comprender e interpretar la relación entre tecnología y sociedad, se hace relevante tener presente los contextos en los que se establece dicha relación. Para ello, se desarrolla una investigación doctoral en ciencias sociales titulada "Interacciones sociotécnicas entre movimientos sociales e internet", la cual tiene como objetivo comprender y

describir las interacciones que se producen entre estos dos actores, puntualmente por parte del movimiento social, artístico y cultural por la paz de la Comuna 13 en Medellín, Colombia. Como parte de los resultados, se caracterizan prácticas de apropiación social de internet. Entendiendo la apropiación como procesos tanto individuales como colectivos, que van más allá del uso predeterminado de la tecnología, al convertir un objeto técnico en un objeto social, mediante un potencial creativo e innovador que con el tiempo se transforma en prácticas cotidianas de resistencia (Gómez-Mont, 2002, 2017).

Así, a partir de los entendimientos teóricos, metodológicos y empíricos que arrojó la investigación, se comparten algunos resultados que dan cuenta de cómo a través de la participación de diversos actores en la práctica de apropiación social #OriónNuncaMás se logra reconocer y evidenciar que el diseñador de espacios digitales para la interacción social no puede abstraerse de los contextos de uso ni dejar a un lado las posturas éticas, ya que su trabajo puede fortalecer los vínculos sociales o los intereses particulares de organizaciones y/o Estados.

2 Metodología

La investigación se orientó en los supuestos epistémicos y metodológicos que propone la TAR, entre ellos, seguir de cerca a los actores (Latour, 2008). Por consiguiente, se privilegió el método etnográfico, el cual permite la descripción de lo que la gente hace y sus significados (Restrepo, 2018). Para ello, se articularon dos técnicas: la observación participante (OP), tanto en el espacio físico como virtual y las entrevistas a profundidad. El trabajo de campo duró 15 meses, partió del seguimiento de la actividad en línea de diez organizaciones que trabajan por la paz en Medellín y, a través de un diario de campo, se registró la actividad de las que vinculaban internet con procesos colectivos que contribuyen a transformar los marcos de violencia en el territorio, de las cuales se identificaron AgroArte Colombia y Casa Kolacho.

Ambos colectivos trabajan en la Comuna 13 de Medellín, liderando procesos que fortalecen la paz en el territorio y participan en las prácticas de apropiación social de internet analizadas en la investigación. Las entrevistas a profundidad se orientaron mediante preguntas abiertas, con el objetivo de llenar los vacíos de la OP en espacio virtual e indagar sobre el propósito de los actores que participaron en las prácticas de apropiación. Para el análisis de los datos, con el objetivo de caracterizar las prácticas de apropiación social de internet, se codificó la información a partir de un sistema categorial que da cuenta de la acción individual y colectiva, la trayectoria, el propósito de la acción, las habilidades cognitivas y técnicas, la articulación entre el espacio físico/digital y el papel de los contenidos. La codificación se hizo con el *software* Nvivo, asistente para el análisis de datos cualitativo.

3 Resultados

Se divulga la caracterización de una de las prácticas de apropiación social de internet analizadas en la investigación. Esta se asocia a la iniciativa Orión Nunca Más, la cual surge en contraposición a una de las 25 operaciones militares realizadas en la Comuna 13 de Medellín. El 16 de octubre de 2002 se ejecuta la última de las operaciones militares denominada Operación Orión, la cual buscaba arrebatar el control del territorio a las milicias que tenían presencia en la Comuna. Fue un acto realizado por más de mil hombres de la fuerza pública, acompañados de tanquetas blindadas y helicópteros de combate, considerado la más grande intervención militar en una zona urbana de Colombia (Aricapa, 2015). Este acto de violencia dejó civiles muertos, desaparecidos, detenciones arbitrarias, casos de tortura, desplazamiento forzado y, según la población y algunas organizaciones sociales y jurídicas, las operaciones militares en vez de acabar con la violencia le dieron el poder del territorio a los grupos paramilitares, que siguen actuando bajo el nombre de la delincuencia común (Rodríguez *et al*., 2021).

Como acto de resistencia, el movimiento social por la paz en la Comuna 13 moviliza acciones para conmemorar cada año la Operación Orión como un proceso simbólico bajo el lema Orión Nunca Más. La iniciativa surge desde el año 2004, inicialmente con eventos colectivos, marchas e intervenciones en el territorio, las cuales con el tiempo se articulan a actos de resistencia, prácticas de apropiación social de internet, que se gestan en las plataformas de redes sociales y forman parte de las acciones para denunciar los abusos contra la población civil y las desapariciones forzadas, recordar a los muertos, acompañar a las víctimas y pedir justicia y reparación al exigir a los victimarios que siguen en el poder decir la verdad y reconocer su participación.

La práctica de apropiación social #OriónNuncaMás se caracteriza a partir de cuatro categorías, las cuales evidencian los vínculos que se generan entre tecnología, personas y contexto sociocultural.

3.1 Acción individual y colectiva

Se promueve, por parte de colectivos y líderes sociales que trabajan por la paz en la Comuna 13, la acción de publicar contenidos en plataformas de redes sociales digitales con las etiquetas #OriónNuncaMás y/o #OperaciónOriónNuncaMás. La práctica es denominada por los mismos actores sociales como Twitteratón, ya que nace en esa plataforma en 2012 y posteriormente se expande a Facebook e Instagram. La acción de publicar contenido promueve otras acciones que también posibilita la interfaz gráfica de usuario, como indicar algunas emociones, compartir con otros la publicación, ya sea en la misma plataforma o en otras, en las que se incluyen la mensajería instantánea y los comentarios.

Con el uso de las etiquetas se logra indexar las publicaciones orientadas a un mismo asunto, en este caso la conmemoración de la Operación Orión. Así,

al incentivar su uso, lo que en primer lugar es un acto individual, como la publicación de contenidos a través de un perfil en redes sociales, se convierte en una acción colectiva que articula publicaciones bajo una misma taxonomía y así, mediante el diseño y publicación de contenidos, los usuarios de redes sociales se unen para decir Orión Nunca Más.

3.2 Habilidades cognitivas y técnicas

El uso de las redes sociales digitales requiere habilidades técnicas y cognitivas para interactuar con los dispositivos tecnológicos y para comprender el guion de interacción que propone la interfaz gráfica de usuario. Además, se evidencia una serie de habilidades que poseen los usuarios que participan en la práctica de apropiación, como la lectoescritura, tanto para el uso de la interfaz gráfica de usuario como para la publicación y entendimiento de los mensajes textuales que se comparten. Igualmente, las etiquetas son una concatenación de caracteres que conforman una o varias palabras y, por tanto, su lectura le da sentido a la misma. Además de los caracteres alfabéticos, utilizan los emoticones, íconos incorporados en los teclados de los dispositivos móviles o en la interfaz de usuario, que expresan mediante lenguaje no verbal otro tipo de mensajes. Su uso y entendimiento demandan al lectoescritor una serie de competencias para dotarlos de significados y, así, poder emplearlos para expresarse.

Se reconocen habilidades para el diseño de piezas gráficas digitales como afiches, infografías y carteles en los que se articulan varias técnicas de creación, al igual que toma de fotografías y realización de videos. También, a través de estos soportes se evidencian habilidades artísticas, como es el caso de la música, ya que se comparten varios videos musicales, canciones interpretadas por los usuarios e, incluso, poesías. Las personas publican, además, otros contenidos no realizados por ellas, lo que determina la necesidad de acortar y copiar la URL, principalmente por las restricciones en cantidad de caracteres que impone Twitter. Esto conlleva que los usuarios usen una herramienta especializada para acortar las direcciones web y, así, vinculen contenidos alojados fuera de las plataformas como blogs y páginas web.

3.3 Articulación espacio físico/digital

Por la naturaleza de la iniciativa, que surge en resistencia a las operaciones militares que se dieron en la Comuna 13, la práctica se fundamenta en la localidad de la lucha. Aunque las plataformas de redes sociales son espacios de interacción deslocalizados geográficamente, las resistencias que se apoyan con su uso convierten las reivindicaciones en glocales. Son locales, al estar vinculadas a problemáticas del territorio; y globales, al comunicar al mundo sus luchas e, incluso, lograr persuadir usuarios de otras geografías para apoyar y sumarse a sus causas. Igualmente, algunas publicaciones visibilizan los actos

simbólicos que se hacen durante las conmemoraciones en el territorio, mediante transmisiones en vivo, videos y fotografías que dan cuenta de ello.

3.4 Contenidos

Los contenidos publicados presentan el propósito de la práctica: usar las plataformas de redes sociales para contar al mundo lo que pasó en la Comuna 13 en medio de las incursiones militares, acompañar a las víctimas; y pedir justicia y reparación. Además, evidencia las habilidades cognitivas y técnicas que poseen los usuarios que participan, el potencial creativo e innovador de los usos, y lo entrelazado que se encuentra lo social con la tecnología, que en el caso de las redes sociales digitales se vinculan a los intereses sociopolíticos y culturales de cada usuario. Para fines demostrativos, se visibilizan algunas publicaciones, las cuales permiten ejemplificar las características de los contenidos, que comprenden en sí la práctica de apropiación.

Entre las publicaciones relacionadas con denuncias, en el marco de la Operación Orión, se reconoce constantemente el caso de la alianza del Estado colombiano con los grupos ilegales paramilitares para llevarlas a cabo. La denuncia la realizan en las redes sociales digitales a través de cuentas personales y de organizaciones sociales y jurídicas que tienen vínculos con el territorio. La alianza es respaldada con el uso de una fotografía realizada por el fotoperiodista colombiano Jesús Abad Colorado en medio de la Operación Orión. La fotografía es constantemente publicada en diferentes años y por diferentes usuarios, reutilizada para el diseño de piezas gráficas e, incluso, recreada (figura 1).

Otros contenidos evidencian el diseño de piezas gráficas creadas específicamente para participar en la práctica. Los usuarios, en los que se encuentran personas y organizaciones sociales y gubernamentales, usan diferentes técnicas y soportes para comunicar, promocionar y contextualizar a otros usuarios sobre lo ocurrido en 2002 en la Operación Orión. Se crean imágenes para denunciar otros actos de violaciones a la sociedad civil, como el uso de una escombrera como fosa común, e igualmente se diseñan y publican piezas gráficas para informar sobre los actos simbólicos que se dan en el territorio y acompañar a las víctimas que siguen esperando el esclarecimiento de lo ocurrido (figura 2).

En la plataforma de Instagram se observan publicaciones con mayor potencial creativo y visual, entre las que destacan contenidos que ponen en tela de juicio el accionar del Estado, visibilizando a los líderes que participaron como victimarios (figura 3). Aunque son muchos y diversos los contenidos, la muestra destaca las muchas maneras de hacer y la creatividad que caracteriza la práctica de apropiación #OriónNuncaMás.

Figura 1. Publicaciones en Twitter 2020 y 2021 relacionadas con la fotografía de Jesús Abad Colorado.

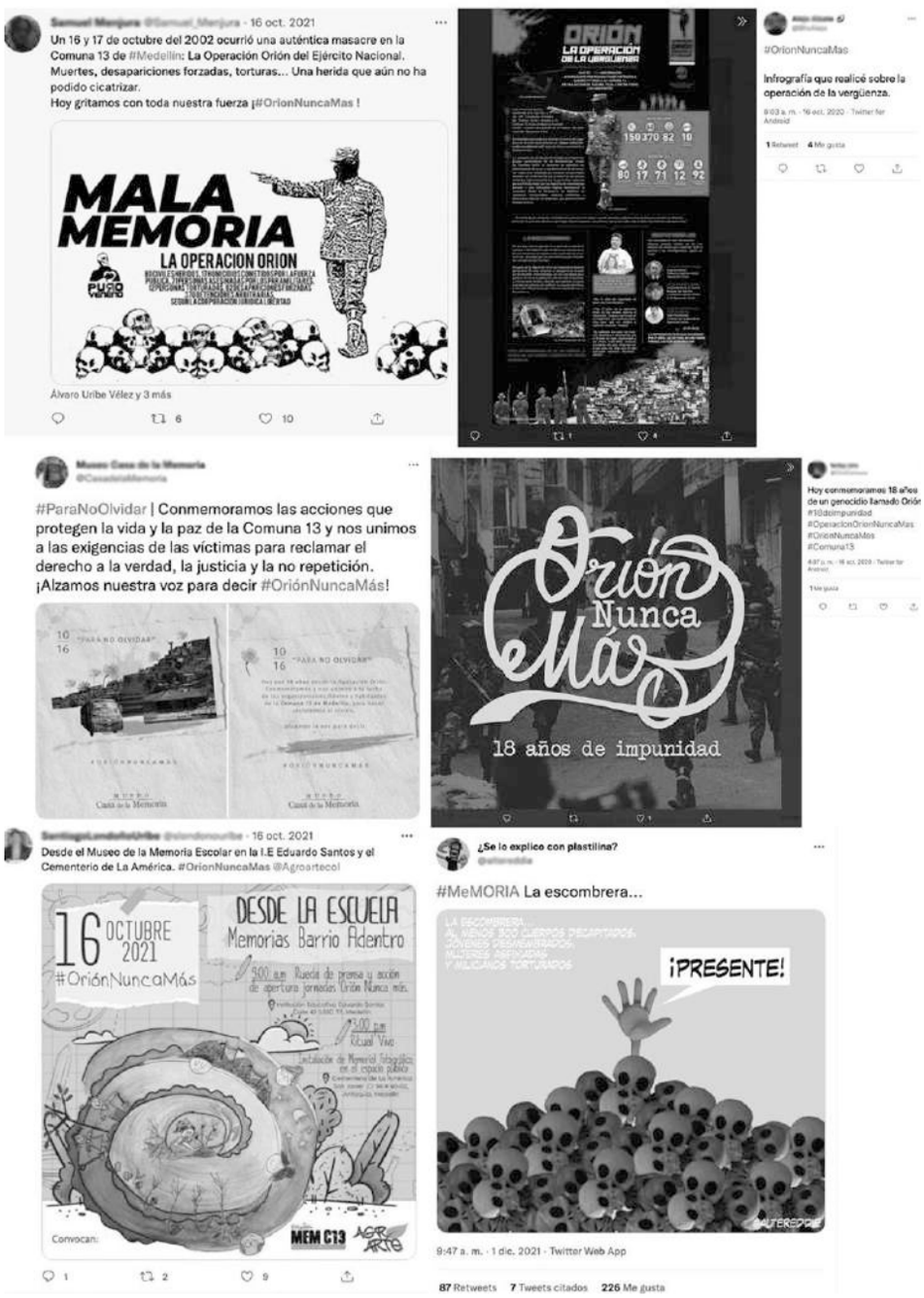

Figura 2. Publicaciones en Twitter 2020 y 2021 de piezas gráficas.

Figura 3. Publicaciones en Instagram 2020 y 2021 de piezas gráficas asociadas al Estado.

4 Discusión

Los resultados evidencian, en el caso de la práctica analizada, que las redes sociales digitales son espacios de interacción donde es posible llevar a cabo proyectos colectivos y visibilizar o promover las luchas sociales. Se consolidan como marcos de interacción, donde los usuarios las dotan de relaciones, discursos, simbolismos y significados mediante los contenidos que publican. Las prácticas de apropiación social de internet vinculan a las personas con la tecnología y los contextos sociales, a través de una serie de acciones individuales y colectivas, y aunque se consolidan a través del potencial creativo e innovador de los usuarios, estos deben tener unas habilidades técnicas y cognitivas para relacionarse con la tecnología, con otros y emplearla.

El diseño inclusivo debe comprender el papel de las plataformas de redes sociales como mediadoras de las interacciones sociales contemporáneas; por tanto, mapear sus entramados sociotécnicos, los cuales no solo vinculan los usos sociales de esta tecnología, sino también aspectos éticos y críticos sobre la manera en cómo se están direccionando los asuntos de privacidad y las estrategias comerciales de estas plataformas. Aspectos como el capitalismo de vigilancia, que se consolida mediante inteligencia artificial y minería de datos para vigilar la actividad en línea y el diseño de estrategias, que se valen de las interfaces de usuario para cambiar los hábitos de las personas y persuadirlas para que pasen más tiempo conectadas (Orlowski, 2020). Igualmente, cada vez más se reconoce el poder económico y político de empresas multinacionales como Meta, que mantienen un monopolio en plataformas para la interacción social como Facebook, Instagram y WhatsApp (Sánchez-Vallejo, 2020), y han sido objeto de críticas por influir en asuntos políticos y poseer un poder comparable con la industria armamentista (Cobo, 2019; Morozov, 2015).

Estos aspectos no pueden estar invisibilizados por los diseñadores, lo que plantea la discusión sobre la importancia de vincular los entramados socioculturales en el proceso de diseño tecnológico; ya que, como lo señala Parselis (2017), si esta vinculación no se produce, no hay libertad en el contexto de uso. Por consiguiente, debemos complementar el propósito de diseñar experiencias de usuario eficientes y eficaces con dimensiones éticas, sociales, económicas y políticas, pues las plataformas digitales entrelazan una gran cantidad de actores sociales en los que se encuentran inmersos los diseñadores.

Este aspecto toma mayor relevancia en el diseño de plataformas de redes sociales, ya que estas posibilitan las conexiones con otras personas, asunto que es fundamental para lo social. Como se señaló, nuestras relaciones se encuentran constantemente mediadas por objetos técnicos, los cuales son diseñados como mediadores para mejorar las relaciones y, por tanto, no debería utilizarse esta necesidad de conectarse con otros para intereses particulares, donde se prioricen asuntos económicos y de poder.

Así, el dilema no está en dejar de usar plataformas de redes sociales, sino que se deben reensamblar sus relaciones; puesto que las características que posee la tecnología digital, sin lugar a duda, potencia las interacciones que se establecen con su uso, sobre todo, si el interés es llevar a cabo acciones colectivas para aportar a la transformación social. En consecuencia, es imperante que el diseño inclusivo ponga el acento no en la tecnología, sino en lo que las personas hacen con ella.

Referencias

Albornoz, M. B. (2020). Habitar las redes: las controversias sobre la privacidad en Facebook. *FLACSO Ecuador*. https://doi.org/10.46546/20209atrio

Aricapa, R. (2015). *Comuna 13. Crónicas de una guerra urbana. De Orión a la Escombrera* (1.ª ed.).

Cobo, C. (2019). Acepto términos y condiciones. Usos y abusos de las tecnologías digitales. *Fundación* Santillana. https://static.wixstatic.com/ugd/cd84b5_07c284bde2864e42ad51f7f1e2ac8c02.pdf

Goffman, E. (1970). *Ritual de la interacción. Tiempo contemporáneo*.

Gómez-Mont, C. (2002). Los usos sociales de las tecnologías de información y comunicación. *Estudios de Comunicación y Política*, *12*, 287–305.

Gómez-Mont, C. (2017). La ciencia de lo pequeño o cómo aprender a develar lo invisible de las redes sociales digitales. En *Apropiación de las TIC por parte de comunidades y ciudadanos* (pp. 11-23). Editorial Universidad Pontificia Bolivariana.

Gould-Stewart, M. (2014). TED. Ideas Worth Spreading [Conferencia]. *Cómo los gigantes sitios web diseñan para ti (y mil millones más, también).* https://www.ted.com/talks/margaret_gould_stewart_how_giant_websites_design_for_you_and_a_billion_others_too/transcript?language=es#t-205018

Latour, B. (2008). *Reensamblar lo social: una introducción a la teoría del actor-red*. Manantial.

Morozov, E. (15 de mayo de 2015). Siervos y señores de internet. *El País*. https://elpais.com/elpais/2015/05/05/opinion/1430842193_759913.html

Orlowski, J. (2020). El dilema de las redes sociales [Documental; Video]. Netflix.

Parselis, M. (2017). Repensando la relación entre diseñadores y usuarios a través de las tecnologías entrañables. En *Tecnologías entrañables*, *¿es posible un modelo alternativo de desarrollo tecnológico?* (pp. 54-80). Catarata.

Restrepo, E. (2018). *Etnografía. Alcances, técnicas y éticas*. Fondo Editorial de la Universidad Nacional Mayor de San Marcos.

Rodríguez, G. I., Osorno, L. N., Correa, O. & Fernández-Andrade, R. (2021). *Comuna 13. Memorias de un territorio en resistencia*. Centro de Fe y Culturas / Corporación Jurídica Libertad / Instituto Popular de Capacitación.

Sánchez-Vallejo, M. A. (10 de diciembre de 2020). Estados Unidos demanda a Facebook por monopolio. *El País*. https://elpais.com/economia/2020-12-09/estados-unidos-demanda-a-facebook-por-monopolio.html

Scolari, C. (2004). *Hacer clic: hacia una sociosemiótica de las integraciones digitales*. Editorial Gedisa.

Thomas, H., Fressoli, M. & Lalouf, A. (2008). Introducción. En *Actos, actores y artefactos: sociología de la tecnología* (pp. 9-18). Universidad Nacional de Quilmes.

We Are Social & Hootsuite. (2022). *Digital 2022: Global Overview Report*. https://www.hootsuite.com/resources/digital-trends

Whitworth, B. & Ahmad, A. (2014). Socio-Technical System Design. En *The Encyclopedia of Human-Computer Interaction*, 2nd ed. Interaction Design Foundation. https://www.interaction-design.org/literature/book/the-encyclopedia-of-human-computer-interaction-2nd-ed/socio-technical-system-design

Viability study for a sustainable energy policy in informal settlements: The Santa Marta favela case

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Abstract. Architects and urban planners are often challenged by design problems that include public policies for social development. While the use of sustainable energy has been growing, the costs with installation are still a problem to underprivileged communities such as informal settlements. In this sense, energy justice is a relatively new concept. This paper is part of a larger research that aims to propose a framework for a sustainable energy policy. In this paper we use a case study to estimate the capacity for solar energy production. Research steps include data collection, modeling, simulation, and analysis. Results show that the case study has the capacity to produce several times more energy than it consumes, with potential of selling the overproduction to generate benefits to the community. Future research includes a more detailed simulation of the case study's potential using machine learning techniques.

Keywords: Inclusive Design, Favela, Informal Settlements, Affordable and Clean Energy, Sustainable Cities and Communities.

1 Introduction

Informal settlements are widely present around the world, and it is estimated that they house over one billion people (United Nations, 2019). Informal settlements have diverse origins and many times their physical characteristics are a product of the needs, cultural values, and opportunities that their residents encounter (Davis 2006). Informal settlements are a solution for the lack of affordable housing units as their constructions follow an incremental fashion, the units do not follow building or planning codes, and their locations are usually in areas that are not suitable for the formal construction sector (Compans 2007; Salingaros et al. 2006).

In an international context that focuses on climate change adaptation (Sharifi et al. 2021) it is a cruel irony that residents of low-income areas still struggle to have access to essential urban infrastructure. While there are

diverse national and international initiatives to foment the use of renewable energy, in a country like Brazil, informal settlements account for 7.8% of the total residences (Instituto Brasileiro de Geografia e Estatistica, 2020).

Essential urban infrastructure includes transport, sanitation, water supplies, electricity, and waste disposal. In this research, we approach the lack of access to electricity in favelas. There is an effort to combat the illegal electricity connections in Brazilian informal settlements and since the 1990s, attempts have been made to formally supply electricity to them. However, energy is a very expensive commodity in an informal settlement. Law 3735/2015 (Câmara dos Deputados, 2015) establishes that energy should be more financially accessible for the population in need. However, few initiatives based on that law were conducted and the need for accessible electricity in informal settlements is still a problem to overcome.

In this research, we study a favela (a Brazilian informal settlement) called Santa Marta and located in the city of Rio de Janeiro, Brazil. The monthly energy consumption at the settlement is 264,858.33kWh (Paradis 2015). Santa Marta favela is well located within the formal city (Minoja 2010) being at a short distance from the downtown, prime neighborhoods, iconic monuments, and touristic attraction of the city. The settlement is physically contained by the high reliefs from the hill where it is located and the formal part of the city.

This paper presents a viability study for a sustainable energy policy in informal settlements.

2 Methodology

In this research, we use a case study, Santa Marta favela, to model its capacity to generate solar energy and to ponder the economic benefits of this clean energy solution. The hypothesis for this paper is that the economy from preventing illegal electric connections justifies the costs for the installation of residential solar energy kits. The research was developed in four main steps: (1) data collection of the case study, (2) modeling the case study, (3) running computational simulations for energy consumption and energy generation for the case study, and (4) analyzing the results and drawing conclusions.

2.1 Data collection and processing

The first step involves data collection from the Santa Marta favela to create a digital 3D model of the settlement. Table 1 shows a description of the collected data, with the type of data, source, and additional important comments. Figure 1 shows examples of the data collected.

Table 1. Santa Marta favela data collection.

Type of data	Source	Comments
Topographic chart	Municipal Archives of Rio de Janeiro	The chart did not include urban information as the favela is not officially recognized by the municipal bureau.
Map of Santa Marta favela	Public Construction Company (EMOP)	Outdated map (from 2012) with building footprints, building uses, building materials, and streets.
Imagery of Santa Marta	site visits (2015, 2016, 2018, 2019)	Imagery helped to update information about changes in the urban fabric and to establish the height of the buildings.

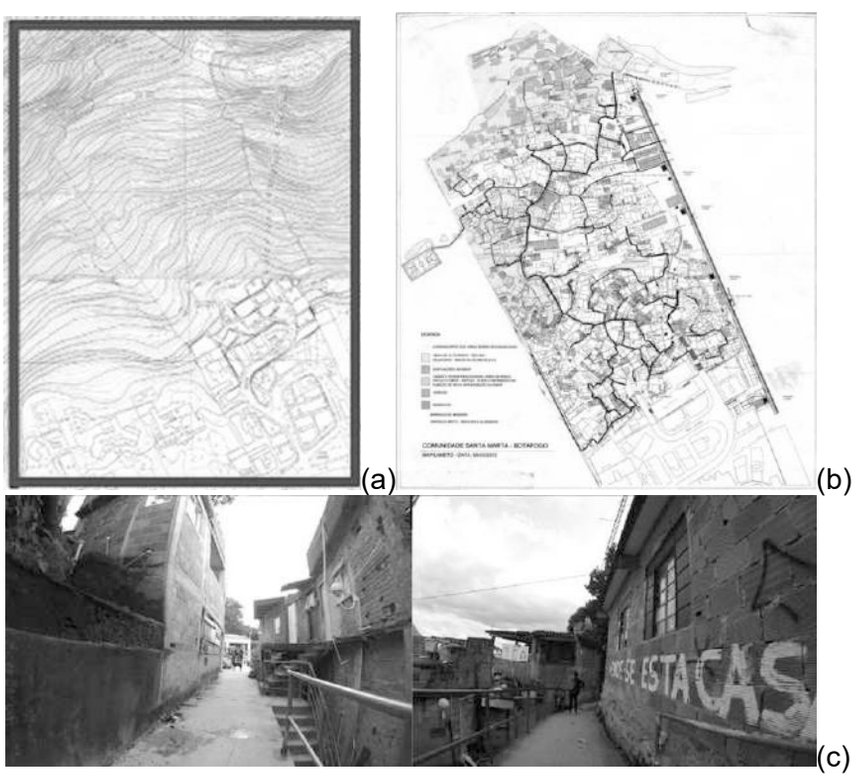

Figure 1. Examples of data collected from Santa Marta favela: (a) topographic chart, (b) Map of the settlement, and (c) examples of imagery. Source: Made by the authors.

The topographic chart and the map of the Santa Marta favela were not available in digital format. Both were scanned and the distortions were corrected using a LISP routine on AutoCAD. Then the scanned images were used as the base to create a ".cad" file of the Santa Marta favela with topographic and urban information (2D plan). Figure 2 shows the resulting 2D plan.

Figure 2. 2D plan of Santa Marta favela. Source: Made by the authors.

2.2 Modelling the case study

Researchers used the case study's data to construct a 3D digital model of the case study. The construction of the digital model used the 2D plan and imagery from the settlement. The 2D plan provided information about the terrain and the location of the buildings while visual data provided information about building heights, which was entered in a spreadsheet file.

The construction of the model used Rhinoceros 3D (Rhino) CAD software and standard Grasshopper (GH) plug-in components of. The contour lines provided the information necessary to generate the terrain surface in Rhino using the command "Surface>Path". To speed up his procedure, a code was developed in GH (Figure 3).

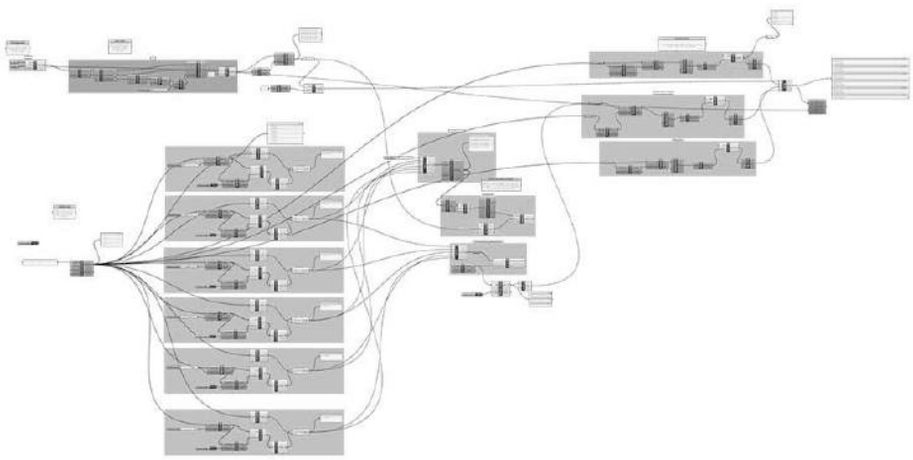

Figure 3. General view of the Grasshopper code developed to aid the 3D modeling process. Source: Made by the authors.

This code imports information on terrain surfaces and building footprints to create the three-dimensional projection. Building height information from imagery is retrieved from the spreadsheet file and projected in the 3D model. Figure 4 shows the finished 3D model.

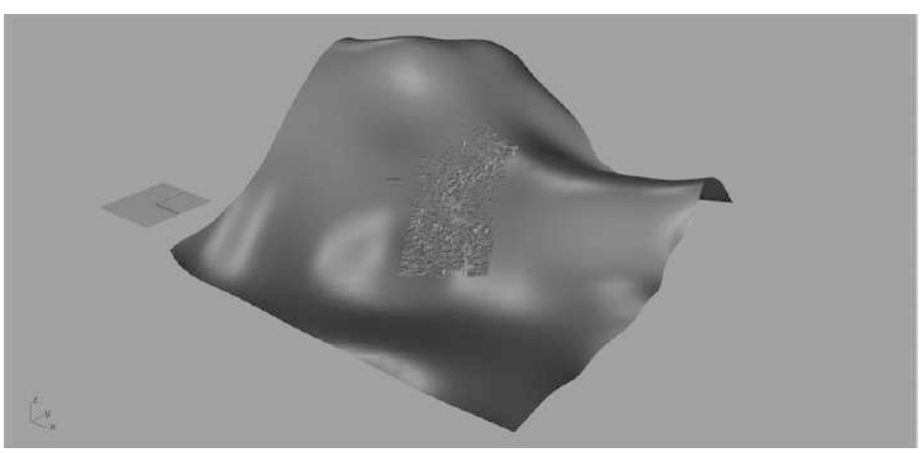

Figure 4. 3D model of Santa Marta favela. Source: Made by the authors.

2.3 Simulation and analysis

The researchers used the 3D model to run solar simulation. This step is important because the case study is located at the side of a hill and researchers were not sure if the area would receive solar exposition due to its

topography. Researchers were interested to know if the roofing of the buildings would receive direct solar irradiation.

The simulation was performed using Rhino, GH, and the Ladybug (LB) add-on. The source of climatic data, from the LB website, was a ".epw" file (https://www.ladybug.tools/epwmap/) and the location was the closest to the favela available (Rio de Janeiro - Vila Militar lat: -22.86, lon> - 43.41, tz: -3.0, elev:45.00). A code in GH imports the climate data and crosses it with the 3D model of Santa Marta favela (Figure 5) using the add on LB to analyze solar irradiation during different times of the year. Figure 6 shows the projection of the sun chart over Santa Marta favela, marking the position of the sun in each hour of each day of a one-year period, from 6 am to 6 pm.

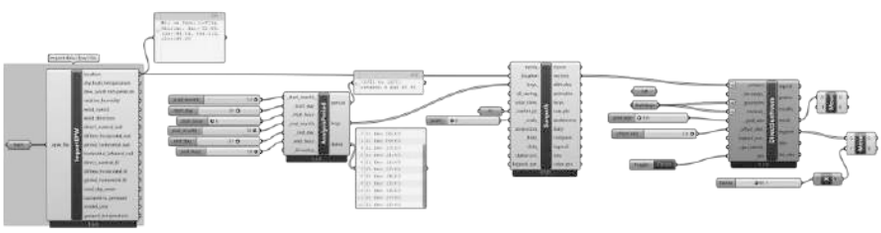

Figure 5. Climatic analysis algorithm. Source: Made by the authors.

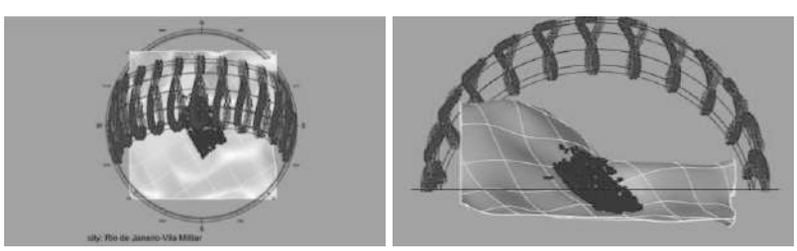

Figure 6. Projection of the sun chart over Santa Marta favela. Source: Made by the authors.

To determine if the settlement had solar exposition on the building roofs, the researchers simulated both solstices as these would be the days where the settlement would receive the highest (Summer - December, 21st) and lowest (Winter - June 21st) irradiation.

For the Summer solstice, the simulation starts at 6:00 am and ends at 6:59 pm. Figure 7 shows the respective projections for sunrise, noon, and sunset and Figure 8 shows the total exposition during that day for Santa Marta favela.

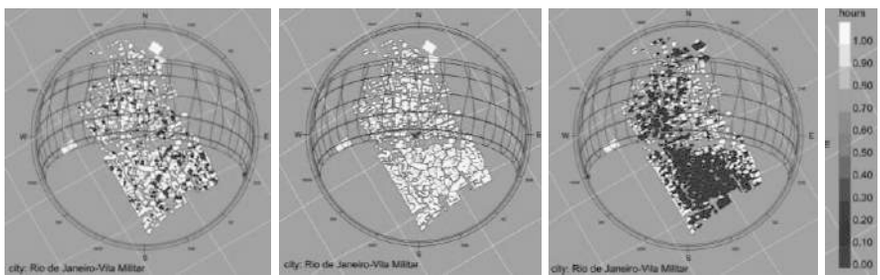

Figure 7. Solar exposition at 6 am (left), 12 pm (center), and 6 pm (right) during the Summer solstice. Source: Made by the authors.

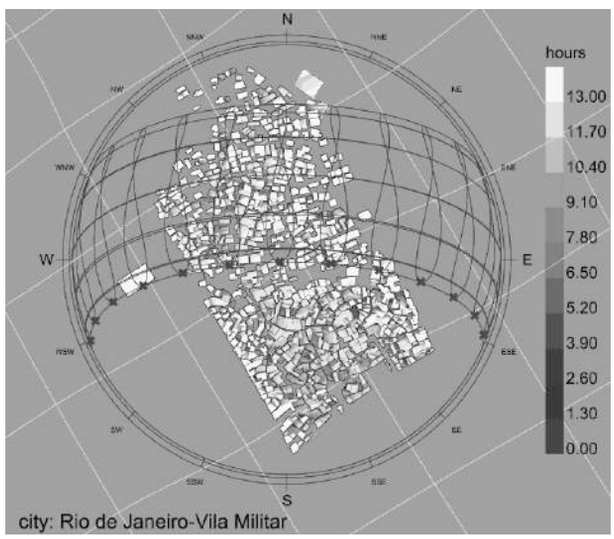

Figure 8. Projection of solar exposition during the Summer solstice. Source: Made by the authors.

For the Winter solstice, the simulation starts at 7 am and ends at 5:59 pm. Figure 9 shows the respective projections for sunrise, noon, and sunset and Figure 10 shows the total exposition during that day for Santa Marta favela.

The solar simulation using LB shows that Santa Marta favela has solar exposition even during the Winter solstice. To determine the amount of energy that could be generated, we followed the steps presented by Neris (2021):

The author (Neris 2021) first determines the production per panel per month (considering a generic panel with potency equals 410W):

$$Emp= p*r*30 \quad (1)$$

Emp: energy generated per month per square meter; p: panel's potency; r: daily average radiation. To determine the average radiation, we used the Global Solar Atlas, available at (https://globalsolaratlas.info/map?c=

11.523088,7.998047,3). For the city of Rio de Janeiro, r= 4.035kW/sqm. Emp= 0.410*4.035*30*0.19= 9.43kWh/sqm per month.

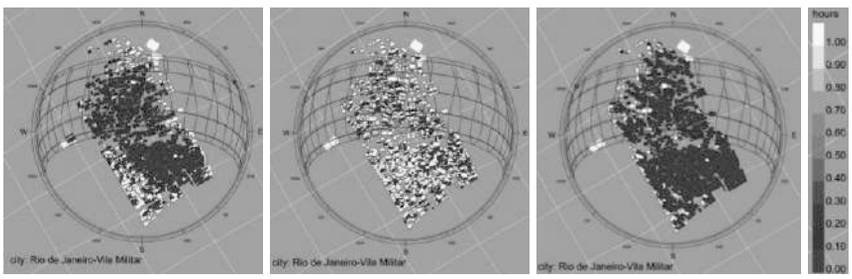

Figure 9. Solar exposition at 7 am (left), 12 pm (center) and 5 pm (right) during the Winter solstice. Source: Made by the authors.

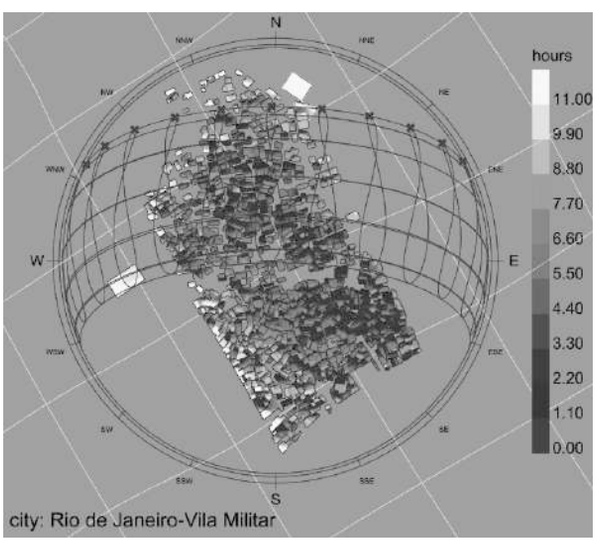

Figure 10. Projection of solar exposition during the Winter solstice. Source: Made by the authors.

Considering that Santa Marta favela has 1177 buildings with a total area of 154,424.33 sqm, the maximum potential energy production in a month for the settlement equals to 1,456,221.43 kWh.

The settlement has the capacity to generate 5.5 times more energy than the amount it consumes, being able to sell the overproduction back to the city of Rio de Janeiro. This could be part of a sustainable energy policy where the profit generated from overproduction could be used to pay for the costs of installment and maintenance of the solar panels.

3 Results

In this paper, we showed the estimation of the capacity for energy production of the Santa Marta favela. First, we generated a 3D digital model of the case study. Then we used this model to verify if the roof of buildings in the Santa Marta favela were receiving sunlight, a necessary condition for the installation of solar panels. These preliminary steps were important to understand the geography of the case study and its potential for the implementation of a sustainable energy policy, related to solar energy production.

The next step was to estimate the capacity of the case study for solar energy production. Results show that Santa Marta has an estimated monthly consumption of 264,858.33kWh and a potential for producing almost 5.5 times that amount (1,456,221.43kWh/month).

4 Discussion

This paper presents a methodology for analyzing the viability of an informal settlement to produce solar energy, where the production surplus cloud be re-soled to generate benefits for the community. Although applied to a specific case study, this methodology can be applied to different scales of similar problems, using the potential to produce solar energy as an instrument for energy justice.

The work shown in this paper is an estimation of the settlement's potential to generate solar energy. The community was not consulted at this stage. For future work, that estimate should be reviewed to reflect the interest of the residents in installing solar panels in their homes. The study will also benefit from a more precise calculation of solar radiation using, for example, machine learning strategies.

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5 References

Câmara dos Deputados. (2015). Lei 3735/2015 Estabelece o Programa de Eletrificação de Interesse Social (Establishes the program for accessible electricity) . Disponível em: https://www.camara.leg.br/proposicoesWeb/prop_mostrarintegra;jsessionid=F8C2A232675F5954775235587558F5F1.proposicoesWeb1?codteor=1419928&filename=Avulso+-PL+3723/2015

Compans, R. (2007). A cidade contra a favela: a nova ameaça ambiental (The city agains the favela: the new environmental threaten). Revista Brasileira de Estudos Urbanos e Regionais, 9(1), 83–99.

Davis, M. (2006). Planet of slums, London; New York: Verso.

Instituto Brasilerio de Geografia e Estatística - IBGE. (2020). Aglomerados subnormais 2019 : classificação preliminar e informações de saúde para o enfrentamento à COVID-19 : notas técnicas. (Subnormal clusters 2019: preliminar classification and health information to combat the COVID-19: technical notes). IBGE: Rio de Janeiro.

Minoja, L. (2010). Favelascape. Tools of integration for the favela Santa Marta in Rio de Janeiro. (Bachelor), Politecnico di Milano, Milano, Italy. Retrieved from https://issuu.com/livia.minoja/docs/favelascape-part1

Neris, A. (2021) Artigos Técnicos Energia Solar. Como fazer o cálculo do sistema fotovoltaico com eficiência? (Technical articles, Solar Energy. How to calculate an efficient photovoltaic system?) In: https://www.aldo.com.br/blog/como-fazer-o-calculo-do-sistema-fotovoltaico-com-eficiencia/. Retrieved: July, 10th 2022

Paradis, E. S. (2015). Estudo de implantação de um sistema de produção de energia solar na comunidade Santa Marta (Study for a system of solar energy production on Santa Marta favela). Bachelor thesis. Federal University of Rio de Janeiro.

Salingaros, N. A., Brain, D., Duany, A. M., & Mehaffy, M. W. (2006). Favelas and Social Housing: The Urbanism of Self-Organization. In Proceeding of the Brazilian and Ibero-American Congress on Social Housing, Federal University of Santa Catarina, Florianopolis, Brazil, p. 48.

Sharifi, A., Pathak, C. J., He, B.J. (2021). A systematic review of the health co-benefits of urban climate change adaptation. Sustainable City and Society (74). https://doi.org/10.1016/j.scs.2021.103190. https://www.sciencedirect.com/science/article/pii/S2210670721004686

Tavares, F. R. (2017). Gatos na favela: Eletrificação, segregação espacial e des-integração da vida cotidiana nas favelas cariocas. (Illegal electricity connections in the favela: electricity, spatial segregation, and disintegration of the everyday life in Carioca favelas) In: Zaar, M., Vasconcelos P. Junior, M., Capel, H. (Org.). La electricidad y el territorio. Historia y futuro. 1ed.Barcelona: Geocrítica, 2017, v. , p. 01-. http://www.ub.edu/geocrit/Electr-y-territorio/FelipeTavares.pdf

United Nations (Ed.). (2019). The sustainable development goals report 2019. In: https://unstats.un.org/sdgs/report/2019/The-Sustainable-Development-Goals-Report-2019.pdf. Retrieved: July, 10th 2022

United Nations Human Settlements Programme (Ed.). (2003). The challenge of slums: global report on human settlements. London; Sterling, VA: Earthscan Publications

Architectural Diversity of Residential Buildings through Digital Design and Robotic Construction

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Abstract. The housing demand in Latin America has promoted to build big complexes with repetitive designs to ensure their execution and commercialization, but neglecting the differences in occupation, cultures, ages, abilities, genders, climates and locations. Producing low quality, environmental deterioration and social alienation. This work exposes a parametric programming and robotic construction strategy to develop a varied residential process. Based on structural volumes and 3d-printed walls, to provide a diversity of housing configurations. The modular generation of volumes and development of the envelope is programmed to meet various thermal and occupational conditions, with printing trajectories for the walls according to the equipment, execution processes and material capacities. A repertoire of 494 residential volumes has been defined and prototype walls have been made, suggesting an innovative design system, wich provides a new paradigm for housing construction with digital technologies and robotic execution to diversify residential quality.

Keywords: housing, digital fabrication, 3D printed, construction, parametric design, mass-customization

1 Introducción

América Latina tiene la tasa de urbanización más alta del mundo y una demanda creciente de viviendas para renovación y crecimiento poblacional (Greene & Mora, 2021; Gilbert, 2001). Esto ha impulsado una producción inmobiliaria mayormente basada en sistemas constructivos convencionales con formas repetitivas de vivienda, a pesar de la alta diversidad geográfica y social del territorio (Salas, 2000). En estas iniciativas masivas, muchas veces el diseño arquitectónico se supedita a estrechas normativas y resultados económicos, generando soluciones similares basadas en una intuición comercial con razonamientos financieros, que producen un panorama urbano con alienación cultural y desánimo social (Rojas, 2017).

Sin embargo, las tecnologías avanzadas de diseño y construcción permiten desarrollar edificios con producción automatizada y diversidad mediante la personalización masiva de viviendas (Pinto Duarte, 2005). Para ello, se usa la modelación digital, para definir diferentes diseños, programar los recursos y dirigir máquinas de control numérico para elaborar la construcción (Sass, 2007; Cascone *et al.,* 2017). Varias experiencias alrededor del mundo están mostrando incipientes capacidades al respecto, en particular con construcción impresa-3D, aunque esta tecnología todavía requiere refuerzos estructurales y desarrollar procesos de diseño adaptados a condiciones locales (Khajavi *et al.*, 2021; Guaman *et al.,* 2022). Además, se cambia el trabajo arquitectónico orientado a soluciones únicas para desarrollar procedimientos basados en secuencias de tareas y parámetros variables para planificar viviendas diversas y adecuadas (Weger *et al.*, 2021). Este artículo presenta una experiencia en desarrollo de programación de diseño y construcción robótica para edificios residenciales en América Latina, con el fin de explorar nuevas vías para la demanda habitacional.

2 Desarrollo

La metodología está compuesta por tres fases: (1) la conceptualización de una estrategia constructiva modular, (2) la programación del proceso de diseño y construcción, y (3) la ejecución de prototipos y edificios ejemplares que verifican la estrategia, culminando con una discusión de condiciones y proyecciones.

2.1 Definición de volúmenes

La propuesta se inició por la participación de los autores en un concurso internacional, y se basa en combinar una estructura principal modular y muros impresos-3D para realizar edificios de vivienda diversos y eficientes. La estructura principal se define con una trama de columnas y losas de hormigón armado, con pocos muros centrales, para poder soportar edificios de diferentes tamaños con un sistema constructivo habitual en América Latina. Luego, se pueden ejecutar muros impresos-3D en cada piso para las divisiones y envolventes externas conformando distintas unidades habitacionales, de formas variadas y condiciones térmicas adecuadas a diferentes climas.

La estructura se compone de una retícula longitudinal con un módulo central de 2 m de ancho para desarrollar un corredor central, y módulos residenciales a ambos lados de 3 x 6 m transversales, más 1 m extendido en el borde. La trama se establece con unas reglas según longitud y número de plantas para cubrir varias alternativas de edificios, desde un solo módulo residencial en una planta (sin pasillo) hasta 24 módulos de longitud y 25 plantas

con pasillo y escalera lateral y ascensores, con el mismo sistema estructural (figura 1).

Esta estrategia permite definir 600 formas diferentes de edificios entre los rangos establecidos, de los cuales 106 se descartan por su estrecha proporción vertical (que requiere más elementos estructurales), pero las 494 alternativas permitidas pueden albergar edificaciones desde 40 hasta 29 600 m^2 de superficie total y de 29 a 24 600 m^2 de superficie útil (descontando circulaciones y la mitad de los bordes para balcones). Este repertorio puede abarcar desde viviendas unifamiliares y series adosadas hasta bloques residenciales y torres, como la mayoría de los proyectos inmobiliarios y sitios urbanos de América Latina, así como también formar conjuntos con combinación de volúmenes edificatorios. Un conjunto puede disponer de diferentes tipos de vivienda con el mismo sistema constructivo y procesos de diseño para promover la diversidad social y una organización eficiente.

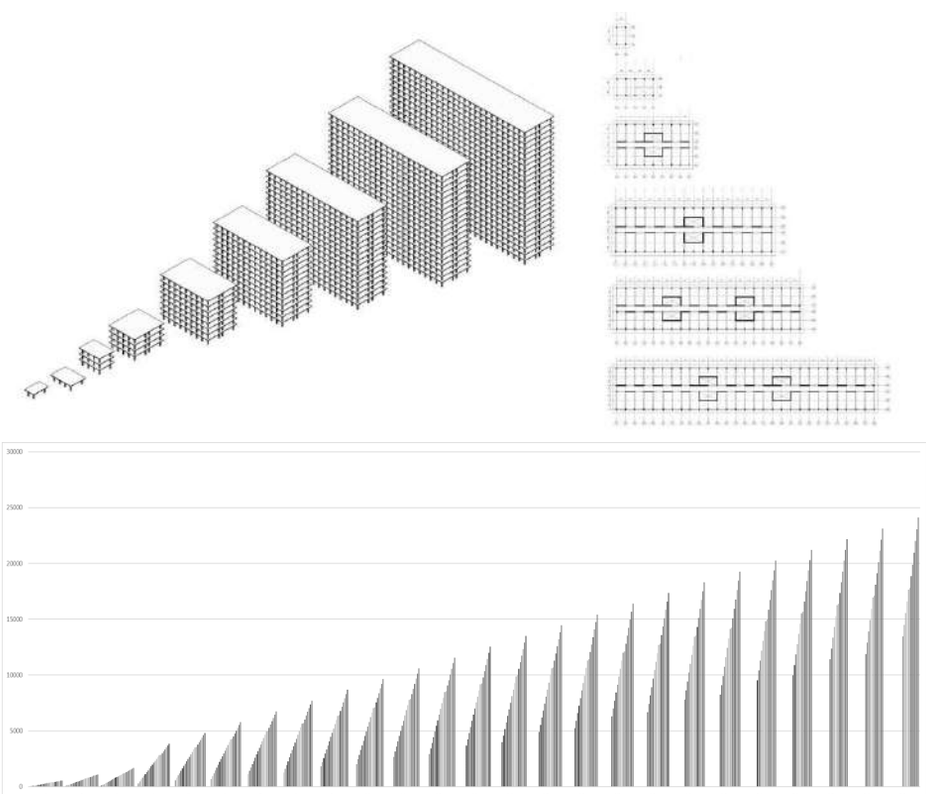

Figura 1. Ejemplos de volúmenes y plantas (arriba), y gráfica de superficie total de cada alternativa según cantidad de módulos y plantas (abajo)

Los elementos estructurales definidos ocupan alrededor del 2 al 3% de la superficie total construida por planta, por lo que la estrategia puede involucrar menos material estructural que una configuración tradicional. Además, las edificaciones residenciales en las zonas sísmicas habituales en América Latina tienen alrededor del 50% al 75% de divisiones como muros de carga, incluyendo la separación entre unidades, lo que suele limitar los tipos de casas o departamentos, definiendo usualmente de 2 a 6 posibilidades con cambios menores (solo cantidad de dormitorios). La trama propuesta tiene unos pocos muros de carga en el corredor principal (más columnas en el borde), por lo que se puede ocupar la mayor parte de superficie en planta libre para distribuir desde un módulo para un estudio individual hasta todo el piso (48 módulos más corredor) para un gran departamento o recinto comunitario, o muchas combinaciones, incluso de dos o tres plantas con escalera interior y vacíos. Esto otorga una gran versatilidad para acomodar diferentes tipos de viviendas y diseños en el mismo edificio, incluyendo terrazas, espacios comunes, diferentes formas de habitaciones y relaciones exteriores (en particular en la envolvente). Los que se pueden combinar con el diseño digital y la construcción automatizada para definir con los propios habitantes, incluso durante la ejecución, y desarrollar cambios en la vida útil del edificio para adaptarse a la diversidad y progresión de la vida contemporánea.

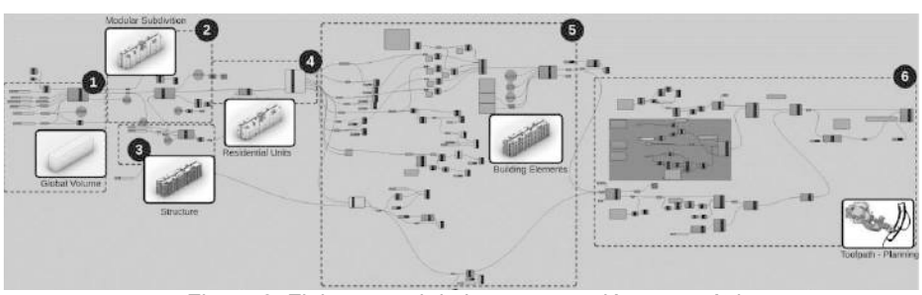

Figura 2. Flujo general de la programación paramétrica

2.2 Diseño paramétrico

Además, se está desarrollando un flujo de trabajo paramétrico en relación con modelos BIM, dibujos CAD y datos de diferentes especialidades hasta la elaboración de archivos para planificar la ejecución y controlar la impresión 3D robótica (Davtalab *et al.,* 2018; Anane *et al.,* 2021; Ashrafi *et al.,* 2022). También se producen visualizaciones para revisar los diseños, que pueden ser elaborados para la participación de los usuarios en algunas decisiones de diseño y/o modificación de las viviendas a través del tiempo.

La programación se desarrolla en varios pasos (figura 2); primero, la definición del volumen global de acuerdo con el tamaño del sitio y la regulación local, así como el monto de la inversión [1], con base en las reglas establecidas para los planos y pisos [2]. En segundo lugar, la subdivisión modular según la

grilla definida [3] y, luego, el modelado de la estructura en base a los tamaños y elementos definidos [4]. La información geométrica generada se puede vincular a un modelo BIM para detallar piezas y datos asociados, y también al análisis estructural para verificar el desempeño de acuerdo con las condiciones locales. Se ha detallado por completo y analizado estructuralmente el diseño de dos edificios, con elaboración de planos y planificación constructiva.

El paso siguiente de la programación es la distribución de las unidades residenciales con base en los requerimientos de los usuarios y el plan comercial del conjunto [5]. Esta parte se puede integrar con el modelo BIM para la elaboración de *renders* y recorridos de realidad virtual, tal como se ha realizado en los dos edificios en desarrollo, con el fin de revisar el tratamiento interior y distribución de espacios. La organización de las unidades se basa en reglas de adyacencia y permite incluir espacios externos como terrazas y balcones, y también puede elaborar una lista de tipos de vivienda con superficie por unidad para la gestión comercial y de instalaciones (figura 3).

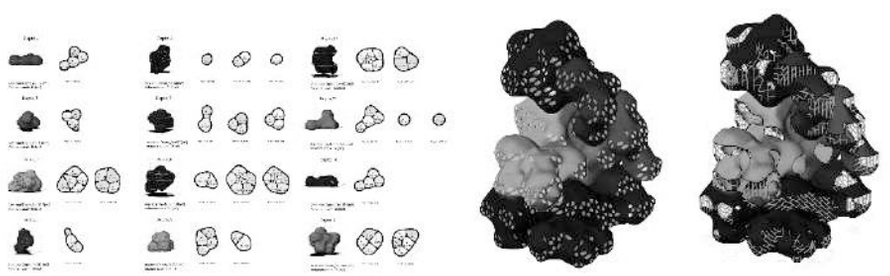

Figura 3. Unidades residenciales

Luego, en la programación se detallan los elementos constructivos a ejecutar con construcción automatizada [6], en particular los muros impresos en 3D (figura 4). Esta elaboración implica la generación de algunas formas digitales nuevas para unir y/o dividir elementos de construcción, y para exportar datos para programación y planificación. Los muros impresos en 3D son, en su mayoría, de forma curva para aprovechar la flexibilidad geométrica de la impresión robótica y la mayor resistencia lateral, así como la fluidez del espacio interior, la diversidad y la identidad de la expresión exterior. Por último, la programación de la trayectoria para la impresión 3D se genera en función de la subdivisión de las paredes. Estas trayectorias están definidas por las características del equipo específico y la mezcla que se utilizará, incluyendo el corte vertical de elementos con la altura de capa adecuada y la deformación del material, y la duración de la movilidad del equipo. Además, la capacidad de producción o almacenamiento de la mezcladora y la bomba puede condicionar los tamaños de las piezas y la secuencia de impresión. En ese paso, las normas locales consideran la textura de la superficie de la pared, el refuerzo

interno y el aislamiento para los requisitos térmicos, acústicos y contra incendios. Los archivos para ejecutar la construcción se generan y normalmente se verifican en el sitio con algunos refinamientos.

2.3 Construcción robótica

La ejecución de los edificios residenciales propuestos combina elementos prefabricados para la estructura principal e impresión 3D robótica para los muros. La estructura principal está compuesta por piezas regulares de hormigón armado; losas, columnas, vigas y muros de las mismas formas y tamaños (10 elementos diferentes). Además, presenta barras de refuerzo de acero similares y encofrados modulares, en particular tableros monolíticos de aluminio, que pueden usarse repetidamente y producir una terminación lisa, evitando tratamientos adicionales. El hormigón se puede preparar en fábrica y vaciar en obra con bombas elevadoras, utilizando una mezcla autocompactante que proporciona un acabado plano y de rápido endurecimiento. Esta técnica en los últimos años ha sido cada vez más implementada en varios países latinoamericanos para diferentes tipos de construcciones, demostrando una importante reducción de tiempos de ejecución y presupuesto adecuado, en particular con piezas regulares. Este procedimiento implica un detallado proceso de modelado y planificación del edificio para organizar el suministro e instalación de piezas, así como la coordinación y actuación de proveedores; estudios de ingeniería y arquitectura con una adecuada gestión del diseño, e integración de servicios y otros elementos constructivos con plataformas BIM. Estas capacidades también están aumentando en la región con una producción inmobiliaria regular.

Los refuerzos de barras de acero se suelen preparar en obra con plantillas trazadas con base en láminas generadas por el modelo BIM e instaladas con gráficas por teléfono o tabletas, y en algunos casos marcas de realidad aumentada (RA). Los encofrados modulares se preparan igualmente por familias y láminas preparadas en modelo BIM, y se montan en obra con máquinas de apoyo automatizadas y fijación manual. El concreto puede ser provisto y volcado por empresas de concreto premezclado, y el proceso general controlado por un gemelo digital del modelo BIM y revisar la calidad de las partes realizadas mediante monitoreo automatizado.

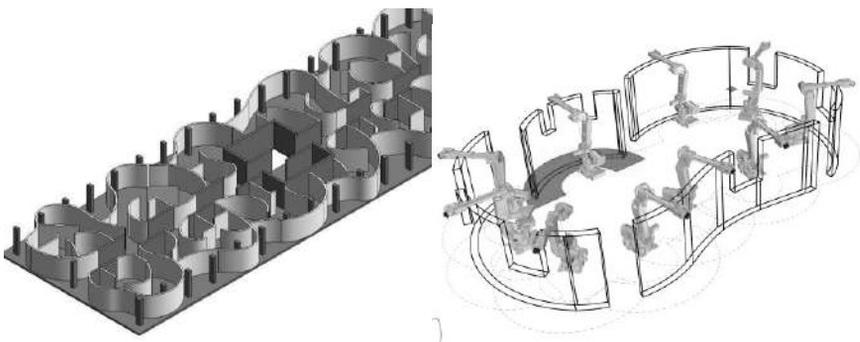

Figura 4. Estrategias de impresión 3D de los muros

La impresión 3D de elementos constructivos es todavía una tecnología incipiente, con pocas experiencias en Latinoamérica y en el mundo. Por ello, para esta propuesta se está probando su aplicación mediante una estrategia de ejecución en obra, y de la disposición secuencial de un brazo robótico de largo alcance para ejecutar las divisiones y paramentos con diferentes condiciones térmicas y tratamientos. Se realizaron pruebas con un robot Kuka R120 2500 en funcionamiento estacionario, con bomba de impulsión y mezcladora de hormigón de 120 l.

Figura 5. Ejemplos de muros impresos en 3D

Se han realizado prototipos de muros impresos en 3D con diferentes características y tamaños (figura 5), algunos de baja altura para probar el proceso de ejecución y la incorporación de revestimientos, aislamientos y barras de apoyo; además, otros segmentos de altura completa con superficies texturizadas, formas curvas e integración de servicios, ventanas y puertas. También se está ensayando la duración y el mantenimiento, así como el traslado, el afianzamiento a los suelos y la estanqueidad entre piezas. Asimismo, se han probado los diferentes roles de las personas involucradas

en este nuevo proceso de construcción: arquitectos que desarrollan y ajustan el diseño y programación, técnicos de construcción que gestionan la bomba de hormigón, y expertos en automatización que configuran el robot y la impresión. Estos prototipos han demostrado la capacidad de imprimir elementos con materiales y trabajadores locales, y adaptar equipos extranjeros. También se realizaron visitas con público a los prototipos de muros, consultando la apreciación de sus propiedades materiales y formales. Los visitantes expresan mayormente una valoración positiva de estos elementos, en particular por su originalidad, durabilidad y curvatura, cuestionando algunos aspectos de color y textura, pero con amplias expectativas de integrar en ambientes domésticos.

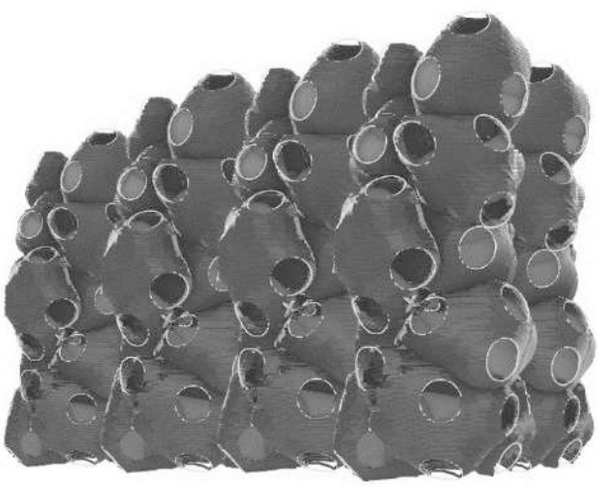

Figura 6. Agrupación residencial

3 Discusión

Propuestas de edificios habitacionales con una estructura principal y divisiones variables o cabinas intercambiables han sido sugeridas varias veces durante el siglo XX (Canales, 2021), aunque escasamente aplicadas. En América Latina, los conjuntos de Proyecto Experimental de Vivienda (Previ) Lima y Elemental Chile plantearon intenciones similares, con viviendas unifamiliares, pero sin un sistema constructivo o procedimiento de diseño. También muchas viviendas actualmente consideran o realizan espontáneamente autoconstrucción de sus habitantes, pero con baja calidad de ejecución debido a la falta de control de diseño y construcción. La estrategia planteada aquí integra procesos formales y equipos automatizados para regular la elaboración del diseño y construcción habitacional, con una gran

diversidad de tipos y formas de edificación, incluyendo alternativas de baja a alta densidad urbana; aunque todavía en desarrollo y con varias condiciones que deben ser verificadas y sistematizadas.

El repertorio de volúmenes permite un sistema de ejecución para la estructura principal, con piezas regulares, que pueden ser realizadas por constructores locales para diferentes edificios. Para ello, se deben comprobar condiciones particulares, como la resistencia estructural y la disponibilidad de moldajes y concretos adecuados. La integración de muros impresos en 3D para divisiones y envolventes proporciona una gran flexibilidad y variedad arquitectónica, que debe combinarse con los servicios para baños y cocinas, y también con sistemas de calefacción y refrigeración. Además, la ejecución en cada planta debe planificarse y prepararse en obra, lo que presenta diferentes ventajas y desventajas, y en ambos casos tener una solución adecuada para aislamiento, sellado y afianzamiento. Asimismo, el perfil curvo de las paredes es atractivo, pero debe integrar ventanas, puertas y muebles. Estos desafíos se están gestionando en la ejecución de unos edificios iniciales, por lo que se adquirirá experiencia al respecto.

Probablemente, la característica más prometedora de la estrategia es la participación de los usuarios en el diseño y la construcción, ya que esta posibilidad ha sido sugerida en muchas iniciativas, pero se ha implementado poco en la ejecución real de viviendas. La organización del proceso de diseño, con desarrollo algorítmico, de manera que pueda integrar diversas variables y generar alternativas de formas, es una capacidad central para esta condición, aplicando un proceso “anexacto” de protogeometrías (Lynn, 1998). En esta interacción se debe probar la participación de usuarios a través de visualizaciones y decisiones de diseño, incluido valorar su impacto en los resultados económicos y desempeño del edificio, así como en su ejecución. Además, la oportunidad de cambiar las particiones durante la vida útil de la vivienda es un potencial particular que depende de la tecnología de los muros. Este desarrollo avanza en el sueño largamente planteado de casas adaptables, y también desafía el rol de la arquitectura en este proceso, en el que la calidad y sensación emocional de los espacios se puede regular y adaptar a sus habitantes según características constructivas variables. Así, el diseño arquitectónico puede cambiar desde establecer formas únicas por intuiciones básicas hasta gestionar sistemas y equipos de trabajo con soluciones variadas que abarquen la diversidad y la sensibilidad de la vida.

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Referencias

Ashrafi, N., Nazarian, S., Meisel, N. & Pinto, J. (2022). A Grammar-based Algorithm for Toolpath Generation: Compensating for Material Deformation in the Additive Manufacturing of Concrete. *Additive Manufacturing*, *55*, https://doi.org/10.1016/j.addma.2022.102803

Anane, W., Iordanova, I. & Ouellet-Plamondon, C. (2021). The use of BIM for Robotic 3D Concrete Printing. En *CSCE 2021 Annual Conference* (pp. 325-336).

Cascone, P., Galdi, F., Giglio, A. & Ciancio, E. (2017). Architectural Self-fabrication. *International Journal of Parallel, Emergent and Distributed Systems*, *32*, S39-S53.

Canales, F. (2021), *Mi casa, mi ciudad: privacidad en un mundo compartido*. Editorial Puente.

Davtalab, O., Kazemian, A. & Khoshnevis, B. (2018). Perspectives on a BIM-integrated Software Platform for Robotic Construction through Contour Crafting. *Automation in Construction*, 89, 13-23.

Gilbert, A. (2001). *La vivienda en América Latina*. Banco Interamericano de Desarrollo.

Greene, M. & Mora, R. (2021), *Hábitat residencial*. Editorial ARQ.

Guamán, R., Martínez, A., García, R., Muñoz, C., González, L. F. & Auat Cheein, F. (2022). Recent Developments and Challenges of 3D-printed Construction: A Review of Research Fronts. *Buildings*, (2), 1-32.

Lynn, G. (1998). *Folds, bodies & blobs.* Editorial La Lettre voLee.

Khajavi, S., Tetik, M., Mohite, A., Peltokorpi, A., Li, M., Weng, Y. & Holmström, J. (2021). Additive Manufacturing in the Construction Industry: The Comparative Competitiveness of 3D Concrete Printing. *Applied Sciences*, vol. 113865.

Pinto, J. (2005). Towards the Mass Customization of Housing: The Grammar of Siza's Houses at Malagueira. *Environment and Planning B: Planning and Design*, *32*(33), 347-380.

Rojas, L. (2017). Ciudad vertical: la “nueva forma” de la precariedad habitacional. *Revista 180*, *39*, 1-17.

Sass, L. (2007). Synthesis of Design Production with Integrated Digital Fabrication. Automation in Construction,*16*, 298-310.

Salas, J. (2000). *La industrialización posible de la vivienda latinoamericana*. Escala.

Weger D, Gehlen, C., Korte, W., Meyer-Brotz, F., Scheydt, J. & Stengel, T. (2021). Building Rethought - 3D Concrete Printing in Building Practice. *Construction Robotics, 5*(3), pp. 203-210.

Special Topics: Media Art

Drawing with bare hands: a hand-gesture based drawing experience with motion sensors.

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Abstract. One of the features that makes analog drawing so fascinating is its manual component. The path of a graphite line on the sheet, the different pressure of the stroke, the texture described by an entropic movement, the unexpected residues of dirt, each of these things virtually refers to the intervention of a hand. This research unfolds around the idea of using the movement and gestures of the hands as a basis for the generation of forms for architectural design. Not three-dimensional models, but flat shapes, two-dimensional digital drawings generated by the author's gestures. Through a Leap Motion sensor and a digital drawing program, all the various forms of freehand drawing were explored, finding an interesting result in the field of free shape generation linked to hand gestures. The result of this experience is a different way of seeing gestures as a generative tool of architectural forms, to be used into architectural design process.

Keywords: Media art, Digital drawing, Shape generation, Gesture, Motion sensors

1 Introduction

The definition "Architectural Representation" includes within it a varied spectrum of graphic outputs. We can include study sketches, definitive drawings, CAD-produced designs, photorealistic renderings, architectural photographs, and any type of output representing a built or unbuilt architectural space. Within this paper architectural representation has been approached with a very specific approach. Among the many paths of representation, the one that has been traveled starts from the most classical premises: a hand holding an object designed to depict something. A stick on the ground or a pencil on a sheet of paper, there is little difference in the moment when the protagonists of the action lead to the same result, albeit with different graphic style: the description of a space.

Hand drawing was for hundreds of years the only tool that architects had at their disposal to control often insurmountable complexity. The continuous

refinement of drawing techniques led in the late 1900s to a quality in analog representation that has never been equaled. The advent of digital drawing, from CAD to its evolutions in terms of 3-D modeling, have slowly widened the mesh of architectural representation leading to an inflation in terms of styles and quality, expanding a field that to this day is trying to find margins that are getting further and further apart. Within this situation a permanent center of gravity is represented by analog hand drawing. It, though often relegated to the background within the most avant-garde faculties of architecture, continues to maintain unchanged its status as the primal locus of architecture's development and eventual study. Sketching allows an immediacy in recording data that digital still fails to provide. In addition, hand drawing possesses something that digital can never even simulate, and that is gesturality. In it often lies the fascination with analog drawing. The way a pencil is gripped, how its tip comes into contact with the sheet of paper, the pressure of the tip on the roughness of the support, and finally the actual gesture of the performer of the drawing, which between muscle memory and creative darting produces strokes impossible to simulate (Fig. 1).

For who is writing beginning with gestures in representation was therefore a due act, if not the only one possible when approaching drawing. The hand is the performer of the gesture, an irreplaceable appendage that allows one to better control spaces and directions previously only imagined. A human hand is subject to error and contradictions. The gestures of our hands are at the basis of creation through drawing: in order to create they are always in contact with the instrument that mediates our thinking. We inevitably pass from some object (pencil, pen, nib, brush, digital pen, mouse, VR controller) to an output. Each of these instruments interprets the gestures of the hands through their own peculiarities. This consideration introduces the possibilities of gestures in the digital realm as well. Some tools such as CAD software do not provide for it, but new technologies are increasingly moving in this direction. The possibility of interacting in digital environments through tools that detect our gestures is becoming more and more essential year by year for hardware manufacturers and not only. Digital giants such as Meta (formerly Facebook) and their Oculus virtual reality headset are granting increasing space to the enjoyment of their devices through simple hand movements. Gestures, in the specific the motion tracking technology, thus become a tool to humanize and make less mechanical operations limited to the digital environment, with mixed results that not infrequently make one regret the classic mouse and keyboard.

At this point the question that arises is: is gestural drawing something easily translatable into the digital environment? Is analog manual dexterity necessarily the starting point, or at least the ambition, of image production in the digital environment?

This study, starting from the assumptions of the Doctoral Thesis of one of the two authors, unfolds trying to answer these questions, starting from the reduction of the parts involved: it is only the hands that generate the signs. The drawing then becomes bare-handed.

Figure 1. Sketches of architectures from the Ostiense Area in Rome. These sketches were produced in less than 3 minutes each. They are the study sketches produced in order to capture the mood and architectural qualitites of a specific area of Rome. Source: Drawings by F. Rebecchini, 2022.

2 Methodology

2.1 Hardware and Software

Motion tracking systems allow the quantitative study of human body motion. With them it is possible, for example, to calculate the angle between two body segments, the position of a body's center of gravity, or the distribution of forces in the limbs. Originating in the medical field for the study of the pathophysiology of the musculoskeletal system, they now find application in numerous fields, from the design of medical prostheses to sports analysis, to digital animation in film and video games, to virtual reality applications REF.

In this study focused on motion capture graphics, a LEAP motion and a digital painting software were used.

LEAP motion is an optical markerless tracking device produced by the American company Leap Motion Inc. and has been on the market since May 2013, the development of which began in 2008. It is, essentially, a device through which it is possible to interface with a computer by tracking the user's hands. The LEAP motion can track the finger movements of both user’s hands, going so far as to define the position of the individual phalanges of each finger, with a claimed accuracy of 0.01 mm. It is a small USB peripheral that is designed to be placed, facing upward, on a desk between the user and the computer screen. With the presence of two cameras and three infrared LEDs, it can map an approximately hemisphere-shaped area about one meter in diameter. The LEAP software analyzes the objects observed in the device's field of view, recognizing hands, fingers, and any tools being used, while simultaneously reconstructing their position, gestures, and movements.

Corel Painter Freestyle is a graphics software developed by Corel Corporation. It is a version of the more famous Corel Painter program specially designed to work with LEAP motion. The classic version of the software is used

to create artistic images by digitally simulating certain painting techniques: Interfacing with the computer via a graphics tablet, the user can create remarkably realistic images by drawing freehand, thanks to the software's opportunity to simulate a wide selection of classic effects such as watercolor, gouache, oil painting, and many others. In its Freestyle version, this software keeps intact the philosophy behind the classic version about the simulative approach to physical painting and expands the possibilities by allowing the user to relate to the program via LEAP motion.

Today, the software has ended its beta testing phase and is no longer currently available to the public in any form.

2.2 First applications of drawing

In the first phase of the study, our goal was mimesis. We wanted to obtain graphic designs that mimicked the results obtainable from other techniques, whether traditional or digital. By exploiting LEAP motion to process different types of drawings, we came to be able to estimate its effectiveness, its distinctive features, as well as its inevitable criticalities. No attempt was made to elaborate a theory to be later applied to practice: on the contrary, it was the practice itself, experimenting with different graphic solutions, that generated its corresponding theoretical apparatus as a logical consequence of trial and error.

At this stage, our study was developed to recreate the experience of drawing from life that takes place in close contact with architecture, and which has its origin in the architect's notebook and in their ability to analyze buildings through freehand drawing (see also Fig. 1) (Chiavoni, Docci, 2017). An attempt was made to try a similar experience by replacing the classic notebook with a laptop computer coupled with a LEAP motion and using a wooden stick as a virtual drawing tool, emulating real drawing gestures. The real-life drawing experience was conducted using a type of line drawing, thanks to one of the digital graphic tools made available by Corel Painter Freestyle, which simulates the characteristic strokes of graphite and marker pen, configured in such a way as to match variations in hand distance from the screen to the intensity of the mark.

This experience of drawing from life showed all the limitations of instrumental accuracy of LEAP motion: the line drawing is particularly uncertain and shaky. Attempting to reconstruct, for example, the elevation alignments of windows is virtually impossible: the result is a series of flickering, overlapping horizontal lines that are, in the end, meaningless (Fig. 2).

Figure 2. Shaky drawings produced with the aid of wooden stick. The stick was motion tracked by the LEAP Motion. Source: Drawings by A. Diacodimitri on Corel Painter Freestyle, 2016.

2.3 Instrumental accuracy

The degree of instrumental accuracy of LEAP motion has been the focus of several studies, which have established through experimental data its level of reliability. A study (Guna et al., 2014) tested through various procedures the degree of reliability of LEAP motion. A set of static and dynamic measurements was prepared with different tracked objects and varying configurations. For static measurements, a plastic model of a human arm was used, while for dynamic measurements, a special V-shaped instrument simulating two fingers placed at a fixed distance from each other was made. In static measurements, the standard deviation was measured as less than 0.5 mm. Furthermore, this value was shown to increase as the distance of the object tracked by the sensor increased. The results of dynamic measurements revealed poor performance, with a collapse in accuracy for greater distances from the sensor. The conclusions of the research team indicate that:

"The Leap Motion Controller undoubtedly represents a revolutionary input device for gesture-based human-computer interaction. In this study, we evaluated the controller as a possible replacement for a fast and high-precision optical motion capture system in a limited space and with a limited number of objects. Based on the current results and the overall experience, we conclude that the controller in its current state could not be used as a professional tracking system, primarily due to its rather limited sensory space and inconsistent sampling frequency." (Guna et al., 2014)

2.4 The instrumental error betweencontrol and randomness

In addition to aspects related to instrumental accuracy, the main instrumental error issue concerns shadow cones that are created during finger

movement and are referred to as occlusion phenomena. The management of the error related to occlusions is crucial for this study, since, as will be seen, the phenomenon actively participates as a semi casual component in the generation of free form. This phenomenon, by its very nature not eliminable, is generated at the very moment when, during the movement of the fingers of one hand, one finger covers another finger relative to the position of the controller that is tracking its movement. In the short period of time in which this phenomenon occurs, the sensor "loses sight" of the finger, which consequently disappears from the relevant frame, only to reappear again in the next frame, but no longer belonging to the previously traced motion, becoming the starting point of a new motion. This occlusion has strong consequences in terms of the graphic result, since all the shapes that are generated with these procedures will present obvious points of discontinuity, as will be better seen in the paragraphs on the experiences of generating simple and complex shapes, causing on the one hand great difficulties in handling the shape, and on the other hand unpredictable graphic peculiarities worthy of interest. Generally, these occlusions tend to occur more frequently when the hand makes rotational movements.

2.5 Two-dimensional free-form generation

All the described instrumental errors led to the unsatisfactory results described in the section 2.2. This brought to the formulation of a new research path, focusing on the generation of free forms associated with hand gestures. These forms can become tools for architectural design research.

The initial phase of the design process in architecture plays a key role within the compositional process. During this stage, drawings are made so to act within that moment in which the conceptual and spatial complexity of the project is formalized through a quick, jet-like, and (almost always) freehand drawing. The nature of such sketches, from a graphic point of view, is characterized by a very strong level of ambiguity; the meaning of the single sign does not yet have those characteristics of univocity proper to the final drawing, but rather, has precisely in the interpretive variables its greatest strength. The idea is hinted at, is beginning to take shape and will later find substance precisely in its unfolding and unraveling in successive stratifications. In this view, the instrumental imprecision of the analog medium (the pencil, the marker, the paper) plays a fundamental role. In employing these instruments, we take part to a phase of partial randomness, in a still not totally controlled environment that can produce results that are still unexpected. These results almost always require numerous successive iterations before finally coming to fruition.

Instrumental errors, which in other areas have, as we have seen, yielded unsatisfactory results, can here be transformed into a positive quality. At this stage of the study, we focused on investigating the ways in which a free form can be generated through LEAP motion, to understand how controllable this is, how it can be interpreted, and in what ways different movements in hand space

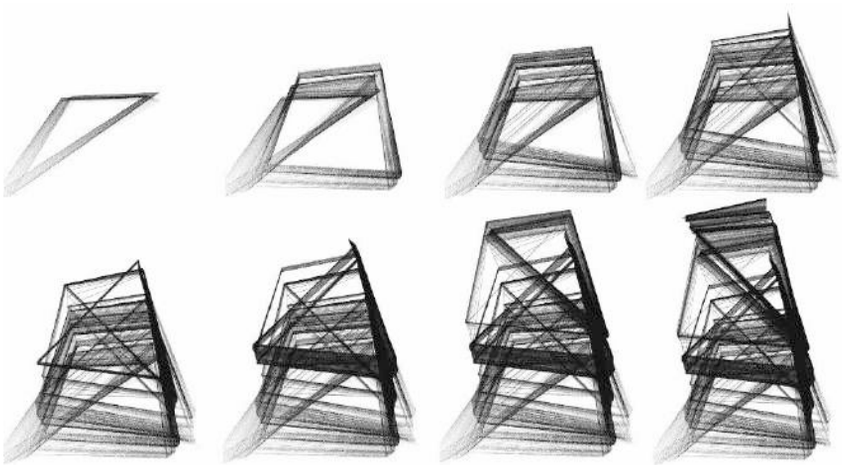

Figure 3. Hand-tracked movements describing a pseudo-axonometric construction. Source: Drawings by A. Diacodimitri on Corel Painter Freestyle, 2016.

are associated with designs that have recurring peculiarities. Within the working environment of Corel Painter Freestyle software, it is possible to act on brush control parameters such as minimum and maximum painting depth, finger spacing, tilt control, and most importantly, it is possible to enable multiple inputs, with 1 or 2 degrees of connection between individual inputs. These possibilities offered by the software make it possible to achieve special graphic results, since they allow several fingers at the same time to collaborate in the realization of the drawing, by tracking the whole opened hand. As a result, compared to single-input operations, the movements that the hand must make are much more organic and complex. This has led to the development of a peculiar graphic language made up of simple 2, 3 and 4-input movements such as translations and rotations, which generate two-dimensional shapes that tend to recur. These forms thus generated were then classified according to the type of gesture that generated them.

When the fingers are made to make movements parallel to each other, a movement is composed, which is here called translation, and which generates simple forms. Such forms develop, of course, according to a single direction. In this case, occlusion phenomena are limited since the fingers all move according to a single direction and thus tend to avoid overlapping one another. This generates shapes that perceptually resemble pseudo axonometric constructions of extrusions along the direction of hand movement (Fig. 3).

By rotating the wrist during hand tracking, the fingers make a rotational movement that graphically transforms into a complex shape. This shape is particularly difficult to read, as the marks tend to overlap without having a chance to develop along a prevailing direction. For this reason, it was preferred to replace the simple rotation movement, which is particularly unmanageable,

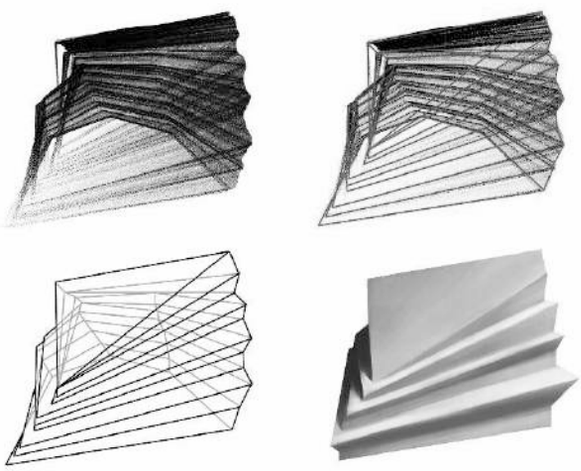

Figure 4. Interpretive process of a form produced by a translation gesture. Source: Elaboration by A. Diacodimitri on Corel Painter Freestyle, 2016.

with a roto translation movement, thus combining the rotation with a linear movement of the whole arm along one direction. In this case the phenomenon of occlusion is particularly present, since at the moment of rotation the fingers tend to create shadow cones and cover each other with respect to the position of the sensor. It has been noted how roto translation movements generate shapes that perceptually recall perspective compositions, probably by virtue of their extreme chaotic nature, within which it is difficult to recognize lines parallel to each other. To this was then added a "modifier gesture," which can be used in both cases, namely finger opening. This distinction between simple and complex forms stems fundamentally from the level of "noise" that the movement generates, caused by the phenomenon of mutual occlusion that is formed between the fingers at the time the gesture itself is performed. As occlusions increase, noise increases and consequently the user's ability to control and manage the form decreases.

This experience can be said to straddle the influences from action painting and those from generative art. Of the former it retains the gestures, the active participation of the body and the transformation of a movement into a representation; with the latter it retains an assonance of results in graphic terms and the fact that the machine, with its errors and imperfections, participates in no small part in the elaboration, although not to the same extent as in generative art.

3 Results

3.1 Interpretation of shapes

It has been said that the shapes elaborated so far undergo a perceptual process by which they are associated with a determined method of representation, although in reality they do not actually respond to any geometrical rules or graphic constructions other than those precedingly described relating to the movements that generated them.

However, indeed, when one observes a shape generated by a translation, it comes naturally to relate it by analysis to an axonometric projection. The reason why this perceptual phenomenon is to be found in several factors. The first factor can be found in the fact that the surfaces that are formed are not graphically pre-sensed as homogeneous and continuous surfaces due to a lag in reception, so a kind of "frame effect" is generated. It allows the entire construction to be seen in transparency and allows all the horizontal sections present on the form to be distinguished. (Fig. 4)

Finally, we must add the component related to the parallelism of the lines: during the translation of the fingers, we obviously tend to keep each finger on a direction vector that (unless there are finger openings) turns out to be always parallel to that of each other finger, because these fingers belong to the same hand. These parallelisms contribute substantially to the perception of the shape as axonometric.

These works remain, as mentioned above, pure suggestions, useful mainly for the advancement of a strongly abstract graphic experimentation. It turns out to be interesting, in this perspective, the component of elaboration linked to the strong randomness of the gesture: in the sphere of artistic expression, the reconnection of such procedures to some aspects of action painting leads to obtaining new and previously not so easily achievable forms. And it is precisely on this principle of "immediacy" of generation that experimentation gains value, aiming at the recognition of gesture and form and free pictorial reinterpretation.

In contrast to what happens with simple forms, where edges and surfaces are clearly visible and exclusively need critical reading, interpretation, and selection; in complex forms this possibility is absent: layered lines, overlaps, intersections and occlusion imperfections are present in such quantity not allowing what in the interpretative process of the simple form took place in the early stages of "polishing" the predominant marks.

3.2 Digital painting over the shapes

By virtue of this, an experimental experience is proposed here that is analogous to the preceding ones in technique but very different in approach, path, and its conclusions, going back to the basic form to a real object that has an extremely elastic connection with that form. Similar to that which a designed architecture may have with one of the first concept sketches that generated it.

Clearly, this implies that the discretionary aspect takes over any kind of analysis in this case: one does not identify lines, surfaces, but rather mass, solid/void ratio and intensity of sign, with the only obligation being to identify each part as being part of a coherent overall perspective representation as far as it can be interpreted.

The initial form worked on Fig. 5 is deliberately extremely complex: it was generated by two particularly articulated rototranslational movements accompanied by a series of finger openings and closings. This shape is first straightened, in order to be able to identify a plausible horizon line and then interpreted as a shape in its entirety. Unlike in the other cases, where the painting operations are "supplementary" to the sign, here the digital pigment becomes preponderant over the original form, and already in the early stages it is possible to see how free the interpreting of the signs is, and how some of them, despite their graphic strength, are not taken into consideration, as they are considered inconsistent with the form that is taking shape. In the subsequent stages, the forms continue to define themselves, seeking a plausible spatial validity: the main triangular forms are configured as covering architectural elements, retaining the spatiality and lines of force of the original form, while other elements are built up for formal coherence until the final elaboration is obtained. Clearly, the representation obtained during this study cannot be defined as a fully designed architecture: too many fundamental elements of the traditional design process are missing to be able to define such forms as architecture, both aesthetically and functionally, constructively and in relation to the context.

3.3 Conclusions

What in the original intentions would have made the difference within this path would have been the variation, induced by the atypicality of the instrument, of the gestuality of the act of drawing.

Almost immediately, these original intentions were contradicted, overturned by the evolution of experimentation, by the realization of the actual potential of these instruments, but also by the instrumental limitations encountered, by the problems that emerged over time, and, why not, by a personal sensibility that led to favoring some solutions at the expense of others, probably just as valid.

The LEAP motion is undoubtedly a valid instrument, fascinating in some ways and with great potential, yet it presents a whole series of problems related to instrumental precision that in fact could easily dilute any easy enthusiasm, especially if one takes into account the fact that, according to its producers, its extraordinary precision should be its workhorse.

Paradoxically, what it should do best, namely the precision design, becomes what it does worst.

In the area of form generation, there are numerous possibilities that new technologies offer, such as parametric modeling; yet, it is precisely here that one can see the decidedly atypical potential of LEAP motion compared to other,

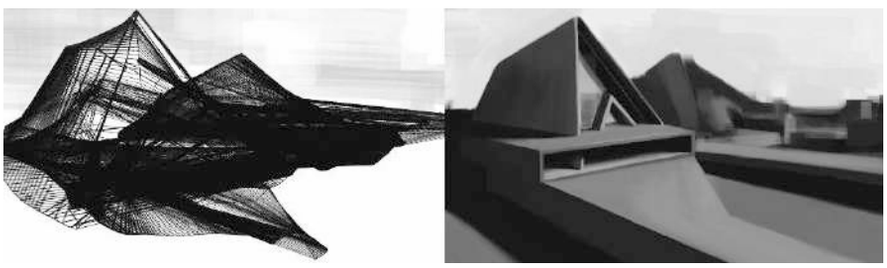

Figure 5. Digital painting over a free form. Source: Elaboration by A. Diacodimitri on Corel Painter Freestyle and Adobe Photoshop, 2016.

more widely used tools: first of all, the figure of the human being, which is "physically" central to the process (and thus not only on an intellectual level), as well as a newfound starring role of drawing as a pure graphic expression of an intention.

The correspondence found between hand gesture and graphic result has in itself a value that relates directly to drawing understood as a material act that performs a certain mental process, thus returning in a sense to the true roots of drawing for design.

Certainly, the results that are obtained with these experimentations are unique, difficult to replicate with other tools (and certainly not with the same immediacy). But their evocative component is still prevalent, especially because of certain cumbersomeness in the process of rationalizing forms.

Further investigation, from a more purely geometric point of view, will be necessary regarding the modalities with which these forms are spatially interpreted, perhaps trying to reconstruct different projection centers that return different patterns of the same projection, in order to hypothesize whether there are some that we are inclined to exclude because they are considered implausible. Precisely the perceptual aspect, which has been addressed here exclusively as a function of the study of the properties of the final products that can be obtained from the two-dimensional forms generated with movement, may become an even more fundamental element of the research, thus necessitating a more reasoned, rigorous, and complete investigation.

4 Discussion

Something as personal and vibrant as the gesture has become the new territory to be colonized by giant technology corporations. Our gestures are increasingly adapted to the tools we are led to purchase, and understanding our movement is just one more attempt to make us familiar with very often unnecessary devices. The example of the Oculus visor from the aforementioned Meta is illustrative in this regard. It is a hardware that has been

constantly implemented (Buckingham, 2021) despite the inevitable problems related to hand tracking (Abdlkarim, …, 2022). The company's CEO Mark Zuckenberg envisions a future where, wearing our headsets, we can meet and work in the Metaverse. Still, everything seems to be extremely vague (Broderick 2022-1). What is implicit is the humanization of a digital space, populated by avatars, that promises endless possibilities. The actual need and usefulness of these digital spaces is all to be proven (Broderick 2022-2), but what this research tries to express is how very often tools born for a certain intent take on completely new connotations.

Experimentation in the field of drawing thus becomes a case study scalable to even very different disciplinary fields. The search for a known and familiar gesture in a novel environment brings to the surface criticalities that are often hidden. Only by changing the point of view, following a trial & error that leads to greater understanding, is it possible to fully understand the possibilities of a tool. What was created for an intent finds through experimentation a new method of expression.

Through the exploration of the possibilities of drawing with bare hands, it is possible to understand how a different gesture, always the result of the human hand, becomes the key to new discoveries. The digital environments in which we will soon move will, hopefully, also find in human gesture a point of reference.

References

Guna, J., Grega, J., Pogačnik, M., Tomažič, S., Sodnik, J. (2014). An Analysis of the Precision and Reliability of the Leap Motion Sensor and Its Suitability for Static and Dynamic Tracking. Sensors, 14, 3702-3720. https://www.mdpi.com/1424-8220/14/2/3702

Buckingham, G. (2021). Hand Tracking for Immersive Virtual Reality: Opportunities and Challenges. Frontiers in Virtual Reality, October 2021, Volume 2, Article 728461, 6 pp. https://doi.org/10.3389/frvir.2021.728461

Abdlkarim D., Di Luca, M., Aves, P., Yeo, S.H., Miall R.C., Holland, P., Galea J.M. (2022). A Methodological Framework to Assess the Accuracy of Virtual Reality Hand-Tracking Systems. A case study with the Oculus Quest 2. Preprint bioRxiv. https://doi.org/10.1101/2022.02.18.481001

Broderick, R. (2022-1). A New World of Cronut Lines. Garbage Day. Retrieved June 28, 2022, from https://www.garbageday.email/p/a-new-world-of-cronut-lines

Broderick, R. (2022-2). You Don’t Need a House in the Metaverse. Garbage Day. Retrieved June 28, 2022, from https://www.garbageday.email/p/you-dont-need-a-house-in-the-metaverse

Bingham, N. (2013). 100 Years of Architectural Drawing. Laurence King Publishing.

Chiavoni, E., Docci, M. (2017). Saper leggere l’architettura. Laterza.

Special Topics: COVID-19

JOI - Personal equipment to manipulate knobs without direct hands contact

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Abstract. The contagious COVID-19 pandemic made it necessary to adopt strategies to avoid contamination. COVID-19 spreads when someone is in direct contact with small droplets and particles that contain the virus. These droplets and particles can be active on surfaces that are shared by many people, so hand sanitation became an important aspect to prevent virus contamination. However, products for hand sanitation may not be available easily everywhere. Moreover, the excessive use of products like hand sanitizers and hand soaps can cause dryness and dermatitis on certain users. This paper describes the rapid prototyping of JOI, a device for users to avoid touching doorknobs, door bolts, switchers, and call buttons. The device was 3D printed (more than 400 units) and distributed to an academic community, which then answered a usability survey. Results show that the device is efficient to avoid the direct contact of users and surfaces that may be contaminated.

Keywords: COVID-19, Digital Fabrication, 3D Print, Personal Protective Equipment, Good Health and Well-Being.

1 Introdução

As infecções derivadas da influenza ou gripe são as maiores causadoras de doenças e mortes na população atualmente, as quais podem gerar patologias agudas do sistema respiratório promovida por vírus e com alta capacidade de transmissão (da Costa, 2016; Merchan-Hammann, 2016). Não muito distante, no início do século XX, o vírus influenza foi o causador de uma das maiores pandemias já ocorridas, a Gripe de 1918 (Pogan, 2021; Feitosa, 2021).

A Organização Mundial da Saúde (OMS), em 3 de dezembro de 2019, recebeu o alerta de casos de pneumonia em Wuhan, na China, e após uma semana as autoridades locais confirmaram a identificação de um novo coronavírus ao qual foi denominado como SARS-COV-2. A OMS, no dia 30 de janeiro de 2020, declarou o ocorrido como Emergência de Saúde Pública

de Importância Internacional (ESPII) e em 11 de março a COVID-19 foi elevada ao nível de pandemia (Opas, 2021).

No Brasil, o Ministério da Saúde foi notificado da primeira confirmação de caso do novo coronavírus no país em 26 de fevereiro de 2020 (Boletim Epidemiológico, 2020), em 17 de março ocorreu o primeiro óbito e três dias depois foi decretado transmissão comunitária em todo território nacional (Cavalcante et al., 2020). E em primeiro de janeiro de 2021, o Brasil ultrapassou a marca de 22 milhões de casos acumulados e 619 mil óbitos acumulados (Ministério da Saúde, 2022).

Apesar do ineditismo da doença, a forma de propagação deste vírus não se difere muito dos demais. O COVID-19 é disseminado por pequenas gotículas e partículas respiratórias contaminadas, oriundas de indivíduos portadores da doença, que contamina outras pessoas ao serem inaladas quando entrarem em contato com olhos, boca e nariz (Center for Diseases Control and Prevention - CDC, 2022).

Ainda vale destacar que, o vírus SAR-COV-2 pode ser identificado em superfície por um tempo que varia de horas a dias de acordo com o material do objeto (Marquès, 2021; Domingo, 2021), no qual pode causar contaminação de mãos, ou outras partes do corpo que podem ser direcionadas para olhos, boca ou nariz. Objetos como maçanetas, trincos, ferrolhos, botões de elevadores, interruptores e torneiras são de uso coletivo e essencial. Assim, com o retorno das atividades presenciais surge a preocupação com contaminação em superfícies compartilháveis.

Devido a fácil proliferação do Coronavírus, foi necessária a adoção de medidas para evitar a disseminação rápida da doença. Dentre os métodos de prevenção destacam-se, a higienização das mãos, a adoção de lenço ou braço ao tossir e espirrar, a ventilação de ambientes, o uso de máscaras, a não aglomeração e o não compartilhamento de objetos (Tribino et al., 2021). Além disso, com o intuito de minimizar a propagação do vírus, medidas de suspensão de aulas presenciais, cancelamentos de eventos e fechamento de fronteiras foram adotadas por governadores no Brasil (Antunes et al., 2020).

É certo que, com o retorno das atividades presenciais e a maior circulação de pessoas em salas e locais de trabalho, uma alternativa seria a higienização frequente das mãos. Porém, a frequente e repetida limpeza delas com água e sabonete é associada a problemas como ressecamento e a dermatite crônica de contato e o uso assíduo de soluções alcoólicas sem emolientes, umectantes, etc. podem causar ressecamento da pele (Alves et al., 2020).

A pandemia do COVID-19 gerou uma demanda repentina por equipamentos de proteção individual (EPI's) em todo um mundo, na qual a indústria não estava preparada para suprir de imediato, e diante desse fato uma poderosa ferramenta utilizada como alternativa foi a fabricação digital (Quintella, 2021; Florêncio, 2021).

Makers e designers fizeram parte de iniciativas no qual desenvolveram e produziram equipamentos com a finalidade de combater a pandemia, com o

auxílio de tecnologias como a impressão 3D e a cortadora a laser que permitem agilidade na produção e customização (Ferreira et al., 2020).

Assim, esse trabalho objetiva apresentar um acessório individual, produzido por meio da fabricação digital, denominado de JOI. O JOI tem como principais funções auxiliar o usuário a acionar interruptores e botões, para ligar e desligar torneiras, abrir e fechar portas e janelas sem a necessidade de tocar com as mãos nas maçanetas, ferrolhos, trancas ou qualquer outra parte do objeto acionado. Sendo assim, apenas o equipamento JOI terá contato com as superfícies que possam estar contaminadas, evitando o ressecamento e dermatite em virtude do excesso de uso de produtos de higienização das mãos. Apenas JOI precisaria ser higienizado com frequência.

2 Metodologia

A fim de diminuir a disseminação do vírus por meio de superfícies potencialmente contaminadas, foi adotada uma metodologia de caráter experimental para estudos de ergonomia, contato e usabilidade.

Os procedimentos metodológicos adotados se dividem em cinco partes: 1- Investigação teórica e similares; 2- Estudo de superfícies potencialmente contaminadas no campo; 3 - Desenvolvimento de alternativas e testes com protótipos confeccionados por fabricação digital com auxílio de impressoras 3D; 4- Dispersão de protótipos com aplicação de questionário com utilizadores e; 5- Análise dos resultados.

Na primeira parte foram pesquisados projetos semelhantes em buscadores de patentes e repositórios de modelos 3D. Quanto às patentes registradas, não foi identificado nenhum produto que desempenhasse a mesma tarefa. Já nos repositórios colaborativos foram encontrados extensores de maçanetas e um acessório em específico que abria exclusivamente portas.

Na segunda parte foi feita uma pesquisa de campo no campus de uma universidade pública da região nordeste do Brasil a fim de estimar as alternativas possíveis para diminuir o contato das pessoas com os utensílios do dia-a-dia, com mais atenção nas maçanetas presentes no ambiente de estudo, salas de aula, laboratórios, janelas e ferrolhos.

Percebeu-se que devido ao grande número de portas da Universidade, e os diferentes modelos de maçanetas, a melhor alternativa era buscar por algo com o desenho universal, que em um único objeto fosse possível manusear diferentes superfícies. Também seria importante seguir um desenho mais simplificado para agilizar a produção.

Na terceira parte, foram feitos esboços criativos do objeto de manuseio sem contato. A partir disso, foi dado início à modelagem virtual dos protótipos, testando formatos, tamanhos e quais eram os elementos necessários para

manusear as diversas superfícies. Foram feitos vários testes de usabilidade a cada redesign e prototipagem por impressão 3D, até encontrar uma solução tecnicamente adequada.

Na quarta parte, para validar a usabilidade do objeto, foram impressas mais de 400 unidades do objeto e dispersos randomicamente no campus. Foi apresentado um pequeno vídeo com explicação dos diversos usos e solicitado que após um tempo de teste fosse preenchido um questionário anônimo.

O questionário foi desenvolvido com cinco perguntas objetivas com base na ISO 9241 (Tabela 1), que define cinco critérios para produtos com boa usabilidade. São eles: Eficácia, Eficiência, Engajamento, Tolerância ao erro e Facilidade de aprendizado. As respostas foram feitas com base na escala de Likert (Pontes, 2020), com relação à concordância de cinco pontos - dois negativos (discordo totalmente e discordo) e três positivos (nem concordo e nem discordo, concordo, concordo totalmente).

Tabela 1. Perguntas de usabilidade do produto

Número da pergunta	Elemento de avaliação	Pergunta
1	Aprendizagem (easy to learn)	Você conseguiu realizar as tarefas básicas do JOI, marcadas na questão anterior, de forma simples, ao primeiro contato com o acessório?
2	Eficiência (efficient)	Depois de entender como o JOI funciona e de ter testado algumas vezes, você consegue realizar as tarefas (abrir/fechar portas, acionar botões...) sem dificuldade?
3	Efetivo (effective)	Depois de um tempo sem utilizar o JOI, você consegue realizar as tarefas sem dificuldade?
4	Tolerância a erros (Error tolerant)	O produto é simples? Você fica satisfeito por usar o JOI e evitar tocar em superfícies potencialmente contaminadas?
5	Satisfação (Engaging)	O produto é simples? Você fica satisfeito por usar o JOI e evitar tocar em superfícies potencialmente contaminadas?

Fonte: Autores, 2022

3 Resultados

Como resultados são apresentados o produto final desenvolvido e a avaliação com os utilizadores.

3.1 Resultados do produto desenvolvido

O produto desenvolvido, batizado de JOI, que está registrado no processo de patente BR 10 2022 006730 9, se mostrou útil no manuseio de maçanetas, janelas e ferrolhos, tal como apertar botões e acionar interruptores, funciona ainda como uma espécie de chaveiro, tornando-o um elemento de fácil acesso para usar e transportar.

O JOI foi desenhado com inserção de elementos ergonômicos como detalhes antiderrapantes e chanfrados visando o melhor uso e desempenho do protótipo, de forma que ele pode ser utilizado com conforto e facilidade.

O modelo foi concebido utilizando o software de desenho tridimensional Rhinoceros e prototipado em material ABS com impressora 3D de filamento. As figuras 1, 2, 3 e 4 mostram o modelo final que seguiu para testes com utilizadores.

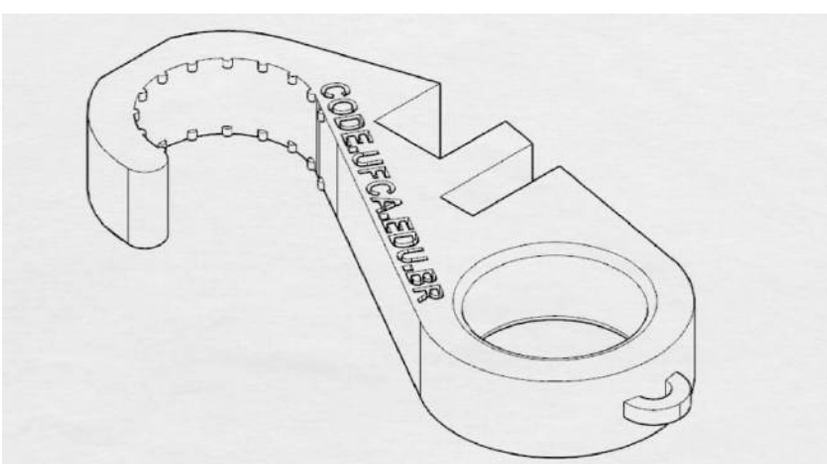

Figura 1. Vista isométrica do JOI em software de desenho: Autores, 2022**.**

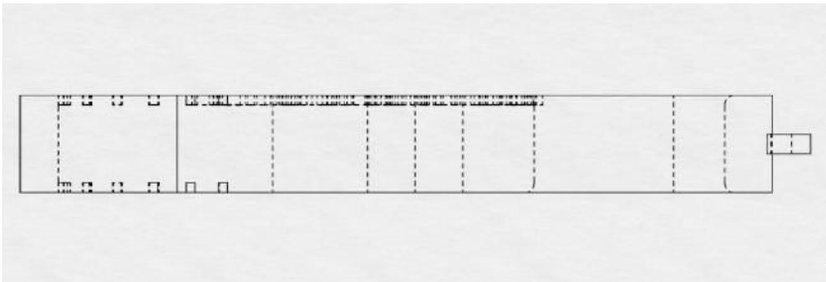

Figura 2. Vista lateral do JOI em software de desenho: Autores, 2022**.**

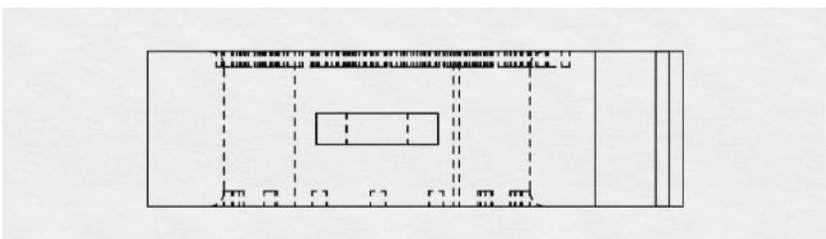

Figura 3. Vista fundo do JOI em software de desenho: Autores, 2022**.**

Cada detalhe do JOI foi desenvolvido para desempenhar uma funcionalidade diferente. Na Figura 4 estão apontados esses detalhes e na Tabela 2 tem a legenda dessas partes e suas funções para as quais foram projetadas.

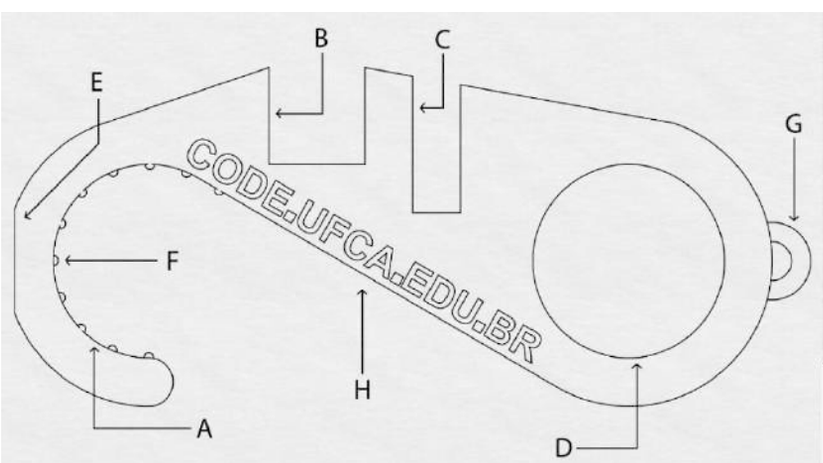

Figura 4. Vista topo do JOI em software de desenho: Autores, 2022**.**

Tabela 2. Relação das partes do JOI com relação de uso.

Parte	Indicação de uso
A	para agarrar os modelos longos de maçaneta
B e C	para abrir janelas e ferrolhos
D	para encaixar o dedo do usuário
E	para apertar botões e interruptor
F	para aumentar o atrito e fixação do gancho nas maçanetas
G	para inserir a argola para chaveiros
H	para indicar o website com o questionário de avaliação

Fonte: Autores, 2022

3.2 Resultados da avaliação do produto

Com o modelo definido, deu-se início à etapa de produção ampliada para dispersão e avaliação do JOI. O método escolhido para a fabricação dos protótipos foi o de impressão 3D, com impressoras do tipo FDM (Fused Deposition Modeling), com filamentos de ABS (Acrilonitrila Butadieno Estireno), um filamento polímero feito a partir do petróleo que possui uma boa resistência, durabilidade, esterilizável com álcool e fácil acesso no Brasil.

Foram produzidos mais de 400 JOIs, que foram distribuídos randomicamente para a comunidade acadêmica, no período de volta às aulas e atividades presenciais, como forma de minimizar a disseminação do vírus devido ao aumento no contato dos usuários com o ambiente acadêmico.

Os usuários tiveram acesso a um vídeo explicativo do uso do JOI e foram solicitados que, após o teste do dispositivo, o usuário respondesse a um questionário sobre a usabilidade do produto.

Do total 400 JOIs distribuídos, houveram 71 respondentes (N = 71). Destes 69% alegaram usar o JOI no período de uma semana a um mês, 25,4% menos de uma semana e 5,6% alegaram que usaram o JOI num período de mais de um mês.

Em relação a Quantas vezes o JOI foi utilizado por dia, 39,4% alegaram que usaram de 3 a 5 vezes ao dia, 38% menos que 3 e 22,6% alegaram usar o JOI mais de 5 vezes por dia.

A Tabela 3 apresenta as respostas oriundas da pergunta que busca saber para quais utilidades o JOI foi acionado.

Tabela 3. Resposta da pergunta: Você já utilizou seu JOI em (marque todas as opções em que se encaixa).

Opções de respostas	Porcentagem de pessoas que marcaram
Abrir/fechar porta (maçaneta regular)	87,3%
Abrir/fechar janela	35,2%
Abrir/fechar trinco	42,3%
Acionar interruptor	62%
Acionar botão	69%

* item multivalorado

Fonte: Autores, 2022

Diferentes utilizadores descreveram ter utilizado o JOI de outras maneiras além das pensadas pelos criadores do produto. Foram elas: 1- usado como chaveiro; 2- para empurrar porta; 3- para tirar máscara alheia; 4- como brinquedo; 5- em guarda-roupa e gaveta; 6- como cabide para máscara; 7- como fidget toy (brinquedo antiestresse); e 8- para tirar a máscara. Assim, fica evidente que o JOI foi mais utilizado na função de abrir e fechar portas seguido da funcionalidade de acionar botões.

No segundo bloco do questionário de usabilidade adotado, as questões avaliaram o JOI quanto à aprendizagem, eficiência, efetivo tolerância a erros e satisfação, conforme ISO 9241. A Tabela 4 apresenta os resultados.

Tabela 4. Dados provenientes do questionário

	Discordo totalmente	Discordo	Nem concordo/ Nem discordo	Concordo	Concordo totalmente
1. Aprendizagem (easy to learn)	0,0	1,4	14,1	46,5	38,0
2. Eficiência (efficient)	0,0	2,8	4,2	53,5	39,4
3. Efetivo (effective)	0,0	1,4	28,2	39,4	31,0
4. Tolerância a erros (Error tolerant)	0,0	11,3	22,5	46,5	19,7

5. Satisfação (Engaging)	0,0	4,2	5,6	42,3	47,9

Fonte: Autores, 2022

Deste modo, após apresentação dos dados, pode-se observar que a respeito da aprendizagem 46,5% concordaram, seguidos de 38% que concordaram totalmente. Além disso, sobre eficiência, mais da metade (53,5%) afirmaram concordo e 39,5% concordo totalmente. Como também, 39,5% concordaram e 31% concordaram totalmente no que tange à afetividade do produto.

Ainda mais, quando verificado a respeito da tolerância a erros, 46,5% concordaram, enquanto 22,5% afirmaram nem concordar e nem discordar. Entretanto, ao questionar sobre a satisfação 47,9% concordaram totalmente e 42,3% concordaram.

4 Conclusões

No mundo, vários objetos foram fabricados em impressoras 3D para o combate ao COVID-19, desde produtos de auxílio às atividades médicas até equipamentos de proteção individual e coletiva. O JOI pretende ser mais um destes produtos de fácil dispersão mundial, uma vez que as impressoras 3D estão mais acessíveis.

Quanto aos resultados da avaliação com utilizadores, temos uma eficiência e satisfação superiores a 90%. A aprendizagem e efetividade do produto também apresentaram bons resultados, trazendo valores positivos para o acessório. O menor índice da avaliação foi o da tolerância ao erro, porém este ainda foi positivo. Ressalta-se que a maior parte dos utilizadores que avaliou mal este item, preencheu o questionário com menos de uma semana de uso.

Portanto, após os estudos realizados fica evidente a importância do JOI no dia a dia dos usuários, funcionando de forma adequada, para acionar interruptores e botões, para abrir e fechar portas e janelas sem tocar nas maçanetas, ferrolhos, trancas ou qualquer outra parte do objeto acionado, e assim minimizar a possibilidade de contágio do SARS-COV-2 ou outros vírus de transmissão similar que provoquem prejuízo à saúde humana.

Referências

Alves, B. B.; Ferreira, D. B; Santos, G. C. D.; Neto, L. C.; Conforte, M. D. S.; Silva, M. R.; Bertini, P. V. R. (2020). *Cuidados com a pele durante a pandemia de coronavírus - orientações para prevenir lesões de pele relacionadas ao uso de epis e à lavagem de mãos*. Escola paulista de enfermagem. Universidade Federal de São Paulo.

Antunes, B. B. D. P., Peres, I. T., Baião, F. A., Ranzani, O. T., Bastos, L. D. S. L., Silva, A. D. A. B. D., ... & Bozza, F. A. (2020). Progressão dos casos confirmados de COVID-19 após implantação de medidas de controle. *Revista Brasileira de Terapia Intensiva*, 32, 213-223.

Cavalcante, J. R., Cardoso-dos-Santos, A. C., Bremm, J. M., Lobo, A. D. P., Macário, E. M., Oliveira, W. K. D., & França, G. V. A. D. (2020). COVID-19 no Brasil: evolução da epidemia até a semana epidemiológica 20 de 2020. *Epidemiologia e Serviços de Saúde*, 29.

Center for Disease Control and Prevention. (2022). *Protect yourself*. Disponível em: www.cdc.gov/coronavirus. Acessado em: 17 de fevereiro de 2022.

da Costa, L. M. C., & Merchan-Hamann, E. (2016). Pandemias de influenza e a estrutura sanitária brasileira: breve histórico e caracterização dos cenários. *Revista Pan-Amazônica de Saúde*, 7(1), 15-15.

Ferreira, T. C. B., de Lima, K. M. P., & Araújo, K. M. *Designers do Movimento Maker no Combate ao COVID-19: análise de iniciativas em Pernambuco*

Ministério da Saúde (2022, fevereiro 17). Centro Nacional de Vacinação e Doenças Respiratórias (NCIRD), *Divisão de Doenças Virais*. Disponível em:https://covid.saude.gov.br/. Acessado em 15 de março 2022 .

Marquès, M., & Domingo, J. L. (2021). *Contamination of inert surfaces by SARS-CoV-2: Persistence, stability and infectivity*. A review. Environmental research, 193, 110559.

OPAS (sine die). *Definição de mídia social*. Organização Pan-Americana da Saúde. Recuperado em abril 01, 2022, em https://www.paho.org/pt/covid19/historico-da-pandemia-covid-19.

Pogan, I., & Feitosa, S. G. (2021). Da Gripe Espanhola à Covid-19 histórico das pandemias dos séculos XX e XXI e impactos da pandemia do coronavírus. *Redes-Revista Interdisciplinar do IELUSC*, (4), 77-88.

Pontes, T. B. (2020). *"ENSINO DA PROGRAMAÇÃO INFORMÁTICA PARA ESTUDANTES DE ARQUITETURA: Aplicação Do Modelo Instrutivo 4C/ID e Seus Efeitos Nos Conhecimentos, Motivação e Aprendizagem Autodirigida."* Universidade de Lisboa.

Quintella, I. P., & Florêncio, E. Q. *A CONTRIBUIÇÃO DA FABRICAÇÃO DIGITAL NAS AÇÕES DE COMBATE À COVID-19. EDUCAÇÃO MEDIADA POR TECNOLOGIAS*, 136.

Tribino, U. M., do Amaral, C. P., Kasperavicius, J. P., dos Santos, R. M., Simonetti, A. B., Lindemann, I. L., ... & Acrani, G. O. (2021). Adesão às medidas de prevenção à Covid-19 no Rio Grande do Sul. *Revista da AMRIGS*, 65(1), 44-51.

Life Long Learning and Digital Education:
Hybrid Education

Emergency Immersive Stimulation: An Approach to Educational Artifacts

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Abstract. The case study describes the effects of immersive stimulation and its factors that affect the attitude of students in pandemic times. The experiment used an educational plan and immersive artifacts with a situated approach. The case study used a survey, their reliability calculation had 9 items that were rated with a Likert scale. The experiment had 17 participants and two questions as axis. “How is your information about immersion?” was the first question, “Which factors affect the students’ attitude in an immersive space?” was the second question. Last question was a disaggregated survey with 3 variables. As a result of the research, there were an average of 9.3 in male participation with 12.5 years old; average of 4.5 in female participation with 12.3 years old. Cronbach’s Alpha coefficient was 0.969, as a positive influence of the immersive artifacts and a situated learning perspective.

Keywords: hybrid education, media art, COVID-19, DIY culture, immersion.

1 Introducción

La ponencia expone los resultados de un experimento que se apoyó en artefactos e interfaces inmersivas que se implementaron dentro de una actividad educativa. Dicha actividad tuvo como objetivo indagar los efectos de la inmersión mediante la descripción y la explicación de factores que inciden en la actitud de los estudiantes para motivar su aprendizaje. Sus resultados, así como su organización conceptual y metodológica, se muestran a continuación.

En el campo de la educación, la tecnología inmersiva es el resultado de la búsqueda de espacios educativos para motivar el aprendizaje en los estudiantes mediante la estimulación de sus sentidos. La idea de motivación tiene un sentido externo e interno al proceso de enseñanza-aprendizaje, donde se comprende como un desencadenante de acciones dirigidas hacia la incorporación de un objeto determinado del saber (Puiggrós, 1990).

La motivación tiene la virtud de mover y hasta cambiar la conducta humana, determinando la energía con la que se actúa (Carrillo *et al*., 2009). De acuerdo con algunos teóricos, la motivación es una necesidad fundamental para el crecimiento y es parte importante de la autorrealización (Maslow, 2021). Otros la definen más como el conjunto de procesos que dan dirección a la conducta y es una actitud significativa para el aprendizaje, siendo un proceso endógeno que mueve la conciencia (Beltrán, 1995). Desde la pedagogía constructivista, para Ausubel (1973), la motivación es un requerimiento esencial para el aprendizaje en su estructura cognitiva en la que el sujeto puede establecer relaciones entre conocimientos previos y nuevos.

Así, el experimento tuvo como propósito motivar y extender el pensamiento epistémico al ofrecer una experiencia que permitió concentrar los sentidos en un campo de visión ampliado y dirigirlos a distintos campos del conocimiento y el aprendizaje. Para lograrlo, utilizó un plan curricular con enfoque situado y un instrumento de evaluación para personas con bajo dominio en la escritura. El plan se apoyó en los siguientes artefactos: proyecciones hemisféricas, un sistema de audio multicanal e imágenes anaglifas. Su instrumento se diseñó para evaluar los factores que estimulan el cambio de actitud en un espacio inmersivo. La investigación fue de tipo experimental y transversal, su muestra fue intencionada y no probabilística. El marco conceptual del experimento, así como su descripción metodológica, desagregación, resultados y discusión, se muestran a continuación.

1.1 Marco conceptual

Mediante el presente apartado se podrá dimensionar la relación que guardan los artefactos inmersivos con el plan de enseñanza implementado. Se abordan sus principales definiciones y, en algunos casos, la evolución de los conceptos.

1.2 Inmersión

La inmersión se puede entender como una experiencia producida por espacios delimitados, reales o imaginarios que permiten confrontarnos con los diversos mecanismos que la producen y, por tanto, nos obliga a fundamentar nuestra percepción mediante el análisis empírico (Casales, 2022).

Algunos autores proponen que en la inmersión es posible identificar estímulos para profundizar y describir el sentido de compromiso de un espectador contra un sistema de presentación visual o artefacto tecnológico que la produce (Novy, 2013).

Desde otra perspectiva, la inmersión es un concepto holístico que refiere a sus medios de reproducción desde distintas épocas, como las ilusiones visuales en los muros de antiguos palacios, trampantojos pictóricos que engañaban al espectador a través del uso de la perspectiva del sombreado y de efectos ópticos, así como panoramas, proyecciones hemisféricas, mecanismos de realidad virtual, aumentada o mixta (Grau, 2003).

Con esto, es posible definir que la inmersión se conforma de ilusiones visuales que han evolucionado mediante el desarrollo de su tecnología. Ahora

bien, crear una experiencia inmersiva implica generar un espacio perceptivo con una narrativa que puede tener distintas estrategias de interacción y dirección. Igualmente, es posible ubicar diversos tipos de inmersión mediante sus artefactos y, para esta investigación, se utilizaron proyecciones hemisféricas, un sistema de audio multicanal e imágenes anaglifas. La definición de cada uno se muestra a continuación.

1.3 Proyecciones hemisféricas

Son proyecciones lumínicas en una pantalla de media cúpula en 180º. Su diseño hace posible presentar hechos tridimensionales con todo tipo de contenidos con bases científicas. Su realismo y detalle producen una sensación inmersiva amplia (Sumners *et al*., 2008).

1.4 Imágenes anaglifas

Se refiere al conjunto de ilusiones visuales multiplexadas en longitud de onda que pueden verse mediante gafas anaglifas.

1.5 Audio multicanal

Se define como un conjunto de bocinas en espacio abierto o cerrado que puede crear un campo sonoro. Tiene la capacidad de crear un envolvente sonoro acorde con nuestra experiencia aural de 360º, incluso puede aumentar la intensidad del campo hasta lograr una inmersión sonora (Schumacher, 2021).

1.6 Plan de aprendizaje situado

Es la actividad que involucra el contacto entre sus participantes mediante la práctica, el ensayo y el error, y tiene como resultado el perfeccionamiento de las habilidades aprendidas, a diferencia del aprendizaje formal, que es una adquisición consciente que involucra el análisis de cada proceso. No debe ser visto como un proceso individual, pues es un proceso de participación social que evoluciona y se renueva, en la medida en que se integran nuevos aprendices (Lave & Wenger, 1991). Con este enfoque, se planeó un currículo mediado con artefactos inmersivos. La tabla 1 muestra su contenido.

Tabla 1. Contenido curricular

Contenido	**Definición**	
Concepto curricular	Currículo diseñado para la enseñanza inmersiva que permite explorar conocimientos complejos que ahora pueden ser útiles para estudiantes desde los 11 años. Por ejemplo, el estudio virtual de temas científicos que ayudan a comprender y resolver problemas tridimensionales con distintas variables (KC Yu, 2001).	
Tipo de currículo	Multimodal e inmersivo	
Rango de edad	11 a 16 años	
Enfoque de enseñanza	Aprendizaje situado	
Determinación del perfil de salida	Obtener conocimientos para reflexionar el espacio habitable.	
Determinación de contenidos para alcanzar los objetivos	Estimular la creatividad a través de artefactos e interfaces inmersivas.	
Actividades	1. Reconocimiento 60 min	Tema: ciencia básica y reconocimiento. Contenido: temas de ciencia básica, la esfera celeste, los puntos cardinales y su influencia en la vida diaria. Se usa el programa de código abierto Stellarium (Chéreau, 2002). Artefacto: planetario de autoconstrucción de 2.5 m^3, cuenta con un sistema de proyección con espejo esférico.
	2. Audio multicanal 60 min	Tema: envolvente sonoro con audio multicanal. Contenido: revisión de manifestaciones inmersivas audibles. Artefacto: sistema cuadrafónico, articulado en 80 watts, una interfaz multicanal y *software* libre.
	3. Imágenes anaglifas 60 min	Tema: imágenes anaglifas. Contenido: revisión de ilusiones anaglifas. Artefacto: cuatro panoramas para gafas anaglifas.
	4. Proyecciones hemisféricas 80 min	Tema: imagen hemisférica y conclusión. Contenido: se integran todas las referencias visuales y sonoras al sistema hemisférico del planetario, se exponen cuatro películas inmersivas y se lleva a cabo la encuesta de evaluación. Artefacto: planetario y sistema de audio cuadrafónico.
Requerimientos	Se limitan a espacios educativos amplios, limpios, electrificados, equipados con sillas y mesas.	

Fuente: Casales, 2022

2 Metodología

La naturaleza de la investigación deviene del uso de distintos métodos que circunscriben como un estudio de caso, en el entendido de que conformó un método propio para comprender su objeto de estudio. Dicho objeto es una particularización y eso implicó el conocimiento de todo lo que le rodea (Stake, 1995). Asimismo, se diseñó un instrumento de medición que permitió registrar datos confiables, válidos y vinculados directamente a las variables de la investigación (Cronbach, 1971). Finalmente, para aumentar la confianza en la interpretación de los resultados desde diferentes circunstancias, se optó por triangular metodológicamente (Campbell & Fiske, 1959).

El experimento se realizó con 17 participantes y dos cuestiones como eje de la indagación. La primera cuestión fue exploratoria y se aplicó oralmente el primer día a todos los participantes: ¿cómo es la información que tienen acerca de la inmersión?, la segunda cuestión se desagregó y aplicó mediante un instrumento a 14 participantes que aceptaron colaborar y fue ¿cuáles son los factores que inciden en la actitud de los estudiantes en un espacio inmersivo?

En cuanto al género y a la edad, se tuvo un promedio de 9.3 en participación masculina, promedio de su edad 12.5 años; promedio de participación femenina 4.5, promedio de su edad 12.3 años. Para llevar a cabo la actividad, se difundió una convocatoria pública mediante las redes sociales del Sistema Nacional para el Desarrollo Integral de las Familias, Ciudad de México. El diseño de la investigación fue de tipo experimental y transversal. La muestra de su población fue intencionada y no probabilística. Para el experimento se consideró la salud de sus participantes, su consentimiento y el respeto a su confidencialidad al excluir sus datos personales. Los datos recopilados se utilizaron únicamente con fines educativos en la investigación.

2.1 Instrumentación

El instrumento se diseñó para el contexto específico de una población con bajo dominio en la escritura y, para mantener la objetividad en sus resultados, se estandarizó (Hernández *et al*., 2010). Asimismo, fue diseñado para medir los cambios en las variables del experimento. Por un lado, la variable independiente se denomina plan de aprendizaje situado y artefactos inmersivos. Por el lado de la variable dependiente, factores que inciden en la actitud de los estudiantes en un espacio inmersivo. Para evitar sesgos entre la diversidad de respuestas en la variable dependiente, se usaron las variables valor de lo aprendido, motivación externa y motivación interna. Su cálculo de confiabilidad se compuso de nueve ítems, que se calificaron mediante una escala tipo Likert con cinco valores. La tabla 2 muestra la estructura del instrumento.

Tabla 2. Estructura analítica del instrumento

Cuestión	Variables	Ítems	Definición	Escala de evaluación
¿Cuáles son los factores que inciden en la actitud de los estudiantes en un espacio inmersivo?	Valor de lo aprendido	1	Son las capacidades de apropiación cultural que involucran la afectividad y la comprensión del alumno, en términos de sus propias posibilidades (Díaz, 2006).	Likert
		2		
	Motivación externa	3	Es la confianza del estudiante al dominar los contenidos, alcanzar cierto nivel de rendimiento y mejorar a cambio de una recompensa externa (Maslow, 1970).	
		4	Es la percepción del alumno hacia la asertividad del profesor sobre el control de lo aprendido (Beltrán, 2003).	
		5	Son experiencias que detonan la confianza en el estudiante al dominar contenidos y aplicar significativamente el conocimiento en su desarrollo (Díaz, 2006).	
	Motivación interna	6	El alumno dentro de sus capacidades cognoscitivas determina si el material es o no potencialmente significativo. No basta que este sea intencionado, debe afirmarse su pertinencia acorde a su contexto (Ausubel, Novak & Hanesian, 1983).	
		7	Es la tendencia innata de autodeterminación donde el alumno muestra sus intereses, con el fin de perfeccionar sus capacidades (Maslow, 1970).	
		8	Alude a la necesidad del estudiante para controlar su trabajo y rendimiento, aunque muchas veces dependerá de un equilibrio emocional, apoyo familiar, del mentor de la naturaleza del entorno escolar (Carrillo, Padilla, Rosero & Villagómez, 2009).	
		9		

Fuente: Casales, 2022

En la opinión de los expertos, cuando se planea estudiar una población con bajo desarrollo, es recomendable administrar cuestionarios por entrevista o con gráficos de elección (*ibid.*). Por tal motivo, se realizó un diseño gráfico para las escalas de respuestas, véase figura 1.

Figura 1. Gráficos de elección para escala tipo Likert. Fuente: Casales, 2022.

2.2 Procedimiento del instrumento

La recolección de datos se realizó durante cuatro días de enero de 2022, en el Albergue del Sistema Nacional para el Desarrollo Integral de las Familias, Central de Abastos, Ciudad de México. El instrumento fue impreso en hojas de tamaño carta y se aplicó en un solo momento. Posteriormente, se realizó el análisis de consistencia interna entre los ítems, mediante el programa SPSS v.27, y se calculó el alfa de Cronbach.

3 Resultados

La primera pregunta fue exploratoria y se efectuó oralmente en 17 individuos, solo 3 habían tenido una experiencia inmersiva hemisférica en un planetario móvil, pero no recordaban algún tema de ciencias o explicación dedicada a la esfera celeste. Asimismo, nunca habían experimentado la inmersión de un envolvente sonoro mediante audio multicanal ni ilusión visual a través de imágenes anaglifas.

La segunda pregunta se implementó a 14 participantes mediante el instrumento y su consistencia interna presentó un alfa de Cronbach de 0.969, lo que explica su confiabilidad (Hernández *et al*., 2010). Los resultados por variable se muestran en la tabla 3.

Tabla 3. Alfa de Cronbach del instrumento

Variables	Ítems	Alfa de Cronbach
Valor de lo aprendido	2	0.874
Motivación externa	3	0.881
Motivación interna	4	0.923

Fuente: Casales, 2022

Los datos estadísticos del instrumento se muestran en la siguiente tabla 4.

Tabla 4. Estadísticos

Variables	Ítems	Media	Mediana	Moda	Desviación estándar	Varianza	Rango
Valor de lo aprendido	1	4.3	5	5	0.9	0.8	3
	2	4.2	4.5	5	0.9	0.8	3
Motivación externa	3	4.3	5	5	0.8	0.7	2
	4	4.2	4.5	5	0.9	0.8	3
	5	4.5	5	5	0.9	0.8	3
Motivación interna	6	4.2	4.5	5	0.9	0.8	3
	7	4.3	5	5	0.8	0.7	2
	8	4.2	4.5	5	0.9	0.8	2
	9	4.5	5	5	0.9	0.8	3

Fuente: Casales, 2022

La interpretación descriptiva de la tabla 4 muestra que las respuestas que dan forma a las variables son factores que inciden favorablemente en la actitud de los estudiantes en un espacio inmersivo. La puntuación de moda fue 5, siendo favorable. Igualmente se desvían favorablemente entre 0.8 y 0.9 unidades de la escala. No hubo puntuaciones cercanas al mínimo de 1.

En síntesis, se podría confirmar la relación entre las variables independientes y la dependiente. Los resultados fueron positivos e intrínsecamente motivantes para la mayoría de los participantes, solo que para algunos fue externamente motivante. Esto indica que la tendencia general es de valores superiores. Sin embargo, ¿qué significa que el valor de lo aprendido, la motivación interna y la motivación externa sean factores que inciden favorablemente en la actitud de los estudiantes en un espacio inmersivo? Implica que el valor de lo aprendido fue apropiado como un medio cultural que permitió desarrollar las habilidades de los estudiantes. Por su parte, la motivación externa fue atractiva y ofreció la confianza necesaria para alcanzar los contenidos y lograr recompensas externas, como presenciar una obra inmersiva dentro del planetario. La motivación interna involucró la evaluación de los participantes para determinar la eficacia del material educativo. A pesar de las limitaciones, se encontraron sentimientos satisfactorios que permitieron equilibrar las necesidades requeridas mediante el apoyo familiar para participar en todas las sesiones.

4 Discusión

El objetivo del experimento fue la indagación de los efectos de la inmersión mediante la descripción y la explicación de factores que inciden en la actitud de los estudiantes para estimular su aprendizaje en tiempos de pandemia. En lo referente al enfoque del aprendiz situado, hubo un efecto disruptivo por la capacidad de motivación, logrando ganar importancia dentro del actual contexto pandémico.

Una característica del enfoque situado con entornos inmersivos sucede al contextualizar su proceso, a pesar de las limitaciones que se pueden encontrar cuando se trabaja en distintas escalas. Desde la perspectiva sociocultural de Vygotsky, una experiencia educativa inmersiva implica el entendimiento contextual acompañado de la apreciación de símbolos y signos culturales; su internalización sucede mediante la interacción con miembros experimentados que crean un andamiaje para los aprendices. De esta manera, el enfoque situado permite traducir las prácticas pedagógicas deliberadas con instrumentos y mecanismos que se ajustan a un contexto cultural determinado (Díaz, 2006).

En la triangulación de las variables, el valor de lo aprendido identificó que los participantes involucrados en los contenidos obtuvieron sentimientos de satisfacción y goce.

Algunos investigadores enfatizan que aquellos que se encuentran intrínsecamente motivados disfrutarán su ejecución, ya que obtendrán de la labor *per se* recompensas internas de autorrealización (Hernández *et al*., 2010). Además, el aprendizaje siguió un plan no arbitrario, sin tornarse en juego; lo que permitió manifestar la actitud de los aprendices en el instrumento, demostrando su valor significativo intencionado. Esto se contrapone al proceso educativo que busca arbitrariamente el uso mecánico de la repetición y memoria en el estudiante (Ausubel, 1983).

La motivación externa logró objetivos pedagógicos robustos que se direccionan con las estrategias de aprendizaje y su calidad. Es decir, los alumnos percibieron significativamente creando estrategias de selección, organización y elaboración alrededor de los temas del currículo. Dichas estrategias se han propuesto como parte de todo proceso educativo, ya que permiten identificar el rendimiento del alumno y su confianza (Beltrán, 2003).

Desde otra perspectiva, la motivación externa que ofrecen los artefactos inmersivos es eficaz y atractiva para la enseñanza de temas intrínsecamente tridimensionales en la ciencia. Asimismo, un sistema portátil para proyecciones hemisféricas permite llegar a sitios donde los estudiantes desatendidos no disponen del tiempo o de la economía para viajar a los museos (Sumners *et al*., 2008).

Por su parte, la motivación interna mostró el nivel de energía y la dirección del aprendizaje. Desde la teoría de Maslow (1970), hubo una prioridad para responder a la autorrealización, resolver problemas y aceptar hechos; lo que jerárquicamente indica una superposición en las necesidades humanas, por encima del éxito, la amistad, la seguridad y las necesidades fisiológicas (Carrillo *et al*., 2009).

En general, se hallaron buenos resultados mediados por su instrumento de evaluación y, desde la triangulación, se confirma este hecho por otros estudios donde el disfrute de la experiencia inmersiva se puede predecir en otros artefactos tecnológicos como las plataformas de juegos y gafas de realidad virtual, aunque disten en su escala y contenido.

En esta línea, se ha encontrado que la inmersión se puede predecir en el involucramiento emocional en ambientes virtuales inmersivos y la disposición a tener episodios de atención que comprometen totalmente a la persona. De esta forma, a mayores niveles de involucramiento emocional y de disposición, se genera una mayor presencia espacial hasta lograr el máximo umbral de percepción inmersiva (Hofer *et al*., 2012).

Desde un sesgo dirigido a la creación de futuros contenidos inmersivos, cualquier interesado debería reconocer las capacidades receptivas de sus observadores. Esto puede identificarse mediante el análisis de la ilusión inmersiva.

La ilusión inmersiva funciona en dos niveles, según Grau (2003), primero, se encuentra la sumisión lúdica y consciente a la apariencia del goce estético de la ilusión; segundo, por la intensificación de los efectos inmersivos a través de su apariencia. Sin embargo, lo segundo puede abrumar temporalmente la percepción al tratar de identificar la diferencia entre la ilusión y la realidad, de ahí el poder sugestivo de la inmersión.

Por un lado, en la inmersión, se suspenden por un tiempo la relación entre el sujeto observador y el objeto proyectado, teniendo como resultado efectos sobre la conciencia. Lo anterior se reitera por Torres, Blanca y Pérez (2021), quienes afirman que la ilusión de la inmersión ha sido descrita como un modelo de dos pasos que, en un primer momento, involucra la construcción de un modelo mental del ambiente mediado, predicho por la atención y los rasgos individuales de la imaginación visual-espacial. Una vez creado este modelo mental surge la inmersión, la cual es mediada por el involucramiento cognitivo, la suspensión de la no creencia y el interés de dominio específico.

Por otro lado, es necesario agregar el envolvente sonoro inmersivo que se forma con un sistema de audio multicanal. De acuerdo con Schumacher (2021), dicho sistema involucra cognitivamente el sonido y el sentido de la escucha dentro de un ambiente inmersivo.

Finalmente, la experiencia inmersiva contribuye a producir buenos resultados que inciden en la actitud de los estudiantes. Influye positivamente cuando tiene el apoyo del maestro y el uso de actividades que refuerzan la experiencia. Asimismo, demostró estadísticamente un incremento significativo en el corto plazo. Lamentablemente, no existen iniciativas gubernamentales ni políticas educativas mexicanas que animen a utilizar masivamente los artefactos inmersivos para motivar el aprendizaje. Por el momento, las iniciativas que puedan existir serán de aventureros educativos, investigadores y diseñadores, debido a que la evidencia producida por la investigación se sigue estimando desde su relación indirecta como modo de sensibilizar a los responsables políticos acerca de las formas de resolver problemas (Ornelas, 2022).

Referencias

Ausubel, D. (1973). Algunos aspectos psicológicos de la estructura del conocimiento. En S. Elam (Ed.), *La educación y la estructura del conocimiento. Investigaciones sobre el proceso de aprendizaje y la naturaleza de las disciplinas que integran el currículum* (pp. 211-239). El Ateneo.

Ausubel, D., Novak, J. & Hanesian, H. (1983). *Psicología educativa. Un punto de vista cognoscitivo.* Editorial Trillas.

Beltrán, J. (2003). Estrategias de aprendizaje. *Revista de Educación, 332*, 55-73. http://s623319320.web-inicial.es/wp-content/uploads/2019/03/Lectura-estrategias-de-aprendizaje.pdf

Campbell, D. & Fiske, D. (1959). Convergent and discriminant validation by the multitrait-multimethod matrix. *Psychological Bulletin, 56*(2), 81-105. https://doi.org/10.1037/h0046016

Casales, A. (14 de marzo de 2022). *Artefactos inmersivos aplicados al diseño y a la educación mexicana* [Ponencia]. Noveno Coloquio de estudiantes de Doctorado, División Ciencias y Artes para el Diseño, Universidad Autónoma Metropolitana.

Carrillo, M., Padilla, J., Rosero, T. & Villagómez, M. (2009). La motivación y el aprendizaje. *Alteridad*, 20-32. https://doi.org/10.17163/alt.v4n2.2009.03

Chéreau, F. (2020). Stellarium (versión 0.22.1) [*Software* educativo]. https://stellarium.org/es/

Cronbach, L. J. (1971). Test validation. En R. L. Thorndike (Ed.), *Educational measurement* (2nd ed., pp. 443-507). American Council on Education.

Díaz, F. (2006). *Enseñanza situada: vínculo entre la escuela y la vida.* Editorial McGraw Hill.

Grau, O. (2003). *Virtual Art. From Illusion to Immersion*. MIT Press.

Hernández, R., Fernández, C. & Baptista, P. (2010). *Metodología de la investigación*. Editorial McGraw Hill.

Hofer, M., Wirth, W., Kuehne, R., Schramm, H. & Sacau, A. (2012). Structural Equation Modeling of Spatial Presence: The Influence of Cognitive Processes and Traits. *Media Psychology*, *15*(4), 373-395. https://doi.org/10.1080/15213269.2012.723118

Lave, J. & Wenger, E. (1991). *Situated Learning. Legitimate Peripheral Participation*. Cambridge University Press.

KC Yu. (2005). Digital Full-Domes: The Future of Virtual Astronomy Education. *Planetarian*, *34*(3), 6-11. https://www.researchgate.net/publication/253271921_Digital_Full-Domes_The_Future_of_Virtual_Astronomy_Education

Maslow, A. (9 de marzo de 2021). *Teorías de la personalidad.* http://webspace.ship.edu/cgboer/maslowesp.html

Maslow, A. (1970). *Motivation and personality.* Harper & Row Press.

Novy, D. (2013). *Computational immersive displays* [Master of Science and Media Arts Thesis, Massachusetts Institute of Technology]. http://hdl.handle.net/1721.1/82430

Ornelas, C. (21 de junio de 2022). Posverdad, evidencia y política educativa. *Periódico Excelsior*. https://www.excelsior.com.mx/opinion/carlos-ornelas/posverdad-evidencia-y-politica-educativa/1522184

Puiggrós, A. (1990). *Sujetos, disciplina y currículum en los orígenes del sistema educativo argentino (1885–1916)* [Archivo PDF]. https://campus.fahce.unlp.edu.ar/pluginfile.php?file=%2F162492%2Fmod_resource%2Fcontent%2F1%2FPUIGGR%C3%93S%2C%20Adriana%20%281990%29%20Sujetos%2C%20disciplina%20y%20curriculum%20en%20los%20or%C3%ADgenes%20del%20sistema%20educativo%20argentino%20%281885-1916%29.%20Buenos%20Aires%2C%20Galerna.%20Cap%C3%ADtulo%207..pdf

Schumacher, F. (2021). *La espacialidad en la experiencia musical acusmática: un enfoque cognitivo.* Editorial Centro Mexicano para la Música y Artes Sonoras.

Stake, R. (1995). *The art of case study.* SAGE Publications.

Sumners, C., Reiff, P. & Weber, W. (2008). Learning in Immersive Digital Theater. *Advances in Space Resarch, 42*(11), 1848-1854. https://doi.org/10.1016/j.asr.2008.06.018

Torres, D., Blanca, E. & Pérez, R. (2021). Inmersión y activación de estados emocionales con videojuegos de realidad virtual. *Revista de Psicología, 39*(2), 531-551. https://revistas.pucp.edu.pe/index.php/psicologia/article/view/23932

The Use of Parametric Mapping as an Analysis Method in Contextual Design Studio

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Abstract. This paper is discussed an experimental study carried out in the undergraduate Contextual Design Studio (CDS). The studio comprises four stages: Site Analysis Phase, Conceptual Design Studies, Design Development Phase, and Final Presentation. The site analysis stage lasts for about four weeks,10 hours a week in the studio. Particular importance is given to this part of the project so that students have a chance to gain different perspectives on multiple meanings of context and, more specifically, the historical, social and physical context of the the neighborhood. Besides conventional mapping and representation techniques and tools, some new design tools have been introduced in the studio, one of which was this experimental study in question. The study aims at the integration of the Parametric Mapping techniques, at a basic level, into the site analysis process in the contextual design studio to provide an entry point to thinking through the tool used for the students. In this term, the method of abstracting site features through Parametric Mapping was used in the site analysis process and the effect of this form-oriented data on the concepts of the projects was interpreted. NudiBranch, an add-on to the Grasshopper program, was used in the Parametric Mapping workshop. Students' works were discussed briefly with the help of some representative instances.

Keywords: Parametric mapping, Contextual design studio, Architectural design studio, Architectural education, Hybrid Education

1 Introduction

The Contextual Design Studio (CDS), which deals with the issue of “the design of a new building in existing urban fabric” or new building design in a historic environment, occupies a particular position among other design studios in the architecture curriculum. The studies related to it are generally based on a series of interconnected steps, i.e, site analysis, interpretation of the data

gathered, development of some design scenarios, proposals, and presentations. Research is an inseparable part of each phase.

Some conventional mapping techniques and tools are widely used such as mapping the transportation network or street layout, figure-ground mapping, structural/functional/land-use analyses, analyses of building heights and materials, street elevations, silhouette, modeling, and other interpretive drawings developed through personal observations, research or defined methodologies, which mainly stem from the place making theories. A series of representations obtained through new computational design tools have also been developed. Various hybrid or integrated methods enrich the design process dealing with the complex data of urban space. These methods both provide individual understanding/reading of an existing environment and, hence, offer new opportunities in solving design problems peculiarly (Şahin et. al. 2016).

Many experimental studies are being conducted in architectural education in terms of integration of computational tools into the design studio course (Headley, 2013; Lima et.al. 2020) and teaching parametric design tools and their functioning logic to design students (Aish and Hanna, 2017; Celani and Vaz, 2012; Globa et.al. 2015; Schnabel, 2013; Agirbas, 2022). Although teaching these tools as a series of lectures is common in many schools, integrating and working principles into the design process could be very challenging for students and lecturers in the early years of architectural education.

In this study, within the scope of hybrid education, an experimental study was conducted on the integration of parametric design digital tools into the analysis stage of the projects of the 2nd year students.

2 Methodology

In CDS, students are expected to develop coherent design senarios and solve certain complexities of multifunctional buildings to be inserted in the existing urban fabric. The studio conventionally comprises four stages: Site Analysis Phase, Conceptual Design Studies, Design Development Phase, and Final Presentation. The site analysis phase lasts for about one month four weeks,10 hours a week in the studio. In this period, students study the physical, historical and socio-cultural characteristics of the selected area and reflect what they have learned through site analysis. This phase of the course has many parameters and compexities that the students are expected to think about simultaneously (Figure 1).

Two areas were offered as project sites -Tophane and Üsküdar districts of Istanbul. Tophane district is located on the European side of Istanbul. It is a tourist attraction point as it contains many historic buildings such as Tophane-i Amire (Ceylan, 2003), Kllıç Ali Pasa Mosque (Bayrakal, 2018; Ostwald and Ediz, 2015), Tophane Fountain (Yüngül, 1958) (Figure 3). Üsküdar district is

located on the Asian side of Istanbul and has a significant urban fabric with many historical buildings as well (Gelengül Ekimci and Ahunbay, 2016; Kahraman, 2019; Gocek Karabey et.al, 2021; Aydin Ipekci and Ozer, 2015). The population of these two districts is mainly based on local inhabitants. Therefore, it is expected from students to design their building complex by taking into consideration not only local inhabitants but also passive users and visitiors such as tourists and students of the universities nearby.

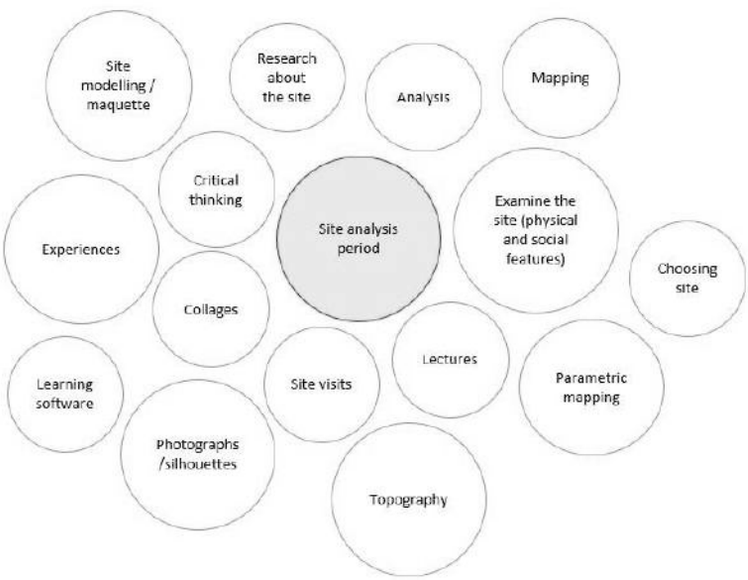

Figure 1. This site analysis period and its parameters. Source: Authors, 2022.

Within the scope of this study, a workshop was held in the studio. There were 2 studio groups with a total number of 22 students (11 students for each group). Eight students among them participated in this experimental Parametric Mapping.

The workshop planned was held during the site analysis process (Table 1) Students were asked to use the Parametric Mapping in their site analysis. Since the workshop was conducted in the 3rd week, the students had preliminary information about, the project site, before the workshop. Students were expected to interpret this prior knowledge with Parametric Mapping.

The architectural design studio was conducted face-to-face and online (hybrid education). The choice to attend the course face-to-face or online has been left to the students. Most of them preferred to participate in classes face-to-face. The lectures of the workshop have been recorded for students to watch the lectures anytime needed. The following lesson after the workshop, a face-to-face session was held to answer students' various questions regarding the implementations.

Table 1. The information about the workshop

Student level	2nd year Bachelor of Architecture students
Course type	Context-based design studio Compulsory course
The site	Istanbul (Tophane or Üsküdar districts)
The total period of the course	14 weeks (10 hours a week)
Students registered to the course (2 sections)	22 students (11 students for each group)
Workshop period	3rd week of the course
Content of the workshop	Use of parametric mapping as an analysis method
Students participated	8 students

2nd-year students generally have some familiarity with some design tools like AutoCAD, SketchUp, and Photoshop. Some students can also use Rhino. Most students do not have Grasshopper experience. Therefore, within the scope of the workshop, the explanation of the basic commands (such as installation, moving, and saving) related to the use of Rhino and Grasshopper is also included. In the study, ready-made scripts of the Nudibranch add-on working with the Grasshopper program were used. First of all, the students were shown how to import the AutoCAD drawing file of the chosen area into the Rhino program. Afterward, how to use the ready-made scripts that come with the installation of the Nudibranch (2022) add-on was shown (Figure 2). Information on how to play with the number sliders in these ready-made scripts, how to change the number slider value ranges, how to change the size of the initial grid, and how to increase the number of points were given. The lecture was recorded and uploaded to YouTube so students could look at it anytime. In this way, students were able to look back at this YouTube link whenever they needed.

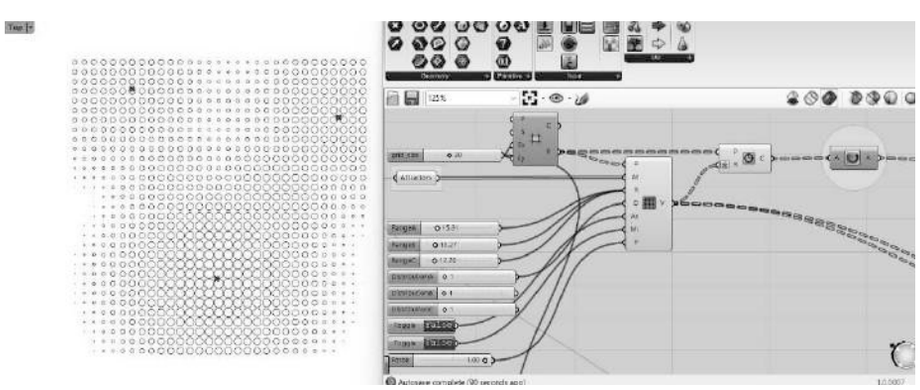

Figure 2. Sample Nudibranch ready-made script. Source: Authors, 2022.

Figure 3. Representation of the atmosphere in Tophane and its nearby districts.
Source: Authors, 2022.

3 Experimenting with the parametric mapping tools: representative instances

Eight students from the studio groups adopted parametric mapping techniques to analyze the project areas. In this context, parametric mapping was used to reflect various characteristics of the existing urban space studied such as the distribution of functions and historical buildings, the dispersion of sound, noise, and smell, the display of the transportation points and pedestrian densities of streets and the determination of visually and physically accessible areas. The students determined which of the ready-made scripts they would use according to the subject they wanted to analyze. The majority (7/8) of students used the ready-made scripts with 2D features, maintaining the habit of 2D mapping used in traditional mapping methods, and ignored the possibility of including the data of the site in the third dimension, provided by parametric mapping.

The students rearranged the parameters of the ready-made scripts according to the data in their site analysis. For example, while analyzing the smell on the site, by rearranging the existing points in the script according to the points that are the source of the smell, and representing the intensity of the smell with the changes in the force parameters, a mapping showing the dispersion of the smell was obtained. Some of the students enabled the production of new analyses by exporting their parametric mapping studies from Rhino and combining them with representations such as photo collages, maps of green areas and topography curves created in different media. The two sample studies of the students were discussed in the following sections.

3.1 Project 1

The student working in the Tophane benefited from parametric mapping in the functional analysis in the region. The student, who designed handicraft shops and a tourist center, analyzed the distribution of carpet making and

weaving workshops, ceramic workshops, coppersmiths, art galleries, hotels,and cafes in the neighbourhood. First, individual mappings were made for the distribution of each function. The locations of the functions were marked by changing the numbers and places of the points in the ready-made script. Then, the increase and decrease in the number of functions at the marked points were expressed by changing the density and force parameters. In this way, the areas on the map where the functions increase could be represented as denser and larger patches, and the areas where the functions decrease could be represented as lighter and smaller patches. After analyzing each function separately and assigning a different color to each of them, all analyzes were superposed on a single map. The site analysis and the superposed map are shown in Figure 4 and Figure 5. The resulting mapping provided a visual data of where the investigated functions are concentrated and where they are diluted. The analysis made through parametric mapping was used as a determining factor in the student's project area selection. Instead of areas where similar functions were concentrated, the student chose the area where it is less frequent and not far from the tourist attraction center.

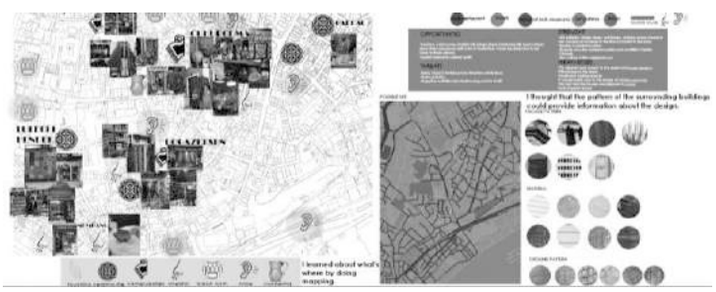

Figure 4. Site analysis. Source: Authors, 2022.

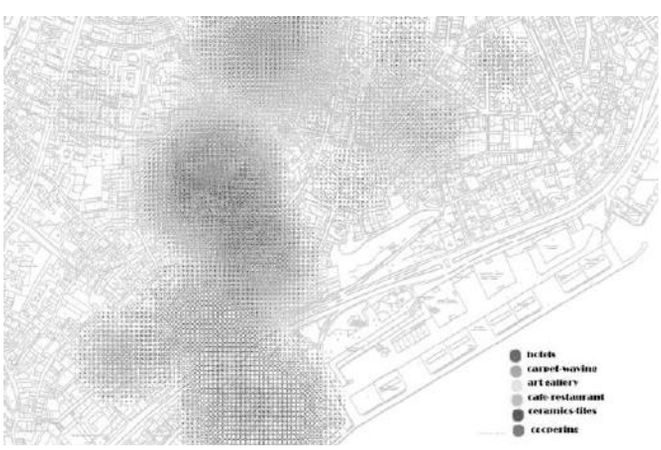

Figure 5. Site analysis with parametric mapping, Project 1. Source: Authors, 2022.

3.2 Project 2

Addressing the accessibility issues, the student underscored some visual and physical connection problems between the inland and the waterfront. The primary intent was to create access through the spaces and connections to be designed. The student first determined the potential points where it could provide visual continuity and physical accessibility in the existing urban pattern. The points were also positioned to form a route that ensures continuity. Then, he transferred the determined points to a gridal map of the ready-made script. The density and force parameters of the ready-made script were changed according to the positions of the points, thus transformations occurred in the gridal pattern (Figure 6). The regions where the impact areas of the points intersect showed the areas with the maximum potential in terms of accessibility and are used as data to create the building design form. The student evaluated the gridal pattern created by parametric mapping as an input for his design project and tried to transform the mapping into a form. In addition, the gridal pattern overlapped with the topography curves to include the slope, which is an important site-specific element, in the design process. The resulting mapping prevented the form from being evaluated in only two dimensions, and made the stratifications that could be made in the third dimension visible (Figure 7). In this way, some site-specific features were visualized by parametric mapping and contributed to the formation of the design concept and form. The student also reflected the mapping form on the building facade and landscape design (Figure 8).

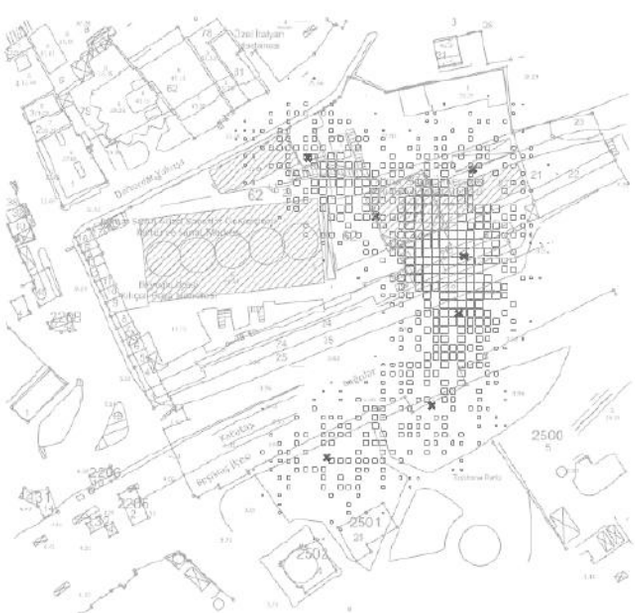

Figure 6. Site Analysis with Parametric mapping, Project 2. Source: Authors, 2022.

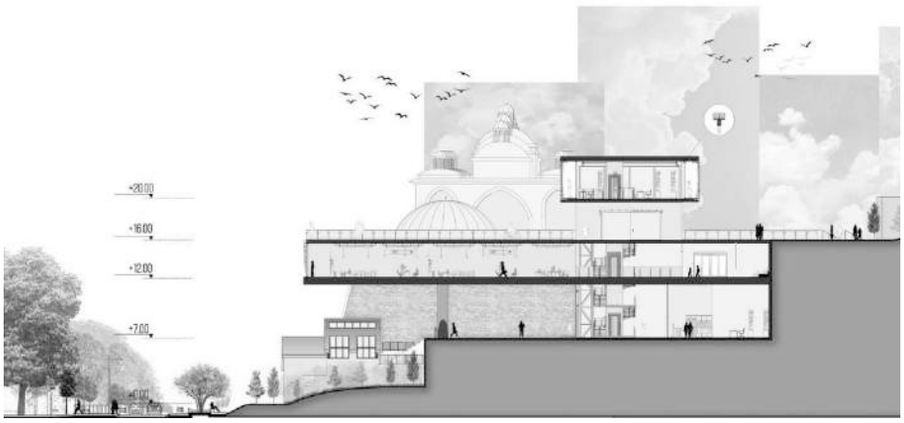

Figure 7. The section of the building design proposed. Source: Authors, 2022.

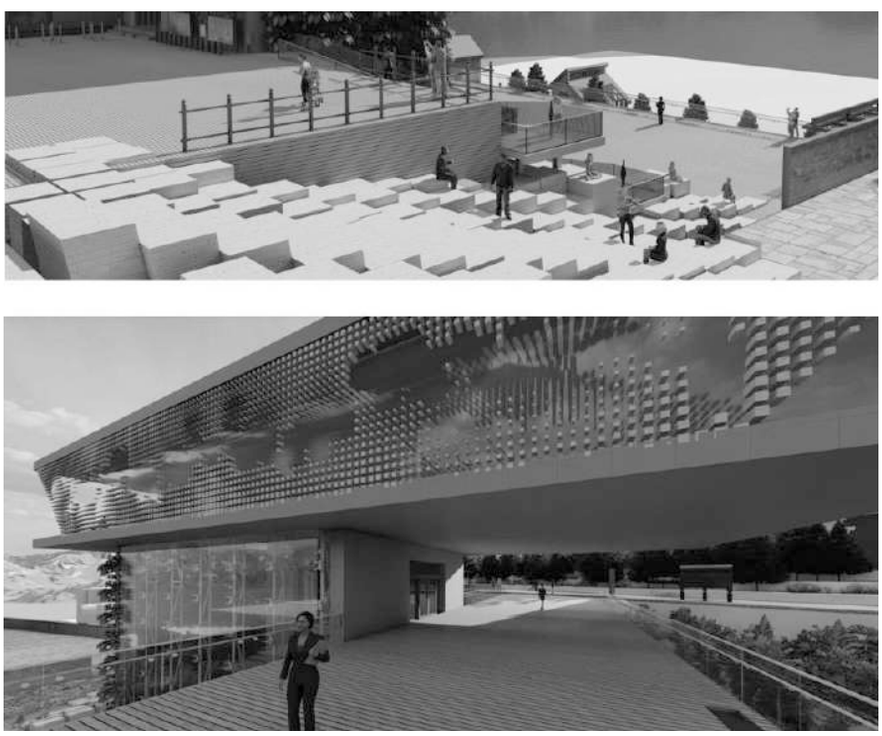

Figure 8. Reflections of parametric mapping study to landscape and facade design. Source: Authors, 2022.

4 Discussion

Integration of new digital tools into projects has become a necessity. Especially in the early years of architectural education, this integration can be challenging for both the student and the educator. It is necessary to conduct various trials and discuss the results to achieve such integration. In this context, an experimental study was carried out to adapt the studio curriculum to the new requirements.

According to the results of the study, it was seen that some students interpreted the parametric site analysis to develop their designs. It was also observed that some students performed site analysis with parametric mapping tools in the analysis stage only as representation.

One of the main goals of the Contextual Design Studio, the approach of analyzing the site-specific features and providing input to the design process, was a point emphasized by the instructors in the process. It was observed that the students' parametric mappings of certain spatial elements such as function, smell and sound dispersion, and pedestrian density were generally decisive in the project area selection. One of the students included the pattern he obtained through parametric mapping during the analysis process as a direct input to his design concept and form-finding processes. In other words, he abstracted the site-specific features with the help of parametric mapping and included them in the design process using the same thinking attitude, which was relatively new for the student. This parametric mapping attempt, which is very promising in the analysis stage of the project, provided an entry point for the student to adopt the parametric way of thinking, which might be applied through the entire design process, from site selection all the way to design details.

It was seen that video recording of parametric mapping lecture helped students to implement the process quickly and conveniently since they can stop and watch the video recording anytime.

References

Agirbas, A. (2022). A Teaching Methodology on the Combination of Architectural Tradition and Parametric Design: A Case Study with Birdhouses. *International Journal of Islamic Architecture* 11 (1), 149-168. https://doi.org/10.1386/ijia_00068_1

Aish, R. & Hanna, S. (2017). Comparative evaluation of parametric design systems for teaching design computation. *Design Studies* 52, 144–172. https://doi.org/10.1016/j.destud.2017.05.002

Aydin Ipekci, C. & Ozer, H. (2015). Current Situation Analysis of Ottoman Era Buildings Located within Historical Bazaar Square of Üsküdar and Surrounding. In: Efe, R., Ayışığı, M., Düzbakar, Ö. & Arslan, M. (Eds) *Turkey at the Beginning of 21st Century: Past and Present* (pp.39-51). St. Kliment Ohridski University Press, Sofia.

Bayrakal, S. (2018). A Study on the Application Lighting Project of Kılıç Ali Pasha Mosque at Tophane District. *Mehmet Akif Ersoy Üniversitesi Sosyal Bilimler Enstitüsü Dergisi*, 10 (25), 520-533.

Celani, G. & Vaz C.E.V. (2012). CAD Scripting and Visual Programming Languages for Implementing Computational Design Concepts: A Comparison From A Pedagogical Point of View. *International Journal of Architectural Computing* 10 (1), 121–137. https://doi.org/10.1260/1478-0771.10.1.121

Ceylan, O. (2003). Top Döküm Binaları (Tophane-i Amire) ve Onarımları. *Tasarım+Kuram*, 3, 43-56.

Gelengül Ekimci, B. & Ahunbay, Z. (2016). Üsküdar'ın Vakıf Kültür Mirası ve Korunması için Öneriler. *Restorasyon Yıllığı Dergisi*, 12, 6-15.

Globa, A., Donn, M. & Moloney, J. (2015). Abstraction versus Case Based: A Comparative Study of Two Approaches to Support Parametric Design. *International Journal of Architectural Computing*. 13(3-4), 313-333. https://doi.org/10.1260/1478-0771.13.3-4.313

Gocek Karabey, F., Kurtulus, I. & Kubat, A.S. (2021). The Tales of Two Sacred Buildings in Urban Pattern of a Transportation Hub: The Case of Üsküdar, İstanbul. *Annual Conference Proceedings of the XXVIII International Seminar on Urban Form (ISUF 2021)* (pp. 970-978). 29th June – 3rd July, Glasgow, UK.

Headley, D. (2013). Integration of Parametric Thinking within Undergraduate Design Studios. In: M.A. Schnabel (Ed.) *Cutting Edge: 47th International Conference of the Architectural Science Association* (pp. 167–176). The Architectural Science Association (ANZAScA), Australia.

Kahraman, K. (2019). Üsküdar'ın Kayıp Sarayları. *Milli Saraylar Sanat Tarih Mimarlık Dergisi*, 17, 103-121.

Lima, F., Muthumanickam, N.K., Miller, M.L. & Duarte, J.P. (2020). World Studio: a pedagogical experience using shape grammars and parametric approaches to design in the context of informal settlements. *Proceedings of SiGraDi Conference* (pp. 627-634). 18 - 20 November, Medellín, Colombia.

Nudibranch, 2022. https://www.food4rhino.com/en/app/nudibranch

Ostwald, M.J & Ediz, Ö. (2015). Measuring Form, Ornament and Materiality in Sinan's Kılıç Ali Paşa Mosque: an Analysis Using Fractal Dimensions. *Nexus Network Journal* 17, 5–22. https://doi.org/10.1007/s00004-014-0219-3

Şahin, M., Dervishi, S., Özbil, A. & Tekçe, I. (2016). Changing context of contextual design studio. In Saleh Uddin, M., Şahin, M., Özbil Torun, A., Bayazıtoğlu, Ü.C. (Eds.), *2016 Design Communication European Conference Proceedings* (pp.23-32). 11-14 May, Özyeğin University, Istanbul, Turkey.

Schnabel, M.A. (2013). Learning Parametric Designing. In *Industrial Engineering: Concepts, Methodologies, Tools, and Applications* (pp. 197-210). IGI Global.

Yüngül, N. (1958). *Tophane Çeşmesi*. İstanbul Belediyesi Sular İdaresi Müdürlüğü Yayınları, Istanbul.

Round The Table, Education without the 2d frame constraints: a WebVR experience from a glocal perspective

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Abstract. Round-the-Table, as a researcher-led initiative, was an experimental virtual roundtable in a 3D format that invited twenty-one organisations worldwide from education, research, and technology to open a broad dialogue about a more sustainable, inclusive, interactive, and accessible educational environment, which may help pedagogical communication beyond the 2D frame. This was made possible by the implementation of a Web-VR platform supported by Mozilla, by which each participant had the opportunity to co-create with the organisers, a collaborative immersive sensory experience, together with the simultaneous dialogue between Local and Global. Participants were asked two critical questions: 'decentralised education' and 'phygital exchanges' : how can we work beyond the 2d frame and how to distribute tasks between physical and digital. The responses were by far diverse, but it was indeed possible to map a cohesive picture from this cloudy but colourful panorama.

Keywords: volumetric roundtable, planetary classroom, virtual reality, decentralised education, phygital exchange

1. Introduction

Round-the-table - a series of experimental roundtables in web-based virtual reality (VR) - invited guests worldwide to bring about international and interdisciplinary discussion on the future of education. Happened during the pandemic lock down, this series of roundtable tries to facilitate an inclusive and accessible real-time digital communication beyond the conventional 2D telecommunication. It aims to utilise open-source and web-based strategies in democratising VR classrooms to any educators and students with just computers or mobile devices and internet. Also, the design pipeline of the

spaces and avatars stresses on collaborative means with very simple ways of configuration for participation and interactivity. It invited 18 institutions and companies both in public and private sectors, 37 guests and speakers working in fields of education and technology, with over 700 participants and viewers from all over the world.

The series of VR roundtables happened in over 20 VR spaces and focused on two topics: ‘decentralised education’ and ‘phygital exchange’; each VR space was customised to the content of discussion. The entire organising and operational team consisted of just two people without any additional support, both located at different places at the time because of the pandemic lock down. The workflow includes tailoring VR spaces and cardboards, 3D modelling, photogrammetry of physical space, personalising avatars, inviting guests, drafting agenda, arranging and composing scenes, rehearsing navigation, broadcasting events, troubleshooting, and documentation. Each event takes about a week to set up the VR rooms and a month to organise agenda and invitation; the cost of the event was zero, and the guests were kind enough to contribute to this open-source experimental effort. A symposium of the same scale and efficiency would normally require at least three teams of people to organise, assist operation, set up physical spaces, sometimes with extra audio-visual technicians; the environmental and monetary cost of bringing in guests physically would also be very considerable without the help of web-based telecommunication and livestreaming tools.

Through utilising Mozilla Hubs for web-based VR (fig. 1), this paper induces the theoretical discussion on the embodiment of education in the phygital age, revealing the behind-the-scene to the design of the events, discusses its production pipeline going from Reality Capture, Rhino Grasshopper, Blender, to Hubs for more advanced configurations, tips in broadcasting real-time VR to Youtube and other streaming platforms, and different modes of navigation to enhance engagement.

Fig. 1. The first configured web-based VR room out of 20 on Mozilla Hubs platform. Image credit: authors.

2. Theoretical Discussion: Future of Education

Education is a fundamental human right and one of the Sustainable Development Goals (UN, 2022) that strives to promote comprehensive and equal access to education while maintaining high quality standards. One of the most difficult conditions in this respect is the lack of access to educational infrastructure, which allows us to deliver teaching processes. According to the same goal, the Covid Crisis erased 20 years of educational gains, resulting in a new scenario in which higher education is now serving as a sharing platform for leading and supporting new initiatives based on virtualisation of what we understand of education, opening, exploring, and finally consolidating new areas.

While digital communication has some advantages, such as reducing carbon footprints through transportation, building international communities, and innovating industrial infrastructure (SDGs 9, 11, and 13), it can also undermine communication quality, digital equality, mental wellbeing, and decency in work and learning (SDGs 3, 4, 8, and 10). (Mpungose, 2021). All of these issues are crucial to present educational debates, in which traditional pedagogical methods are increasingly being challenged by pandemic lockdowns, developing online educational platforms, and open-source learning practises (Bailenson,, 2021)(Agnihotri, Bhattacharya, 2022). (Coppola, Neelley, 2004). Both institutional and crowdsourcing methods provide top-down and bottom-up strategies, the two have the ability to meet halfway and harness the strengths and drawbacks of each to change the character of education. For example, Wikipedia has become a frequent tool in research; rather than fully condemning its usage, it is arguably more necessary to understand what influences the quality of its use, and even more pertinent is the concept of dispersed knowledge and crowd intelligence being used to education.

This paper focuses on three core issues: data communication, spatial distribution, and volumetric navigation, where the critical scale in open-source tools that errors may average out statistically, open-endedness of the platform so many invisible hands may help the system to consistently self-correct, and the level of digital literacy in the user to filter out misinformation and disinformation (Wiley, 2006).

To begin, institutions must collaborate with the open-source industry to achieve network effects; moodle (Costello, 2013) is an example. Schools all around the world are establishing their various programmes and instructional methods on a platform that allows for the administration and creation of private online portals for management in educational institutions, bridging the demands of instructors, students, and administrators. In this regard, data communication is one of the crucial variables to be studied and developed as a cornerstone on the future of education and how to accelerate changes in a crowd dispersed style of development, comprehending information from two perspectives: abstract (metadata) and spatial (images) (experiential).

Second, textbooks may be reissued in order to self-correct. Nonetheless, tools like Reddit and StackOverflow have already become an efficient way for educators, researchers, and developers to network and discuss problems ranging from grammar to mathematical definitions and coding and are increasingly being used in postgraduate education classrooms for advanced thematic and topical studies. However, there is another more issue to consider in the educational fresh views on where we are studying and teaching inside the space. In this example, the virtual environment enabled an immersive approach, with visual information serving in the same capacity as textbooks and other fresh sources of knowledge on a broadway.

Third, from the standpoint of digital literacy, we are confronted with the significance of employing digital tools in research and collaboration across institutes, as well as open-source initiatives in co-validating material (Reosa, Et al. 2021). (Archibald, Et al.2019). This may be as easy as encouraging academics to contribute and share information for open platforms using their institutional expertise, testing with new technologies firsthand to provide empirical data, or bringing up such debates in classrooms to enhance students' understanding. But in a parallel perspective, how we face digitalisation as an ongoing phenomenon is rapidly giving way to a "business as usual" idea. It is no longer possible to conceive education with digital-only, instead of a digitally-driven learning process, based on a context constantly fed by dynamic information, in which interactivity is fundamental as part of the learning curve.

The concept of a Planetary Classroom is a transformation from the actual current space for learning, not attempting to substitute the dimension about what we know as an effective teaching and learning space, but rather broadening what we know as "frame" into a whole new territory that began with channels such as Zoom, Blackboard, Meet, and MS Teams as primary actors in this virtual educative framework. However, we may also find a different terrain, the world of 3d online spaces, which were traditionally explored by gamers as a place for engagement, as an extended reality that, owing to the expansion of these platforms, is now feasible to exploit the use of WebVR technology (fig. 2).

Questions like How can educators with minimum support utilise open-source methods in teaching to evolve in a virtual way of learning? What are the latest available means to enhance engagement and inclusiveness in such education? Are now part of our journey, redefining the concept of transmitter and receptor, professors and students, in where content is not just a lecture in a unidirectional way of bringing content (horizontal way of learning, as opposed to vertical), instead of a space being constantly rewritten by teachers and students rather just a planar approach that translate books from physical to digital. These new educative experiences belong in particular to the concept of “embodiment” in where systems that have evolved for perception, action, and emotion, contribute to “higher” cognitive processes (Glenberg, 2008), being finally the new territory to explore by the use of virtualisation, not as a replacement of physical. In that sense, we are now working on creating new opportunities

towards a definitive evolution from static modes of learning based on objectives in a model in which skills are equally validated together with theoretical contents (experience=skills - theory=objectives).

Fig. 2. Multiple players interacting and taking selfies in the VR scenes during the second roundtable event. The avatar was personalised using neural networks by the authors, and the room was tailored by Mozilla

3. Theoretical Discussion: Future of Education

Mozilla Hubs and Spoke were the VR tools chosen for this project (fig. 3). Mozilla Hubs was the frontend to 'meet, share and collaborate together in private 3D virtual spaces', whereas Mozilla Spoke was the backend web editor to build and create 3D social scenes, with 'No external software or 3D modelling experience required' (Mozilla, 2022). This web-based platform was founded in 2018, multi-accessible with any web browser to increase inclusivity in VR, as individuals would not have to pay a considerable amount of headsets to participate in such events. It is also real-time communication, with a limit of 25 players interacting with one another in the same VR room for optimal network communication capacity; it can be opened to a maximum of 100 players at the same time. Hub has distance-aware audio configuration, meaning sounds are quieter afar and louder close up, and can be adjusted with different physical simulations, including audio roll off factors, reference distances, cone angles and gains, with a user-friendly interface. Compared to platforms such as Oculus, Hubs is not as high resolution, nor as sophisticated in its ray-tracing, but these were deliberately designed for its real-time multiplayer purpose, with very light-weight data communication, loading, and processing.

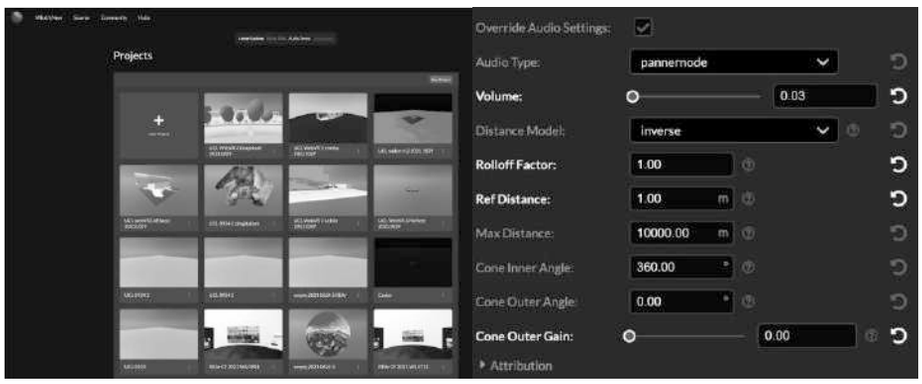

Fig. 3. User-friendly interface of Mozilla Spoke, and its distance-aware audio configuration. Image from the authors.

Round-the-table invited a member of the Hubs team for presentation and interview, who shared with us that the team was around 10 people under Mozilla's support; it is very streamlined, their strategy of open-source and crowdsourcing not only plays to their advantage, they contribute back to the Creative Commons by facilitating such open interactive platforms. It enables linking to Github to directly import open-sourced scripts; developers can script onto their platform for further personalization of VR functions, but would require proficient skills in coding. It also has an API (Application Programming Interface) to Sketchfab - an open-source 3D asset database, where users can simply drag-and-drop 3D objects on the front-end. Hubs did not engineer its developer page like many tech enterprises, but based its communication on Discord, where anyone can communicate with their team and share information in real-time, building an open community around such initiatives. Mozilla (moz://a), founded in 1998, is a free software community with open standards, supported by the non-profit Mozilla Foundation, its main product is the web browser Firefox (Mozilla, 2022).

3.1 Data Communication

Data communication in the production of VR spaces and avatars involves turning 2D data into 3D and the feedback between organizers and contributors in its processing. For spatial data, it involved turning sets of sequential images into a 3D digital reconstruction of the physical space through photogrammetry, mapping 360 photos and renderings in spherical projections, mapping presentation materials on panel geometries, and designing some of the spaces from scratch (fig. 4). For avatar data, it involved the 3D digital reconstruction of the participants using head or full-body shots. Both involve the translation between proprietary and open-sourced data format amongst the different processing and generative software interfaces and algorithms. Guests were invited to submit raw materials in open-sourced formats for us to tailor their VR spaces, or primary base information as .obj file and images for textures. The open-source structure enables free flow of 3D data from Blender, Sketchfab, to Hubs and Spoke. These files were the base for the creation of each scene, creating a synergic relationship between the graphical content, 3d space, and the audience.

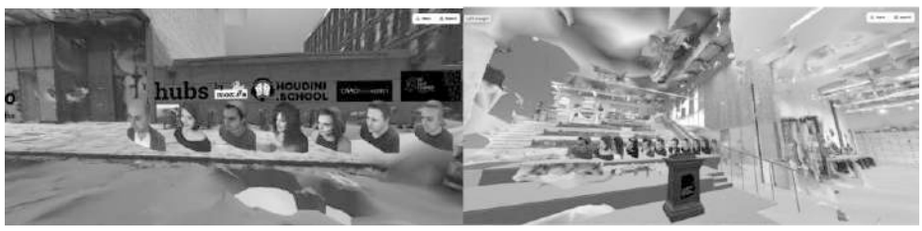

Fig. 4. Photogrammetry spaces with all of the avatars for event 2 and 3, Image from the authors.

Images sent by guests were used as the source for photogrammetry in Reality Capture to reconstruct their physical spaces, each space required at least 100-200 images for optimal reconstruction; beyond 500 images, the reconstructed model would be quite heavy for Hubs to load, especially in mobile devices. This constrains the size of the room that can be scanned, if guests wish to scan a larger space, the room resolution has to be lower to leverage real-time constraints. Alternatively, their images or videos can be mapped in panel or spherical projection inside Spoke for a more volumetric experience, especially with 360 photos and videos.

Fig. 5. Performance check of one of the scenes before export, showing the figures on 3D assets, and their recommended optimal. Image from the authors.

The above figure (fig.5) shows the performance check panel from the backend of Spoke, the strict limitation to polygon count, materials, textures, lighting, and file size can be seen. At the same time, certain materials are not supported for visualisation, such as glass or mirrors, and the complexity of generative geometry requires heavy decimation; in one case, one of the guests shared a generative landscape model, which was impossible to load. We used one of the three strategies in resolving such a situation: decimation, voxelization, rendering the models into 360 images for spherical mapping, or splitting the models into several adjacent scenes (fig. 6).

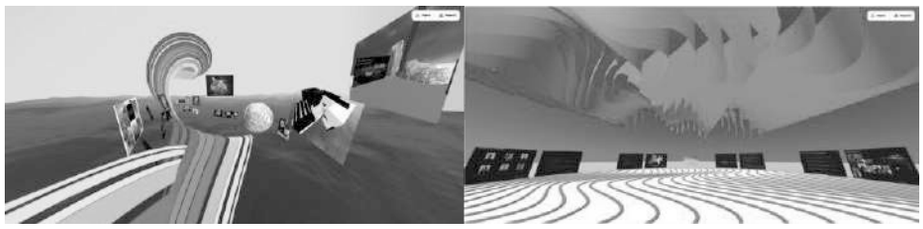

Fig. 6. Two spaces with objects customised via front-end (Hubs) and backend (Spoke) respectively, showing the amount of control in object manipulation with the two modes. Image from the authors based on Houdini academia and CAAD futures spaces.

3.2 Spatial Distribution and Streaming

We were working with the idea of suppressing the typical boundaries provided by a webcam and microphone, as well as the borders of our developed virtual environment. The notion of materiality is redrawn in all of the preceding cases, as well as numerous others, providing the user with such a greater set of possible tools for interactivity and customization. (Including the avatar design), allowing the individual to immerse themselves in a digital persona (a personalized character) that assures the presence (Schuemie, Et al. 2021) of sentiments, emotions, and ties to the place via your digital alias.

Interactivity (Christou, 2010) on the other hand, is described as the capacity to manage events in this virtual environment by utilizing our body and its motions in response to our stimuli, therefore generating a responsible place that responds to our senses. A VR experience is defined as a multi-sensory spatial method that creates the impression of "being there" by linking the user with the place as an experience in a continuous loop of in/out data.

Instead than focusing just on the plain content, we're broadening the scope of what may be learned from experience. The idea is that the learner tries to incorporate new experiences into their current world picture (Barrouillet, 2015). If they are unable to assimilate further knowledge, learners modify their worldview to accommodate the most recent facts. We must adapt to the new experience by reframing our understanding of how the world works (and webVR serves as a catalyst for this notion); we learn from the experience, and learning may therefore be viewed of as a form of active environmental sampling and testing.

In terms of how the teaching and learning experience was configured, we started with the idea of a space that triggers the conversations through the questions that were asked as part of each meeting: Session 1: Decentralized Education: P2p Learning / Session 2: The Phygital in Education / Session 3: Phygital and Cyber-physical discourses. The main target was firstly to ask to our guest about material as images and/or three dimensional models to be used as part or the discussion. The next step in terms of configuring the experience was the distribution of the information inside each space, using basically three main strategies: 1.- a concentrated strategy in which the content was contained in a set of virtual panels inside the virtual space, 2.- a virtual “shared screen” presentation, 3.- a spatial based distribution. In all the cases, the information was in constant dialog with the whole diversity of virtual environments, creating all these possible configurations.

We employed a "spatial derive theory" (Theraulaz, 1999) method in the process, which is founded on the ideas of abandoning standard movement

styles and adopting a strategy that results in persistent random wandering inside an area or specific location. Instead of linear motions, we propose a pseudo drift viewpoint as a first step in gathering information and sentiments that will help us understand where we are. In that way, the "random" sequence of spaces, changing sizes and content, allowed us to expand the learning process from the entire experience, starting and finishing in the same introduction area as the conclusion for each spatial loop, eventually calling all visitors to a conversation time.

3.3 Volumetric Navigation

Fig. 7. Two scenes where one required flying and another did not. Image from the authors based on Sigradi and Strelka VR scenes.

The advantage of adopting VR for teaching is that the situation and content may be modified for each speaker rather of constantly being in the same classroom and surroundings. In Hubs, there are three options for volumetric navigation: walk, teleport, or scene change. WASD buttons on the keyboard and a mouse to tilt the camera were the primary controls for walking, with G enabling flying mode. It took some people around 10 minutes to become acclimated to these controls. In one of the rooms, Hub guests ask various questions on whether users are comfortable with such navigation, and 6 out of 9 visitors with no gaming experience say they are.

On two instances when flying was required, some of the visitors battled for more than 15 minutes lost in the model since flying mode has no ground sensitivity and it was difficult to figure out the North-West direction within confined places. This occurred even with an additional rehearsal session. Dropped items can also bounce off collidable objects in Hub's gravity simulation, however errors can arise when things disappear through the ground plane (fig. 7).

4. Conclusion and Next Steps

The development of this series of Virtual Round-tables has provided us with the opportunity to demonstrate that a 3D VR approach in education enriches the experience in terms of possible interaction between expositors, resulting in a more confident approach that allows for better communication in a perceptual way (with the use of avatars as mediators). The time and resources invested in the development of these 21 talks under three main conversation topics far outweigh the resources used, with the main issue being training from our side (we spend one day in advance for training to our guests) as well as daily support from us to our guests in the construction of virtual scenes to host each talk. (via tutorials, capturing spaces with pictures, or modelling spaces in advance with them). The final arrangement was part of our job, as were all of the organizational features that allow a team of two (like us) to lead effectively with a one-month gap between events (the distance between the first and the second round-table was just in the limit for the delivery of a good product).

Mobile device and Web VR evolution is still ongoing, and tight ecosystems such as Safari are now impeding appropriate advancement of these technologies owing to compatibility difficulties (a close API for developers). This causes issues in navigation mode for a full VR experience, as well as a lack of ability to recognize textures and shadows, resulting in a restricted experience for consumers.

Because of the limits of current webVR technology, streaming should be addressed as part of the distribution plan (it is not possible to host more than 25 persons without lacking performance and responsiveness). In this regard, the total number of attendees through streaming surpasses this figure 3.6 times in the worst case (second round table) and 13.6 times in the best scenario (first round table), with the last session having 6.8 times more maximum potential users than the baseline from the webVR platform.

The formation of permanent support for this project as a chance to utilize them for similar events as part of the prospective agendas of hybrid forms of communication in the academic environment, rather than simply a standard zoom/meets/teams gathering, are viable future stages. Here, we visualized the fruit of collaborative work between visitors and organizers, in the sense of two types of collaborative environments, which ultimately expanded the richness of the expected results in a massive set of possible educative scenarios that will serve as the foundation for more elaborated designs (asset of archetypes webVR educative scenarios).In the near future of educational strategies, we believe it is perfectly possible to push the boundaries of the actual massification of 2d academic frames into an immersive educational experience.

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References

United Nations “Sustainable Development Goals”. https://sdgs.un.org/goals Accessed 10 Feb 2022.

Mpungose, C. B. (2021). Lecturers’ reflections on use of Zoom video conferencing technology for e-learning at a South African university in the context of coronavirus. African Identities, 1-17. Access: https://www.tandfonline.com/doi/abs/10.1080/14725843.2021.1902268

Bailenson, J. N. (2021). Nonverbal overload: A theoretical argument for the causes of Zoom fatigue.

Agnihotri, A., & Bhattacharya, S. (2022). MasterClass: Exploring Growth. SAGE Publications: SAGE Business Cases Originals.

Coppola, C., & Neelley, E. (2004). Open source-opens learning: Why open source makes sense for education.

Wiley, D. (2006). Open source, openness, and higher education. Innovate: Journal of Online Education, 3.

Costello, E. (2013). Opening up to open source: looking at how Moodle was adopted in higher education. Open Learning: The Journal of Open, Distance and e-Learning, 28(3), 187-200.

Reñosa, M. D. C., Mwamba, C., Meghani, A., West, N. S., Hariyani, S., Ddaaki, W. & McMahon, S. (2021). Selfie consents, remote rapport, and Zoom debriefings:

collecting qualitative data amid a pandemic in four resource-constrained settings. BMJ global health, 6(1), e004193.

Archibald, M. M., Ambagtsheer, R. C., Casey, M. G., & Lawless, M. (2019). Using zoom videoconferencing for qualitative data collection: perceptions and experiences of researchers and participants. International journal of qualitative methods, 18, 1609406919874596.

Arthur M. Glenberg, 2008, 18 - Embodiment for Education, Editor(s): Paco Calvo, Antoni Gomila, In Perspectives on Cognitive Science, Handbook of Cognitive Science, Elsevier, Pages 355-372, https://www.sciencedirect.com/science/article/pii/B9780080466163000189, Accessed 1 Feb 2022.

Mozilla. (n.d.). Hubs by Mozilla. Hubs. Retrieved March 11, 2022, from https://hubs.mozilla.com/ Accessed 7 Feb 2022.

Mozilla. (n.d.). History of the mozilla project. Mozilla. Retrieved March 11, 2022, from https://www.mozilla.org/en-US/about/history/ Accessed 7 Feb 2022.

Shunsuke S., Simon T.,Sarahi J., Hanbyul J.,(2020), PIFuHD: Multi-Level Pixel-Aligned Implicit Function for High-Resolution 3D Human Digitization https://shunsukesaito.github.io/ PIFuHD/

Avatar SDK, -https://avatarsdk.com/ Accessed 8 Feb 2022.

PIFuHD AI generated 3D digital human avatar texturing in Blender https://youtu.be/XNgB5qffgtU Accessed 20 Feb 2022.

Martijn J. Schuemie, Peter van der Straaten, Merel Krijn, and Charles A.P.G. van der Mast. Research on Presence in Virtual Reality: A Survey CyberPsychology & Behavior https://doi.org/ 10.1089/109493101300117884 Accessed 01 Dec 2021.

Christou, C. 2010. Virtual Reality in Education. In A. Tzanavari, & N. Tsapatsoulis (Eds.), Affective, Interactive and Cognitive Methods for E-Learning Design: Creating an Optimal Education Experience (pp. 228-243). IGI Global. https://doi.org/10.4018/978-1-60566-940-3.ch012

Barrouillet, P (2015). Theories of cognitive development: From Piaget to today, Developmental Review, Volume 38, Pages 1-12.

Teoria de la deriva: espacio y territorio (versión en español) https://taccuinodibordo.wordpress.com/2012/05/11/teoria-de-la-deriva-espacio-y-territorio-versionen-espanol/ Accessed 25 Feb 2022. 18.-Theraulaz, G. & Bonabeau, E. (1999). A Brief History of Stigmergy. Artificial life. 5. 97-116. 10.1162/106454699568700.

Life Long Learning and Digital Education:
Online Learning

Parameterization and active methodologies in the online learning of Descriptive Geometry

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Abstract. Descriptive Geometry demands abstraction and spatial visualization. In this case, parameterization can be useful as a supporting tool. However, in an online learning scenario, where the students have no access to software, it is necessary to re-think and adapt the use of parametric simulation. The active character from the parametric modeling manipulation can be compensated by adopting active teaching-learning methodologies. This didactic experimental study was applied to two classes in a technical and high school education context, focusing on two subjects: points and lines in descriptive geometry. The study intends to analyze the application of parametrization and active methodologies, mostly gamification, in the online learning of Descriptive Geometry. The results indicate that it is still possible and efficient to apply parametric modeling in online learning articulating with active methodologies, and it hence improves the teaching-learning process.

Keywords: Online learning, Parameterization, Active teaching-learning methodologies, Descriptive Geometry, Didactic experiment.

1 Introduction

Geometria descritiva exige visualização espacial e abstração para que seja possível entender os objetos posicionados no espaço e suas representações projetadas nos planos. Pode ser considerado um assunto de difícil compreensão, sobretudo para os estudantes de ensino técnico de nível médio. Todavia, é possível adotar estratégias e recursos didáticos que facilitem e motivem este processo de ensino-aprendizado.

A temática é abordada na disciplina de Desenho Técnico, do curso técnico de nível médio em Edificações, contemplando o estudo de pontos, retas e planos. Tem como base teórica a Geometria Projetiva e o Sistema Mongeano, que se caracteriza pela projeção cilíndrica ortogonal.

A Geometria Descritiva, assim como a disciplina de Desenho Técnico, tem natureza prática e instrumental, tradicionalmente explorada pelo desenho manual com uso de instrumentos técnicos. Todavia, conforme defende Wilson Florio (2012), considerando que os conhecimentos de geometria são fundamentais para compreensão e projetação das formas, no contexto de crescente inserção tecnológica é necessário que se *faça uma re-valorização destes conhecimentos diante das facilidades trazidas pelas novas tecnologias de representação e de simulação de espaços* (Florio, 2012).

Neste sentido, apesar da complexidade inerente à modelagem paramétrica, articulada sobretudo à geração de formas geométricas complexas, Mendes, Lima e Griz (2018) demonstraram ser possível explorar a parametrização no ensino da geometria quando aplicada à manipulação de construções geométricas simples. Os autores destacam a urgência na proposição de *metodologias de ensino que incorporem as tecnologias digitais na área de ensino da geometria gráfica, constituindo uma associação do conhecimento tradicional para a apropriação consciente dos recursos tecnológicos atuais* (Mendes et al., 2018).

Nesta perspectiva, a parametrização torna-se oportuna e eficaz pois é possível desenvolver modelagens com variáveis simples e conhecidas pelos discentes e, através do manuseio dos parâmetros, permite visualizar os resultados geométricos de maneira automática e dinâmica (Asevedo et al., 2020).

Todavia, diante do cenário de pandemia do Sars-Cov-2, da consequente adoção do ensino remoto emergencial, e da impossibilidade de acesso dos estudantes aos softwares de modelagem paramétrica, adotar a parametrização exigiu mudanças metodológicas. Tornou-se possível apenas disponibilizar vídeos de simulação da modelagem, ocasionando perdas no caráter ativo ora apresentado pelo manuseio dos parâmetros pelos próprios discentes.

Com o intuito de mitigar esta perda, a adoção das metodologias ativas de ensino se apresentou como um caminho. Categorizam-se como metodologias ativas: a Aprendizagem Híbrida ou *Blended Learning*; a Sala de Aula Invertida ou *Flipped Classroom*; a Instrução entre Pares ou *Peer Instrucion*; o Método de Casos; a Aprendizagem Baseada em Problemas e Problematizações; a Avaliação por Pares e Autoavaliação; o *Desing Thinking*; os *Games*, Gamificação e Simulação; a Pesquisa; e a Aprendizagem baseada em Projetos (Santos & Tezani, 2018, p. 108).

Especificamente a gamificação, em destaque neste estudo, é caracterizada pela adoção de elementos de jogos em contextos de não-jogos, e tem intuito de promover a motivação, interesse e engajamento dos estudantes no processo de ensino-aprendizagem. Para isto, utiliza-se de elementos típicos de *games*, tais como: lançamento de desafios, narrativa (*storytelling*), cumprimento de regras, sistema de *feedback* e de recompensas, conquista por pontos e troféus, superação de níveis, interatividade e criação de avatares (Fardo, 2013; Navarro, 2013).

Considerando a afinidade entre a parametrização e a prática de *games* (Nogueira et al., 2015), a crescente investida nas metodologias ativas de ensino, sobretudo no cenário pandêmico, e as vantagens da integração destas com as tecnologias digitais de informação e comunicação (TDIC), surge então este estudo que objetiva, a partir de uma experiência didática, analisar a adoção da parametrização e das metodologias ativas no ensino remoto de Geometria Descritiva.

2 Metodologia

O método adotado neste trabalho é experimental e utiliza-se da pesquisa-ação. O estudo foi aplicado a duas turmas (A e B) da disciplina Desenho Técnico, do curso técnico de nível médio em Edificações, no semestre letivo de 2021.1, caracterizado pelo ensino remoto emergencial.

Considerando a distribuição das aulas em momentos síncronos – correspondentes à 1/3 da carga-horária - e assíncronos – 2/3 da carga horária -, foram adotados diversos procedimentos metodológicos, sendo incluídas as metodologias ativas de ensino (Tabela 1).

Tabela 1. Procedimentos metodológicos aplicados nas aulas de Geometria Descritiva

AULA	CONTEÚDO	PROCEDIMENTOS METODOLÓGICOS
1	Teoria das Projeções e Sistemas de Representação Gráfica	Sala de Aula invertida. Aula Expositiva.
2	Introdução à Geometria Descritiva e Sistema Mongeano	Sala de Aula invertida. Aula expositiva. Maquete
3	Estudo do Ponto **Jogo de Detetive (EXPERIMENTO 1)**	Sala de Aula invertida. Aula expositiva. Jogos digitais. **Exercício com *storytelling* e simulação paramétrica**
4	Representação de pontos em épura	Exercício gráfico manual
5	Estudo das Retas **Jogo de Detetive – 2ª missão (EXPERIMENTO 2)**	Sala de Aula invertida. Aula expositiva. Jogos digitais. **Exercício com *storytelling* e simulação paramétrica**
6	Representação de retas em épura	Exercício gráfico manual
7	Estudo dos planos	Sala de Aula Invertida. Aula expositiva. Jogos digitais.
8	Representação de planos em épura	Exercício gráfico manual
9	Desafio de Criatividade	Exercício em formato de jogo. Desenho digital. Modelagem digital ou maquete.
10	Desafio de Criatividade	Exercício em formato de jogo. Desenho digital. Modelagem digital ou maquete.

Fonte: Autores, 2021

Os assuntos de cunho teórico-conceitual foram introduzidos por meio de materiais didáticos previamente disponibilizados no *Google Classroom* como atividade assíncrona, aplicando-se a Sala de Aula Invertida. E no momento síncrono, os conteúdos eram revisados em aula expositiva, seguidos da aplicação de jogos digitais para fixação do conteúdo, elaborados na plataforma WorldWall.net. Também foi explorada a maquete móvel do sistema diédrico transformando-se em épura (Aula 2).

Nas Aulas 3 e 5, foram introduzidos o Jogo de Detetive e o Jogo de Detetive – 2ª missão, respectivamente, que consistem em atividades que integram gamificação com simulação paramétrica.

As aulas 4, 6 e 8 foram destinadas à orientação e exemplificação dos exercícios gráficos manuais.

E para finalização da temática, as aulas 9 e 10 destinaram-se à aplicação do Desafio de Criatividade, que consistia em uma atividade com características de jogos, em que era solicitada a criação de um objeto geométrico tridimensional, acompanhado do seu modelo digital ou físico, sua perspectiva isométrica - elaborada na plataforma Geogebra Geometria -, e a identificação e classificação de retas e planos que o compunham.

Como este estudo tem ênfase na aplicação da parametrização e metodologias ativas no ensino remoto de Geometria Descritiva, sobretudo a gamificação, haverá destaque para os Experimentos: 1) Jogo de Detetive, que contempla o assunto de Pontos; e 2) Jogo de Detetive – 2ª missão, correspondendo ao conteúdo de Retas. Ambos, adotaram o método de *storytelling* e incluíram a simulação paramétrica. Foram aplicados em formato de formulário eletrônico, e apresentaram três etapas (Tabela 2).

Tabela 2. Etapas dos Experimentos de parametrização e gamificação

ETAPAS POR EXPERIMENTO	1 JOGO DE DETETIVE (PONTOS)	2 JOGO DE DETETIVE – 2ª MISSÃO (RETAS)
a) PRÉ PARAMETRIZAÇÃO	10 questões sobre o posicionamento dos pontos no sistema diédrico	7 questões sobre a identificação do tipo de reta
b) SIMULAÇÃO PARAMÉTRICA	Vídeo de simulação paramétrica dos 10 pontos	Vídeo de simulação paramétrica das 7 retas
c) PÓS PARAMETRIZAÇÃO	repetição das 10 questões sobre o posicionamento dos pontos + 3 questões de sondagem	repetição das 7 questões sobre o tipo das retas + 3 questões de sondagem

Fonte: Autores, 2021

No *Rhinoceros* e *Grasshopper*, foram desenvolvidas as modelagens paramétricas de pontos e retas no sistema diédrico. Devido à impossibilidade de manipulação dos softwares pelos estudantes, tendo em vista a falta de

acesso dos alunos aos programas, foi realizada a gravação das simulações paramétricas dos pontos e retas e, posteriormente, disponibilizados os vídeos.

A etapa de PRÉ PARAMETRIZAÇÃO era composta por questões sobre o posicionamento dos pontos, e sobre o tipo das retas. Na SIMULAÇÃO PARAMÉTRICA era disponibilizado o vídeo com o manuseio da modelagem paramétrica dos pontos e das retas. E a etapa POS PARAMETRIZAÇÃO, era composto pelas mesmas questões da etapa pré parametrização sendo acrescidas três questões de sondagem sobre o experimento, conforme será explicitado a seguir.

2.1 EXPERIMENTO 1

O experimento 1, denominado Jogo de Detetive, consistia no exercício de identificação da posição de 10 pontos no sistema diédrico.

O experimento contou com o método do *storytelling* para contar uma estória em que o estudante seria um detetive em busca da gangue nomeada “PONTOS”, composta por 10 integrantes que haviam se escondido no “Prédio do Sistema Diédrico” (Figura 1.a).

O exercício foi elaborado na plataforma *Google Forms*. Na etapa PRÉ PARAMETRIZAÇÃO, apresentou-se o enunciado da missão e as 10 questões acerca do posicionamento do ponto em que eram dadas as fichas (Figura 1.b) dos 10 integrantes da gangue, onde se incluíam as suas coordenadas, e se apresentavam 13 alternativas de posicionamento dos pontos: os 4 diedros, os 2 semiplanos horizontais, os 2 semiplanos verticais, os 2 planos bissetores nos 4 diedros, e a Linha de Terra (L.T.).

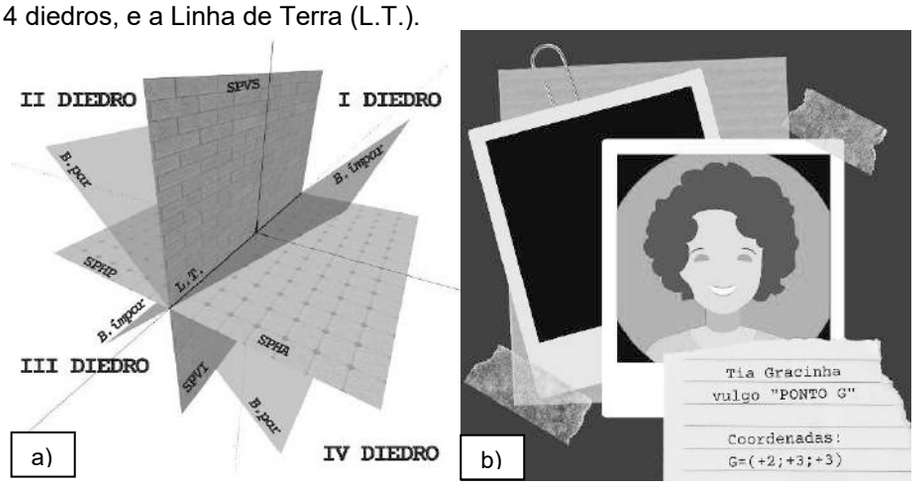

Figura 1. a) Prédio do Sistema Diédrico. b) Ficha do Ponto G. Fonte: Autores, 2021.

Na etapa de SIMULAÇÂO PARAMÉTRICA, o estudante tinha acesso a uma nova pista: um vídeo que demonstrava a movimentação dos pontos no Sistema

Diédrico. O vídeo consistia na gravação da simulação paramétrica dos pontos nos softwares, sendo manuseadas as coordenadas dos 10 pontos dados (Figura 2).

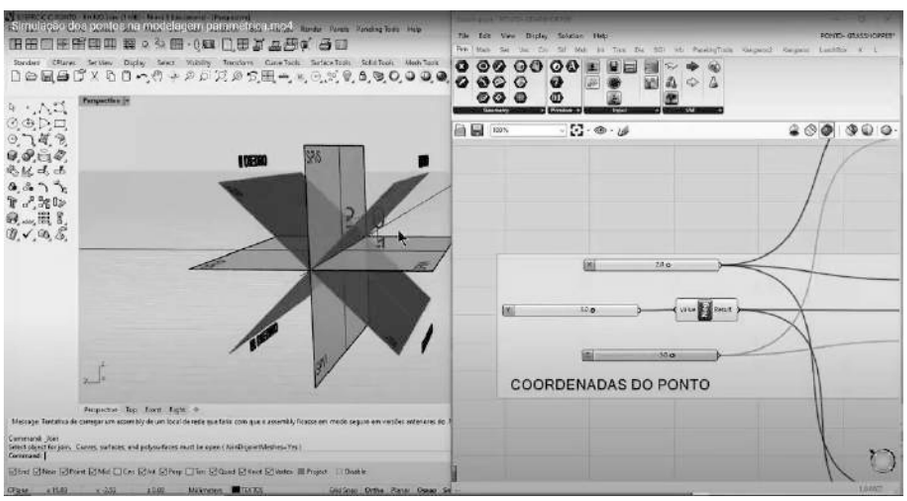

Figura 2. Vídeo de simulação paramétrica dos pontos. Fonte: Autores, 2021.

Após a pista do vídeo, o estudante era mais uma vez solicitado a responder a posição dos 10 mesmos pontos (POS PARAMETRIZAÇÃO). E, por fim, havia três perguntas de sondagem cuja primeira questionava: “Você acredita que o uso do vídeo (de simulação dos pontos na modelagem paramétrica) contribuiu para você identificar o posicionamento dos pontos?”, e as alternativas dadas eram: Sim, muito; Sim; Não, foi indiferente; e Não assisti ao vídeo. Na sequência, a segunda pergunta solicitava justificar a resposta da questão anterior. E a última pergunta requeria comentários sobre o formato de jogo adotado na atividade.

2.2 EXPERIMENTO 2

No Jogo de Detetive – 2ª missão, os estudantes foram convidados a desvendar as “armadilhas”, em formado de segmentos de retas, criadas por cada dupla de integrantes da gangue “pontos”.

Para este experimento, foram definidos 7 segmentos de retas, sendo um de cada tipo, conforme a classificação das retas quanto a sua posição espacial.

A etapa PRÉ PARAMETRIZAÇÃO contemplou o enunciado da missão, o esquema das armadilhas - que apresentava a classificação das retas -, e as 7 questões onde eram dadas as fichas da dupla de pontos (Figura 3) e solicitados o tipo de armadilha entre as opções: Horizontal, Frontal, De topo, Vertical, Fronto-horizontal, Qualquer, e De perfil.

Figura 3. Ficha dos Pontos M e N. Fonte: Autores, 2021.

Na etapa de SIMULAÇÃO PARAMÉTRICA, introduzia-se a nova pista: o vídeo de movimentação dos “Pontos” na Sala do I Diedro, onde era disponibilizado o vídeo de simulação paramétrica dos pontos que compunham as retas dadas (Figura 4).

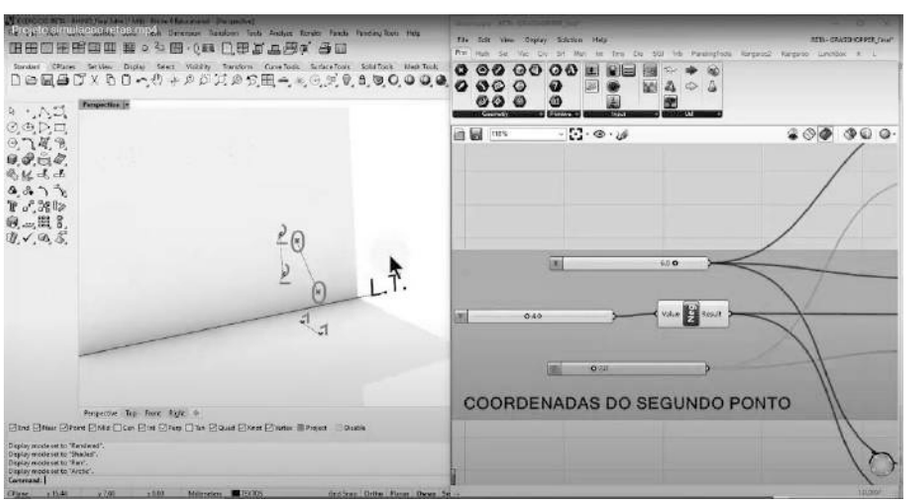

Figura 4. Vídeo de simulação paramétrica das retas. Fonte: Autores, 2021.

Na sequência, os estudantes eram solicitados a responder novamente às mesmas 7 questões sobre o tipo de reta (etapa POS PARAMETRIZAÇÃO), e a três últimas perguntas de sondagem. Questionou-se: “Você acredita que o uso do vídeo (de simulação dos pontos na modelagem paramétrica) contribuiu para você identificar o tipo de armadilha (RETA)?”, tendo como alternativas as respostas: Sim, muito; Sim, Não, foi indiferente; e Não assisti ao vídeo.

Também foi solicitada a justificativa para esta resposta, e, a última questão, aberta, requeria comentários acerca do formato de jogo adotado.

3 Resultados

No que diz respeito aos dois experimentos em destaque, foi possível averiguar resultados de ordem quantitativa e qualitativa. Quantitativamente, comparadas as respostas entre as etapas PRÉ e PÓS acesso à simulação paramétrica, obteve-se um aumento no percentual de acertos, nos dois experimentos e nas duas turmas, no momento posterior à parametrização.

No geral, qualitativamente, nas respostas abertas acerca da contribuição do vídeo de simulação paramétrica, os discentes comentaram que a parametrização facilitou a visualização espacial, esclareceu o assunto, e trouxe a demonstração prática de um conteúdo abstrato. E quanto à adoção do formato de jogo, os estudantes caracterizaram a experiência como lúdica, divertida, interessante, descontraída, interativa, motivadora, dinâmica e criativa. A seguir, serão descritos os resultados por experimento.

3.1 EXPERIMENTO 1

O experimento 1 foi respondido por 39 estudantes na turma A, e por 40, na turma B. Na turma A, na etapa PRÉ PARAMETRIZAÇÃO, do total de 390 respostas, 221 respostas foram acertadas, o que corresponde à 56,7% do total das respostas. Já na etapa POS PARAMETRIZAÇÃO, das 390 respostas, 323 foram corretas, correspondente à 82,8% do total de respostas. Para tanto, houve um aumento em 26,1% no índice de acertos.

Já na turma B, de 400 respostas, na etapa PRÉ PARAMETRIZAÇÃO, 245 foram as respostas corretas, o que computa 61,3% do total de respostas da etapa. E no momento POS PARAMETRIZAÇÃO, este número subiu para 344 respostas certas, equivalente a 86,0% do total de respostas. Portanto, com um aumento de 24,7% de acertos.

A Tabela 3 apresenta os resultados por questão.

Tabela 3. Resultados do Experimento 1, PRE e POS parametrização, turmas A e B.

Questões por PONTO	TURMA A				TURMA B			
	PRE		POS		PRE		POS	
	Certas (%)	Erradas (%)	Certas (%)	Erradas (%)	Certas (%)	Erradas (%)	Certas (%)	Erradas (%)
A	71,8	28,2	79,5	20,5	67,5	32,5	77,5	22,5
B	66,7	33,3	87,2	12,8	50,0	50,0	90,0	10,0
C	46,2	53,8	82,1	17,9	67,5	32,5	85,0	15,0
D	61,5	38,5	89,7	10,3	52,5	47,5	87,5	12,5
E	48,7	51,3	76,9	23,1	72,5	27,5	87,5	12,5
F	51,3	48,7	84,6	15,4	55,0	45,0	90,0	10,0
G	53,8	46,2	79,5	20,5	60,0	40,0	90,0	10,0
H	56,4	43,6	84,6	15,4	72,5	27,5	95,0	5,0
I	66,7	33,3	87,2	12,8	65,0	35,0	90,0	10,0
J	43,6	56,4	76,9	23,1	50,0	50,0	67,5	32,5

Fonte: Autores, 2021

Averígua-se que a turma B, comparada à turma A, obteve maiores índices de acertos, no geral, em ambas as etapas do experimento.

Quanto às questões de sondagem, acerca da contribuição da parametrização para a identificação do posicionamento dos pontos, em ambas as turmas os estudantes consideraram que o uso do vídeo de simulação paramétrica foi positivo (Figura 5).

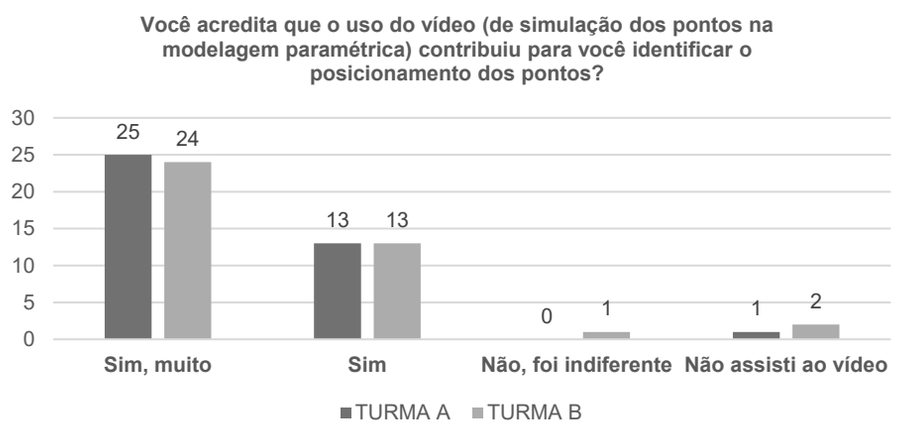

Figura 5. Gráfico sobre a contribuição do vídeo de modelagem paramétrica para a identificação do posicionamento dos pontos, turmas A e B. Fonte: Autores, 2021.

Os estudantes justificaram principalmente que a simulação auxiliou na visualização dos pontos. Destacam-se as seguintes respostas:

O vídeo ajudou muito pelo fato da visualização da modelagem 3D ficar mais clara e fácil de identificar os pontos. (Respondente n.13, turma A)

A atividade se torna mais fácil quando conseguimos ver o objeto e acharmos o ponto preciso de cada localização sem deixar dúvidas. (Respondente n.19, turma A)

O estudo dos pontos no sistema diédrico é muito abstrato, a simulação na modelagem paramétrica permite que seja mais didático o aprendizado. (Respondente n.5, turma B)

Quanto à adoção da gamificação, através do *storytelling*, os estudantes afirmaram que o formato de jogo tornou a atividade lúdica e divertida, e despertou o interesse no assunto. Destacam-se os comentários:

Gostei muito do formato dessa atividade, facilitou o entendimento do conteúdo pela forma lúdica de ser abordado. (Respondente n.9, turma A)

Muito interessante, faz com que o aluno se sinta mais motivado a fazer a atividade. (Respondente n.31, turma A)

Achei muito legal essa abordagem de uma atividade mais lúdica, deixa tudo bem mais divertido e estimula o interesse em estudar e fazer as atividades. (Respondente n.27, turma B)

3.2 EXPERIMENTO 2

O experimento 2 foi respondido por 38 estudantes na turma A, e por 37, na turma B. Na turma A, na etapa PRÉ PARAMETRIZAÇÃO, do total de 266 respostas, 140 respostas foram corretas, o que corresponde à 52,6% do total das respostas. Já na etapa POS PARAMETRIZAÇÃO, das 266 respostas, 222 foram corretas, correspondendo à 83,5% do total de respostas. Para tanto, houve um aumento em 30,9% no índice de acertos.

Já na turma B, de 259 respostas, na etapa PRÉ PARAMETRIZAÇÃO, 167 foram corretas, o que computa 64,5% do total de respostas da etapa. E no momento POS, este número subiu para 236 respostas certas, equivalente a 91,1% do total de respostas. Portanto, computando um aumento de 26,6% no índice de acertos. Na Tabela 4 verifica-se os resultados por questão.

Tabela 4. Resultados do Experimento 1, PRE e POS parametrização, turmas A e B.

Questões por RETA	TURMA A				TURMA B			
	PRE		POS		PRE		POS	
	Certas (%)	Erradas (%)	Certas (%)	Erradas (%)	Certas (%)	Erradas (%)	Certas (%)	Erradas (%)
AB	52,6	47,4	81,6	18,4	70,3	29,7	86,5	13,5
CD	57,9	42,1	89,5	10,5	59,5	40,5	89,2	10,8
EF	44,7	55,3	78,9	21,1	64,9	35,1	94,6	5,4
GH	55,3	44,7	84,2	15,8	73,0	27,0	94,6	5,4
IJ	50,0	50,0	86,8	13,2	59,5	40,5	91,9	8,1
KL	52,6	47,4	76,3	23,7	67,6	32,4	91,9	8,1
MN	55,3	44,7	86,8	13,2	56,8	43,2	89,2	10,8

Fonte: Autores, 2021

Verificou-se que, no geral, a turma B teve melhor desempenho que a turma A em ambas as etapas.

Quanto às questões de sondagem, os estudantes das duas turmas consideraram que a simulação paramétrica contribuiu positivamente para a identificação do tipo de reta (Figura 6), colaborando, assim com o aprendizado do conteúdo.

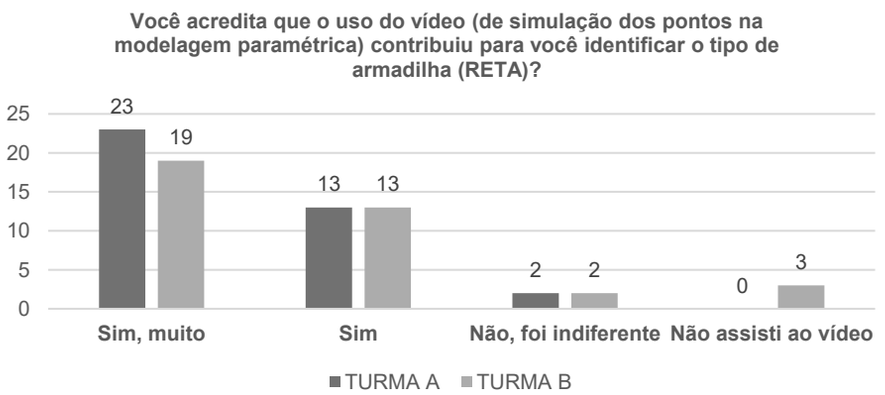

Figura 6. Gráfico sobre a contribuição do vídeo de modelagem paramétrica para a identificação do tipo de reta, turmas A e B. Fonte: Autores, 2021.

Destacam-se alguns comentários:

Graças ao vídeo tive exemplos de como a teoria funciona na prática e assim me ajudou para realizar essa atividade e a aprender o conteúdo. (Respondente n.15, turma A)

Com auxílio da modelagem paramétrica é possível aprender de forma menos abstrata, facilitando o aprendizado. (Respondente n. 9, turma B)

Estava enxergando tudo de maneira abstrata e com o vídeo facilitou bastante a visualização das retas. (Respondente n.17, turma B)

E no que se refere ao formato de jogo adotado no Experimento 2, os estudantes se sentiram interessados e motivados. Destacam-se os seguintes comentários:

O formato da atividade é muito interessante, pois adaptar essa atividade em forma de jogo, deixa o aprendizado muito mais divertido e simples. (Respondente n.35, turma A)

A forma lúdica dessa atividade deixa qualquer um motivado a querer aprender mais sobre o assunto para encontrar os criminosos. (Respondente n.2, turma B)

O jogo influenciou os alunos a se dedicarem a aprender de uma forma dinâmica e sem complicação na aprendizagem. (Respondente n.36, turma B)

4 Discussão

Os resultados demonstram que, mesmo na impossibilidade de aplicação da modelagem paramétrica de maneira ativa, com manuseio dos parâmetros pelos próprios discentes, ainda foi possível adotar a parametrização e conferir a eficácia desta ferramenta como recurso didático no ensino remoto de Geometria Descritiva. O caráter ativo ora perdido pela impossibilidade de acesso dos estudantes aos softwares, foi contornado pela inserção das metodologias ativas, que trouxeram motivação e interesse para com este conteúdo de caráter abstrato e de difícil compreensão. A experiência contribui como exemplo prático de antecipação da inserção digital no ensino técnico de nível médio, e de integração com as metodologias ativas, em busca de constantes melhorias para o processo de ensino-aprendizado no campo da representação gráfica.

Como trabalhos futuros, indicam-se: a aplicação da pesquisa no ensino presencial, a adoção do experimento em nível superior, o estudo com ênfase nos aspectos cognitivos de aprendizagem, e o comparativo entre as metodologias tradicionais e ativas de ensino da Geometria Descritiva.

Referências

Asevedo, L. F. de, Medeiros, D. C. A. de, Barbosa, G. M., & Silva, M. K. (2020). Parametric modeling as a supporting tool for teaching in a technical drawing course. *SIGraDi 2020*, 783–790. https://doi.org/10.5151/sigradi2020-107

Fardo, M. L. (2013). a Gamificação Aplicada Em Ambientes De Aprendizagem. *Renote*, *11*(1), 1–9. https://doi.org/10.22456/1679-1916.41629

Florio, W. (2012). Modelagem Paramétrica, Criatividade E Projeto: Duas Experiências Com Estudantes De Arquitetura. *Gestão & Tecnologia de Projetos*, *6*(2), 43–66. https://doi.org/10.4237/gtp.v6i2.211

Mendes, L. T., Lima, E. C. da S., & Griz, C. (2018). The use of parametric modeling and rapid prototyping in teaching graphic expression. *SIGraDi 2018*, 383–389. https://doi.org/10.5151/sigradi2018-1872

Navarro, G. (2013). Gamificação : A transformação do conceito do termo jogo no contexto da pós-modernidade. In *Biblioteca Latino-Americana de Cultura e Comunicação*.

Nogueira, T., Borda, A., Felix, L., & Vasconcelos, T. (2015). O agir na urgência e o decidir na incerteza: entre métodos e tecnologias de representação gráfica. *III Aproged's International Conference & XI International Conference on Graphics Engineering for Arts and Design*.

Santos, L. F. dos, & Tezani, T. C. R. (2018). Aprendizagem colaborativa no ensino de História: a Sala de Aula Invertida como Metodologia Ativa. *Renote*, *16*(2), 101–111. https://doi.org/10.22456/1679-1916.89302

Online Footprint - A Serious Game for Reducing Digital Carbon Emission

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Abstract. Life is getting digital more than ever as technology improves. While the Internet is responsible for two percent of global greenhouse gas emissions, it is underestimated as a pollutant. Since public awareness is one of the most important preservation methods, it can contribute to protecting the environment from carbon emissions by raising people's understanding. In this regard, serious games, as a type of gamification transmitting educational content besides entertainment, immerse the player in enjoyment while teaching them a specific topic or enhancing their skills in a field. This study proposes a serious game, taking the digital unseen carbon footprint and its effects on the landscape into the topic. The game considers SDG goals provided by the United Nations Department of Economic and Social Affairs. In this regard, the research uses SDGs 4 and 7 by providing quality education for all and access to sustainable energy by changing people's everyday habits.

Keywords: Online learning, Internet footprint, Climate change, Serious games, SDGs.

1 Introduction

Carbon footprint, which refers to the total amount of greenhouse gasses emitted directly and indirectly by an organization, person, product, or event (Gombiner, 2011), is one of the most undesirable and inevitable issues of the current era human beings are dealing with. The amount of the released carbon into the air has a solid connection with the people's living environment quality. Hence, the amount of emitted greenhouse gasses is being monitored to guarantee a safe habitat for the current and upcoming generations (Pătărlăgeanu et al., 2020). Since the carbon footprint includes gasses other than only carbon dioxide, the amount of global warming each activity causes is calculated by measuring its effect considering the equivalent amount of all

emitted gasses as carbon (Gombiner, 2011). This ecological footprint has a prominent role in climate change which the world is tackling, and urgent solutions are required to hinder the planet from being uninhabitable (Matthews et al., 2008). However, prior to looking for methods of dealing with it, it is important to be aware of its minor causes, as well as the more obvious ones.

Following the emergence of the Internet, it conversed from being a medium for only a minority of society to an everyday factor in the whole of humanity's life. Hence, it raised plenty of questions concerning the impact it puts on social interactions and communities and the accessibility of the resources. This novel technological invention transformed the planet by bringing new enlightenment. Its pervasive use not only functions on its own but also penetrates the everyday activities and functions of the people. For instance, in shopping, the Internet is being used in both innovative and familiar ways (Haythornthwaite and Wellman, 2002). While the capabilities of this technology captivated people, and they assumed that the Internet would be a cure for the planet's climate change problem by reducing the greenhouse gas amount emitted by plenty of activities, they underestimated the carbon footprint of the Internet itself. According to Gombiner (2011), global Information Technology (IT) emits approximately two to four percent of the current greenhouse gasses. This amount is generated in two ways, first, the manufacture and shipment of the required hardware, such as servers, personal devices, etc., and second, the energy needed for power and cooling these systems.

According to Hurst (2017), if the Internet were a country, it could be ranked as the 5th most pollutant compared to the various countries' contamination rates. The Google search engine can serve as a great example to understand energy usage and the Internet's carbon footprint. According to Pandia's 2007 news, this corporation has more than one million worldwide servers processing about one billion search queries daily. In 2009, Kuhn, in a CNN news report, revealed Google's servers as 100,000 per quarter. In addition to these servers' production and distribution of greenhouse gas outputs, each user's Google search has an additional emission. To speed up the search results, Google uses more servers than needed, consuming plenty of unnecessary energy. Due to Alex Wissner-Gross, a physicist from Harvard, each Google search emits seven grams of carbon dioxide, equaling boiling a teapot or driving a car for 52 feet. Considering the different statistics by various organizations, even if this amount is an average of one gram, with one billion daily searches, the related CO2 amount reaches one billion grams, similar to driving 2,375,000 miles with a car.

Additionally, Alex Wissner-Gross has an estimation regarding watching pictures or videos on web pages. According to him, each second viewing media on the Internet produces 0.2 grams of CO2. With the approximately two billion daily videos on YouTube, considering a ten-second watch for each, four billion grams of carbon dioxide is emitted each day by only watching videos (Gombiner, 2011). Another surprising and underestimated rate is related to emails. Depending on being spam, regular, or containing a photo attachment,

emails can vary in carbon footprint amount. They may respectively produce an approximate amount of 0.3, 4, and 50 grams of carbon dioxide. Considering a business user, one person could emit 135kg of CO2 yearly by only sending emails. If the adult users of the UK only stop sending one 'thank you' email, they can reduce 16,433 tonnes of carbon emission yearly (Griffiths, 2020).

Considering the effect of the Internet on different sectors' carbon footprint, while the reduction of business travel will reduce the related emitted gasses (Nairn, 2007), a significant increase will be needed in the Internet's capacity to replace face-to-face meetings with desirable quality video conferences. Consequently, the increased Internet capacity will increase energy consumption and, subsequently, carbon footprint (Baliga et al., 2007). As Owen (2010) quotes Saul Griffith, a green technology innovator, the Internet's carbon footprint may exceed air travel, a major pollutant in this regard, by almost two times. Generally, while this replacement would contribute to carbon emission reduction, the Internet's footprint should also be considered for a more precise calculation (Baliga et al., 2009). The Data Centers supporting the cloud computing architecture and the users' requests are the other major digital causes of greenhouse gasses with their huge energy consumption (Thakur and Chaurasia, 2016). Considering the US, for instance, since it burns coal, a brown energy source, as the main fuel for electricity production, the issue has gained more importance (Le et al., 2010).

Information and communication technologies (ICTs) affected even the movie sector. The Internet provided new means for producers and users in terms of platforms for watching and distribution methods such as webcasting, streaming, and downloading specific content. While the penetration of the Internet to the movie industry decreased the distribution and production costs, the energy efficiency of the increased opportunity for downloading the media contents should be considered, including various factors like manufacturing laptops and other Internet-related materials (Hochschorner et al., 2015). However, regarding the knowledge industry, Chowdhury (2010) states that even if people do not transfer digital content via the Internet, the related power is being consumed in any case. Hence, the small portion of knowledge-related transactions in the Internet carbon footprint is neglectable compared to the environmental and financial costs of physical knowledge distribution.

However, according to UNESCO (2021), the current global challenges, including climate change affected by carbon footprint, could be an education topic for learners of all ages. Such training will prepare the future generation to take vise solutions and actions regarding the current and upcoming environmental issues. This approach, called Education for Sustainable Development (ESD), is a subtopic of Sustainable Development Goal (SDG) 4. Hence, increasing public awareness about reducing carbon footprints and sustainable development can also lead to the desired outcome in the long term in addition to the physical methods dealing with the carbon footprint. For this purpose, serious games serving educational content besides entertainment are a remarkable sample of educational medium for the young generations

regarding a more sustainable future (Alvarez and Djaouti, 2011). Currently, serious games encompass a broad spectrum of topics, including health (Clochesy et al., 2015), military (DeFalco et al., 2018), ecology (Ameerbakhsh et al., 2019), heritage (Vaez Afshar et al., 2021), language learning (Johnson, 2007) and many other fields for both youngsters and higher education students.

This research proposes a serious game to introduce the hidden carbon emission of the Internet and the related activities to the players and make them aware of their daily activities' effect on the sustainability of the surrounding environment. The proposed game teaches the users the amount of carbon emission for various online activities such as broadcasting, emailing, Googling, etc. The players are informed and awarded based on the carbon amount they reduced or increased in a metaphoric ratio according to their selections during the assigned tasks. They also observe its effect on the jungle trees they are responsible for. To develop the Online Footprint game, the researchers reviewed the currently available serious games and the related studies in sustainability and carbon emission.

2 Literature Review

Plenty of researchers developed and investigated the role of serious games in sustainability and carbon footprint, considering the climate change issue. For instance, Dib and Adamo-Villani (2014) developed and evaluated the effect of a serious game in sustainable building development education for the undergraduate students enrolled in various related courses to cover the corresponding gap in the curriculum of the relevant faculties due to the importance of the topic in the current era. The research compared procedural and declarative knowledge gained by students while playing the game versus traditional educational methods. SimGreen is a serious game focusing on the companies' sustainability regarding reducing their environmental effects. Zhang and Zwolinski (2015) proposed a serious game engaging the players to find various methods to tackle environmental issues. In another study, Xu et al. (2014) generated a serious game framework named Makahiki for sustainability with built-in content, gaming elements, and mechanics playable on various devices. The framework had already been used to develop some games via different organizations. Whittaker et al. (2021) focused their study on the effect of rewards and points on the game's ultimate consequence regarding sustainability outcomes. Additionally, while Knol and De Vries (2011) declare the unpopularity of serious games among students, they claim the positive effects of the EnterCities game on the players' energy-related life activities.

Regarding carbon footprint reduction, Archana et al. (2016) developed a game using Bloom's Taxonomy for the course design in their research. In the game, the player gets knowledge and directly experiences the issue by replacing objects in an office area to reduce carbon emissions. In the study by

Yang (2009), a gamified learning tool was proposed to educate non-experts about designing and deciding on energy-related issues in their homes. It is a sample of low-budget computation for public awareness.

Despite all the existing research on sustainability and carbon footprint in various fields, the lack of serious games and relevant studies specifically regarding Internet-related carbon footprint in the literature inclined the researchers toward developing the Online Footprint serious game.

3 Methodology and Game Design

The methodology of the game follows a broad literature review mentioned previously. After the background phase of the study, among the various age ranges, the study chose middle school students aged 11 to 13 as its target audience. Afterward, the possible functionalities that the Internet could have for this age range were listed. Later, to fulfill the game's primary purpose, at the level design stage, using XMind Software, the researchers created a comprehensive mind map for conveying all the intended information to a user engagingly. As a result of this process, the game design part proceeded with the game development phase, which will be discussed more in the paper. However, the game is still in its alpha phase due to time constraints, and the first stage has only been developed (Fig. 1).

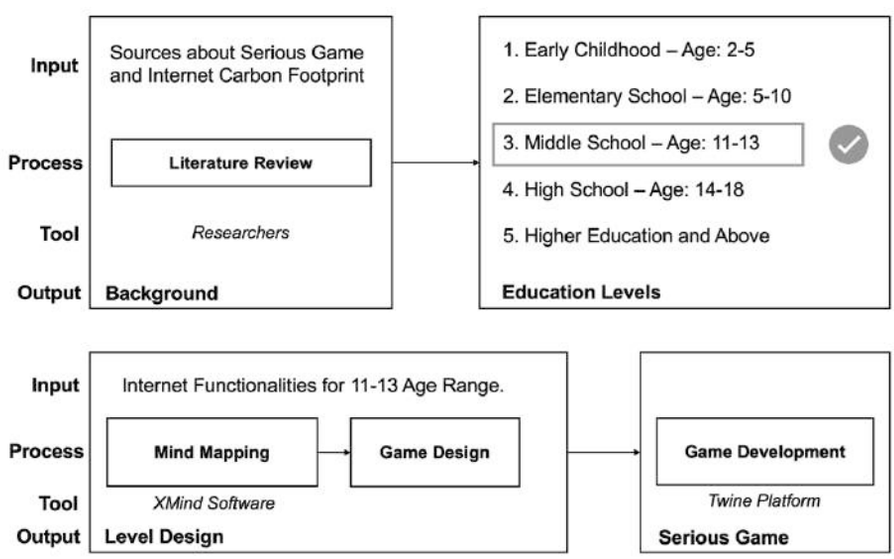

Figure 1. Methodology.

The online Footprint game assigns the player a Jungle to take care of at the beginning of each level. The player also got informed of some important information about that jungle. Subsequently, the game asks some duties or questions to the player, and in each of them, the player should make the best decision to produce as little carbon as possible. While doing the required activities, besides being aware of the emitted carbon dioxide amount, the player will also observe its effect on the trees he/she is responsible for (Fig. 2).

At the end of the level, the game demonstrates the same jungle to the player with the number of trees successfully preserved. Players understand the carbon footprint they leave behind by their daily activities during the game, which has penetrated their lives and left them unaware of their impact on the environment. Since the Internet has an important role in the lifestyle of everyone at any age nowadays, this game can target a wide spectrum of various ages. The game serves the SDG 7 goal provided by the department of economics and social affairs of the United Nations by contributing to affordable, reliable, sustainable, and modern energy access for all by changing people's everyday habits regarding their Internet-related carbon footprint.

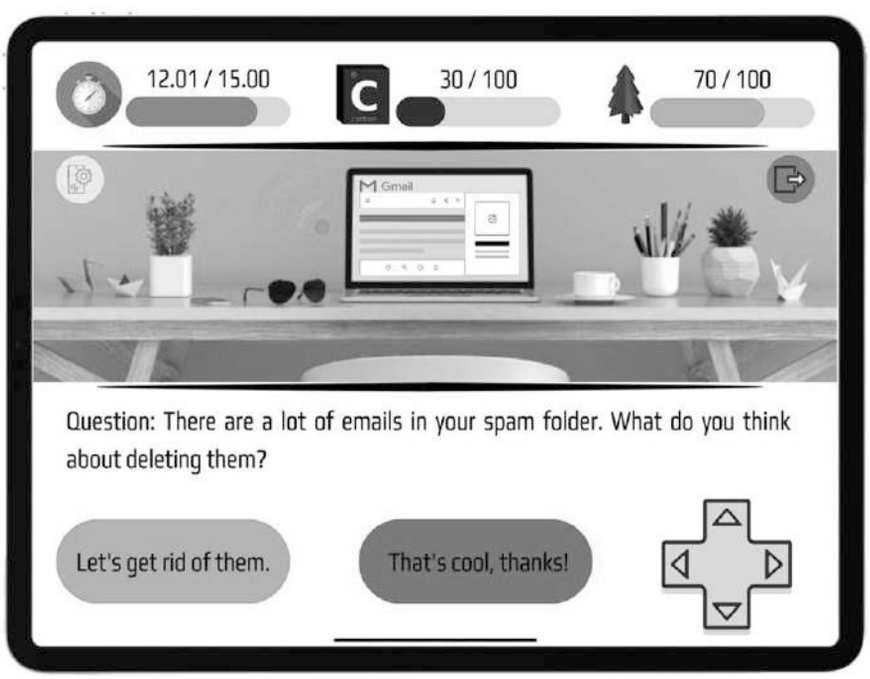

Figure 2. Game's interactive selection sample.

4 Game Development

The game's main goal is to transmit the mentioned data to the player and raise the user's awareness of their daily Internet-related activities. Hence, the paper seeks an easy-to-use platform fitting its aim to develop the game. Twine platform (Twine, 2021) is a free and open-source tool with almost no need for coding, generating interactive non-linear text-based games. The tool can be used online as a web application and installed easily on the desktop. The platform enables game development for non-experts in the game industry. It opens up the opportunity of providing any information in the form of an appealing digital game. Outcomes of the platform are in the form of HTML web pages, available for a mass user, with no need for a high technology device. The game development occurs in a branching system serving the game in a decision-making nature. This non-linearity and possibility of the various endings attract the player to play the game repetitively. By integrating the developed game with Twine macros, HTML, CSS, and JavaScript, it is able to publish a perfectly enhanced and complicated game (Fig. 3).

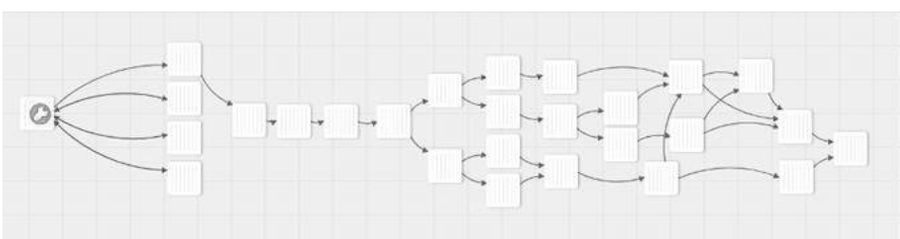

Figure 3. The development process of the game on the Twine platform.

5 Conclusion

To conclude, carbon footprint and global climate change are the planet's vital issues humans are tackling. However, while people are aware of many factors leading to carbon emission, plenty of everyday activities that seem innocent are responsible for this world's trouble. The Internet, which with its emergence facilitates peoples' lives and reduces the carbon emission of several activities, at the same time is responsible for a considerable amount of greenhouse gas production. Public awareness is one of the best and first solutions to facing such a phenomenon. To do so, an interactive and engaging method, immersing a wide range of ages, seems a wise decision. Hence, serious games conveying educational content besides entertainment can raise people's knowledge of the issue. Therefore, this paper proposes the development of a serious game regarding the Internet's unseen carbon footprint. The players would be aware of their daily online activities' carbon

emissions and their effect on the green infrastructure of the world. A game like Online Footprint may help people to change their lifestyle habits. In a pervasive and worldwide topic like the Internet, pretty small changes by each individual can make enormous changes in the world's carbon emissions.

As previously mentioned, the game is in the alpha stage due to time constraints. Hence, as a further study, the game has the potential to be expanded and published for use in schools to raise students' awareness of the issue as the game's first phase. At this level, the game can be evaluated while being used in the curriculum of a class. The test can compare the results of serious game education with conventional educational methods. Afterward, it can be developed for older age ranges, addressing the functionalities of the Internet in business, or higher education, for instance. In that case, the game can be a motivational application for the employees to teach them the required alerting information and directly influence their daily habits while doing their job-related tasks and duties by awarding them among co-workers.

References

Alvarez, J., & Djaouti, D. (2011). An introduction to Serious game Definitions and concepts. Serious Games & Simulation for Risks Management, 11(1), 11-15.

Ameerbakhsh, O., Maharaj, S., Hussain, A., & McAdam, B. (2019). A comparison of two methods of using a serious game for teaching marine ecology in a university setting. International journal of human-computer studies, 127, 181-189.

Archana, U. V., Rajeshwaran, A., McLain, M. L., Bijlani, K., Rao, B., & Jayakrishnan, R. (2016). Game Based Learning to Reduce Carbon Footprint. In Emerging Research in Computing, Information, Communication, and Applications (pp. 89-98). Springer, New Delhi.

Baliga, J., Hinton, K., & Tucker, R. S. (2007, June). Energy consumption of the Internet. In COIN-ACOFT 2007-Joint International Conference on the Optical Internet and the 32nd Australian Conference on Optical Fibre Technology (pp. 1-3). IEEE.

Baliga, J., Hinton, K., Ayre, R., & Tucker, R. S. (2009). Carbon footprint of the Internet.Telecommunications Journal of Australia.

Chowdhury, G. (2010). Carbon footprint of the knowledge sector: what's the future?. Journal of Documentation.

Clochesy, J. M., Buchner, M., HICKMAN JR, R. L., Pinto, M. D., & Znamenak, K. (2015). Creating a serious game for health. Journal of health and human services administration, 162-173.

DeFalco, J. A., Rowe, J. P., Paquette, L., Georgoulas-Sherry, V., Brawner, K., Mott, B. W., ... & Lester, J. C. (2018). Detecting and addressing frustration in a serious game for military training. International Journal of Artificial Intelligence in Education, 28(2), 152-193.

Dib, H., & Adamo-Villani, N. (2014). Serious sustainability challenge game to promote teaching and learning of building sustainability. Journal of computing in civil engineering, 28(5), A4014007.

Gombiner, J. (2011). Carbon footprinting the Internet. Consilience, (5), 119-124.

Griffiths, S. (2020, March 6). Why your internet habits are not as clean as you think. BBC Future. Retrieved 7 February 2022, from https://www.bbc.com/future/article/20200305-why-your-internet-habits-are-not-as-clean-as-you-think

Haythornthwaite, C., & Wellman, B. (2002). The Internet in everyday life: An introduction. The Internet in everyday life, 3-41.

Hochschorner, E., Dán, G., & Moberg, Å. (2015). Carbon footprint of movie distribution via the Internet: a Swedish case study. Journal of Cleaner Production, 87, 197-207.

Hurst, M. (2017, September 5). How Polluting is the Internet? CCCB LAB. Retrieved February 8, 2022, from https://lab.cccb.org/en/how-polluting-is-the-internet/

Johnson, W. L. (2007). Serious use of a serious game for language learning. Frontiers in Artificial Intelligence and Applications, 158, 67.

Knol, E., & De Vries, P. W. (2011). EnerCities-A serious game to stimulate sustainability and energy conservation: Preliminary results. eLearning Papers, (25).

Kuhn, E. (2009, December 18). Google unveils top political searches of 2009. CNN. Retrieved February 7, 2022, from https://politicalticker.blogs.cnn.com/2009/12/18/google-unveils-top-political-searches-of-2009/

Le, K., Bilgir, O., Bianchini, R., Martonosi, M., & Nguyen, T. D. (2010). Managing the cost, energy consumption, and carbon footprint of internet services. ACM SIGMETRICS performance evaluation review, 38(1), 357-358.

Matthews, H. S., Hendrickson, C. T., & Weber, C. L. (2008). The importance of carbon footprint estimation boundaries. Environ. Sci. Technol. 2008, 42, 5839–584210.

Nairn, R. J. (2007). Broadband telecommunications and urban travel.

Owen, D. (2010). The Inventor's Dilemma. New Yorker, 86(13), 42-50.

Pandia. (2007, July 2). Google: One Million Servers and Counting. Retrieved 7 February 2022, from http://www.pandia.com/articles/gartner

Pătărlăgeanu, S. R., Negrei, C., Dinu, M., & Chiocaru, R. (2020). Reducing the Carbon Footprint of the Bucharest University of Economic Studies through Green Facades in an Economically Efficient Manner. Sustainability, 12(9), 3779.

Thakur, S., & Chaurasia, A. (2016, January). Towards Green Cloud Computing: Impact of carbon footprint on environment. In 2016 6th international conference-cloud system and big data engineering (Confluence) (pp. 209-213). IEEE.

Twine, 2021. Twine. [online]. Retrieved 7 February 2022, from http://twinery.org/

UNESCO, 2021. Education for sustainable development. Retrieved 7 February 2022, from https://en.unesco.org/themes/education-sustainable-development-esd.

Vaez Afshar, S., Eshaghi, S., Varinlioglu, G., & Balaban, Ö. (2021). Evaluation of Learning Rate in a Serious Game-Based on Anatolian cultural heritage.

Whittaker, L., Russell-Bennett, R., & Mulcahy, R. (2021). Reward-based or meaningful gaming? A field study on game mechanics and serious games for sustainability. Psychology & Marketing, 38(6), 981-1000.

Xu, Y., Johnson, P. M., Lee, G. E., Moore, C. A., & Brewer, R. S. (2014). Makahiki: An Open-Source Serious Game Framework for Sustainability Education and Conservation. International Association for the Development of the Information Society.

Yang, L. (2009). BIM Game: a" serious game" to educate non-experts about energy-related design and living (Doctoral dissertation, Massachusetts Institute of Technology).

Zhang, F., & Zwolinski, P. (2015). SimGreen: a serious game to learn how to improve environmental integration into companies. Procedia CIRP, 29, 281-286.

Digital-Cultural Inclusion ERT/VDS; Workshop Indigenous Housing for Purépechas Autonomous Communities

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Abstract. Since March 2020, architecture schools in the world took significant decisions to abandon face-to-face learning; overnight, for security reasons, institutions around the world had to close their doors, confining professors, and students at home to teach online. Education before the COVID-19 pandemic was moving towards digitalization and online teaching, so the emergency exponentially detonated this phenomenon, bringing the Virtual Design Studio (Virtual Design Studio, VDS) as a practical-pedagogical option for distance education. Therefore, defining the concept of Emergency Remote Teaching (ERT). Firstly, the identification and intercession of the previous notions, this work approaches an applicative case with the realization of a workshop, which under the modality Multilevel Workshop —also called Vertical Workshop—, the Faculty of Architecture of the UMSNH proposed to integrate knowledge, skills, and competences under the scheme of Problem Based Learning (PBL).

Keywords: digital-cultural inclusion, emergency remote teaching, virtual design studio, problem based learning, housing design

1 Introducción

El proceso de enseñanza en los talleres de arquitectura demanda en gran medida de espacios de intercambio, de reflexión compartida, de acompañamiento crítico, pero sobre todo de una interacción grupal donde se expongan ideas, se debatan y se den iteraciones sucesivas que llevan a encontrar propuestas originales que, además de buscar una demostración de innovación y creatividad, identifiquen soluciones que dejen ver que los objetivos pedagógicos fueron alcanzados.

Lo habitual antes del 11 de marzo del 2020, día que se declaró oficialmente la pandemia de COVID-19 (*Alocución de apertura del Director General de la OMS en la rueda de prensa sobre la COVID-19 celebrada el 11*

de marzo de 2020, s. f.), era que este proceso se realizara de manera presencial y grupal en un taller donde el seguimiento de un profesor era determinante, lo que cambió de manera emergente y sustancialmente al usar la modalidad de educación a distancia para hacer viable el seguimiento de los cursos, cumplir con los objetivos pedagógicos y al mismo tiempo acatar las disposiciones sanitarias para proteger la salud de la población.

2 Inclusión digital-cultural

El valor de la inclusión es cada vez más reconocido y considerado dentro de las sociedades a nivel global (*Technology for inclusion-UNESCO Biblioteca Digital*, s. f.). En el caso de la inclusión digital ha implicado prever la adaptación y los recursos tecnológicos que permitan acortar la brecha en relación con los países más avanzados. Las TIC son una de las estrategias más empleadas para combatir el rezago educativo de los países pobres y a la vez promover de diferentes maneras la equidad social. En el caso de emergencia ante pandemia por COVID-19 es importante destacar que desde la perspectiva de lo digital la inclusión representó una herramienta más que un fin mismo o una solución universal. Buscó el acompañamiento con una adecuada estrategia pedagógica que tomara en cuenta las necesidades de los estudiantes, así como su diversidad cultural, una formación adecuada de los profesores y que las soluciones tecnológicas fueran accesibles para todos desde lo social, económico y cultural (Heemskerk *et al*., 2005).

El aprendizaje para el mundo real implica un reto bastante complejo. En un primer momento comprender el contexto y la interacción con el objetivo de aprendizaje invita a construir un enfoque de inclusión y asociación con la realidad que amplía las habilidades personales de flexibilidad, receptividad y autenticidad. Se trata de un cambio de mentalidad y actitud respecto a la naturaleza del aprendizaje, entendido este como un proceso experiencial de reflexión y transformación. Se trata de un cambio cultural en la academia, y de abrazar la complejidad, a menudo desorientadora, del mundo contemporáneo sin dejar de lado la curiosidad (Harrington *et al*., 2014)

La diversidad lingüística y cultural de las poblaciones migrantes y de las comunidades indígenas también debe ser atendida. Asimismo, se debe incorporar una perspectiva de género para visibilizar y erradicar las situaciones de desigualdad o violencia de género o de violencia que podrían agravarse bajo el aislamiento social (Caribbean, 2020).

3 Aprender en línea versus ERT

Una aproximación al concepto de "aprendizaje en línea" identifica una interacción de un alumno con contenidos o personas a través de internet con el fin de aprender. El aprendizaje puede ser parte de un curso o programa formal, o simplemente algo que los alumnos persiguen por su propio interés. Tanto la instrucción dirigida por el profesor como los recursos diseñados para instruir sin la presencia de un profesor se ajustan a nuestra definición de aprendizaje en línea si se llevan a cabo a través de internet (Means *et al*., 2014).

"Dado que el aprendizaje a distancia incluye otras tecnologías, que se remontan a los cursos por correspondencia impresos, tratamos el aprendizaje en línea como un subconjunto del aprendizaje a distancia y no como un sinónimo de este" (Hodges *et al*., 2020).

El traslado de la enseñanza convencional presencial a un súbito aprendizaje a distancia, derivado del confinamiento por la emergencia sanitaria de la pandemia por COVID-19, da paso a un nuevo concepto denominado "enseñanza emergente a distancia" (Emergency Remote Teaching-ERT). Este se define como un cambio temporal repentino del modelo analógico de enseñanza a un entorno virtual como resultado de una emergencia, a diferencia de los cursos en línea que se planifican y se diseñan bajo un esquema de *e-learning* (Mohmmed *et al*., 2020). La migración a esta modalidad, aunque no era desconocida ni por profesores ni estudiantes, tuvo las dificultades siguientes:

1. El rediseño de las unidades de aprendizaje se tuvo que realizar en un lapso muy corto.
2. La adaptación de profesores y estudiantes al nuevo sistema resultó difícil y tediosa.
3. El contacto visual, la comunicación no verbal y el ambiente colaborativo que se dan en un aula-taller de manera presencial no fue posible lograrlo.
4. El ambiente doméstico de la casa tuvo condiciones desfavorables para el desarrollo de actividades en línea.
5. Los estudiantes en zonas remotas tuvieron dificultad para acceder a las plataformas en línea.

Por otro lado, las ventajas que se pudieron observar en esta migración a los ambientes digitales ERT fueron los siguientes:

1. La grabación de las sesiones de clase permitió una asincronía que facilitó la flexibilidad en la atención de las actividades del curso.

2. El sistema brinda la posibilidad de ampliar las búsquedas de conocimiento permitiendo a la vez una autogestión de este por los mismos estudiantes.
3. Profesores y estudiantes desarrollaron habilidades de adaptación al cambio de una manera positiva.
4. El conocimiento organizado por las plataformas digitales permitió homogeneizar los conocimientos en el manejo de herramientas tecnológico-digitales de tal suerte que la brecha de conocimiento se redujo en este tema.

Los recursos mínimos requeridos son los siguientes:

1. *Hardware*: computadora/portátil + acceso a internet

2. *Software*: aplicaciones y bases de datos en línea, incluye chats en tiempo real, videoconferencias, presentaciones y redes sociales.

3. Contenidos de aprendizaje en línea: bibliotecas, cursos abiertos, *dossiers*, etc.

4 Taller virtual de diseño (VDS)

Se puede afirmar que la educación antes de la pandemia por COVID-19 avanzaba de manera importante a la digitalización y la enseñanza en línea. No obstante, la emergencia sanitaria detonó de manera inimaginable este fenómeno, lo cual resultó en la práctica de los talleres virtuales de diseño (Virtual Design Studio, VDS), una formidable opción de estrategia pedagógica para la educación en línea.

Los talleres virtuales de diseño realizados en el entorno académico muestran cómo las diferentes tecnologías pueden apoyar el diseño colaborativo a distancia evitando realizar reuniones presenciales a partir de medios electrónicos digitales que faciliten la comunicación, y que promueven un diseño colaborativo.

En el ámbito académico se pueden observar tres estilos diferentes de diseño colaborativo:

1. Los estudiantes que trabajan estrechamente con todo el grupo para lograr un consenso sobre la decisión de diseño.
2. Los estudiantes que trabajan independientemente en dos partes del diseño comprobando entre sí solo en la interacción de las dos partes.
3. Los estudiantes que definen un líder para dictar las decisiones de diseño con las que están de acuerdo.

Estas observaciones nos llevan a pensar que en un entorno de red es necesario apoyar diferentes estilos de colaboración para promover un taller de diseño virtual (Maher *et al*., 2000).

La realización de un taller de diseño virtual plantea numerosos retos técnicos y sociales. Las dificultades técnicas surgen de las condiciones adecuadas para establecer un entorno apropiado para el intercambio de información. Estos problemas técnicos están presentes tanto si existe un taller de diseño totalmente virtual como si no, pero se exageran cuando la colaboración a distancia es el único medio posible para intercambiar información. Los problemas sociales surgen por la falta de comprensión de las diferencias entre trabajar a distancia y trabajar cara a cara (Maher *et al*., 2000).

5 Taller de vivienda indígena para comunidades purépechas autónomas

Es frecuente que en la enseñanza del diseño arquitectónico se trabaje a partir de resolver problemas de diseño situados en la realidad o, cuando menos, con un enfoque que pretende ser así, lo cual permite explorar un proceso lleno de aciertos y errores en el cual las aproximaciones sucesivas llevarán a encontrar la mejor propuesta posible. Este enfoque se ha practicado durante las últimas décadas bajo la rúbrica de aprendizaje basado en problemas (PBL) (Kvan, 2001).

El aprendizaje basado en problemas estableció el eje de acción pedagógico del taller, ya que se tenía un trabajo de investigación previo del lugar y del problema que representaba la vivienda dentro de una idea general de hábitat justo; de esta manera, se resolvió la información inicial del ejercicio pedagógico planteado. De la misma manera se planteó que el trabajo fuera realizado en equipos de estudiantes que cursaran diferentes niveles para que la interacción generada por la dinámica de trabajo permitiera un intercambio de saberes, habilidades y competencias direccionadas a resolver el problema planteado de inicio.

5.1 La comunidad purépecha autónoma de San Francisco Pichátaro

La comunidad de San Francisco Pichátaro es una entidad autónoma indígena localizada a la biorregión purépecha de Michoacán, en el municipio de Tingambato. El trabajo se plantea precisamente en este lugar por reconocer su comunidad como un ejemplo de defensa y resistencia al arraigo

de su cultura, conservación de su lengua; su capacidad de autogestión, cohesión y resiliencia social.

El objetivo del taller “Hábitat justo; vivienda indígena resiliente” en la comunidad purépecha autónoma de San Francisco Pichátaro fue definido a partir de un análisis previo: realizar el diseño de un modelo de vivienda sustentable y un hábitat sostenible adecuado para mejorar las condiciones de vida de la comunidad del lugar; además, realizar propuestas pertinentes para la adaptación y crecimiento progresivo de la vivienda familiar en uso y por construir.

5.2 Formulación didáctica

La formulación de la propuesta didáctica fue planteada en cuatro etapas: planeación, instrumentación, evaluación y presentación de resultados. Estas fueron reflejadas en la documentada digital compartida en la plataforma de la institución, como en el trabajo de asesoría en plataformas educativas *online* de acceso gratuito.

Se desarrolló una base de información en línea que permitiera a los estudiantes entender el problema a resolver, siempre pensando que no era viable visitar el lugar, ni tener contacto directo con los habitantes, por las condiciones de confinamiento derivadas de la emergencia sanitaria por la pandemia de COVID-19. En el taller participaron 1979 estudiantes de diferentes niveles académicos organizados en 469 equipos, con la asesoría de 64 profesores.

El esquema para realizar el ejercicio evidenció dos líneas estratégicas de trabajo. La primera consistió en la instrumentación didáctica, la cual significó un gran reto, ya que implicó resolver el acceso a la información en línea, y la organización para trabajar a distancia y en equipo. La segunda consistió en la instrumentación del seguimiento de los asesores (profesores) en los equipos, lo que resignificó el papel del docente, convirtiéndolo en guía, no solo con el objetivo de resolver el diseño planteado, sino de motivar y orientar a los participantes para realizar una propuesta en condiciones de trabajo remoto en formato digital.

5.3 Ponderación general

Comparando los resultados obtenidos del ejercicio del taller se identifican resultados importantes en la acción didáctica del aprendizaje en línea del diseño, donde se pueden destacar que en el planteamiento de objetivos pedagógicos y criterios de evaluación es necesario que estos sean claros, precisos y definidos. En la parte creativa y de propuestas, la condición de

emergencia da pie a explorar nuevas soluciones de diseño, donde no solo es importante el resultado, sino el proceso y cómo se resuelven las insuficiencias y dificultades para poder llegar a la solución del problema.

Esta experiencia de diseño situado en una comunidad enfrentó circunstancias y problemas de un grupo en situación de pobreza y segregación étnica; al mismo tiempo, ofreció a los estudiantes una oportunidad muy valiosa para experimentar la teoría de diseño multidisciplinar en contextos multiculturales, así como herramientas creativas y metodológicas que permitan desarrollar actitudes y habilidades para la formulación de soluciones y aprendizaje de aspectos esenciales de la enseñanza académica y de la práctica profesional del diseño arquitectónico.

6 Metodología

La instrumentación metodológica contempló una duración de ocho días del taller, así como la realización del proyecto en equipos de cuatro a cinco estudiantes de diferentes niveles con la asesoría de un profesor. Para darle seguimiento al trabajo del taller, se habilitó por parte de los profesores-asesores un curso en la plataforma de Google Classroom con el objetivo principal de orientar a los estudiantes en su trabajo por equipos, además de impulsar que la entrega de propuestas fuera con la mejor calidad posible.

Las propuestas de diseño de las viviendas se realizaron en predios asignados por los representantes del Consejo Comunal de San Francisco Pichátaro, asignando a cada equipo alguno de los predios ubicados en cada uno de los siete barrios ancestrales.

Previo al inicio del taller, los coordinadores académicos llevaron a cabo una visita a San Francisco Pichátaro, y realizaron un recorrido en conjunto con miembros del Consejo Comunal y especialistas del pueblo, con el objetivo de registrar la información de la problemática del lugar en todas sus dimensiones y escalas. Asimismo, se elaboró material cartográfico, se desarrolló un banco de fotografías y entrevistas a los habitantes de los siete barrios; complementariamente, se realizó una guía para estudiantes y asesores, la cual contenía introducción, instrumentación didáctica, competencias a desarrollar, rúbrica de evaluación, productos entregables, alternativas de diseño de lámina, localización de predios, delimitación de barrios y material de consulta con un *link* a la información (Google Drive). En este se concentró información sobre San Francisco Pichátaro, documentos oficiales, entrevistas, videos, fotografías, plantillas y editables, bibliografía sobre diseño de comunicación y una selección de libros, tesis y artículos vinculados con la el tema abordado en el taller.

La presentación del taller en línea en vivo se realizó el día 16 de marzo de 2021 en el canal de YouTube oficial de la Facultad (Facultad de Arquitectura

UMSNH, 2021), y contó con la participación del director de la Facultad, los coordinadores académicos del taller, especialistas del área adscritos a la Universidad Indígena Intercultural, de autoridades de la comunidad autónoma de San Francisco Pichátaro, presentándose en idioma español y en lengua purépecha. Además, se contó con la participación de tres destacados especialistas en el área de vivienda purépecha, con las siguientes conferencias:

1. La transformación de la vivienda purépecha
2. Los procesos constructivos en la meseta purépecha
3. Los barrios en las comunidades purépechas de la meseta

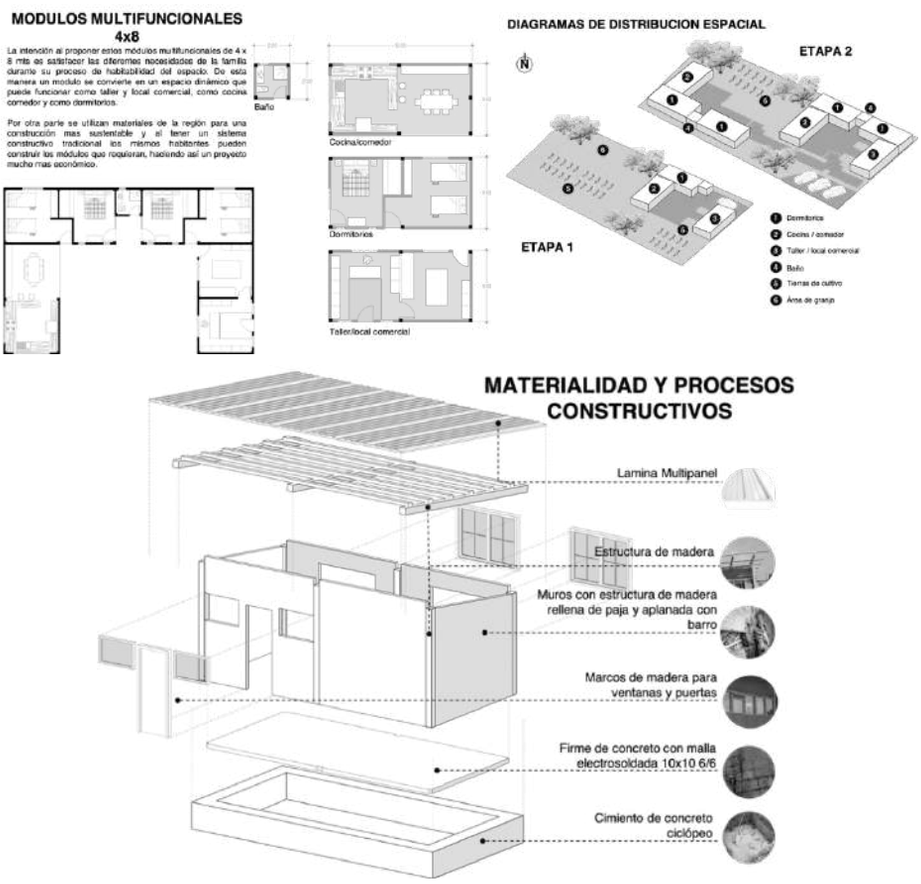

Figura 1. Diagrama de distribución espacial, módulos multifuncionales, y materialidad y procesos constructivos. Propuesta presentada por un equipo participante del “Hábitat justo; vivienda rural sustentable para la comunidad Purépecha Autónoma de San Francisco Pichátaro”. Fuente: Estefani Judith Herrejon Herrera, María Janeth Bello Solís, María Guadalupe López Gutiérrez, Alan de Jesús Cervantes López, 2021.

7 Resultados

Después de haber realizado el taller, se hizo una pequeña encuesta para conocer la opinión de los estudiantes; esto dio como resultado que el 65% de los encuestados no estaban satisfechos con el taller en línea, ya que los profesores tenían dificultades para discutir ideas visualmente sin *hardware*.

Sin embargo, algunos profesores entrevistados comentaron que la enseñanza de talleres de diseño en línea no fue efectiva debido a problemas como el plagio, el aumento de los niveles de estrés, la pérdida de interés de los estudiantes, la reducción de la calidad del diseño, la falta de acceso a los recursos, los desafíos psicológicos, emocionales y la falta de automotivación.

Otros problemas detectados por el equipo de coordinadores fueron las malas prácticas durante el taller, la falta de interacción, fijación en el diseño, dificultad para emular el entorno de estudio tradicional, dificultad en la discusión creativa, conectividad social reducida y falta de apoyo entre pares.

8 Discusión

Una reconceptualización de los proyectos, alejándose de los proyectos como modelo de gestión hacia los proyectos como modelo de práctica, ofrece la oportunidad de ver el aprendizaje basado en proyectos (PBL) como una práctica social. Wenger, fundador de la noción que el aprendizaje del mundo real se produce dentro de una comunidad de práctica (Wenger, 2018), argumenta que los educadores de las IES deben fomentar las comunidades de práctica en las que los estudiantes puedan participar como miembros productivos (Morley & Jamil, 2021).

Se propone reconceptualizar el taller de diseño en un espacio híbrido, equilibrado y deslocalizado, donde se establezca una relación directa con la realidad profesional, se fomente una participación más activa, se establezcan sinergias con diferentes actores dentro y fuera de la escuela y se promueva el uso de tecnologías digitales (Masdéu & Fuses, 2017).

Referencias

Alocución de apertura del director general de la OMS en la rueda de prensa sobre la COVID-19 celebrada el 11 de marzo de 2020. (s. f.). https://www.who.int/es/director-general/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19---11-march-2020 [Consulta: 7 de julio de 2022].

Education in the time of COVID-19. (2020). CEPAL. https://www.cepal.org/en/publications/45905-education-time-covid-19

Facultad de Arquitectura UMSNH. (16 de marzo de 2021). *Prueba rápida [Archivo de video]*. https://www.youtube.com/watch?v=WqD1ECQQMwc

Harrington, K., Flint, A. & Healey, M. (2014). *Engagement through Partnership: Students as Partners in Learning and Teaching in Higher Education* [Monograph fía]. Higher Education Academy. http://repository.londonmet.ac.uk/5176/

Harry, S. & Kumar, A. (2022). Transformation of the Design Studio in New Learning Spaces: Virtual Design Studio in Architecture Pedagogy. *ECS Transactions*, *107*(1), 6251. https://doi.org/10.1149/10701.6251ecst

Heemskerk, I., Brink, A., Volman, M. & Ten Dam, G. (2005). Inclusiveness and ICT in Education: A Focus on Gender, Ethnicity and Social Class. *Journal of Computer Assisted Learning*, *21*(1), 1-16. https://doi.org/10.1111/j.1365-2729.2005.00106.x

Hodges, C. B., Moore, S., Lockee, B. B., Trust, T. & Bond, M. A. (2020). *The Difference Between Emergency Remote Teaching and Online Learning*. https://vtechworks.lib.vt.edu/handle/10919/104648

Kvan, T. (2001). The Pedagogy of Virtual Design Studios. *Automation in Construction*, *10*(3), 345-353. https://doi.org/10.1016/S0926-5805(00)00051-0

Maher, M. L., Simoff, S. J. & Cicognani, A. (2000). Understanding Virtual Design Studios *Springer Link*.

Masdéu, M. & Fuses, J. (2017). Reconceptualizing the Design Studio in Architectural Education: Distance Learning and Blended Learning as Transformation Factors. *Archnet-IJAR*, *11*, 6-23. https://doi.org/10.26687/archnet-ijar.v11i2.1156

Means, B., Bakia, M. & Murphy, R. (2014). *Learning Online: What Research Tells Us About Whether, When and How.* Taylor and Francis. https://public.ebookcentral.proquest.com/choice/publicfullrecord.aspx?p=1664236

Mohmmed, A. O., Khidhir, B. A. Nazeer, A., & Vijayan, V. J. (2020). Emergency Remote Teaching during Coronavirus Pandemic: The Current Trend and Future Directive at Middle East College Oman. *Innovative Infrastructure Solutions*, *5*(3), 72. https://doi.org/10.1007/s41062-020-00326-7

Morley, D. A. & Jamil, M. G. (2021). *Applied Pedagogies for Higher Education Real World Learning and Innovation across the Curriculum*. Bristol: University of Bristol. https://directory.doabooks.org/handle/20.500.12854/30980

Technology for inclusion-UNESCO Biblioteca Digital. (s. f.). Prueba rápida [Archivo de video]. https://unesdoc.unesco.org/ark:/48223/pf0000373655# [Consulta: 11 de julio de 2022].

Wenger, E. (2018). *Communities of practice: Learning, meaning, and identity.* Cambridge: Cambridge University Press.

Online conversational strategies in technical advisory meta-learning for socio-spatial groups

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Abstract. The article makes a critical reflection on a remote learning experience for training specialists in Spatial Agency for Social Housing - ATHIS. The objective was to promote conditions for students to problematize about 'how' digital technologies could be appropriated in ATHIS. A meta-learning process was envisioned with the objective of experiencing in practice a co-creative dynamic using digital tools. Based on radical constructivist thinking, the proposed methodology used the digital platforms Zoom and Miro to associate two cybernetic collaborative ideation strategies: Team Syntegrity (Beer, 1994), and GIGAmapping (Sevaldson, 2012). The results showed that the experience significantly contributed to the expansion of knowledge of each participant regarding the topics studied and allowed the reverberation of individual contributions throughout the team. Once it has been verified that collaboration interfaces enable but do not guarantee collaborative work, we bring to the discussion three other structuring components that can be allies of simultaneous and integrated online work between groups.

Keywords: Online Learning, Gigamapping, Team Syntegrity, Conversation Theory, ATHIS.

1 Introdução

A antropóloga Mary Catherine Bateson (2018) afirma que a tragédia da revolução cibernética foi o abandono de suas reflexões sistêmicas em favor das amenidades da automação acrítica. Diante da trágica diminuição de participação dos alunos em aulas online durante a pandemia, em parte devido ao que ficou conhecido como “Fadiga de Zoom” (Shoshan, Wehrt, 2022), a pesquisa retratada neste artigo partiu da hipótese de Bateson para experimentar estratégias sistêmicas que tomassem proveito das características presentes nas ferramentas digitais para o ensino online.

Apesar das dificuldades no acesso de todos às Tecnologias Digitais (TD), e a própria fadiga de seu uso adaptado às condições emergenciais, para Schlemmer et al. (2021) foram as TD, que durante a pandemia, mantiveram grande parte da população conectada, possibilitando certa continuidade das interações sociais. Sem elas, de fato haveria não só um isolamento físico, mas social.

Este artigo, portanto, reflete criticamente sobre uma experiência de aprendizagem remota com a utilização de plataformas digitais para a formação de especialistas em ATHIS, promovida pelo Departamento de Arquitetura e Urbanismo da UFPB. As Residências Acadêmicas em ATHIS surgiram no contexto dos movimentos de luta por moradia digna e cidades mais justas com o objetivo de formar especialistas em diversas áreas, aptos ao desenvolvimento de processos multidisciplinares de assessoria técnica para projeto. O presente relato discute a estratégia pedagógica de um dos módulos dessa residência em ATHIS, intitulado “Programa, Projeto e execução em ATHIS, do analógico ao digital: Sistemas, processos e tecnologias", que ocorreu entre outubro e novembro de 2021.

A motivação por buscar novas metodologias surgiu durante o período de isolamento físico da pandemia do Covid-19. Devido à conjuntura, os primeiros módulos foram ministrados adaptando para aulas remotas as metodologias expositivas tradicionais de sala de aula presencial. Apesar de um esforço significativo em preparar aulas ilustradas, houve uma baixa interação dos alunos. Uma vez que o conceito de participação ativa entre os atores envolvidos é um paradigma central em ATHIS, a metodologia proposta foi usar as plataformas digitais Zoom e Miro para associar duas estratégias sistêmicas de ideação colaborativa que pudessem melhorar este cenário: Sintegridade em Equipes (Beer, 1994), ou SE, e Gigamapping (Sevaldson, 2012).

1.1 Conversação paralela em pequenos grupos – Sintegridade em Equipes

A Sintegridade em Equipes (SE) é um processo desenvolvido por Stafford Beer (1994) onde, de forma sucinta, trinta pessoas se reúnem em doze grupos de cinco. Cada pessoa discute em dois grupos, entrelaçando o todo na forma

de um icosaedro (Figura 1a). Conexões adicionais entre grupos distantes são realizadas pelo papel de crítico, onde cada participante faz um comentário final nas reuniões de dois outros grupos (Figura 1b). Em cada rodada de discussão, dois grupos opostos discutem tópicos diferentes sugeridos pelos próprios participantes. Os doze grupos se reúnem em seis rodadas, uma iteração, que normalmente é repetida três vezes. No intervalo para refeições pode ser feita uma rodada informal extra, arranjando as mesas em cinco grupos de seis pessoas que, juntas, participaram de todos os doze grupos (Figura 1c). Os tópicos são criados após uma pergunta de abertura em um *brainstorming* inicial e, em seguida, refinados em uma discussão descentralizada auto-organizada.

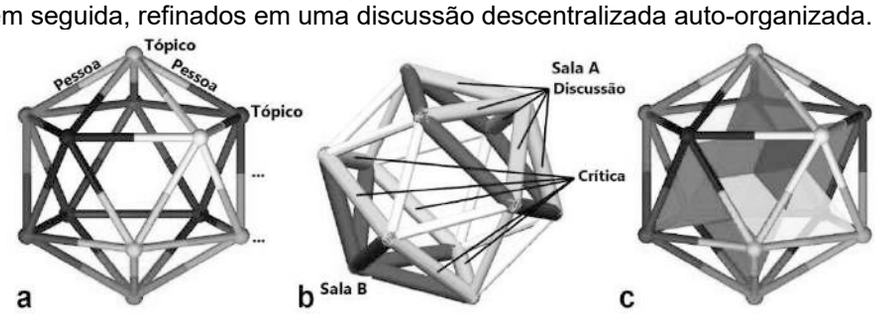

Figura 1. Organização do protocolo de Sintegridade em Equipes - Fonte: Autores.

Quando o SE modela pessoas como conectores de discussões ele traz a propriedade de reverberação da informação entre os grupos, mas seu formato especificamente icosaédrico tem também outras propriedades, dentre as quais a mais relevante para o estudo é não ter periferia nem distinção entre suas partes. Apesar das características únicas da estrutura icosaédrica, variações para grupos menores (Truss, Cullen, Leonard, 2000, p.7–11) ou maiores (Bernardo, 2021a) foram desenvolvidas tentando manter suas principais propriedades.

Além da literatura existente sobre o protocolo, outros experimentos de Sintegridade em Equipes realizados online foram importantes para refletir sobre interfaces e estratégias de colaboração na internet (Schwaninger, 1997; Cusin, 2005; Bernardo, 2021b; Schlemmer et al.,2021).

1.2 Conversação síncrona e assíncrona por teleconferência ou texto

A discussão central nas experiências estudadas gira em torno da função da conversação na deliberação e aprendizado coletivo, assim como sua relação com as estruturas de interação oferecidas pela conjunção interface-protocolo. A Teoria da Conversação é um modelo formal que embasa o paradigma construtivista radical ao explicar como, por meio da conversação, é possível que duas entidades independentes, sejam elas pessoas ou máquinas sem acesso ao mecanismo interno uma da outra, consigam recursivamente

expressar e checar as suas ideias até chegar a um acordo quanto a uma percepção comum (Scott, 2001).

Como contraponto, Cusin (2005, p.62-69) traz Schrage (1995, p.94) para afirmar que conversações face-a-face são vitais, mas não o suficiente como instrumento de colaboração devido ao seu caráter serial, “os participantes respondem ao que foi dito agora, e não minutos atrás”, e efêmero, “os participantes têm memória, conversas não”. E continua afirmando que para a colaboração é necessário haver um espaço compartilhado, onde memórias de ideias compartilhadas são representadas, preservadas, manipuladas e construídas. A partir dessa conjuntura, aponta que a comunicação assíncrona por texto e imagens é mais prática e produtiva para compartilhamento de conhecimento.

Por outro lado, a forma de conversação por escrita pode mudar substancialmente os conteúdos discutidos. Cusin (2005, p.62) utiliza Palloff e Pratt (1999) para ressaltar este aspecto: “introvertidos podem se tornar extrovertidos, online no meio escrito, enquanto extrovertidos que não escrevem bem se tornam introvertidos”.

Além disso, segundo John Hill (2021), outro perigo é entrar em uma “lógica da plataforma”, que tem dominado meios digitais e vem se traduzindo em organizações sociais. Hill (2021, p.155-157) explica que plataformas são instituições de compartilhamento cuja utilidade é trazida pelos próprios usuários, enquanto seu poder reside na habilidade de prover ou negar permissões de compartilhamento a estes mesmos usuários. Neste sentido, Hill (2021, p.157-158) afirma que o protocolo SE tem uma lógica antiplataforma, ao focar na construção de relações entre os participantes em vez de produção de conteúdo. Cusin (2005, p.70) corrobora a visão de Hill ao trazer as afirmações de Schrage (1995): de que a colaboração termina quando o propósito dela foi atingido e; sendo assim, nós precisamos mudar a noção de tecnologias gerenciando informação para ideia de tecnologias como meios de relacionamento. Cusin (2005, p.72) adiciona também que além de “apoiar o processo colaborativo mais que o produto”, tecnologias precisam ser desenhadas para “apoiar relações mais que indivíduos, grupos ou reuniões”.

Podemos compreender melhor os pontos de Cusin e Hill a partir da distinção que Mejia e Espinosa (2007, p.5) fazem entre as intervenções sistêmicas nas estruturas de conteúdo e aquelas nas estruturas de interação. Enquanto as primeiras “tentam redescrever as perspectivas trazidas pelas discussões por meio de questões e conceitos que buscam melhorar a compreensão mútua”, intervenções nas estruturas de interação tentam garantir que a visão de todos os participantes tenha chances iguais de ser expressa, assim como criticamente examinada (Id. Ibid. p.6). Na SE o objetivo é intervir exclusivamente na estrutura de interações, mas somente sua estrutura não garante a igualdade de participação. Os autores apontam para a importância de intervenções dos facilitadores para evitar “mecanismos mais sutis de exclusão” como “simplesmente ignorar o que uma pessoa diz” (2007, p.10). Vimos que outra forma de desequilibrar as interações é utilizar um único meio

de expressão. Formas de conversação síncrona face-a-face podem, portanto, ser associadas a formas de conversação assíncronas via texto, imagens e vídeos.

1.3 Conversação gráfica – GIGAmapping

Outra estratégia de intervenção na estrutura das interações que pode ser associada ao SE é um processo que Sevaldson (2011) chama de GIGAmapping. O processo de GIGAmapping corresponde a criação de diagramas extensos de mapeamento visual desenvolvidos em múltiplas seções, camadas e escalas para investigar as relações entre coisas, categorias e campos aparentemente separados (Id. Ibid). Sevaldson destaca que, enquanto os processos de mapeamento em geral procuram ordenar e simplificar os problemas, para "domá-los", o GIGAmapping, pelo contrário, procura compreender a natureza de tais problemas, considerando-os em sua complexidade e "perversidade", como de fato são os problemas do cotidiano. Enquanto muitas vezes uma visão mais sistêmica é sacrificada na prática por uma falta de habilidade de manter a complexidade durante o processo de ideação, o GIGAmapping se apresenta como uma das estratégias possíveis para manter a complexidade latente (Id. Ibid). O GIGAmapping é, portanto, uma ferramenta de auxílio à conversação útil como canal de comunicação, participação e produção coletiva de informação entre pessoas e grupos.

2 Metodologia

A dinâmica colaborativa, denominada aqui *Gingamapping* foi dividida em duas etapas: uma, assíncrona, partia da leitura de artigos e visualização de vídeos disponibilizados pelos professores e caminhava para a sugestão de conteúdos relatos pelos alunos; outra, síncrona, consistia em dinâmicas conversacionais adaptadas para o meio digital a partir do protocolo de SE (Beer, 1994) associado ao processo de GIGAmapping (Sevaldson, 2011).

Na primeira etapa todo conteúdo didático assíncrono foi organizado em grupos temáticos dispostos ao redor de um círculo maior (figura 2b). Os temas eram: (1) Sintegração e GIGAMapping - conteúdo sobre o próprio processo de sintegração e GIGAmapping; (2) Mapeamento - conteúdo sobre estratégias, métodos e programas para mapeamento; (3) Conversação - introdução à Teoria da Conversação e cibernética; (4) Fabricação Digital - introdução à técnicas e processos de fabricação digital e exemplificação de seu uso em contextos da autoconstrução; (5) Auto-Organização - introdução ao pensamento sistêmico e gerenciamento de complexidade; (6) Projeto Paramétrico e Variedade - exploração da automação para criação de variedade; (7) Polivalência - introdução aos conceitos de Hertzberger;

(8)Computação x Computerização - introdução às diferentes formas de explorar o uso do computador na arquitetura.

Para cada eixo temático foram criados círculos grandes ao redor do círculo maior. Estes foram conectados a círculos menores, alguns já com conteúdos relacionados aos eixos temáticos, outros vazios convidando os participantes a colaborar com mais dados e informações. Foi feita uma reunião preliminar de forma síncrona com os participantes para explicar o funcionamento da plataforma MIRO e demonstrar como estes poderiam acessar os conteúdos de vídeo, textos, imagens, etc.

Para organizar a segunda etapa - síncrona - foram propostas duas adaptações: uma para adequar o processo de SE ao número de participantes e tempo disponível; e outra para promover sua associação ao processo de GIGAmapping. Para a primeira adaptação foi utilizado como poliedro organizador um octaedro estrelado com 24 arestas e 14 vértices (figura 2c). Uma particularidade desta geometria é que seus vértices formam dois tipos de grupo, os internos e os externos, com, respectivamente, quatro e três participantes, que podem se reunir todos ao mesmo tempo, reduzindo uma iteração a duas rodadas. Essa conformação eliminou os papéis de observador e crítico, diminuindo a interconexão entre grupos distantes. Como forma de amenizar esse impacto, foi criada uma rodada de reunião extra com as características das reuniões ortogonais, onde três grupos de oito pessoas contavam com um participante de cada um dos oito grupos temáticos.

Para associar a SE ao GIGAmapping foram feitas outras adaptações, uma na estrutura de interação, e outra na estruturação de conteúdo: A primeira foi criar uma diagramação espacial na plataforma Miro que buscava, ao refletir a estrutura do protocolo de SE, trazer suas propriedades à dinâmica de GIGAmapping. Isso foi feito projetando-se a geometria do octaedro estrelado no plano dentro do círculo maior. Suas oito pontas foram associadas aos círculos grandes dos eixos temáticos de discussão (figura 2b). Números ajudavam a localizar as sínteses gráficas das discussões em cada grupo enquanto setas com os nomes de cada participante ajudavam a localizar as interconexões que eles deveriam elaborar entre as discussões.

Uma segunda adaptação do SE foi criar uma tabela que auxiliava na compreensão do cronograma da dinâmica e indicava o que fazer em cada rodada (figura 1a). Havia instruções para focar na síntese gráfica durante as reuniões em grupos temáticos menores, e na discussão para conexão entre temas durante as reuniões dos grupos maiores. Os participantes continuaram tendo papéis equivalentes e simétricos na estrutura, cada um levando a um grupo interno a discussão temática de seu grupo externo. Uma iteração completa era composta por cinco rodadas de aproximadamente trinta minutos, duas de discussão entre grupos internos alternadas com duas entre grupos externos, somadas a uma ortogonal em grupos de oito. No total, foram realizadas duas iterações completas, uma no primeiro dia e outra no segundo. Esta etapa síncrona foi realizada por meio de videoconferência na plataforma Zoom e da elaboração simultânea de sínteses gráficas na plataforma Miro. Ao

final de cada rodada, os participantes eram levados automaticamente às suas novas salas usando a função *breakout rooms*, configurada previamente pelo facilitador.

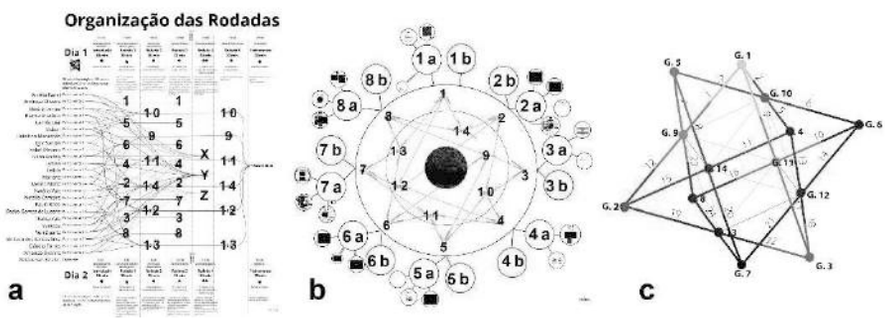

Figura 2. (a) tabela com grupos que discutem em cada rodada de reunião (colunas) conectados à lista de participantes; (b) estrutura de organização das sínteses visuais; (c) geometria organizadora. Fonte: autores

No segundo dia coube aos alunos propor quais temas seriam discutidos na dinâmica. Os oito temas propostos faziam referência aos do módulo, mas também foram trazidas temáticas discutidas nos módulos anteriores do curso. Foram propostos os seguintes temas no segundo dia: (1) Controle/descontrole; (2) Local/Global; (3) Athis para além do poder público; (4) Sustentabilidade; (5) Autonomia e Heteronomia na prática; (6) Interfaces de conversação; (7) Estratégias de ação em Athis; (8) Engajamento.

Nesta etapa da dinâmica foi colocado no centro um mapa da Vila do Amanhecer e foi solicitado aos participantes refletir, representar e sintetizar quais práticas, estratégias e assuntos discutidos poderiam ser explorados e levados para o trabalho de campo junto à comunidade.

3 Resultados

Para obtenção dos resultados foram analisados o processo, por observação participante, e um questionário submetido aos alunos após a experiência. A observação participante indicou que a estratégia didática do Gingamapping favoreceu maior expressão individual, envolvimento interpessoal e apropriação dos conteúdos quando comparado aos módulos anteriores do curso. Os alunos relataram que a dinâmica ofereceu a primeira oportunidade de se conhecerem melhor e trocar experiências. O processo de desenho do gigamapa revelou correlações importantes e inovadoras entre os temas, como refletido nesta síntese produzida pelos alunos: “A técnica deve ser submetida aos ‘desejos’ (o desejo é pré técnico). A parametrização e a computação no contexto da Athis devem ser pensadas como técnicas a serviço dos desejos manifestados nos

processos de cocriação". A exemplo desta síntese, as anotações suscitam curiosidade ao apresentarem temas de pesquisa importantes, indo além de compreensões estruturadas dos assuntos tratados.

O questionário obteve 16 respostas entre os alunos, apontando, entre outros, que a conversação: (a) mudou expressivamente a impressão dos participantes sobre seu conhecimento de cada subtema (Figura 4); (b) permitiu reconhecer a reverberação indireta de suas ideias nas falas de outros. Todos responderam positivamente a essa pergunta, e alguns citaram observações muito específicas que introduziram em uma discussão e a ouviram em outra nas rodadas seguintes; (c) possibilitou identificar conexões entre os subtemas; Quanto ao nível de conexão entre os assuntos, antes das discussões 40% respondeu alto, 40% médio e 20% baixo, enquanto após as discussões 86,7% respondeu alto e o restante médio; (d) não foi suficiente para que ideias discutidas por grupos em lados opostos da geometria reverberassem entre si. 86,7% dos participantes afirmou que houve algum assunto que viu pouco nas discussões. Quando perguntados qual, a resposta em todos os casos indicou o grupo no extremo oposto da geometria.

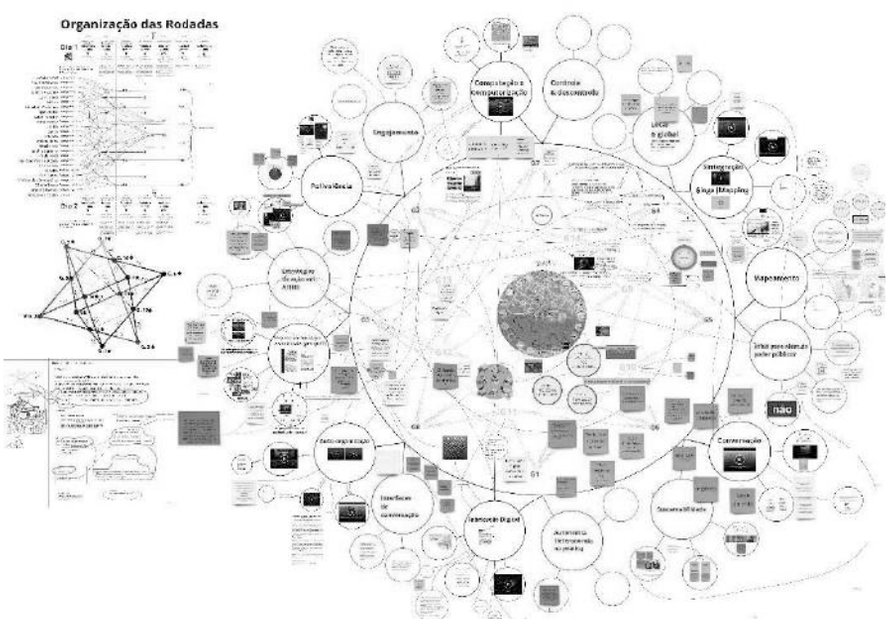

Figura 3 - Representação visual da experiência. Fonte: Registro autores.

Todos os participantes afirmaram também achar pertinente utilizar a estratégia ou variações dela em assessorias a grupos sócio-espaciais a partir do que aprenderam.

Figura 4. Resultado questionário. Fonte: Autores.

4 Discussão

Foram apresentadas neste artigo estratégias que exploram o uso de plataformas de colaboração gráfica e videoconferência no ensino. Vimos que existe a possibilidade de combinar a SE e o GIGAmapping com estratégias sistêmicas de intervenção nas estruturas de conteúdo, empreendidas por meio do facilitador (Mejia, Espinosa, 2007, p.10) e do direcionamento das discussões para conteúdos específicos, predeterminando subtemas. Uma vez que as interfaces de colaboração possibilitam, mas não garantem um trabalho colaborativo, esses três níveis estratégicos de intervenção — na estrutura das interações, nas estruturas de conteúdo e no direcionamento dos conteúdos — se mostraram importantes para manejar discussões auto-organizadas para finalidades específicas e permitir o trabalho simultâneo e integrado entre grupos. Uma contribuição importante da experiência para essa discussão, além de viabilizar a combinação das estratégias de SE e GIGAmapping usando plataformas digitais, foi mostrar os benefícios de: estruturar zonas de interação; endereçar espaços aos participantes nas colaborações gráficas e; organizar os diferentes momentos de interação entre os grupos e participantes.

Estas estratégias se inserem em uma importante discussão sobre como aumentar a qualidade das conversações e seu caráter crítico (Sweeting, 2014, Mejia, Espinosa, 2007, Herr, 2014, Baron, 2018), algo que precisa ser cuidadosamente trabalhado. Como lembrado por Baron (2018, p.11), “o professor criativo usa as referências dos estudantes para ancorar os tópicos do currículo escolar”. Neste sentido, a experiência foi capaz de referenciar várias camadas de reflexão importantes para a tecnologia: os conteúdos abordados, além de se referirem ao próprio processo de interação entre os

alunos, foram o mote para que eles planejassem seu formato de aproximação à comunidade Vila do Amanhecer. Quando discutindo sobre essa aproximação emergiram questionamentos quanto à plausibilidade de se utilizar ferramentas de Fabricação Digital e Parametrização sem prejudicar a participação ativa dos moradores. Mais do que levar a tecnologia a campo, concluiu-se que entender as relações entre as pessoas seria primordial. De maneira semelhante, como abordou Cusin (2005), a valorização do processo, mais que o produto, contribuiu para a consolidação das relações afetivas entre os alunos. Cada integrante se reconheceu como parte fundamental dessa roda de 'capoeira digital', de maneira que as relações se intensificaram mesmo após o fechamento da disciplina. Isso foi fundamental para o trabalho de campo junto à comunidade, mostrando um grupo diverso, porém coeso e acolhedor.

Um desdobramento dos questionamentos levantados pelos alunos é a reflexão de que as estratégias conversacionais utilizadas online nessa experiência podem também ser adaptadas a contextos sócio-espaciais onde não há acesso a tecnologias digitais. A partir de uma perspectiva sistêmica, as estratégias podem ter seus mecanismos adaptados para outras ferramentas analógicas de auxílio à computação, como tabuleiros, ábacos, cartas, modelos físicos, entre outros. Como apontado por Wiener, "todo processador é analógico, a analogia é selecionar coincidências que são relevantes perante uma eternamente desconhecida realidade de funcionamento. O computador digital é uma analogia digital." (Wiener apud PIAS, 2003, p. 158).

5 Conclusão

A discussão apresentada aponta que o uso das bases teóricas da cibernética de segunda ordem, teoria da conversação, design orientado a sistemas, construtivismo radical, entre outras vertentes do pensamento sistêmico, tem potencial de revolucionar as possibilidades de trabalho paralelo e descentralizado que são facilitadas pelas interfaces digitais em rede – corroborando com a hipótese de Bateson (2018). É uma forma de apagamento da memória coletiva e deslumbramento com as tecnologias digitais de comunicação acreditar que os amplos potenciais das plataformas online se realizarão naturalmente de maneira revolucionária em vez de simplesmente reforçar tendências existentes. O potencial de comunicação entre as pessoas pode carecer de sentido se não primar por uma cuidadosa reflexão crítica.

Por sua vez, Schlemmer et al. (2021) alertam para a necessidade de inovação nas práticas pedagógicas e destacam que o maior desafio após o acesso às tecnologias digitais é, justamente, trabalhar com o híbrido e o multimodal, compreendendo que a educação acontece no universo de relações que se estabelecem em rede, por meio de novos ecossistemas educativos que envolvem humanos, máquinas e natureza, sem hierarquia entre tais atores, numa nova compreensão de mundo transorgânico.

Nessa experiência apresentada, como apontamento futuro, propomos uma revisão da estrutura de organização da variação de SE utilizada no experimento para evitar a desconexão entre grupos opostos, já que esta pode ter sido resultado tanto da remoção dos papéis de crítico e observador, como também da utilização de uma geometria onde o grau de separação máximo entre grupos é de duas pessoas em vez de uma, como recomendado por Beer (1994, p.197-210).

References

Baron, P. (2018). Heterarchical reflexive conversational teaching and learning as a vehicle for ethical engineering curriculum design. Constructivist Foundations, 13, 309-319

Bateson, M. C. How to Be a Systems Thinker, interview by John Brockman, dir. Nina Stegeman, Edge, April 17, 2018, video, 42 min. Accessed September 15, 2021. https://www.edge.org/conversation/mary_catherine_bateson-how-to-be-a-systems-thinker.

Beer S. (1994). Beyond Dispute: The Invention of Team Syntegrity (The Management Cybernetics of Organization). London, England: Wiley

Bernardo, M. (2021a) Integrating parallel conversations in an institutionalized society: Experiments with Team Syntegrity online. Technoetic Arts: A Journal of Speculative Research, 19:1&2, pp. 61–69.

Bernardo, M. (2021b) Cibernética e Convivencialidade: integração de conversações paralelas como estratégia para auto-organização. Tese. Belo Horizonte: Universidade Federal de Minas Gerais.

Cusin, J. (2005). Online Team Syntegrity® for Large-Group E-Deliberation: An Action Research Project. Ottawa, Canada: Royal Road University

Herr C. M. (2014) Radical constructivist structural design education for large cohorts of chinese learners. Constructivist Foundations 9(3): 393–402. http://constructivist.info/9/3/393

Hill, J. (2021). Syntegration against the platform: Experimentation with the Team Syntegrity protocol for viable institutional forms that counter the logic of algocracy in institutions of contemporary art. Liverpool, England: John Moores University.

Mejia, A., Espinosa, A. (2007). Team Syntegrity as a Learning Tool: Some Considerations about its Capacity to Promote Critical Learning. Systems Research and Behavioral Science, 24(1), 27-35

Palloff, R. M. Pratt, K. (1999). Building learning communities in cyberspace: Effective strategies for the online classroom. San Francisco: Jossey-Bass.

Pias, C. (2003). Cybernetics/Kybernetik. The Macy-Conferences 1946-1953 vol.1, Berlin: Diaphanes Verlag.

Schlemmer et al. (2021). O habitar do ensinar e do aprender em tempos de pandemia e a virtualidade de uma educação OnLIFE. Revista Práxis Educacional v.17, n.45, p. 137-161.

Schrage, M. (1995). No more teams! Mastering the dynamics of creative collaboration. New York: Currency Paperback/Doubleday.

Schwaninger, M. (1997). Global transdisciplinary research co-operation: thirty cyberneticians online. Kybernetes, 26(4): 459±463.

Sevaldson, B. (2011, may 29). GIGA-Mapping: Visualisation for complexity and systems thinking in design. Nordes 2011: Making Design Matter. https://doi.org/10.21606/nordes.2011.015

Shoshan, N., Wehrt, W. (2022). Understanding “Zoom fatigue”: A mixed-method approach. Applied Psychology, 71 (3), 827–852.

Sweeting, B. (2014). Not all conversations are conversational: A reflection on the constructivist aspects of design studio education. Educational Research: Experiments on Radical Constructivism, 10, 405-406.

Truss, J. Cullen, C. Leonard, A. 2000. The Coherent Architecture of Team Syntegrity: From Small to Mega Forms, In Proceedings of the World Congress of the System Sciences, Allen JK, Wilby J (eds). (on CD ROM), Toronto, Canada.

ePortfolio as a Techno-pedagogical Strategy for Networked Learning in the Architectural Design Studio

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Abstract: This paper shows and describes the experience of the ePortfolio implementation in architectural training for promoting Networked Learning (NL). The aim was to analyze the potential of ePortfolio, as a techno-pedagogical strategy to develop and enhance connections and learning integrations among students who belong in the second year of the Architectural Design Studio. The research had a descriptive methodology with a mixed approach over fourteen cohorts of the same training cycle across the years 2012 to 2018, considering a total of 336 students. The results reveal that ePortfolio, conceived inside the techno-pedagogical model, articulates a set of learning connections between students and learning situations and promotes the construction of an active collaboration net, which evidence NL development in the formative process.

Keywords: ePortfolio, networked learning, ICT, architectural teaching, techno-pedagogy

1 Introducción

Las instituciones de educación superior están utilizando las tecnologías de información y comunicación (TIC) como un recurso para mejorar y ampliar su oferta educativa, con una formación universitaria cada vez más influenciada por ellas, llegando a ser un poderoso mediador cultural que transforma el ámbito educativo y, según sea su uso, la calidad del proceso de enseñanza y aprendizaje (Barberà *et al*., 2008). El uso de las TIC en educación puede ampliar el acceso y las oportunidades de aprendizaje, mejorar sus logros y calidad, incorporando métodos avanzados de enseñanza e impulsando transformaciones a los sistemas educativos (Prieto *et al*., 2017). Sin embargo, la simple introducción o presencia de las TIC no es suficiente (Gil & Cano,

2012), pues requiere una reflexión acerca del contexto formativo, su didáctica e instrumento a implementar para el éxito de su inclusión.

1.1 Contexto formativo de la arquitectura

La enseñanza de la arquitectura es considerada una pedagogía particular, donde la situación profesional es reproducida en el contexto académico a través de específicos temas, estructurados para educar a los estudiantes para su futura práctica profesional (Masdéu & Fuses, 2017). Shulman (2005) distingue tres dimensiones en esta particular pedagogía: una estructura superficial de actos operativos de enseñanza y aprendizaje, un profundo sistema de suposiciones acerca de la mejor manera de impactar el aprendizaje, y un sistema implícito de un conjunto de valores, creencias y actitudes constituido como un currículo oculto.

En este contexto, el Taller de Diseño Arquitectónico (TDA) constituye la instancia central para llevar adelante el proceso de enseñanza y aprendizaje (Pasin, 2017). Se concibe como un entorno socialmente activo de experimentación y colaboración entre los participantes, cuyas interacciones definen oportunidades de aprendizaje en las que se comparten y discuten ideas, temas e intereses, pero que en su mayoría adquieren un carácter poco valorado para la planificación regulada del proceso de aprendizaje. De acuerdo con Ioannou (2018), en el TDA se aprecian limitadas opciones formales donde los participantes puedan compartir su material con otros, monitorear de cerca lo que otros están haciendo o relacionar sus trabajos con el de sus compañeros. En la práctica, se tiende a aislar a los estudiantes en su quehacer, orientándose a producir genios solitarios más que colaboradores (Buchanan, 2012). Sin embargo, los avances tecnológicos en las TIC han permitido mejorar la colaboración y la comunicación entre los participantes de una comunidad educativa, siendo un recurso para el aprendizaje que permite el desarrollo de activas y autónomas agendas formativas (Anderson, 2016).

1.2 La dimensión tecnopedagógica de la enseñanza

Un diseño tecnopedagógico se define como un conjunto de herramientas tecnológicas que posee una propuesta más o menos explícita, global y precisa, sobre la forma de utilizarlas para el desarrollo de actividades de enseñanza y aprendizaje (Dafonte-Gómez *et al*., 2017). Tres son los modelos más usados para la enseñanza tecnopedagógica: Modelo TPACK (Technological Pedagogical and Content Knowledge) (Mishra & Koehler, 2006), donde la tecnología no es independiente de los contenidos pedagógicos, ayudando a comprender las relaciones entre tecnología, contenido y pedagogía; modelo SAMR (Sustitution, Argumentation, Modification and Redefinition) (Puentedura, 2006), donde el uso que se haga de la tecnología es lo relevante para mejorar el proceso de aprendizaje; modelo TAM (Technological Acceptance Model) (Davis *et al*., 1989), donde la utilidad y la sencillez de uso percibido son factores

determinantes de la motivación del usuario para la utilización de una tecnología.

Coll *et al*. (2008) sostienen que un diseño tecnopedagógico debe detallar tres grupos de elementos: una propuesta de contenidos, objetivos y actividades de enseñanza y aprendizaje; una oferta de herramientas tecnológicas; y una serie de orientaciones sobre cómo utilizar estas herramientas en las actividades de enseñanza y aprendizaje propuestas. Incluye normas y procedimientos de uso de las herramientas incorporadas para guiar el desarrollo del proceso formativo, pero estando sujeto a las interpretaciones que de él hacen los participantes.

1.3 El aprendizaje en red

El aprendizaje en red (NL) es definido como el aprendizaje en el cual las TIC promueven conexiones entre las comunidades de aprendizaje y sus recursos (Goodyear, 2005). Constituye un enfoque de aprendizaje que permite a las personas trabajar creativamente, identificando y construyendo problemas, encontrando los recursos para enfrentar los temas identificados y desarrollar soluciones con un esquema de flexibilidad mental (Jones, 2015).

En la búsqueda para generar diseños o programas basados NL, Dohn *et al*. (2018) han establecido cuatro conceptos que enfatizan un conjunto diferente de conexiones en una comunidad de aprendizaje: (1) un énfasis en las conexiones entre las personas y como ellas desarrollan, mantienen y aprenden desde las redes de otros; (2) un énfasis en las conexiones entre situaciones o contextos (cómo las personas hacen conexiones, transformando y reconstruyendo su aprendizaje); (3) un énfasis en las conexiones con las TIC, incluyendo conexiones entre situaciones, traspaso de límites y movilidad; (4) un énfasis en las conexiones entre los participantes y situaciones de aprendizaje.

1.4 El ePortfolio como propuesta tecnopedagógica para el NL

En un contexto formativo mediado por las TIC, la autorregulación del aprendizaje es un factor clave para planear, organizar y facilitar el proceso de aprendizaje, siendo el ePortfolio una de las principales herramientas pedagógicas disponibles para soportar esta tarea (Romero *et al*., 2019). Constituye una de las alternativas más efectivas y contextualizadas al momento social del aprendizaje, apoyando el cambio de rol desde un estudiante pasivo a uno que participa más en su propia historia de aprendizaje, con múltiples beneficios formativos (Gordon, 2017).

Desde el NL, el ePortfolio es considerado una herramienta con alto potencial para la comunicación e interacción de los miembros de una comunidad educativa, soportando los procesos de aprendizaje y ayudando a los aprendices a desarrollar sus itinerarios de aprendizaje autorregulado (Alexiou & Paraskeva, 2019). La integración NL y ePortfolio hace posible

visualizar y facilitar nuevas alternativas para explorar y desarrollar intereses de aprendizaje, con oportunidades en lo académico, profesional y niveles cívicos (Esteban-Guitart *et al*., 2020).

De esta forma, el presente trabajo plantea una mirada sobre la articulación entre tecnología y pedagogía en el proceso de aprendizaje del TDA, que busca dar cuenta de la integración entre una planificación educativa y la dimensión *sociocolectiva* de la formación mediada por la tecnología. El objetivo es analizar el potencial del ePortfolio como estrategia tecnopedagógica para el desarrollo del NL, por medio de la observación crítica de su implementación y resultados, en el nivel inicial del TDA.

2 Metodología

El presente estudio plantea una propuesta metodológica de tipo mixto de carácter aplicado (Creswell & Plano, 2011) con un diseño descriptivo. El análisis consideró 14 semestres académicos entre 2012 y 2018 en el TDA, con un total de 336 estudiantes, del ciclo de formación inicial (segundo año) en la carrera de Arquitectura de la Universidad de Concepción, Chile. Los datos fueron coleccionados por medio de un protocolo de observación del ePortfolio de cada estudiante, con una matriz de registro de evidencias de aprendizaje (niveles de reflexión, niveles de *feedback*, uso del ePortfolio, grado de actualización y nivel de aprobación) en cada semestre considerado, junto con una encuesta de percepción (con una escala Likert de cinco niveles) sobre el uso del ePortfolio para el desarrollo del NL, aplicada a una muestra de 65 estudiantes de los diferentes semestres considerados.

2.1 La implementación del ePortfolio

El ePortfolio fue definido como una estrategia tecnopedagógica de uso obligatorio con carácter complementario al quehacer formativo tradicional del TDA. Fue concebido con un particular interés en dos concepciones del NL (Dohn *et al*., 2018): las conexiones entre las personas y su aprendizaje desde las redes de otros, y las conexiones entre los participantes y situaciones de aprendizaje. Para su creación se utilizaron plataformas Web 2.0 tipo blog (Blogger y WordPress), para gestionar y publicar ePortfolios con altos niveles de interactividad (*feedback*, comentarios y ediciones colaborativas), expresión personal y creatividad (Barrett, 2008). Los ePortfolios fueron creados por los estudiantes, teniendo libertad de utilizar recursos tecnológicos propios o institucionales (*laptop*, acceso a internet, laboratorio de computación) para facilitar el desarrollo de las evidencias de aprendizaje. La URL de cada ePortfolio fue incorporada en un registro abierto dentro de un sistema de gestión de aprendizaje (LMS) institucional, administrado por el tutor del curso y que permitió el libre acceso a todos los ePortfolios creados.

Cuatro etapas fueron abordadas para la inclusión del ePortfolio: (1) inducción, de las condiciones de uso y la normativa de implementación; (2) monitoreo, de las evidencias de aprendizaje contenidas en los ePortfolios; (3) análisis y evaluación de las evidencias de aprendizaje reunidas; (4) validación, compartiendo y reflexionando con los miembros del TDA los resultados obtenidos. Además, se establecieron cinco condiciones para el trabajo con ePortfolio: (1) completar una actualización semanal durante el periodo lectivo; (2) presentar un perfil (caracterización del autor, objetivos y metas); (3) presentar reflexiones personales sobre el aprendizaje realizado; (4) realizar diez comentarios (*feedback*) a pares; (5) desarrollar un diseño e identidad personales.

2.2 Estructura para el análisis de los datos recopilados

A través de una interpretación de las dimensiones propuesta por Shulman (2005) se definieron dos dimensiones donde la implementación del ePortfolio permite observar adaptaciones o ajustes en el NL (Alexiou & Paraskeva, 2019). Dimensión 1, la estrategia de enseñanza y aprendizaje (a nivel individual y colectivo) con acciones propuestas para facilitar y mejorar el aprendizaje; dimensión 2, el contexto de formación (a nivel individual y colectivo) con acciones asociadas a la tradición formativa de la arquitectura. Una matriz para relacionar las dimensiones del proceso con las evidencias de aprendizaje fue definida con una mirada integrada hacia elementos con significativa contribución para el desarrollo del NL (tabla 1).

Tabla 1. Relación de evidencias de aprendizaje y dimensiones del proceso de aprendizaje

Evidencia de aprendizaje	D1	D2
Niveles de reflexión	x	x
Nivel de feedback con tutor	x	
Nivel de feedback entre pares		x
Uso del ePortfolio	x	x
Grado de actualización	x	x
Nivel de aprobación del taller	x	x

Fuente: Roco, 2022

La encuesta de percepción vinculó los aspectos relevantes para la implementación de un diseño tecnopedagógico (Coll *et al*., 2008) con las dimensiones del proceso formativo (tabla 2). Las acciones innovativas se desprenden de las cinco condiciones establecidas para el trabajo con

ePortfolio, y buscaron propiciar un rol más proactivo del estudiante en relación con su propio proceso y trayectoria de aprendizaje. Ello en diálogo con la estructura formal definida, desde la planificación del taller, para el desarrollo del quehacer formativo de sus estudiantes. El grado de contribución de las acciones innovativas del ePortfolio para el desarrollo de NL se refleja a través de la suma de los valores, asignados a los cinco niveles de la escala Likert, para cada dimensión propuesta.

Tabla 2. Resumen de las acciones innovadoras y su relación con las dimensiones del proceso de aprendizaje

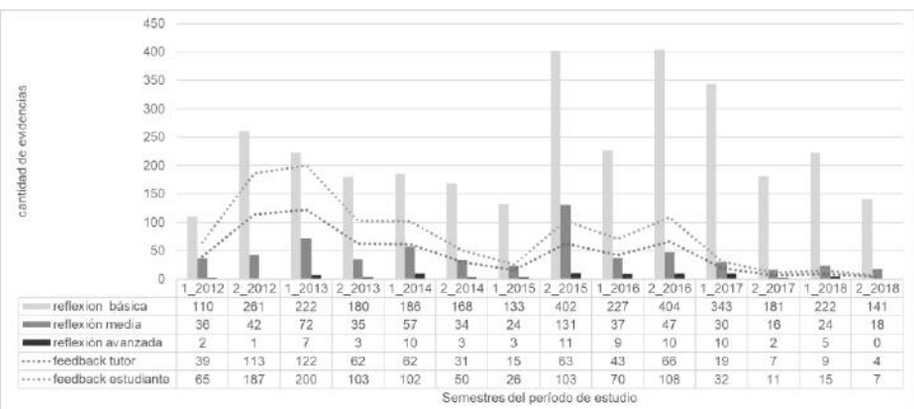
		Acciones innovadoras	Dimensiones	
			D1	D2
Condiciones operativas	1	Uso obligatorio del ePortfolio	x	x
	2	Libertad para seleccionar la plataforma Blog para desarrollar el ePortfolio	x	x
	3	Libertad para expresar identidad en el ePortfolio	x	x
	4	Libertad para incorporar diversas evidencias de aprendizaje	x	x
	5	Libertad para desarrollar el contenido del ePortfolio	x	x
	6	El estudiante es propietario del ePortfolio	x	x
	7	Visibilidad del ePortfolio para todos los miembros del TDA	x	x
	8	Revisiones a petición de los estudiantes	x	x
	9	Libertad para usar ePortfolios previos de otros cursos	x	x
Condiciones técnicas	10	Uso de Plataforma Blog para el desarrollo del ePortfolio	x	x
	11	Uso de los recursos tecnológicos de los estudiantes	x	x
	12	Requerimiento de acceso a Internet	x	x
	13	Visibilidad de la información cuando se haga una entrada en el ePortfolio	x	x
Procedimientos	14	ePortfolio complementa el proceso de enseñanza y aprendizaje tradicional en el TDA	x	x
	15	Actualizaciones semanales en el ePortfolio	x	x
	16	Comentar en el ePortfolio de otros miembros del taller	x	x
	17	Incorporar reflexiones dentro del proceso de aprendizaje	x	x
	18	Cumplimiento de la estructura básica para el desarrollo del ePortfolio	x	x
	19	Revisiones evaluadas del ePortfolio	x	x
	20	ePortfolio como parte de la evaluación del semestre académico (10%)	x	x

Fuente: Roco, 2022

3 Resultados

Las conexiones entre las personas y cómo ellas desarrollan, mantienen y aprenden desde las redes de otros se vincularon a los niveles de reflexión y *feedback*. Los niveles de reflexión, asociados a las categorías establecidas por Roberts (2012), mantuvieron una presencia constante durante todo el periodo

de estudio, con prevalencia de los niveles básico (83%) y medio (15%), mostrando la existencia de una comunicación desde distintos estados de aprendizaje de los miembros del taller. A su vez, se observó la presencia constante de *feedback*, tanto del tutor como de pares, lo que evidenció diálogo e intercambio de ideas asociadas al aprendizaje realizado (figura 1). La presencia de *feedback* del tutor se apreció como un soporte para el desarrollo del *feedback* de los estudiantes, lo que puede constituir un indicativo para la interacción del estudiante con las conexiones de aprendizaje reflejadas por el ePortfolio.

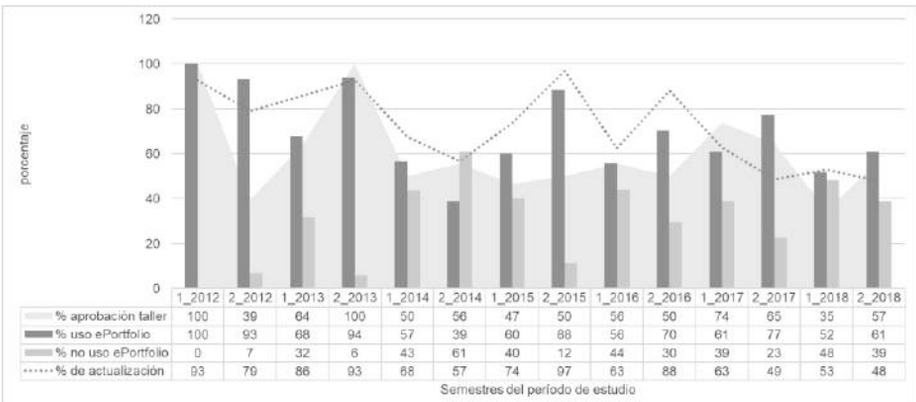


	1_2012	2_2012	1_2013	2_2013	1_2014	2_2014	1_2015	2_2015	1_2016	2_2016	1_2017	2_2017	1_2018	2_2018
reflexion básica	110	261	222	180	186	168	133	402	227	404	343	181	222	141
reflexión media	36	42	72	35	57	34	24	131	37	47	30	16	24	18
reflexión avanzada	2	1	7	3	10	3	3	11	9	10	10	2	5	0
feedback tutor	39	113	122	62	62	31	15	63	43	66	19	7	9	4
feedback estudiante	65	187	200	103	102	50	26	103	70	108	32	11	15	7

Figura 1. Relación entre niveles de reflexión y niveles de *feedback* reflejados por el ePortfolio en el periodo de estudio. Fuente: Roco, 2022.

Con ello, fue posible observar la construcción de redes de aprendizaje entre los participantes, que impulsan un proceso colaborativo, que tiende a desarrollar articulaciones sostenidas en el tiempo.

Las conexiones entre los participantes y las situaciones de aprendizaje fueron asociadas a los niveles de uso del ePortfolio, actualización y aprobación del TDA. Los niveles de uso y actualización fueron constantes durante el periodo de estudio, con porcentajes promedio de 70% y 72%, respectivamente. Esto evidenció la relevancia por mantener una comunicación y muestra permanente de situaciones de aprendizaje, mediante las TIC, por parte de los estudiantes, que les permita generar nuevas oportunidades formativas. El 30% de no uso del ePortfolio correspondió a estudiantes que no terminaron el proceso lectivo. El nivel de aprobación del TDA, con una media del 60%, demuestra el desarrollo de un proceso formativo integrado a situaciones de aprendizaje que facilitan la articulación de relaciones y diálogo entre sus participantes (figura 2).



	1_2012	2_2012	1_2013	2_2013	1_2014	2_2014	1_2015	2_2015	1_2016	2_2016	1_2017	2_2017	1_2018	2_2018
% aprobación taller	100	39	64	100	50	56	47	50	56	50	74	65	35	57
% uso ePortfolio	100	93	68	94	57	39	60	88	56	70	61	77	52	61
% no uso ePortfolio	0	7	32	6	43	61	40	12	44	30	39	23	48	39
% de actualización	93	79	86	93	68	57	74	97	63	88	63	49	53	48

Figura 2. Relación entre los niveles de uso del ePortfolio, actualización y aprobación del TDA para el periodo de estudio. Fuente: Roco, 2022.

Es posible establecer que la inclusión del ePortfolio en las dimensiones del proceso formativo propicia la formalización de redes de intercambio entre sus participantes, y situaciones de aprendizaje con un alto potencial de socialización y colaboración, que impulsa el desarrollo del NL en el TDA, con el soporte de una estrategia pedagógica sustentada en las TIC.

Los resultados de la encuesta de percepción mostraron que el 90% (18 de 20) de las acciones innovadoras implementadas por el ePortfolio impactaron en el desarrollo de NL. Solo en el 10% (2 de 20) no se observó algún efecto (impacto neutro). En la tabla 3, se muestra el porcentaje de contribución para cada ítem percibido en las dimensiones y sus niveles.

Las dimensiones del proceso formativo presentaron diferentes incidencias en el desarrollo del NL: D1 un 54,5% de contribución y D2 un 45,5%. Los niveles de percepción individual y colectivo tienen altas incidencias (52,7% y 47,3%, respectivamente), pero con énfasis diferentes en cada dimensión: mientras en D1 el nivel individual es más significativo, en D2 el nivel colectivo adquiere mayor relevancia.

Tabla 3. Nivel de percepción del impacto del ePortfolio para el desarrollo NL. El puntaje representa el porcentaje promedio por nivel para cada dimensión.

	Dimensiones del proceso de formación	porcentaje de los niveles de percepción	
ítem encuesta	**D1_ Percepción de las innovaciones del ePortfolio en la estrategia de enseñanza y aprendizaje en el TDA**	individual	colectivo
1	D1 _ Revisiones mas personalizadas	4,5	
2	D1 _ encontrar orientación para resolver un problema	3,6	
3	D1 _ comunicar ideas de los proyectos	2,7	
4	D1_ desarrollar una reflexión sobre el propio trabajo	9,1	
5	D1 _ desarrollar una cooperación entre pares	4,5	
6	D1 _ tener continuidad en el trabajo de taller	7,3	
7	D1 _ desarrollo de equipo de trabajo	0,0	
8	D1 _ como revisión del trabajo de taller		5,5
9	D1 _como evaluación del trabajo de taller		3,6
10	D1 _ como comunicación de la información de los proyectos		2,7
11	D1 _ como interacción con pares y tutores		5,5
12	D1 _ como reflejo de la identidad del estudiante		5,5
	D2_ Percepción de las innovaciones del ePortfolio en el contexto formativo		
13	D2 _ reflexión sobre el trabajo realizado	3,6	
14	D2 _ colaboración con otros miembros del taller	4,5	
15	D2 _ la habilidad de comunicar ideas acerca de sus proyectos	7,3	
16	D2 _ la incorporación de mayor información al trabajo realizado	5,5	
17	D2 _ la construcción de reflexiones colectivas sobre el trabajo de taller		5,5
18	D2 _ colaboración con otros miembros del taller		4,5
19	D2 _ el desarrollo de grupos o equipos de trabajo		0,0
20	D2 _ el desarrollo de revisiones entre pares		14,5

Fuente: Roco, 2022

Los aspectos percibidos con más alto porcentaje en cada dimensión permitieron reconocer las acciones innovativas con mayor contribución al desarrollo del NL (tabla 4). Se observó que ambas dimensiones colaboran en una estructura para el desarrollo de NL, constatando un conjunto diverso de relevantes conexiones (ítems 20, 4, 6 y 15) en el proceso de aprendizaje realizado.

Tabla 4. Principales innovaciones del ePortfolio con significante contribución para el desarrollo del NL. Los puntajes corresponden a los más altos porcentajes por nivel.

nivel	Item	acciones por dimensión	porcentaje
individual	4	D1_ desarrollar una reflexión sobre el propio trabajo	9,1
	6	D1 _ tener continuidad en el trabajo de taller	7,3
	15	D2 _ la habilidad de comunicar ideas acerca de sus proyectos	7,3
	16	D2 _ la incorporación de mayor información al trabajo realizado	5,5
colectivo	8	D1 _ como revisión del trabajo de taller	5,5
	11	D1 _ como interacción con pares y tutores	5,5
	12	D1 _ como reflejo de la identidad del estudiante	5,5
	17	D2 _ la construcción de reflexiones colectivas sobre el trabajo de taller	5,5
	20	D2 _ el desarrollo de revisiones entre pares	14,5

Fuente: Roco, 2022

4 Discusión

Con los hallazgos, es posible inferir que las conexiones entre las personas y las situaciones de aprendizaje, las acciones innovativas incorporadas a las dimensiones del proceso de formativo y la implementación del ePortfolio como herramienta tecnopedagógica articulan un conjunto de relaciones que evidencian el desarrollo de NL en el proceso formativo del TDA.

El potencial del ePortfolio de articular múltiples conexiones entre los distintos componentes y miembros de una comunidad de aprendizaje recalca la importancia de las relaciones entre las personas y las conexiones con las situaciones de aprendizaje, siguiendo lo propuesto por (Dohn *et al*., 2018). En la práctica desarrollada en el TDA se advierte la presencia de un proceso conectado guiado por la creatividad, donde se identifican problemas y se buscan los recursos para enfrentarlos y desarrollar soluciones en esquemas reflexivos y mentalmente flexibles, todo lo cual se vincula a la definición para NL planteada por Jones (2015).

La contribución de las acciones innovativas introducidas por el ePortfolio en las dimensiones del proceso formativo, con un percibido impacto en el desarrollo del NL, se puede entender asociada al convencimiento de que la cooperación en red constituye, en la actualidad, la forma usual de trabajo y que es fundamental para promover una visión social del proceso de aprendizaje, como lo proponen Cabero y Marín (2013).

La implementación del ePortfolio como herramienta tecnopedagógica se ajustó al modelo SAMR (Puentedura, 2006), cuyos cuatro niveles de integración y efectos en didáctica pueden ser observados: sustitución, donde se reemplazan los registros previos del proceso formativo de cada estudiante por evidencias digitales; argumentación, donde se incorporan nuevos niveles de diálogo para la comunicación del proceso de aprendizaje; modificación, donde se redefinen la continuidad y oportunidad de la interacción (*feedback*) entre los miembros de la comunidad de aprendizaje; redefinición, donde las situaciones de aprendizaje pueden ser concebidas como una estrategia integral de validación del proceso formativo, siguiendo lo planteado por Dafonte, Ramahí-García y García-Crespo (2017).

Finalmente, el ePortfolio como herramienta tecnopedagógica propicia la participación y articulación de una red activa de colaboración, soportando la gestión, comunicación y responsabilidad colectiva de los integrantes del proceso formativo en las situaciones de aprendizaje; todos aspectos que se enmarcan en la consecución de los principios para el NL.

Referencias

Alexiou, A. & Paraskeva, F. (2019). Examining Self-Regulated Learning Through a Social Networking EPortfolio in Higher Education. *International Journal of Learning Technology, 14*(2), 162-192. https://doi.org/10.1504/IJLT.2019.101849

Anderson, T. (2016). Theories for Learning with Emerging Technologies. En G. Valetsianos (Ed.), *Emergence and Innovation in Digital Learning: Foundations and Applications*. Athabasca University Press.

Barberà, E., Mauri, T. & Onrubia, J. (2008). *Cómo valorar la calidad de la enseñanza basada en las TIC*. Graó.

Barrett, H. C. (7 de setiembre de 2008). Categories of ePortfolio Tools. *Categories of EPortfolio Tools*, 10-11. http://electronicportfolios.com/categories.html

Buchanan, P. (2012). The Big Rethink: Rethinking Architectural Education. *Architectural Review*. https://www.architectural-review.com

Cabero, J. & Marín, V. (2013). Percepciones de los estudiantes universitarios latinoamericanos sobre las redes sociales y el trabajo en grupo. *RUSC Universities and Knowledge Society Journal*, *10*(2), 462-477. https://doi.org/10.7238/rusc.v10i2.1728

Coll, C., Mauri, T. & Onrubia, J. (2008). La utilización de las tecnologías de la información y la comunicación en la educación: del diseño tecnopedagógico a las prácticas de uso. En *Psicología de la educación virtual* (pp. 74-103).

Creswell, J. W. & Plano, V. L. (2011). *Designing and conducting mixed methods research*. SAGE Publications.

Dafonte-Gómez, A., Ramahí-García, D. & García-Crespo, O. (2017). El uso de la tecnología en la educación: modelos para un marco referencial que integre la competencia digital en la docencia. En *Actas del III Congreso Internacional de Educación Mediática y Competencia Digital. Mayo - junio 2017* (pp. 1790-1804). https://bit.ly/374EQYc

Davis, F. D., Bagozzi, R. P. & Warshaw, P. R. (1989). User Acceptance of Computer Technology: A Comparison of Two Theoretical Models. *Management Science*, *35*(8), 982-1003.

Dohn, N. B., Cranmer, S., Sime, J. A., De Laat, M. & Ryberg, T. (Eds.). (2018). *Networked Learning: Reflections and Challenges.* Springer.

Esteban-Guitart, M., DiGiacomo, D., Penuel, W. & Ito, M. (2020). Principios, aplicaciones y retos del aprendizaje conectado. Contextos educativos. *Revista de Educación*, *26*(26), 157-176. https://doi.org/10.18172/con.3966

Goodyear, P. (2005). Educational Design and Networked Learning: Patterns, Pattern Languages and Design Practice. *Australasian Journal of Educational Technology*, *21*(1), 82-101. https://doi.org/10.14742/ajet.1344

Gordon, L. (2017). Students as Co-Designers: Peer and Instructional Resources for Novice Users of ePortfolio. *International Journal of ePortfolio*, *7*(2), 113-127. http://ezproxy.lib.uconn.edu/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=eric&AN=EJ1159903&site=ehost-live

Ioannou, O. (2018). *Opening up Design Studio Education Using Blended and Networked Formats*. *International Journal of Educational Technology in Higher Education*, *15*(1). https://doi.org/10.1186/s41239-018-0129-7

Jones, C. (2015). *Networked Learning: An Educational Paradigm for the Age of Digital Networks*. Springer.

Masdéu, M. & Fuses, J. (2017). Reconceptualizing the Design Studio in Architectural Education: Distance Learning and Blended Learning As Transformation Factors. *ArchNet-IJAR*, *11*(2), 6-23. https://doi.org/10.26687/archnet-ijar.v11i2.1156

Mishra, P. & Koehler, M. J. (2006). Technological Pedagogical Content Knowledge: A Framework for Teacher Knowledge. *Teacher College Record*, *108*(6), 1017-1054.

Pasin, B. (2017). Rethinking the Design Studio-Centered Architectural Education. A Case Study at Schools of Architecture in Turkey. *The Design Journal*, *20*(sup1), S1270-S1284. https://doi.org/10.1080/14606925.2017.1352656

Prieto, M. E., Pech, S. J. & Zapata, A. (2017). *Tecnología y aprendizaje: avances en el mundo académico hispano. Conferencia Conjunta Internacional sobre Tecnologías para el Aprendizaje (CcITA)*.

Puentedura, R. (2006). *Transformation, Technology and Education*.

Roberts, A. (2012). CEBE Briefing Guide Series Recording and Reflecting on. En *System* (pp. 1-11).

Romero, L., Saucedo, C., Caliusco, M. L. & Gutiérrez, M. (2019). Supporting Selfregulated Learning and Personalization Using ePortfolios: A Semantic Approach Based on Learning Paths. *International Journal of Educational Technology in Higher Education*, *16*(1), 1-16. https://doi.org/10.1186/s41239-019-0146-1

Sancho, J. M. & Alonso, C. (2012). La fugacidad de las políticas, la inercia de las prácticas: la educación y las tecnologías de la información y la comunicación. *Octaedro*. https://dialnet.unirioja.es/servlet/libro?codigo=501966

Shulman, L. S. (2005). Signature Pedagogies in the Professions. *Doedalus*, *134*(3), 52-59.

Design, Nature and Ecosystems: Smart Cities & Environments

An Experiment at the Smart Campus UEL: Guidelines for a Technological Tool of Architectural Heritage's Visual Perception

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Abstract. This research aims to think of guidelines, from a Smart Heritage perspective, for the development of an artifact that will aim to "boost" the visual perception of the architectural heritage. Thus, the Smart Campus at UEL works as the research environment, as a living lab to test the points of the Smart City. The research was designed in Design Science Research in six steps: (1) Problem Identification, (2) Suggestion, (3) Development, (4) Demonstration, (5) Evaluation, and (6) Communication. The results presented correspond to phases (1), (2) and structuring of (3). Step (2) had a focus group of four experts in the field of architectural heritage and sought a more realistic epistemological position, focusing on real problems and solutions about the visual perception of architectural heritage in visitation itineraries. Based on the experts' statements, a cross-check was made with the points raised in the Smart Heritage literature to then list the main guidelines for the artifact.

Keywords: Smart Cities and Environments, Smart Heritage, Visual perception, Architectural Heritage, Smart Campus.

1 Introdução

As chamadas *Smart Cities* têm afetado a maneira como interagimos e percebemos a cidade devido ao seu espaço híbrido, interseccionando os ambientes físico e virtual (Ratti; Claudel, 2016; Picon, 2017). Neste cenário emerge a área do *Smart Heritage*, a convergência entre o patrimônio cultural e a *Smart City*, onde se utiliza tecnologias inteligentes para a preservação e difusão do patrimônio cultural (Siountri & Vergados, 2017; Castro & Barracho, 2020). Apesar do surgimento recente desta área de investigação (Castro & Barracho, 2020; Batchelor et al., 2021), existe um razoável consenso que o patrimônio cultural ainda é pouco explorado no escopo das *Smart Cities*

(Damgaard et al., 2015; Siountri & Vergados, 2017; Angelidou & Stylianidis, 2020; Batchelor & Schnabel, 2021).

Neste espaço híbrido, temos a percepção potencialmente afetada por uma sociedade tecnologicamente saturada (Wiegel, 2010) e por um modo "simbiótico" (Sparrow et al., 2011), no qual cotidianamente misturamos recursos tecnológicos e humanos. Como diz Wiegel (2010), as tecnologias digitais afetam, ampliam e redefinem o corpo humano e seus sentidos de modo incomparável a qualquer outra época passada. Torna-nos, inclusive, dependentes de seus recursos de atenção e memória, deixando-nos menos propensos a armazenar percepções por acreditar que uma máquina fará tal tarefa (Sparrow et al., 2011; Wilmer et al., 2017). Tudo isso pode gerar consequências notórias na experimentação visual do patrimônio cultural, pois qualquer análise estética depende da percepção, interpretação, memorização e lembrança de certas particularidades que fazem o espaço distinguível e identificável (Vihanninjoki & Lehtinen, 2019).

Belloni (2003) clama pelo uso das ferramentas digitais, por meio de uma apropriação criativa, como armas para formação. Na mesma direção, Vihanninjoki e Lehtinen (2019, p.218) comentam que as experiencias na *Smart City* "dependem de 'se' e em 'quais' casos a tecnologia se torna uma 'impulsionadora' ou um 'filtro' inibidor para diferentes tipos de experiência". Dessa forma, esta pesquisa visa pensar a tecnologia como um "impulsionador" na chamada fase de observação do patrimônio arquitetônico (Horta et al., 1999, Horta, 2014) em roteiros culturais. A questão da pesquisa é: quais as diretrizes, numa perspectiva de *Smart Heritage* e para a elaboração de um artefato para *smartphones,* conseguiriam "impulsionar" a percepção visual do patrimônio arquitetônico, a fim de sensibilizar as pessoas em relação a este?

Para responder tal questão, como parte de uma pesquisa em desenvolvimento, foi realizada uma discussão com um grupo de especialistas em patrimônio arquitetônico de diferentes locais do país. O intuito foi aprofundar o entendimento do problema de pesquisa, a partir da experiência prática destes especialistas, e definir diretrizes para orientar a construção do artefato/solução.

2 Metodologia

A pesquisa, com caráter exploratório, que, segundo Gil (2008, p.41), tem a finalidade de "proporcionar maior familiaridade com o problema, com vistas a torná-lo mais explícito ou a constituir hipóteses", para então, ampliar o conhecimento sobre um determinado fenômeno. Assim, adotou-se o ambiente universitário, o *Smart Campus* da Universidade Estadual de Londrina, como um *living lab*, testando pontos da *Smart City* (Baletic et al., 2017). Neste Campus estão localizadas 3 casas de madeira oriundas da época da colonização da cidade, reconstruídas e alocadas de tal forma que nos permite

simular um roteiro arquitetônico (Figura 1). As especificidades destas casas são reveladas pelos seus diferentes ornamentos, com características de cada carpinteiro (Zani, 2013). Tomamos tal situação como exercício quase-experimental de percepção visual do patrimônio arquitetônico.

Figura 1. Roteiro Arquitetônico proposto: casas de 1940, 1945 e 1952, reconstruídas no Campus. Fonte: Adaptado do Google Earth pelos Autores, 2022**.**

A pesquisa foi desenhada em *Design Science Research* (DSR), usualmente dedicada a construir artefatos que possibilitem soluções satisfatórias a problemas práticos (Lacerda et al., 2013). O artefato proposto envolve um aplicativo de *smartphone* que visará potencializar a fase de observação patrimonial dentro do contexto de visitação arquitetônica apoiada em um roteiro. Esta pesquisa, alinhada com a DSR, foi pensada em 6 etapas: (1) Identificação do Problema, (2) Sugestão, (3) Desenvolvimento, (4) Demonstração, (5) Avaliação e (6) Comunicação (Peffers et al., 2007; Vaishnavi & Kuechler, 2007).

A etapa (1), Identificação do Problema, foi realizada a partir da revisão de literatura em 35 periódicos, com o cruzamento dos descritores nos seguintes temas: *Smart Heritage, Cultural Heritage, Smart City,* Patrimônio Inteligente. A etapa (2), Sugestão, tem como finalidade uma maior compreensão do problema, através de discussão semiestruturada com grupo de especialistas, assim estes podem “derivar sugestões para abordar o problema de pesquisa” (Vaishnavi & Kuechler, 2007, p.48). Os experts auxiliam na revisão do problema, de uma forma mais condizente com a realidade em que se inserem e podem sugerir soluções, conforme a experiencia prática de cada um.

Os resultados apresentados neste artigo correspondem às etapas (1), (2) e estruturação da (3). A etapa (2) buscou uma posição epistemológica mais realista focada em problemas e soluções reais sobre a percepção visual do patrimônio arquitetônico. Esta etapa contou com um grupo focal de quatro especialistas da área do patrimônio arquitetônico, a seguir o perfil destes:

- Especialista 1 é Arquiteta e Urbanista, com especialização em História e Teoria da Arte, Mestrado em Geografia e Doutorado em andamento na área de Arquitetura e Urbanismo. É membro do Conselho Municipal de Preservação do Patrimônio Cultural de Londrina, com experiência de 15 anos em elaboração de roteiros de visitação;
- Especialista 2 é Arquiteto e Urbanista, com especialização em Artes, Mestrado em Patrimônio Cultural, Doutorado em Educação nas Ciências, Pós-Doutorado em Arquitetura e Urbanismo, e com experiência de 7 anos em elaboração de roteiros de visitação;
- Especialista 3 é Socióloga e Antropóloga, com Mestrado em Sociologia, Doutorado em Teoria e História Literária e pós-doutoramento em História da Arte, e com experiência de 19 anos na área de roteiros de visitação;
- Especialista 4, é Museóloga, possui Doutorado em Semiótica do Museu, e Pós-Doutorado em Cultura Contemporânea. Foi Diretora de Museu por 18 anos, com experiência na área de educação patrimonial e roteiros de visitação.

A discussão foi dividida em dois dias, sendo o primeiro destinado a apresentar aspectos básicos da pesquisa, como o delineamento do problema e o roteiro a ser desenvolvido no Campus (estudo de caso), e questões referentes à importância dos ornamentos para analisar as edificações apresentadas e aos aspectos relacionados a percepção de ornamentos em edifícios patrimoniais. No segundo dia foi retomada a discussão através de um resumo do encontro anterior, foi debatido em seguida conteúdos relacionados com os possíveis recursos para estimular as pessoas a compararem as obras durante o percurso, além disso, foi feita uma síntese da discussão. Destaca-se, por fim, que a etapa (5) será realizada pelo mesmo grupo de especialistas.

3 Contexto contemporâneo do patrimônio cultural: O Smart Heritage

O surgimento de um novo movimento cívico está sendo presenciado à medida que os smartphones se tornam plataformas para reinventar as cidades de baixo para cima (*bottom up*). Diariamente, pessoas de todo o mundo estão utilizando essa tecnologia cada vez mais acessível para resolver problemas locais (Townsend, 2013). Elas estão criando plataformas abertas, aplicativos e redes gratuitas que impulsionam projetos da própria comunidade para cidades do futuro (Dustdar et al., 2017).

Dessa forma, o discurso sobre as *Smart Cities* está mudando de questões estritamente tecnológicas para culturais, com abordagens mais centradas no ser humano (Dustdar et al., 2017; Ratti & Claudel, 2018). Assim, a utilização das Tecnologias de Informação e Comunicação (TICs), deve ser vista como uma ferramenta para empoderar e educar os cidadãos para torná-los capazes de se engajarem no debate sobre o ambiente em que vivem (Ratti & Claudel, 2018).

Nesse contexto, as TICs possuem um grande potencial para melhorar a consciência do cidadão sobre a importância do Patrimônio Cultural e viabilizar instrumentos que podem tornar as visitas a locais históricos mais interessantes, facilitando o aprendizado e as interações entre todos os atores envolvidos (Piccialli & Chianese, 2017). Assim, a convergência entre as TICs e o Patrimônio Cultural contribui para uma virada cultural, na qual a Smart City se torna apta para inovar a dinâmica de desenvolvimento cultural (Brusaporci, 2020). É desse encontro que surge o *Smart Heritage*.

Lupo e Özdil (2013, p. 161), à frente da criação do termo, assinalam que as TICs contribuem para o acesso e enriquecimento da experiência com o patrimônio cultural, mas *"as potencialidades das tecnologias podem levar a uma abordagem acrítica e entusiasta da inteligência"*. Desse modo, elas elucidam que um *Smart Heritage* é mais do que um patrimônio digitalmente acessível em uma *Smart City*. Dessa forma, frente a qualquer simplificação exagerada, as autoras indicam que um *Smart Heritage* é:

"[...] um patrimônio que se difunde de forma mais rica [...], é explorado e ampliado pelas tecnologias digitais e acessível pelos dispositivos digitais, possibilitando uma experiência profunda, densa e intensa que permeia e estende o tempo e o espaço, conectando a dimensão física à virtual, mesclando o indivíduo e o experiência coletiva, articulando conteúdos imateriais com a tangibilidade de um território" (Lupo & Özdil, 2013, p. 161).

Vattano, também apontada como uma das precursoras na área (Castro & Barracho, 2020; Paquin, 2015), define que o *Smart Heritage* "pode ser concebido como a identidade de lugares por meio da implementação de tecnologias inteligentes, do conhecimento e da inclusão social, para a participação total na promoção do patrimônio cultural" (Vattano, 2014, n.p.). Assim, Lupo, Ozdil e Vattano possuem abordagens similares, enfatizando a conexão e o relacionamento entre as pessoas e o patrimônio cultural, entre o físico e o virtual (Paquin, 2015).

3.1 Novas relações com patrimônio cultural mediadas por tecnologias inteligentes

O avanço das tecnologias está transformando as relações entre as pessoas e o patrimônio cultural (Buonincontri; Marasco, 2017), portanto, torna-se necessário entendê-las. Lupo e Ozdil (2013) relatam que as novas tecnologias propiciam um patrimônio "relacional", pois constroem interconexões entre diferentes escalas, tempos e contextos do patrimônio, incitando interações e participação das pessoas. Dessa forma, elas tornam possível o sentido e o significado do patrimônio, através da criação (ou recriação) de conexões entre o patrimônio e seu local de origem ou seu novo contexto (em casos que o patrimônio foi realocado), entre o património e as pessoas e entre as pessoas e as pessoas (Lupo & Ozdil, 2013).

Desse modo, as novas mídias e dispositivos trazem grandes oportunidades para “a valorização e o enriquecimento das experiências patrimoniais, melhorando o envolvimento dos utilizadores” (Prandi et al., 2019, p. 2). Por meio de esferas de experiência o patrimônio se expande e se torna mais divulgado, alcançando mais pessoas e permitindo que elas o sintam como algo seu (Paquin, 2015). Evoluindo, assim, de uma dimensão informativa para uma dimensão relacional (Trovato & Sturiale, 2016).

Enquanto nas formas tradicionais de transmissão do patrimônio, os especialistas têm informações a serem transmitidas, no *Smart Heritage*, com suas possibilidades de experiências participativas e colaborativas, os cidadãos também contribuem com o conteúdo ao usar plataformas e redes sociais (Paquin, 2015; Borda & Bowen, 2017). Ademais, a disponibilização de dados abertos foi uma mudança significativa que aumentou as oportunidades de interpretação, inovação e disseminação das informações relativas ao patrimônio cultural (Borda & Bowen, 2017). Assim, a tecnologia não apenas determina como o patrimônio material é preservado, mas também como os humanos interagem com ele (Damgaard et al., 2015).

3.2 Impacto das tecnologias digitais na percepção

Há indícios que o uso das tecnologias digitais, como os *smartphones*, tem afetado a percepção humana, podendo causar prejuízos na memória e na atenção das pessoas (Wiegel, 2010; Sparrow et al., 2011; Henkel, 2014; Wilmer et al., 2017). Dessa forma, apesar de todas as potencialidades que essas novas tecnologias podem trazer para a relação das pessoas com o patrimônio cultural, deve-se ter um olhar crítico e global, evitando uma visão utópica e mágica. De acordo com Lehtinen e Vihanninjoki (2021, p. 31):

“[...] não devemos permanecer passivos ou impotentes diante das tecnologias emergentes, aceitando silenciosamente todas as implicações possíveis, mas devemos ter mais e melhores meios para avaliar os prós e contras de cada dispositivo ou aplicação tecnológica de forma mais abrangente. Em particular, as repercussões experienciais e estéticas de várias tecnologias têm escapado até agora a um exame mais aprofundado”.

Os autores observam que as tecnologias contemporâneas alteram consideravelmente como uma cidade é vivenciada diretamente, mas também, os hábitos e atividades diárias. Assim, tais alterações vão além das consequências mais imediatas de como uma cidade é percebida, e consequentemente o patrimônio também, visto que as tecnologias direcionam e fixam a atenção sobre certas características, afetando assim as experiências no meio urbano (Lehtinen & Vihanninjoki, 2021). Conforme Wiegel (2010), não é possível simplesmente ignorar ou evitar a influência da tecnologia, visto que os humanos estão inextricavelmente ligados a ela. Desse modo, segundo a

autora, as tecnologias digitais são incorporadas pelo observador por fazerem a mediação entre quem observa e o que é percebido.

Von Simson (2006) destaca que a facilidade e a rapidez dos meios de comunicação, juntamente com a quantidade avassaladora de informações, fazem com que grande parte das pessoas consumam informações de forma acrítica e mecânica. De forma complementar, Stiegert (2018) pontua que a velocidade dos meios de comunicação e a ambiência das redes sociais, podem fazer com que as pessoas se interessem mais pela quantidade de “likes” do que a assimilação profunda de significados.

O seminal livro de Guy Debord, “A Sociedade do Espetáculo”, prenuncia o mundo contemporâneo, repleto de máquinas "inteligentes" que nos perturbam (Belloni, 2003). Debord (1997, p.9) aponta que o espetáculo “*é o lugar do olhar iludido e da falsa consciência”,* onde o mundo real se reduz em simples imagens, as quais se tornam motivações eficientes de um comportamento hipnótico. O autor aponta que a alienação do espectador em relação ao objeto contemplado é resultado da sua própria atividade inconsciente que se manifesta assim: “*quanto mais ele contempla, menos vive; quanto mais aceita reconhecer-se nas imagens dominantes da necessidade, menos ele compreende a sua própria existência e o seu próprio desejo*” (Debord, 1997, p.19). Dessa forma, a alienação produzida pelo espetáculo promove a separação do indivíduo e seu mundo.

Essas máquinas estão cada vez mais presentes no cotidiano da sociedade humana, os *smartphones* protagonizam tal cenário. Estes se tornaram acessíveis para mais pessoas em todo mundo: de acordo com um relatório realizado no final de 2020 pela GSMA 5,2 bilhões de pessoas têm no bolso algum tipo de aparelho celular, o que representa 67% da população mundial. Portanto, é necessário que “*dos instrumentos do espetáculo façamos ferramentas ou armas de formação, pela apropriação criativa das tecnologias*” (Belloni, 2003, p. 135). Deste modo, aumenta a possibilidade de assumir o controle das engrenagens do sistema espetacular, pela apropriação de seus instrumentos e de suas máquinas (Souza, 2014).

Adicionalmente, Ratti e Claudel (2016) indicam que a ideia de cidades inteligentes necessita ser reformulada para ter seu foco no ser humano, o que os autores chamam de *Senseable Cites*. Propõem sistemas e cidadãos interagindo, ao invés destes últimos serem dominados pelas máquinas. Nesse sentido, a tecnologia tem o intuito de ampliar a percepção e nossos sentidos e não os atrofiar. Os autores ressaltam que novas ferramentas estão surgindo com a intenção de conectar pessoas e capacitá-las a assumir um papel ativo. Em vista disso podemos relembrar a frase de Buckminster Fuller: “*Somos chamados a ser os arquitetos do futuro, não suas vítimas*” (apud Ratti & Claudel, 2016, p.9).

4 Resultados e Discussão: Grupo Focal de Especialistas

A inserção das novas TICs abre diferentes perspectivas ao patrimônio cultural, como também, aponta alertas importantes. Assim, com a intenção de produzir diretrizes para um aplicativo que impulsione a atenção e percepção visual de edifícios patrimoniais, foi realizada uma discussão com quatro especialistas da área, com o objetivo de expandir o entendimento com fundamentação na experiência prática destes. Desse modo, a seguir serão discutidos os resultados dessa atividade.

Os especialistas reforçaram alguns pontos que inicialmente haviam sido delineados em relação ao problema: (1) a similaridade entre as casas de madeira poderá produzir maior dificuldade na leitura e percepção dos visitantes; neste sentido, (2) os ornamentos e partes construtivas das casas poderão ser um modo de valoração e entendimento destas, desde que sua relação com o todo não se perca; (3) os ornamentos carregam consigo valores e ações cristalizadas que poderão mais facilmente ser lidas nas atividades de rota; (4) o recurso do zoom da câmera como recurso potencial que poderá acrescentar atenção no processo de leitura, desde que pensada de modo ativo (usuários em ação).

Sobre novos aspectos na construção problema, que não foram levantados inicialmente, podem ser destacados: (5) é necessário considerar o fato destas casas serem transladadas, podendo acrescentar ao visitante o contexto inicial, buscando agregar valor (Especialista 1 e 3); (6) alguns destes ornamentos podem não mais existir, inclusive nas obras existentes fora do roteiro, logo deve-se refletir sobre uma proposição da “ausência” nestes edifícios (Especialista 2); (7) atentar-se para os períodos em que tais casas foram executadas, como também transladadas, para agregar valor no percurso do usuário (Especialista 1); (8) ter atenção ao fato que as pessoas possuem experiências anteriores, inclusive graus de afeto, com casas semelhantes, buscando gerar situações onde estas possam se manifestar e devolver algum tipo de informação (Especialista 3 e 4).

Em relação as estratégias apontadas, podem ser ressaltadas as seguintes: (9) fazer o visitante perguntar-se o porquê de não perceber o ornamento ou parte (Especialista 1); (10) é necessário uma “observação inquisitória”, para estimular indagações, como um trabalho de “detetive” (Especialista 4); (11) trabalhar com situações de algum tipo de reconhecimento ou estranheza, podendo trazer outros exemplos conhecidos pelo visitante ou colocá-lo diante de situações novas (como uma visita em período noturno) (Especialista 2 e 4); (12) trabalhar a narrativa do roteiro estruturada por um elemento ou mais da casa, como modo de agregar sentido ao roteiro (Especialista 1); (13) explorar um tipo de glossário visual para os visitantes serem estimulados a verem as casas como algo a ser lido - conteúdo e expressão (Especialista 4); (14) trazer aspectos mais lúdicos como um jogo de quebra-cabeça, por onde se entenda a posição e importância das partes (Especialista 3).

A partir das colocações dos especialistas, sumarizadas aqui, foi realizado um cruzamento com os apontamentos levantados a partir da literatura sobre o *Smart Heritage* para, então, elencar as principais diretrizes para o artefato:

- O uso do artefato deve envolver um modo ativo, que estimule o usuário a desenvolver algum tipo de ação, como buscar a parte ou o ornamento que está ausente ou montar as partes e ornamentos como um quebra-cabeça, algo que vai ao encontro de pesquisas do uso de forma lúdica e gamificação em *Smart Heritage* (Paquin, 2015; Borda & Bowen, 2017; Khan et al., 2020).
- A percepção visual não pode ser destituída de significados em diferentes camadas, devendo ser agregadas informações significativas das partes (como as origens da carpintaria e relações com a técnica construtiva), como também, conexões entre o local de origem e o novo contexto transladado (Lupo & Ozdil, 2013). Neste sentido, entender a relação que a parte ou ornamento tem dentro de um contexto histórico maior, podendo apropriar-se de estratégias de realidade aumentada (Lupo & Ozdil, 2013; Paquin, 2015)
- O artefato deve fomentar a comunicação do usuário para devoluções de impressões, inicialmente por meio de questões, para enfim, permitir expressões mais livres. Preferencialmente que estas possam ser visualizadas pelos próprios usuários, a fim de gerar uma interação do património e as pessoas e das pessoas e com as pessoas (Lupo & Ozdil, 2013).
- O artefato deve estar relacionado com a narrativa construtora do roteiro, buscando trazer a parte ou ornamento para o centro da narrativa, como uma das motivações para o percurso e para a leitura dos edifícios. A proposição de empregar a tecnologia para ilustrar e reforçar elementos arquitetônicos e processos construtivos (Varinlioglu & Halici, 2019; Pop-Ville, 2021), como neste presente caso, a carpintaria da época.

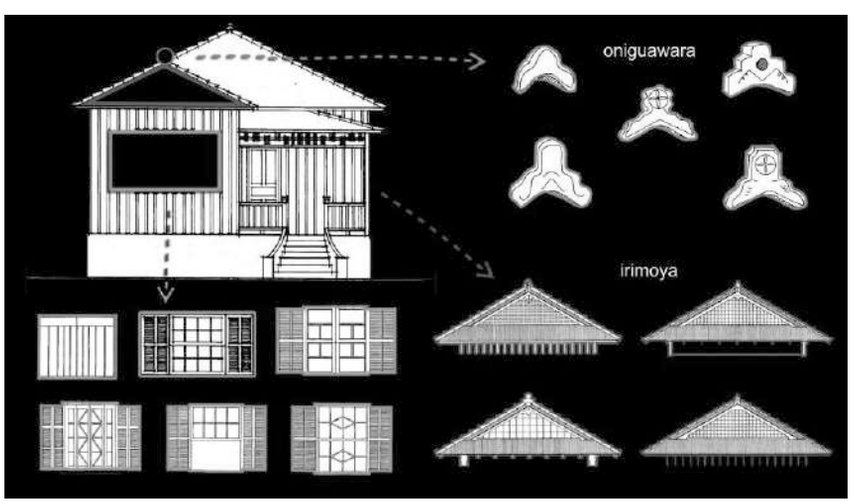

Figura 1. Esquema a partir das diretrizes apontadas. Fonte: Adaptado de Zani (2013) pelos Autores, 2022.

5 Conclusão

O *Smart Heritage* ainda precisa de muita reflexão, assim, aproximar a discussão concentrada na literatura específica à experiência prática de especialistas é fundamental, buscando entender os problemas a partir da vivência prática. Neste trabalho, foram levantadas diretrizes para a confecção do artefato, contudo, destaca-se a importância de ir além dos aspectos meramente visuais no artefato, inclusive, o entendendo como parte de uma narrativa maior constituinte do roteiro, para produzir significação e ganhar relevância para o usuário. Destaca-se também a importância de associar ações lúdicas à fenômenos específicos das casas, como o papel da parte no todo ou do desaparecimento de ornamentos destas casas e a revelação de ornamentos e partes que antes estavam "invisíveis", como também, de seus significados. A próxima etapa, (3) Desenvolvimento, proporá um aplicativo que ligue um quebra-cabeça com os elementos arquitetônicos e ornamentos das casas de madeira apresentadas, a partir de um glossário visual, e um enredo de jogo de detetive. Busca-se inserções de ações com câmera dentro do jogo, com recurso de zoom e estímulo do usuário, em uma tática de *serious game*. Posteriormente será feita a demonstração do artefato, referente à etapa (4), com um grupo controlado, para entender seu impacto na percepção do patrimônio arquitetônico.

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Referências

Angelidou, M., & Stylianidis, E. (2020). CULTURAL HERITAGE IN SMART CITY ENVIRONMENTS: THE UPDATE. ISPRS Annals of Photogrammetry, Remote Sensing & Spatial Information Sciences, 5(2).

Baletic, B., Lisac, R., & Vdovic, R. (2017). Campus living lab knowledgebase: A tool for designing the future. In Handbook of Theory and Practice of Sustainable Development in Higher Education (pp. 441-456). Springer, Cham.

Batchelor, D., & Schnabel, M. A. (2021). Opportunities and Recommendations for Local Governments Delivering Smart Heritage.

Batchelor, D., Schnabel, M. A., & Dudding, M. (2021). Smart Heritage: Defining the Discourse. Heritage, 4(2), 1005–1015. https://doi.org/10.3390/heritage4020055

Belloni, M. L. (2003). A formação na sociedade do espetáculo: gênese e atualidade do conceito. Revista Brasileira de Educação, 22, 121–136.

Borda, A., & Bowen, J. (2017). Smart cities and cultural heritage-A review of developments and future opportunities. In EVA. BCS.

Brusaporci, S. (2020). Toward smart heritage: Cultural challenges in digital built heritage. In Applying Innovative Technologies in Heritage Science (pp. 271-296).

Buonincontri, P., & Marasco, A. (2017). Enhancing cultural heritage experiences with smart technologies: An integrated experiential framework. European Journal of Tourism Research, 17, 83-101.

Castro, J. M., & Baracho, R. M. A. (2020). O patrimônio cultural nas cidades inteligentes. Em Questão, 26(3), 298-326.

Damgaard, M. L., van Heijster, S., Nielsen, E. B., Rodil, K., & Rehm, M. (2015). Preserving Heritage through Technology in a City Undergoing Change. International Conference on Culture and Computing (Culture Computing).

Debord, G. (1997). A sociedade do espectáculo. Rio de Janeiro: Contraponto. Tradução de Estela dos Santos Abreu.

Dustdar, S., Nastić, S., & Šćekić, O. (2017). Introduction to smart cities and a vision of cyber-human cities. In Smart Cities (pp. 3-15). Springer, Cham.

Gil, A. C. (2008). Métodos e Técnicas de pesquisa social. -São Paulo: Editora Atlas.

Henkel, L. A. (2014). Point-and-shoot memories: The influence of taking photos on memory for a museum tour. Psychological science, 25(2), 396-402.

Horta, M. D. L. P., Grunberg, E., & Monteiro, A. Q. (1999). Guia básico de educação patrimonial (Vol. 199). Brasília: Iphan.

Horta, M. D. L. P. (2014). O “link” (ou a relação) das coisas com os objetos, com os sujeitos, com os documentos, com o museu e o que isso tudo quer dizer... Mouseion, (19), 43-52.

Khan, I., Melro, A., Amaro, A. C., & Oliveira, L. (2020). Systematic review on gamification and cultural heritage dissemination. Journal of Digital Media & Interaction, 3, 19-41.

Lacerda, D. P., Dresch, A., Proença, A., & Antunes Júnior, J. A. V. (2013). Design Science Research: método de pesquisa para a engenharia de produção. Gestão & produção, 20(4), 741-761.

Lehtinen, S., & Vihanninjoki, V. (2021). Aesthetic perspectives on urban technologies: conceptualizing and evaluating the technology-driven changes in the urban everyday experience. In Technology and the City (pp. 13-35). Springer, Cham.

Lupo, E., & Özdil, E. (2013). Towards a" Smart Heritage" as Future Diffused Museums: Design and Communication Technologies to Innovate the Experience of the Cultural Patrimony in Smart Cities. International Journal of the Inclusive Museum.

Paquin, A. G. (2015). The 'smart' heritage mediation. The Smart City Journal. https://www.thesmartcityjournal.com/en/articles/smart-heritage-mediation

Pop-Ville – Parcours d’architecture pour les jeunes. (2021). Pop-Ville – Parcours d’architecture pour les jeunes. https://popville.ca/

Peffers, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2007). A design science research methodology for information systems research. Journal of management information systems, 24(3), 45-77.

Piccialli, F., & Chianese, A. (2017). Cultural heritage and new technologies: trends and challenges. Personal and Ubiquitous Computing, 21(2), 187-189.

Picon, A. (2017). Os limites da inteligência: sobre os desafios enfrentados por Cidades Inteligentes. Revista ECO-Pós, 20(3), 39-48.

Prandi, C., Melis, A., Prandini, M., Delnevo, G., Monti, L., Mirri, S., & Salomoni, P. (2019). Gamifying cultural experiences across the urban environment. Multimedia Tools and Applications, 78(3), 3341-3364.

Ratti, C., & Claudel, M. (2016). The city of tomorrow: Sensors, networks, hackers, and the future of urban life. Yale University Press.

Sparrow, B., Liu, J., & Wegner, D. M. (2011). Google effects on memory: Cognitive consequences of having information at our fingertips. science, 333, 776-778.

Siountri, K., & Vergados, D. D. (2018). Smart cultural heritage in digital cities. Journal Saustainable Development, Culture, Traditions, SDCT-Journal, 23-32.

Souza, I. A. N. (2014). Na confluência da roda: educação patrimonial, diversidade cultural e a pedagogia Griô. Dissertação (Mestrado Profissional em Preservação do Patrimônio Cultural). Instituto do Patrimônio Histórico e Artístico Nacional.

Stiegert, I. (2018). Espetacularização do patrimônio urbano: cenário pra quem? Anais do 3º Seminário de Pesquisa, Pós Graduação e Inovação., v. 2, 149–166.

Townsend, A. M. (2013). Smart cities: Big data, civic hackers, and the quest for a new utopia. WW Norton & Company.

Trovato, M. R., & Sturiale, L. (2016). The smart management and the e-cultural marketing of UNESCO heritage. International Journal of Sustainable Agricultural Management and Informatics, 2(2-4), 155-173.

Vattano, S. (2014). Smart Technology for smart regeneration of cultural heritage: Italian smart cities in comparison. MUSEUMS AND THE WEB FLORENCE.

Vaishnavi, V. K., & Kuechler, W. (2007). Design science research methods and patterns: innovating information and communication technology. Auerbach Publications.

Varinlioglu, G.; Halici, S. M. (2019). Gamification of Heritage through Augmented Reality. In Sousa, J. P, Henriques, G. C. & Xavier, J. P. (eds.), Proceedings of 37 eCAADe and XXIII SIGraDi (p. 513-518).

Vihanninjoki, V. J., & Lehtinen, S. T. (2019). Moving in the metropolis: Smart city solutions and the urban everyday experience. Architecture and the Smart City.

Von Simson, O. (2003). Memória, cultura e poder na sociedade do esquecimento. Augusto Guzzo Revista AcadêMica, (6), 14-18. doi:10.22287/ag.v0i6.57

Wiegel, L. (2010). Perception in the digital age: Analysing aesthetic awareness of changing modes of perception (Master's thesis).

Wilmer, H. H., Sherman, L. E., & Chein, J. M. (2017). Smartphones and cognition: A review of research exploring the links between mobile technology habits and cognitive functioning. Frontiers in psychology, 8, 605.

Zani, A. C. (2003). Arquitetura em madeira. Eduel-Editora da Universidade Estadual.

Mapping digital platforms: the delivery apps controversy

Abstract. This article addresses the topic of digital delivery platforms and their performance in the city, especially in the period of the covid-19 pandemic. In a critical essay based on case examples from the city of Rio de Janeiro, we address some key issues that the development of this type of platform generates for existing delivery services, now potentiated by a period of social isolation where this demand has increased considerably. The so-called platform labor is understood as a phenomenon that intensifies social conflicts, leading both to the organization of resistance and to the search for solutions that necessarily involve the development of alternative digital platforms. On the other hand, the proliferation of dark stores and ghost kitchens also affects the lived experience in the city, giving rise to a series of other concerns that deserve greater attention.

Keywords: Mapping controversies, Digital platforms, Mobile applications, Delivery platforms, Dark stores, Ghost kitchens.

1 Introdução

O uso das tecnologias móveis de comunicação digital tem produzido efeitos significativos sobre as interações sociais e com o espaço urbano, alterando as dinâmicas da sociabilidade urbana e adicionando a elas novas camadas de informação (de Souza e Silva, 2013). A convergência das tecnologias de localização, GPS, internet e redes sociais possibilita a criação de diversos dispositivos de interação com a cidade, baseados na localização. Ao mesmo tempo, a portabilidade dos dispositivos de interface, como os aparelhos smartphones, possibilitam o acesso ao ciberespaço de praticamente qualquer lugar na cidade, fazendo com que as plataformas digitais e aplicativos móveis sejam, hoje, parte quase essencial do dia-a-dia da vida nas grandes cidades.

Nesse contexto, partimos do reconhecimento da existência de um ecossistema de plataformas digitais (Barns, 2019) que, de uma forma ou de outra, atuam nas mais variadas esferas da vida pública, com o objetivo realizar uma análise das plataformas digitais de entrega, os “apps” de delivery, como são comumente conhecidos.

Os aplicativos de entrega mais conhecidos no Brasil são o Ifood e o Uber Eats, mas podemos citar também outros que cresceram bastante como Rappi e Loggi. Os dois primeiros foram criados com foco em entrega de comida pronta, ou seja, trabalhando com restaurantes parceiros. Já a Rappi, realiza entregas de compras de supermercados, farmácias e outras mercadorias diversas; e a Loggi, de documentos e objetos, com o foco em empresas e seus clientes.

1.1 A pandemia de COVID-19

A pandemia de Covid-19 afetou o mundo em 2020, trazendo uma realidade de isolamento e distanciamento social que mudou a dinâmica da vida nas cidades. Com as recomendações de distanciamento social, o serviço de entrega – ou como é chamado atualmente, o delivery – aparece como uma opção para limitar o contato interpessoal e, assim, reduzir o risco de contaminação pelo coronavírus.

Enquanto o movimento nas ruas diminuiu, a tendência é que a demanda nos aplicativos de entrega cresça, mesmo com o gradativo fim das medidas restritivas. Durante o primeiro mês de isolamento social devido à pandemia, as compras feitas por meio de aplicativos cresceram 30% no Brasil, de acordo com levantamento do Instituto Locomotiva, divulgado no dia 29 de abril de 2020 (Bond, 2020). Segundo uma pesquisa da Mobills que analisou as despesas dos usuários com os três principais aplicativos de entregas – Rappi, Ifood e Uber Eats – os gastos com delivery cresceram 149% em todo o ano de 2020 (Ribeiro, 2021).

Nessa nova dinâmica, os entregadores se destacaram como categoria essencial para possibilitar que muitas pessoas ficassem em casa. Esse destaque evidenciou também a precarização das condições de trabalho a que estão submetidos nas relações com os aplicativos de entrega. Apesar do grande crescimento das plataformas, a exposição dos entregadores aos riscos da pandemia, somou-se a precarização do trabalho, culminando nas paralisações do movimento dos entregadores, chamado #brequedosapps.

A pandemia complexificou ainda mais um tema que já era polêmico. Ao mesmo tempo que aumenta a demanda em torno do serviço de entrega, tornando-o quase que essencial para a manutenção do isolamento, impõe mais um risco à condição dos entregadores, já bastante precarizados. Nesse sentido, ela intensifica a controvérsia e faz com que os limites sejam pressionados, aumentando a disputa entre os elementos da rede e assim suas relações se tornam visíveis.

2 Metodologia

O objetivo do estudo é mapear as relações que se estabelecem a partir do surgimento e crescimento das plataformas digitais de entrega urbana. Identificando principais actantes e as relações entre eles, analisamos como se comportam em relação uns aos outros e os efeitos que produzem sobre a cidade e a vida cotidiana.

A metodologia se baseia na Cartografia de Controvérsias (Latour, 2012; Venturini, 2010, 2012) proposta pela TAR e parte, inicialmente, da análise dos rastros digitais (Bruno, 2013) que envolvem a controvérsia, como: 1) literatura em revistas acadêmicas; 2) notícias veiculadas em jornais, revistas e blogs; 3) comunicações oficiais dos agentes envolvidos - plataformas, entregadores e estabelecimentos.

A partir dessa pesquisa, foi realizado um diagrama de funcionamento da rede, identificando as ações e mediações que acontecem para que um pedido chegue à casa dos clientes que utilizam essas plataformas. Isso nos permite identificar agenciamentos e *descobrir o padrão de forças como elas são reveladas nas colisões que ocorrem entre diferentes tipos de elementos* (Law, 2012, p. 108)

Em seguida, realizamos a análise de cada um dos principais pontos da rede: plataformas digitais, entregadores e estabelecimentos comerciais. Os clientes, apesar de serem parte fundamental da rede, não foram considerados na análise. Para cada um, buscamos mapear as variações que acontecem, demarcando suas diferentes características e como elas afetam os outros actantes e sua relação com o espaço urbano, realizando uma sistematização que entrelaça os tipos e seus efeitos.

Nesse sentido, foram analisadas quatro plataformas que atuam na cidade do Rio de Janeiro nos últimos 10 anos. Trata-se das principais empresas do tipo no país, as maiores da América Latina, com mercado em expansão: Ifood, UberEats, Rappi e Daki. Entregadores de plataformas são analisados a partir de sua relação laboral com as plataformas de entrega e com os estabelecimentos. Já os estabelecimentos comerciais foram analisados de acordo com a sua relação com o espaço urbano onde se encontram e com as plataformas que utilizam para oferecer o serviço de entrega. Mais especificamente, observamos casos de restaurantes do Rio de Janeiro durante a pandemia de COVID-19.

Adotando a perspectiva da Teoria Ator-Rede, assumimos como rede o conjunto de associações desencadeadas pela agência de humanos e não humanos a partir da capacidade desses de transportar, de deslocar, de fazer circular diferentes tipos de elementos materiais ou simbólicos (D'Andrea, 2016). Aqui nos interessa em especial as redes sociotécnicas desencadeadas por plataformas de entrega urbana, que, ao mediarem pedidos de entrega em domicílio, fazem emergir novas dinâmicas tanto de relações com entregadores quanto em relações espaciais com o ambiente urbano onde se desenrolam.

John Law sugere que é importante tratar os elementos de uma rede em termos do mesmo “vocabulário analítico”, reforçando a ideia de simetria entre os actantes humanos e não humanos e é nesse sentido que direcionamos nosso olhar:

Em vez de tratar, por exemplo, o social de uma maneira e o científico de outra, procura-se seguir o destino da rede em questão e considerar seus problemas, a obstinação dos elementos envolvidos nesses problemas e a resposta da rede à medida que procura resolvê-los. À medida que se move de elemento em elemento, nenhuma mudança no vocabulário é necessária; do ponto de vista da rede, os elementos humanos ou sociais não diferem necessariamente em espécie daqueles que são naturais ou tecnológicos (Law, 2012, p. 108. Tradução nossa).

3 Resultados

Mapear a rede de relações que compõe a controvérsia das plataformas digitais de entrega parece uma tarefa importante e desafiadora, visto que seus efeitos estão em pleno desenvolvimento, se transformando a cada momento.

Como vimos, a pandemia escancarou a precariedade e as más condições enfrentadas pelos trabalhadores plataformizados, principalmente no ramo da entrega em domicílio. As condições, que já eram ruins antes do isolamento social, se intensificaram não só pelo contexto da pandemia, mas também pelo momento de austeridade vivido já há alguns anos, com aumento do desemprego e diversas perdas de direitos sociais.

Os aplicativos de entrega, foco desse artigo, tiveram grandes ganhos – tanto em número de pedidos como de restaurantes parceiros e entregadores cadastrados nas plataformas – com o isolamento social que aumentou a demanda por entrega de comida, compras de mercado e outros serviços, diretamente nas residências.

Acompanhando as redes sociais de estabelecimentos e de entregadores foi possível identificar um embrionário movimento de denúncias e de renúncia ao uso desses aplicativos. Por um lado, os entregadores reivindicavam melhores condições de trabalho, principalmente após a pandemia ter exposto seu trabalho a tantas inseguranças. Por outro, os estabelecimentos buscavam um serviço mais justo – com relação à taxas, preços e remuneração – para as partes envolvidas de fato com o serviço de entrega: restaurantes, entregadores e clientes.

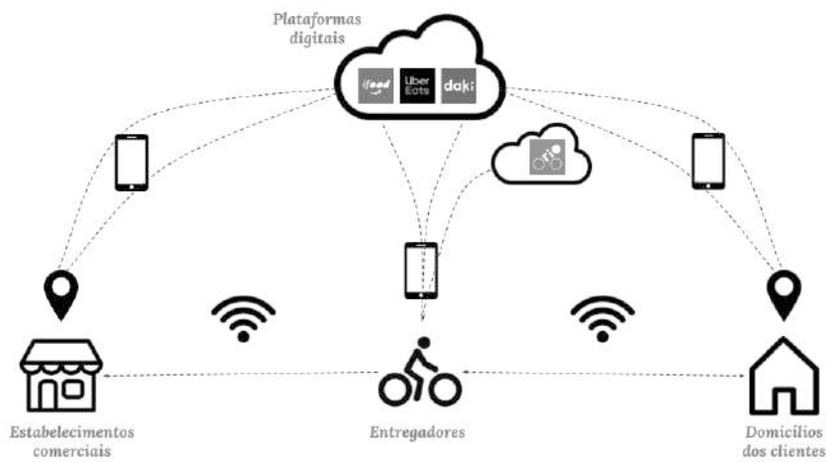

Figura 1. Rede sociotécnica dos sistemas de entrega em domicílio. Fonte: Autor, 2022.

3.1 Plataformas digitais de entrega urbana

Analisamos algumas das plataformas digitais que compõe a rede sociotécnica dos sistemas de entrega em domicílio presentes atualmente no contexto da cidade do Rio de Janeiro. Foram sistematizadas e analisadas algumas características como ano de lançamento, tipo de serviço, tipo de entrega, estabelecimentos atendidos, relação trabalhista, entre outras. As plataformas sistematizadas são as maiores e principais empresas da área no Brasil. São elas: Ifood, Rappi, Uber Eats e Daki.

O Ifood (Bonifácio, 2011) é uma plataforma brasileira fundada em 2011, com o objetivo de realizar entrega de comida pela internet. É a maior empresa do tipo na América Latina, com presença na Argentina, no México e na Colômbia.

A história do iFood começa fora do mundo digital, em 1997, com a Disk Cook, uma empresa que oferecia um guia (impresso) de cardápios, com uma central telefônica para onde se ligava e fazia o pedido. Em 2011, a empresa migrou para as plataformas digitais, passando a funcionar como aplicativo e recebendo então o nome de iFood. Hoje, o aplicativo funciona em mais de 900 cidades, conta com mais de 131 mil restaurantes e 170 mil entregadores cadastrados e a empresa diz entregar dois pratos de comida a cada segundo.

Com o mesmo objetivo inicial, a UberEats (Kalanick & Camp, 2014), lançada em 2014 é um extensão de produto do serviço da Uber. Fazia originalmente parte do serviço de motorista particular, e depois tornou-se um aplicativo e um serviço autônomo. O aplicativo faz parceria com restaurantes locais de cidades selecionadas em todo o mundo e logo tornou-se a principal

concorrência do IFood no contexto brasileiro. Em 2022, a plataforma foi reformulada e passou a oferecer apenas entrega de produtos de mercados e lojas especializadas - através do mesmo aplicativo que foi rebatizado de Cornershop.

Essa é também a principal característica da plataforma Rappi (Ortega, Mejia, Villamarin, Roche, & Borrero, 2015), que realiza entrega de produtos diversos, desde comida de restaurantes à produtos de mercado, farmácia, e até dinheiro em espécie. Criada em 2015, a startup colombiana opera atualmente na Colômbia, Argentina, Brasil, Chile, Equador, México, Peru, Costa Rica e Uruguai. O diferencial da Rappi é justamente o fato de oferecer "de tudo" no seu serviço de entrega. Dessa forma, a empresa faz parcerias com mercados, farmácias, lojas de bebida, pet shops, entre outros.

Nessas três primeiras plataformas a relação com os entregadores se dá na forma de "parceria", onde não há vínculo empregatício, podendo acontecer em diferentes modalidades, como operador logístico e entregador "nuvem".

Na mesma linha da Rappi, a Daki (Maroja, Bretzner, & Vasto, 2022) foi lançada em 2022 com a promessa de realizar entregas "super rápidas", em até 15 minutos. Para isso, a plataforma possui lojas próprias espalhadas pelos bairros da cidade, para onde é distribuído o estoque. Nas lojas é feita toda a gerencia de logística das entregas, desde que o pedido chega até a saída para a entrega, elas contam também com espaço para as bicicletas e pontos de espera para os entregadores. Uma característica importante é que essas lojas não são de acesso ao público. Elas têm a maior parte de suas fachadas fechadas e há apenas uma porta por onde entram e saem os empregados com os pedidos. Essa é uma característica que acompanha a tendência das chamadas "*ghost kitchens*" e "*dark stores*", estabelecimentos fantasma que funcionam apenas para entrega, como veremos mais adiante.

Com relação às relações laborais, na Daki existem duas possibilidades: ou os entregadores são contratados e as bicicletas são de propriedade da empresa, ou podem se cadastrar também entregadores temporários, na mesma lógica de "parceria" das outras plataformas já citadas.

Table 1. Table captions should always be positioned above the tables. Captions, covering more than one line, such as this one, are justified.

Plataformas	Ano	Tipo de serviço	Tipo de entrega	Estabelecimentos	Entregadores
Ifood	2011	Entrega de comida pronta, preparada por restaurantes parceiros.	Entrega normal, com o tempo definido pelo restaurante para o preparo do pedido	Restaurantes "parceiros". Tradicional ou "fantasma"	"Prestadores de serviço" individuais, ou Operadores Logísticos
UberEats	2014	Entrega de comida pronta, preparada por restaurantes parceiros.	Entrega normal, com o tempo definido pelo restaurante para o preparo do pedido	Restaurantes "parceiros". Tradicional ou "fantasma"	"Prestadores de serviço" individuais
Rappi	2015	Entrega de produtos diversos e comida pronta	Entrega normal, com o tempo definido pelo aplicativo	Todo tipo de estabelecimento comercial. Tradicional ou "fantasma"	"Prestadores de serviço" individuais
Daki	2022	Entrega de produtos diversos de mercado	Entrega ultrarrápida, em no máximo 15 minutos, definida pelo aplicativo	Lojas próprias do tipo "fantasma"	"Prestadores de serviço" eventuais e trabalhadores contratados

Fonte: Autor, 2022.

3.2 Entregadores

As plataformas nomeiam os entregadores e restaurantes cadastrados nos aplicativos de parceiros ou colaboradores. O curioso é que essas mesmas empresas sejam chamadas de “empregadores” pelos veículos de comunicação, enquanto aqueles que realizam as entregas para elas sejam considerados “parceiros” e não funcionários, de fato empregados.

A principal polêmica em torno dos aplicativos de entrega é a condição de trabalho dos entregadores, os efeitos do que está sendo chamado de plataformização do trabalho (van Doorn, 2017). Os entregadores, considerados parceiros, não possuem vínculo empregatício formal com as plataformas para as quais trabalham. A falta de vínculo entre os aplicativos e os entregadores torna mais difícil estender a eles direitos comuns a outros trabalhadores, como vale-refeição, vale-transporte e férias remuneradas. Além disso, entregadores usam seus próprios meios de transporte, motos e bicicletas – muitas vezes alugadas do sistema do Itaú – para realizar as entregas.

O crescimento do desemprego em todo o país contribuiu para aumentar a quantidade de profissionais que viram nas entregas uma fonte de renda. Isso acarreta em maior concorrência entre os próprios entregadores e possibilita que, mesmo com o aumento da demanda, os aplicativos de entrega passem a pagar menos pelo serviço e a exigir mais dos profissionais.

Os entregadores relatam que o sistema dos aplicativos é uma “caixa-preta” e não fica claro os critérios para os valores pagos por cada pedido, nem para o “ranqueamento” que pode ocasionar o bloqueio temporário na plataforma por falta de pontuação. Ou seja, os trabalhadores cadastrados nas plataformas

estão submetidos a um “controle algorítmico”, de modo que as plataformas exercem vigilância e controle desse trabalho (Desgranges, 2021).

Com o agravar da pandemia e o crescente número de entregadores indo para as ruas realizar o trabalho, as condições precárias se evidenciaram e questões relativas à segurança e saúde desses trabalhadores foram levantadas, como a falta de fornecimento de equipamentos de proteção individual, além de não haver nenhum apoio no caso de contrair a doença e não poder trabalhar. Essa questão ganhou maior visibilidade em denúncias feitas pelo entregador Paulo Lima, conhecido como Galo, em vídeos do seu canal de Youtube, que viralizaram. O perfil do Instagram “Entregadores Antifascistas”, por ele criado em abril de 2020, reúne os apoiadores e visa organizar a luta da categoria com conteúdo sobre as condições injustas de trabalho a que os entregadores estavam sendo submetidos, denunciando a perversidade da lógica do trabalho plataformizado.

Dessa organização surgiu o #brequedosapps, um dia de paralização das atividades de entrega pelos trabalhadores de aplicativos como forma de reivindicar melhores condições de trabalho e pressionar as empresas. A categoria decidiu paralisar no dia 1° de julho de 2020, e novamente no dia 25, requisitando três pautas: 1) Aumento do valor por km; 2) Aumento do valor mínimo por entrega e fim do sistema de pontuação Rappi; 3) Fim dos bloqueios e desligamentos indevidos.

3.3 Estabelecimentos

Com maior visibilidade, essas questões chegaram também aos estabelecimentos parceiros. Muitos desses que, com o isolamento social, haviam recorrido aos aplicativos para dar conta da demanda de entregas para a qual não estavam preparados. O que a princípio parecia funcionar bem, logo começou a gerar contestações por parte dos restaurantes, que se viram reféns das plataformas.

Os donos dos estabelecimentos relataram o aumento da taxa cobrada pelos aplicativos, onerando-os diretamente e tornando praticamente impossível oferecer preços competitivos dentro das plataformas, onde pequenos estabelecimentos competem com grandes marcas de fast-food. A taxa que o Ifood, por exemplo, cobra por cada pedido feito na plataforma é de 27% e outros aplicativos cobram taxas similares. Mas foi o aumento da taxa de entrega – cobrada dos clientes, afetando a quantidade de pedidos que os restaurantes recebem – que desencadeou um movimento de renúncia ao uso dos aplicativos. A taxa dobrou no início da pandemia, quando os estabelecimentos estavam fechados e funcionando exclusivamente por delivery (Madureira, 2020).

Diversos restaurantes se utilizaram de suas redes para anunciar a saída das grandes plataformas de entrega, denunciando, além das precárias condições de trabalho dos entregadores, as dificuldades encontradas para se manter competitivo na plataforma e cobrar um preço justo dos clientes.

Outra forma de se manter competitivo e reduzir custos – e que durante a pandemia se apresentou como única forma que muitos estabelecimentos encontraram para manterem-se funcionando – são as *ghost kitchens* e *dark stores*, um modelo que vem se tornando uma tendência crescente.

3.3.1 *Dark stores* e *ghost kitchens*

Ghost kitchens e *dark stores* são estabelecimentos comerciais fechados ao público, que funcionam apenas para entrega e retirada. Normalmente possuem localização estratégica para a distribuição de produtos para entrega, vendidos pela internet. A *dark store* funciona como minicentro de distribuição e armazenamento para lojas de produtos diversos, como mercado, farmácia, bebidas, tabacaria e petshop. Com a "vitrine" relegada às plataformas digitais, as lojas podem "ter seus espaços internos otimizados para separar, preparar e atender pedidos de entrega" (Shapiro, 2022, p. 2), alavancando as vendas online sem maiores custos. Alguns locais permitem que o consumidor faça sua compra online e retire no local da loja, modalidade conhecida como "Click and Collect".

Já as *dark kitchens*, ou *ghost kitchens*, são cozinhas de restaurante totalmente voltadas para entrega, é uma cozinha comercial otimizada para operações de delivery. Conhecidos em português como restaurante-fantasma, não possuem salão de serviço, e podem economizar custos ocupando imóveis mais baratos, muitas vezes compartilhado com outras cozinhas. O modelo ganhou força nos últimos anos, à medida que as plataformas digitais impulsionaram a entrega de refeições para o segmento que mais cresce na indústria de restaurantes.

A presente pesquisa aponta para o crescimento desse tipo de estabelecimento, principalmente após a pandemia de COVID-19, que tornou mais comum e aceita essa forma de fazer compras pela internet. Em nossa pesquisa de campo, ainda embrionária, mapeamos duas *dark stores* presentes nos arredores do bairro da Glória, no centro do Rio de Janeiro, para efeito de visualização do fenômeno na cidade. Podemos perceber no mapa abaixo a localização destas lojas: uma loja exclusiva Daki e outra que atende pedidos de plataformas variadas, como Ifood e Rappi.

Figura 2. Mapa com a localização de duas *dark stores* no Rio de Janeiro. Fonte: Autor, 2022**.**

Figura 3. Fachada de uma *dark store* na Rua do Catete. Fonte: Autor, 2021**.**

Figura 4. Fachada de uma loja Daki na Rua Riachuelo. Fonte: Autor, 2021.

4 Discussão

O trabalho traz como contribuição para o campo do Urbanismo pensar a relação e os impactos das plataformas digitais de entrega para o espaço da cidade. Percebemos que as plataformas digitais, como principais agentes mediadores na rede de entregas, atuam sobre os outros actantes da rede, direcionando suas ações e impactando, consequentemente, a cidade.

Os já conhecidos impactos nas relações de trabalho, com o aumento cada vez maior do desemprego de da precarização das condições laborais são alguns dos principais efeitos do crescimento desse tipo de plataforma e vem sendo bastante estudados em diversos campos.

Por outro lado, ainda desconhecemos os efeitos que as fachadas inativas das *ghost kitchens* e *dark stores* poderão gerar para a vitalidade das ruas onde se concentram. A aparição crescente desse tipo de estabelecimento consiste em um fenômeno recente que abordaremos futuramente na pesquisa.

Referências

Barns, S. (2019). *Platform Urbanism: Negotiating Platform Ecosystems in Connected Cities*. Springer Nature. https://doi.org/https://doi.org/10.1007/978-981-32-9725-8

Bond, L. (2020, April 29). Compras por aplicativos têm alta de 30% durante pandemia, diz pesquisa | Agência Brasil. Retrieved September 16, 2022, from https://agenciabrasil.ebc.com.br/economia/noticia/2020-04/compras-por-aplicativos-tem-alta-de-30-durante-pandemia-diz-pesquisa

Bonifácio, G. (2011). iFood: Delivery de Comida e Mercado. Retrieved from https://www.ifood.com.br/

Bruno, F. (2013). Rastros digitais sob a perspectiva da teoria ator-rede. *Revista FAMECOS*, *19*(3), 681. https://doi.org/10.15448/1980-3729.2012.3.12893

D'Andrea, C. (2016). #vergonhabrasil: controvérsias midiatizadas no Twitter durante e após o jogo Brasil 1 x 7 Alemanha. *Intercom: Revista Brasileira de Ciências Da Comunicação*, *39*(3), 99–114. https://doi.org/10.1590/1809-5844201636

de Souza e Silva, A. (2013). Location-Aware Mobile Technologies: Historical, Social and Spatial Approaches. *Mobile Media & Communication*, *1*(1), 116–121. https://doi.org/10.1177/2050157912459492

Desgranges, N. (2021). Os algoritmos do empreendedorismo: A plataformização do trabalho de entregadores de iFood. *Pensata: Revista Dos Alunos Do Programa de Pós-Graduação Em Ciências Sociais Da UNIFESP*, *9*(2). https://doi.org/10.34024/pensata.2020.v9.11136

Kalanick, T., & Camp, G. (2014). UberEats. Retrieved from https://u.cornershopapp.com

Latour, B. (2012). *Reagregando o Social: uma introdução à teoria do Ator-Rede*. Salvador: EDUFBA.

Law, J. (2012). Technology and Heterogeneous Engineering: The Case of Portuguese Expansion. In W. Bijker, T. Hughes, & T. Pinch (Eds.), *The social construction of technological systems: new directions in the sociology and history of technology*. Cambridge: MIT Press. https://doi.org/10.1016/S0008-6215(00)84125-7

Madureira, D. (2020). Como apps de entrega estão levando pequenos restaurantes à falência. Retrieved May 17, 2020, from https://www.bbc.com/portuguese/geral-51272233

Maroja, R., Bretzner, A., & Vasto, R. (2022). Daki. São Paulo. Retrieved from https://www.soudaki.com

Ortega, J. P., Mejia, S., Villamarin, F., Roche, G., & Borrero, S. (2015). Rappi. Bogotá. Retrieved from https://www.rappi.com.br

Ribeiro, D. (2021, January 27). Efeito pandemia: gastos com delivery crescem 187% em 2020. Retrieved September 10, 2022, from https://cultura.uol.com.br/noticias/16003_efeito-pandemia-gastos-com-delivery-crescem-187-em-2020.html

Shapiro, A. (2022). Platform urbanism in a pandemic: Dark stores, ghost kitchens, and the logistical-urban frontier. *Journal of Consumer Culture*, (February). https://doi.org/10.1177/14695405211069983

van Doorn, N. (2017). Platform labor: on the gendered and racialized exploitation of low-income service work in the 'on-demand' economy. *Information Communication and Society*, *20*(6), 898–914. https://doi.org/10.1080/1369118X.2017.1294194

Venturini, T. (2010). Diving in magma: How to explore controversies with actor-network theory. *Public Understanding of Science*, *19*(3), 258–273. https://doi.org/10.1177/0963662509102694

Venturini, T. (2012). Building on faults: How to represent controversies with digital methods. *Public Understanding of Science*, *21*(7), 796–812. https://doi.org/10.1177/0963662510387558

Hydrological Recovery of the Landscape through Generative Design

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Abstract. The climate crisis confronts us with global scenarios of water deficiency, which leads us to optimize rainwater harvesting (RWH) methods applied to landscapes. These are sophisticated projects with high technical investment per hectare designed and executed. Therefore, to balance the cost of engineering, through advanced digital design tools, it has become an objective to use landscape architecture as a resource for mitigating water deficit and climate change. In order to restore the relationship between the natural and built environment through virtual processing. This work exposes a new geometric analysis methodology, verified in a case study, which applies generative parametric programming to increase the water capacity of a natural landscape. This work demonstrates the potential of digital design for the ecological recovery of the territory.

Keywords: smart cities and environments, sustainable design, generative design, mixed realities, hydrological design

1 Introducción

En los últimos años, la Organización de las Naciones Unidas ha alertado sobre cómo el cambio climático ha afectado muchos de los ciclos naturales del mundo, siendo el más preocupante la alteración del ciclo del agua (UN, 2015). Además, según indica la Oficina de Alimentos y Agricultura (FAO), actualmente, se estima que 3600 millones de personas en el mundo viven en áreas que podrían sufrir escasez de agua, al menos un mes al año. Esta cifra podría aumentar entre 4800 y 5700 millones de personas en 2050, provocando un “estrés hídrico” entre usuarios y consumidores del agua (FAO, 2012).

El objetivo de la década según las Naciones Unidas es incrementar a gran escala la restauración de los ecosistemas degradados y destruidos como

medida eficaz para luchar contra el cambio climático y mejorar la seguridad alimentaria, el suministro de agua y la biodiversidad. Enfocándonos en este objetivo investigamos desde Chile, con sus características propias, centrándonos en los variados tipos de paisajes existentes y determinando el secano interior como área de investigación.

Las acciones para asegurar la recolección de aguas de lluvia en los territorios implican altas inversiones de diseño y ejecución (Cortés, 2013). Sin embargo, actualmente, se dispone de nuevas tecnologías gráficas que permiten representar y analizar complejas topografías (Falkenmark *et al*., 2001). Por esta razón, el presente trabajo busca aplicar el diseño generativo en la recuperación hidrológica del paisaje como técnica para homogeneizar el recurso hídrico de agua de lluvia en un territorio geográfico determinado (Yoemans, 1993).

Como antecedente relevante en este tema, en 1956, en Australia, surgió una técnica llamada diseño hidrológico con línea clave (*keyline*), cuyo objetivo es aprovechar al máximo el agua de lluvia, que se distribuye por todo el terreno, permitiendo su retención e infiltración (MacDonald-Holmes, s. f.). En este sentido, el diseño basado en *keyline*, adaptado a la agricultura, consiste en surcar el cultivo siguiendo un patrón preestablecido obtenido de la topografía del terreno mediante sus curvas de nivel. A su vez, el diseño hidrológico tiene como objetivo reducir la escorrentía del agua de lluvia, evitando la erosión y maximizando su aprovechamiento, favoreciendo su distribución e infiltración a través del suelo, y buscando beneficiar la producción de los cultivos (Cortes, 2013).

Esta técnica permite optimizar la escorrentía fluvial y canalizarla controladamente según las propiedades del paisaje, utilizando esta estrategia en un caso de estudio para comprobar el procedimiento digital, y su proyección global en todo tipo de territorios.

El diseño digital consiste, a su vez, en la utilización de computación gráfica e información para generar nuevos modelos de trabajo, especialmente en la producción de imágenes, productos y edificios. Pero también se ha incrementado la utilización en el ámbito urbano y geográfico por sus relevantes demandas ambientales e interacción con el entorno construido, que conforma un paisaje colectivo (Cantrell & Holzmann, 2016). Además, estas herramientas, sustentadas en la tecnología informática, son accesibles con barreras limitadas, fomentando su difusión global. De este modo, construyen una capacidad distribuida y aplicable con autoformación y cooperación social (Davidova & Mc Meel, 2020). La conexión de los desafíos territoriales con la potencialidad digital constituyen indudablemente la mayor proyección posible para mitigar la crisis ambiental y contribuir a la cohesión social (Wittenberg *et al*, 2018). Esto restablece, además, las habilidades humanas en interacción con el entorno natural.

Por otra parte, el diseño generativo es un campo de estudio en el cual ha surgido una tendencia generacional dentro de la arquitectura del paisaje que promueve una forma de “autoría a distancia”, enfatizando los procesos

naturales como la sucesión, la acumulación o la remediación pasiva como agentes para el diseño del paisaje (Cantrell & Holzmann, 2016), logrando ser un mediador de los procesos de diseño basados en evidencia como premisa al momento de abordar la problemática hídrica como parte inicial en las decisiones de proyecto.

Este enfoque privilegia las acciones de la biología y la geología sobre las condiciones estáticas fabricadas y, en cambio, siembra estos procesos dinámicos a través de un régimen ecológico general para adaptar las condiciones diseñadas a lo largo del tiempo (Cantrell & Holzmann, 2016). De esta manera, se da forma a un conjunto de servicios ecosistémicos mediante soluciones basadas en la naturaleza (Davidova & McMeel, 2020).

El caso de estudio corresponde a la validación técnica del ejercicio basado en las tecnologías de optimización del diseño hidrológico en terreno, con el objetivo de analizar métricas del paisaje en cuanto a la masa vegetacional antes y después de la intervención. Esto con la finalidad de verificar la capacidad de la herramienta desarrollada y refinar su aplicación según resultados esperados de restauración ecológica del territorio.

Se definió una zona de estudio en colaboración con el Instituto Nacional de Investigaciones Agrícolas, sede Quilamapu en la comuna de Ninhue (región de Ñuble, Chile), comuna que presenta una condición geográfica de vulnerabilidad hídrica debido a su condición de secano, suelos empobrecidos por un histórico de sobre explotación y malas prácticas. El sitio de la intervención es precisamente en el fundo “Los Cuarzos”, sector San José, lugar con una vocación de estudios agropecuarios

Ejecutamos esta propuesta de arquitectura del paisaje en la búsqueda de la vocación natural de cada territorio en torno a la regeneración y estudio del proceso de construcción del palimpsesto del paisaje (Gastó *et al*., 2012), como una expresión cultural y digital.

2 Metodología

El proceso consiste en la vinculación de tecnologías de teledetección y análisis geoespacial a plataformas de diseño generativo (Grasshopper 3D), las cuales sirven como herramientas para la asociación de los distintos tipos de procesos involucrados.

Plantear una herramienta generativa expuesta a la variabilidad de terrenos existentes en la agricultura de secano en distintas partes del mundo genera el desafío de la identificación de diversos accidentes geográficos, que los procesos de diseño actuales ocupados por profesionales para la delimitación de una microcuenca hidrológica (Argis, Qgis, Mapwingis) no satisfacen los requerimientos específicos necesarios para determinar una variable morfológica que se ajuste a los procesos de diseño hidrológico aplicado a diseño generativo.

Esto debido a que la unidad de área de una microcuenca es demasiado grande y poco específica, lo que impide establecer una ley general de relaciones topológicas en el caso de existir múltiples sistemas hidrológicos en un terreno determinado. Por esta razón, se procede a establecer una unidad de paisaje menor que la microcuenca denominada ladera de aporte (se entiende por unidad de paisaje el área geográfica definida por un tipo de paisaje característico), la cual es un área específica dentro de una microcuenca delimitada por su vínculo directo con la vertiente y parte aguas y su relación con los sistemas hidrológicos vecinos (como se ve en la figura 3).

Para establecer los parámetros de programación, se diseña la investigación asociada a la ejecución real del procedimiento en una locación de secano interior, como se presenta en la figura 1. Este constituye un predio dedicado al estudio científico a modo de parcela demostrativa, la cual establece las comprobaciones técnicas, los criterios de obtención de datos y las propuestas de diseño generativo obtenidos por los distintos algoritmos involucrados.

La propuesta se implementa a través de integrar una programación paramétrica generativa basada en el estudio hidrológico del territorio en recuperación. Comenzando mediante la selección del polígono en una ventana de Maps (API, plataforma de Google Maps), la cual accede a descargar la topografía del terreno desde bases de datos abiertas *online*. Estas se procesan en conjunto con fotogrametrías obtenidas mediante un dron programado en terreno, obteniendo así una modelación 3D del polígono seleccionado y su entorno más cercano.

Para determinar una ladera de aporte se procede a analizar las variables geomorfológicas de los terrenos mediante el ejercicio de discernir las concavidades y convexidades de los terrenos logrando identificar los sistemas de parteaguas y vertientes, según se expresa en la figura 2, así como los ejes medios de las áreas. Concavidad y convexidades son dos variables contrapuestas, las cuales no se intersecan, por lo cual se procede a hacer un estudio topológico de interconexión de sistemas hidrológicos mediante la proximidad de estos y así se logra la segmentación de las laderas de aporte.

Una vez identificadas las laderas de aporte presentadas en la figura 4, se procede al proceso de identificar en cada área su componente de parteaguas. Esta al ser la parte con menos retención hídrica por su condición de convexidad, se vuelve el objetivo a optimizar, sobre este eje se proyectan puntos de inicio del trazado generativo. Se efectúa el algoritmo de pendiente controlada, el cual busca vincular el componente del parteaguas con el de vertientes con un trazado regulador basado en un avance iterativo cada cinco metros y una pendiente del 2%, asegurando así la distribución eficiente de la escorrentía redirigiendo los flujos destinados a la vertiente hacia los parteaguas, logrando la homogeneización del recurso hídrico.

Se procede a replantear los trazados generados en terreno en puntos cada diez metros ocupando un equipo GPS RTK que se indican en la figura 4, interpolados mediante entizado sobre el terreno para posteriormente ejecutar

las obras de subsolado y acanalamiento con un tractor y equipamiento agrícola tradicional, presentado en la figura 5.

3 Resultados

El resultado principal de este trabajo es la validación de la metodología propuesta, a través de la ejecución en terreno de un plan de restauración diseñado generativamente (figura 5), en el Fundo los Cuarzos, Ninhue, Región de Ñuble en Chile. En el año 2021, se intervinieron 52 hectáreas a modo de validación técnica y obtención de datos.

Esta experiencia permitió implementar una aplicación web que facilitó que cualquier usuario obtenga un plan de diseño hidrológico en cualquier parte del mundo dibujando un polígono en un territorio a escoger.

Los datos obtenidos de los estudios a través de teledetección satelital ocupando el NDVI como parámetro nos permiten estudiar el comportamiento de la masa vegetal derivada de la intervención para hacer seguimiento de su evolución en el tiempo. El índice de vegetación de diferencia normalizada, también conocido como NDVI por sus siglas en inglés, es un índice usado para estimar la cantidad, calidad y desarrollo de la vegetación. Para esto se procedió a un estudio comparativo con el propósito de evaluar el efecto del diseño hidrológico aplicado a la agricultura de secano utilizando índices de vegetación derivados de imágenes de alta resolución espacial (Núñez *et al.*, 2021) y comparando la evolución del NDVI a través de los años anteriores a la intervención en comparación con los años posteriores (gráfico 1). Esto reveló un aumento en 0.06 puntos en comparación con la media de los años anteriores resaltada por punto de inflexión del índice de vegetación en la fecha de ejecución de las obras en terreno, comprobando el resultado positivo de la intervención en la retención hídrica.

3.1 Figuras y tablas

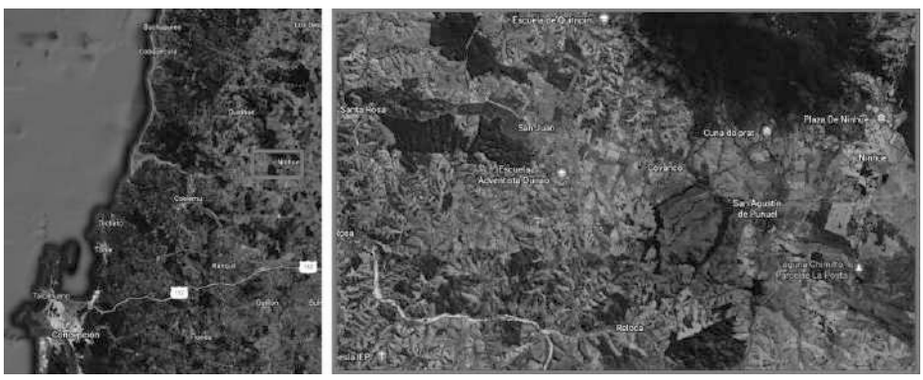

Figura 1. Localización geográfica: Chile, Ñuble, Ninhue, Fundo los cuarzos. Fuente: Gravitacional SPA, 2021.

Figura 2. Identificación de parteaguas y vertientes. Fuente: Gravitacional SPA, 2021.

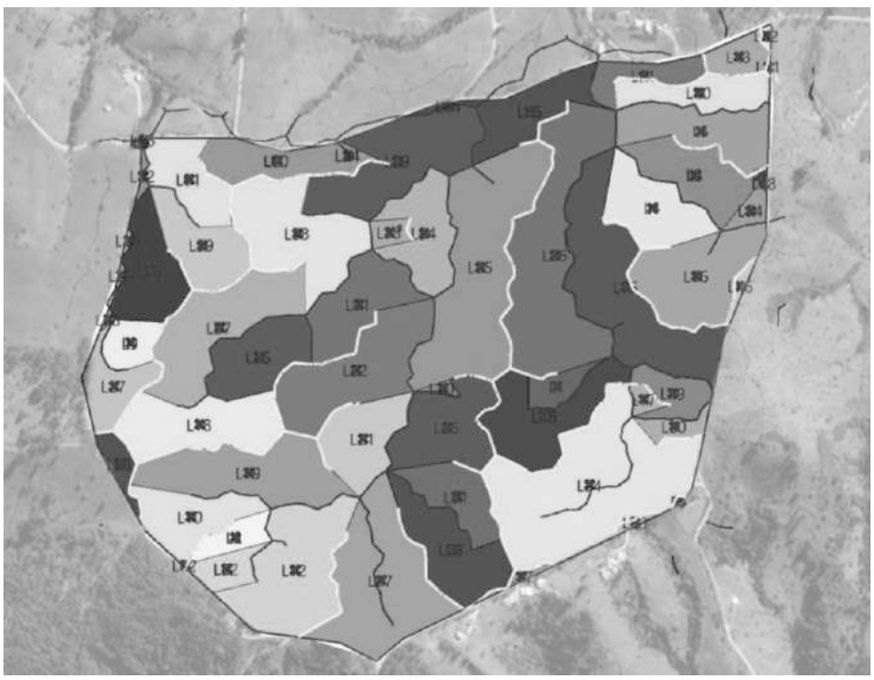

Figura 3. Delimitación de laderas de aporte y sistemas hídricos. Fuente: Gravitacional SPA, 2021.

Figura 4. Proyección de trazados generativos resultantes para replanteo. Fuente: Gravitacional SPA, 2021.

Figura 5. Ejecución de obras en terreno. Fuente: Gravitacional SPA, 2021.

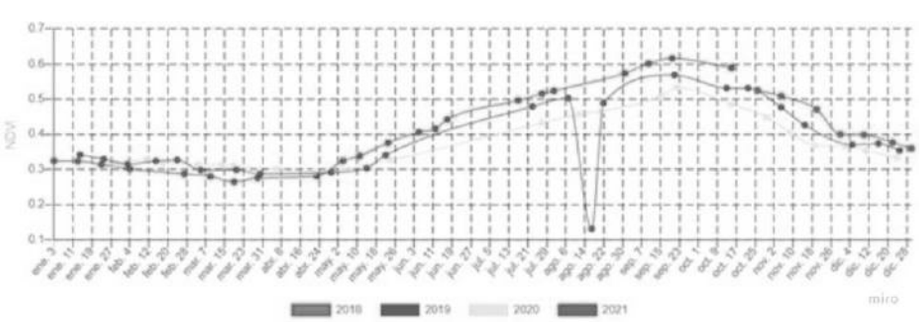

Gráfico 1. Evolución del NDVI a través de los meses anteriores a la intervención en comparación con los meses posteriores a la intervención. Fuente: Gravitacional SPA, 2021.

3.2 Programación

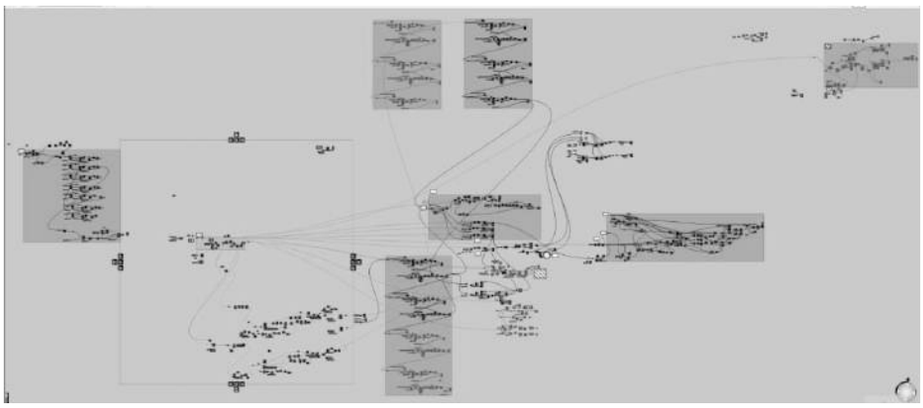

Figura 6. Programación paramétrica general Grasshopper 3D Rhinoceros. Fuente: Gravitacional SPA, 2021.

La implementación del proceso de diseño generativo del territorio se realizó mediante programación paramétrica visual efectuada con la herramienta Grasshopper, sobre plataforma Rhinoceros, basada en su poderosa capacidad de modelación tridimensional de superficies de doble curvatura, que permiten representar territorios complejos, como también las capacidades de definición y procesamiento de los componentes paramétricos. La programación se anida en subconjuntos según las etapas del proceso, con controladores abiertos para el ingreso de datos y parámetros específicos del territorio, y generación de resultados numéricos y gráficos. Esta implementación tiene la virtud de ser adaptable a diferentes casos, como también ampliar sus condiciones de trabajo y empaquetarla para futuras implementaciones avanzadas. En futuros desarrollos puede integrarse en plataformas propietarias y aplicaciones móviles para facilitar su aplicación. Como también relacionarla con herramientas de recolección automática de datos satelitales o geográficos y de visualización espacial en tiempo real, así como conexiones en línea.

4 Discusión

La capacidad de los algoritmos generativos en la arquitectura del paisaje, tiene un gran potencial en su desarrollo, el cual se puede ver implementado en cualquier parte del mundo gracias a la gran base de datos de todo tipo que se encuentran abiertamente a disposición. El uso de estos en la minería de datos geográficos nos permiten ejecutar grandes territorios, estableciendo potencialidades como datasets de implementaciones en inteligencia artificial. Establecer criterios de obtención de datos se hace fundamental, para poder diseñar una nueva generación de *software*, y establecer un camino hacia una “inteligencia artificial de restauración de paisajes a gran escala”.

La implementación de esta propuesta de recuperación hidrológica mediante diseño generativo, demostrada en un caso de estudio, evidencia prácticamente

esta capacidad. Expresando una profunda vinculación entre las capacidades digitales y los desafíos ambientales, que constituyen los dilemas centrales del mundo contemporáneo. Integrando en la “arquitectura del paisaje” la racionalización procedimental de la generación paramétrica y las cualidades ecológicas del territorio para el bienestar humano.

Referencias

Cantrell, B. & Holzman, J. (2016). *Responsive Landscapes: Strategies for Responsive Technologies in Landscape Architecture*. Ed. Routledge.

Cortés, H. (2013). *Manual técnico. Diseño hidrológico del terreno (sistema keyline) en parcelas agrícolas con precipitación limitada*. Jiutepec, Morelos: IMTA.

Davidova, M. & Mcmeel, D. (2020). CoDesigning with Blockchain for Synergetic Landscapes: The CoCreation of Blockchain Circular Economy through Systemic Design*. Proceedings of the 25th CAADRIA Conference, 2*(5-6), 333-342

Falkenmark, M., Fox, P., Persson, G. & Rockström, J. (2001). *Recolección de agua para mejorar la agricultura de secano: análisis de problemas y necesidades de investigación*. Estocolmo: Instituto Internacional del Agua de Estocolmo (SIWI).

FAO. (2012). *Coping with water scarcity: An action framework for agriculture and food security*. Food and Agriculture Organization of United Nations.

Gastó, J., Subercaseaux, D., Vera, L. & Tomic, T. (2012). Agriculture and Rurality as Constructor of Sustainable Cultural Landscape. *Evolution*, *1*, 4.

MacDonald-Holmes, J. (s. f.). The Geographical and Topographical Basis of Keyline.

Núñez, G., Ponce, M., Pulgarin, M., García, E., Reyes, O. & López, P. (2021). Evaluation of a Hydrological Design Applied to Rainfed Agriculture Using Vegetation Indexes. *Modern Environmental Science and Engineering*.

United Nations. (2015). Water and Sustainable Development From Vision to Action, *Report of the 2015 UN-Water Zaragoza Conference*.

Wittenberg, K., Glasser, S., Kirchhoff, A., Morrissey S. & Orphan, S. (2018). Challenges and Opportunities in the Evolving Digital Preservation Landscape: Reflections from Portico. *Insights*, *31*(28), 1-8. https://doi. org/10.1629/uksg.421

Yeomans, P. A. (1993). *Water for Every Farm. Yeomans Keyline Plan*. Griffin Press Pty Limited.

A new approach to design patterns for small public spaces: behaviors, processes and elements

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Abstract. Considering urban design as a manipulation of a complex web of nodes and connections with simultaneous interactions leads us to the systemic thinking that can be applied to the design of public spaces. The development of design pattern systems and urban toolboxes can be identified by different authors who seek to systematize urban elements from systemic thinking, considering the new urban challenges. The objective of this article, therefore, is to propose the start of a new systematization of design patterns for small public spaces based on three main classes: behaviors, processes, and elements. The methodology can be summarized as (a) theoretical foundation and literature review; (b) organization of the system into classes and attributes; (c) development of the patterns and relations. As a result, we have a friendly representation of the system which mainly discusses how new tools and people behaviors can interact with urban elements in small public spaces.

Keywords: Smart cities, Urban toolbox, Systemic thinking, Small public spaces, Pattern language.

Introdução

O desenho de espaços públicos interage com as transformações do macrossistema das cidades em que está inserido, que também é atravessado por tantos outros sistemas, que se entrelaçam em um grande jogo de forças, complexo e mutável. De acordo com Burry (2020), a futura condição urbana vai muito além das "cidades inteligentes", termo muitas vezes usado como um clichê solto que mascara um conjunto de desafios, mostrando muitas oportunidades, mas poucas respostas. Para o autor, a digitalização da sociedade oferece novas rotas aos projetistas, mas a especulação criativa é diferente de prever o futuro, pois o desenho urbano é apenas um componente dentre tantos outros de melhoria da vida urbana. Diante de tantos dados e

ferramentas que os arquitetos têm disponíveis, há que se encontrar caminhos para esses novos desafios, extrair oportunidades de novas tecnologias, mas se relacionar de forma coerente com as disciplinas associadas à arquitetura e ao urbanismo (Burry, 2020).

Dentro dessa temática de desenho urbano, este artigo se propõe a um recorte específico, pequenos espaços públicos. Segundo Burns (2020), o planejamento urbano modernista falhou ao criar lugares pobres em escala humana, não favorecer o florescimento do senso de comunidade, evidenciar demandas dos veículos e focar em praças monumentais. Assim como as grandes praças desempenham seu papel articulador na cidade, a pulverização e descentralização de pequenos espaços públicos auxiliam a permear a vida pública numa escala mais humana ao cotidiano das pessoas, além da própria democratização da cidade. Lynch (1960) e Lefebvre (2004) colocam as praças como lugares de tomada de decisão no tecido urbano.

Em seu livro, A Imagem da Cidade, Lynch (1960) já associava o processo de percepção dos espaços públicos aos sentidos, com mapas mentais que estabeleciam uma linguagem capaz de representá-los com nós, pontos de referência, bordas e caminhos. Enxergar a cidade como uma trama de nós e conexões foi apresentado também por Alexander et al. (1977) com a linguagem de padrões, através de uma lógica matemática de conjuntos, onde os padrões se relacionam e compõem uma linguagem para cada projeto, um microssistema. Esta é a abordagem que este artigo trás, da utilização de padrões no processo de projeto, como uma parte do entendimento sistêmico das dinâmicas complexas da cidade, que não empobrece as relações urbanas, como já defendia Alexander (1965) no livro "A cidade não é uma árvore".

Este artigo é parte de uma pesquisa maior em andamento, que tem como objetivo propor uma nova abordagem para sistemas de padrões, com recorte espacial de pequenos espaços públicos, a partir de três classes principais: comportamentos, processos e elementos, usando como fundamentação teórica o pensamento sistêmico.

1 Pensamento Sistêmico

Ao contrário de um pensamento causal e linear, de solução e problema, partidos arquitetônicos herméticos com um ponto de saída e outro de chegada, um sistema se ampara numa visão mais ampla. Um olhar sistêmico, na concepção de um projeto urbano, pressupõe uma realidade anterior preexistente, uma nova realidade criada no projeto e possibilidades de mudança posterior, ou seja, o projeto se implanta num metabolismo em movimento, que é a cidade. Fundamentar projetos de espaços públicos a partir de uma base teórica linear e estável é desconsiderar a realidade

caótica e mutável em que vivemos e as camadas subjetivas da sociedade, inclusive nós projetistas como atores não isentos neste processo.

O pensamento sistêmico, segundo Vasconcellos (2018), é um novo paradigma que permite ter uma perspectiva mais global, sem tanta distinção de setores, sem tratar os processos de forma individual. Segundo a autora, é uma base epistemológica que busca entender os elementos estruturais, através de modelos mentais mais complexos, o que nos aproximaria também do aspecto transdisciplinar tão importante para a arquitetura e o urbanismo, como defende Burry (2020). O pensamento sistêmico (Fig. 1) apresenta três novos pressupostos: complexidade, instabilidade e intersubjetividade, que consequentemente ultrapassam a ciência tradicional nas crenças de simplicidade, estabilidade e objetividade (Vasconcellos, 2018).

A Instabilidade, que Vasconcellos (2018) cita pode ser relacionada à propriedade de interação da Teoria Geral dos Sistemas (Naciff, 2019). Trata-se também de assumir que um projeto não tem o poder de ser um agente de causalidade simples e fechado, com garantias de transformação das dinâmicas mais abrangentes da sociedade. Pelo contrário, os projetos também estão sujeitos à instabilidades econômicas, sociais, culturais que podem atravessar, modificar, além de interagir internamente com elementos dele mesmo. Outro ponto é permitir incorporar a dimensão do tempo para além das dimensões físicas, nesse olhar sistêmico. Considerar que os espaços estão sujeitos a modificações, formas de manutenção, usos diferentes ao longo do dia, ao longo das estações, ao longo dos anos.

A intersubjetividade é apresentada como uma crítica ao esforço científico de tentar "conhecer a realidade objetivamente como ela é", independente da subjetividade dos observadores (Vasconcellos, 2018). Reconhece-se a impossibilidade de mostrar a realidade independente do observador. Essa visão pode ser associada, por exemplo, à Teoria Ator Rede e a Cartografia das Controvérsias, que incorpora os atores ao processo, um jogo de forças que sobrepõem contradições, resistências e diferentes entendimentos de mundo (Latour, 2007; Sbarra, 2021). Não se trata de individualizar toda e qualquer interpretação, mas dar espaço para que as narrativas dos cidadãos, sobretudo aquelas coletivas, possam também emergir junto neste sistema que é o desenho urbano, condicionado também por quem o projeta.

Sobre o terceiro ponto, a complexidade, Morin (2015) o aponta como um tecido composto por partes associadas inseparavelmente, com uma grande quantidade de interações e conexões, mas longe de ser só isso, compreende também incertezas, indeterminações, fenômenos aleatórios, possui uma relação com o acaso, com o caos. O que não significa que se pode reduzir complexidade à incerteza. Morin (2015) coloca a complexidade como um sistema ricamente organizado e interconectado, assim como na Teoria Geral dos Sistemas, que contém camadas de entropia e desordem, onde o todo é sempre mais complexo que a soma de todas as partes (Naciff, 2019).

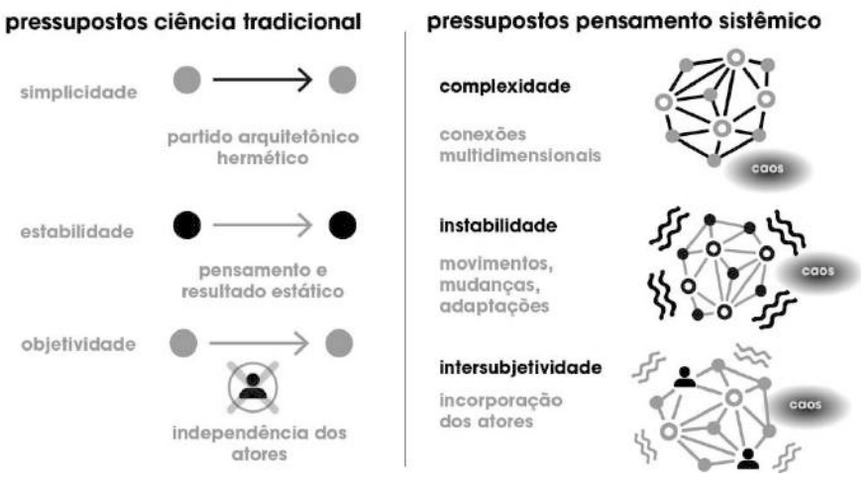

Figura 1. Pressupostos ciência tradicional e pensamento sistêmico. Fonte: Autor, 2022; Vasconcellos (2018).

Seguindo este raciocínio podemos pensar que há sempre uma parcela de caos, de desconhecido, mas há também uma parcela organizada na dinamização do conceber o espaço urbano que pode ser sistematizada, padrões que podem formar microssistemas coerentes. Um questionamento seria a hipótese do uso de padrões encaminharem a uma padronização das cidades. Os padrões, na verdade, são formas de usufruir de estratégias de design bem sucedidas e que fazem emergir de um sistema complexo soluções variadamente coerentes e não esgotáveis. Segundo McGrath and Marshall (2009) os novos padrões de projeto urbano estão num caminho de engajamento das cidades como organismos vivos, que lidam com a rápida urbanização, com a movimentação das pessoas, das mudanças climáticas, as tecnologias de comunicação digital e móvel e infraestruturas inteligentes.

1.1 Novos desafios, novos sistemas de padrões

Autores como Jacobs (1961), Venturi (1966), Whyte (1980), Appleyard et al. (1981) também já corroboravam com essa ideia complexa, sistêmica defendida por Alexander et al. (1977) e ainda são estudados e referenciados, mas com o desafio atual de incluir novas demandas urbanas. Mehaffy et al. (2018), por exemplo, apresentam 80 padrões para uma nova geração de desafios urbanos, focados na qualidade do desenvolvimento de regiões ao redor do mundo, com base nas diretrizes da Nova Agenda Urbana, proposta pela Organização das Nações Unidas (ONU, 2017) . Padrões com estrutura em livro (Fig. 2)., bem próxima a que foi utilizada por Alexander et al. (1977) em "Uma Linguagem de Padrões".

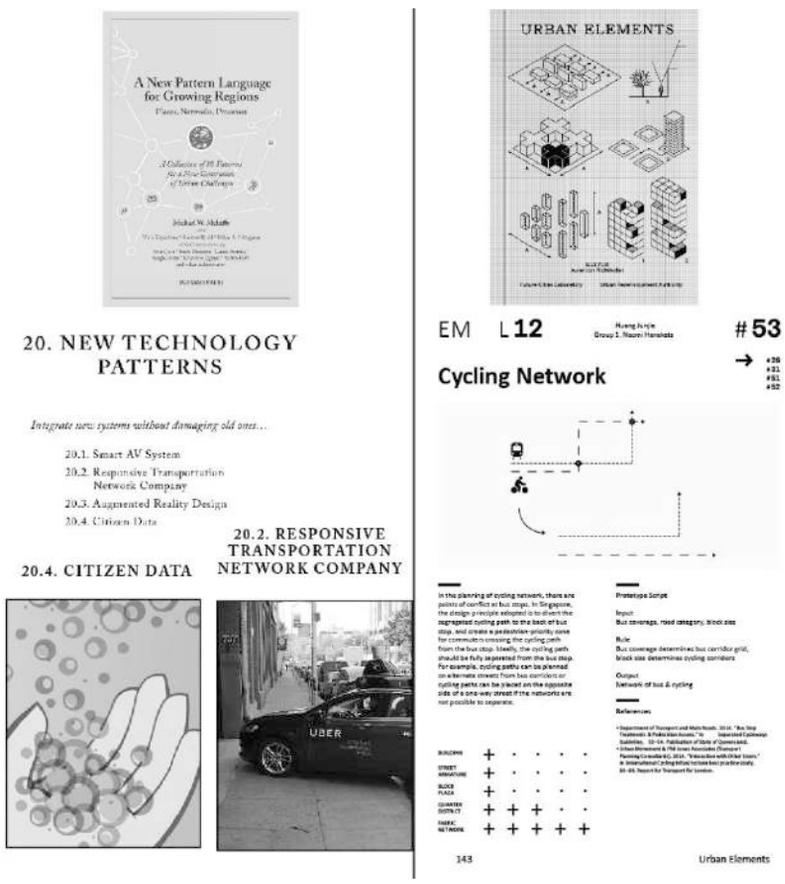

Figura 2. Exemplos de Padrões. Fonte: Mehaffy et al.(2018); Fun et al. (2018);

Trabalhos como o “Urban Elements”, (Fig. 2), de Fun et al. (2018), que considera a cidade como um sistema metabólico no qual o tecido físico da cidade interage com variados fluxos a partir das seguintes temáticas: Forma Urbana; Tipologia & Densidade; Função & Uso; Serviço de Ecossistemas; Mobilidade Atrativa; Energia Sustentável. Além de algumas caixas de ferramentas, como a "toolbox" desenvolvida por OOPEAA (2019) em parceria com Jan Gehl para a cidade de Seinäjoki e "Healthy Urbanization Toolbox" de Dijk et al. (2015), aplicada na cidade de Utrecht como forma de desenvolvimento urbano almejando cidades e cidadãos saudáveis. Estudos e produções como estas, podem ser encaradas como novas abordagens de padrões para espaço público. E apesar de desenvolvidos por diferentes países e contextos, estes sistemas de padrões apresentam algumas semelhanças entre si mostrando a relação entre padrões que permanecem como boas práticas desde as décadas de 1960 e 1970, junto com padrões recentes mais voltados para tecnologias digitais.

2 Metodologia

Este artigo está centrado no desenvolvimento de um protótipo, com as primeiras heurísticas deste sistema de padrões de projeto para pequenos espaços públicos. A metodologia apresentada aqui faz parte de uma metodologia mais ampla, presente numa investigação em andamento, que se baseia no estudo da ciência artificial através de artefatos, fundamentados em conhecimentos multidisciplinares, preocupados em resolver problemas complexos (Dresch et al., 2015; Simon, 1996). O desenvolvimento do protótipo, artefato escolhido, segue três etapas principais: (a) fundamentação teórica e revisão de literatura, já apresentados; (b) organização do sistema em classes e seus atributos; e (c) desenvolvimento dos padrões e suas relações.

2.1 As Classes e seus atributos

A classificação é uma necessidade de filtragem de elementos empíricos, complexos, pois promove a investigação das características de certos elementos a fim de determinar maneiras de agrupá-los com base em algum critério que estabelece semelhanças. Através do agrupamento por qualidades comuns significativas, aplica-se um processo de generalização e simplificação criado para um propósito específico (Pissourios & Lagopoulos, 2017). Transitar entre momentos de aprofundamento, complexidade e outros de síntese, generalização, simplificação nos permite compreender melhor a parcela ordenável de um sistema, neste caso os padrões.

A linguagem de padrões de Alexander et al. (1977) propõe classes com base no critério de escala de intervenção projetual: cidades, edifícios e construção. A proposta neste artigo é de classes baseadas no critério do processo de projeto em si, o que levar em consideração na hora de projetar, quais os atores humanos e não-humanos, como define Latour (2007), estão envolvidos na concepção. A divisão em comportamentos, processos e elementos compreende que um espaço público é formado principalmente por: a) comportamento das pessoas, usos que são atravessados por variadas questões de temporalidade, espacialidade, faixa etária, cultura e contexto local; b) por processos disponíveis para analisar e projetar uma determinada realidade, assim como novas ferramentas digitais. Classe também proposta por Mehaffy et al. (2018); c) os próprios elementos urbanos que vão espacializar e materializar esses pequenos espaços públicos de qualidade no território da cidade. Classe presente em Fun et al. (2018). Desta forma, o sistema busca ao invés de relacionar as escalas de intervenção, relacionar fatores que mexem na "engrenagem" do projeto, os diagramas e "máquinas abstratas" que usamos para projetar. Ao conceber um projeto pensamos basicamente para quem e porque estamos projetando (comportamentos), o que fazer (elementos) e como e quem vai fazer o projeto (processos).

Figura 3. Classes e atributos. Fonte: Autor, 2022.

Dentro de cada classe, elencar atributos auxilia na seleção daquele padrão pelo projetista, pois para haver uma seleção é preciso eliminar e essa eliminação só é possível com base em alguns critérios, que ficam explicitados por meio dos atributos. Se a própria estrutura dos padrões se relaciona com a natureza complexa do pensamento sistêmico que fundamenta teoricamente este protótipo, a intersubjetividade está na colocação do sujeito como avaliador desses atributos, do que está em sua esfera de possibilidades como projetista e depois a própria instabilidade contemplada pelos atributos de temporalidade, como efêmero/permanente, diurno/noturno.

Quanto aos Processos é pertinente compreender se é um processo ou ferramenta que só está para a fase analítica, só para a fase propositiva, ou para os dois. Interessa se é um processo analógico, digital ou até mesmo funciona nas duas modalidades. Do ponto de vista do projetista, se demanda um estudo ou especialização ou é um algo que ele já domina. E os últimos atributos relacionados a serem processos com suporte paramétrico ou não.

Quanto aos Comportamentos é importante saber se é um comportamento local das imediações daquele pequeno espaço público, ou se é algo geral da cidade ou mesmo da sociedade. Outro atributo é definir se é um comportamento já consolidado, tradicional, que faz parte da cultura local, ou algo recente que está sendo inserido, ou até mesmo momentâneo.

Quanto aos Elementos, eles podem ter usos diferentes ao longo do dia, das semanas e das estações principais, são padrões que protegem contra chuva e sol. Interessa também saber se é algo efêmero, desmontável, temporário ou algo mais definitivo. E por último se do ponto de vista do projetista aquele elemento urbano demanda altos ou baixos investimentos.

2.2 Os Padrões e suas relações

A estrutura interna de apresentação de padrões de projeto busca sintetizar uma grande quantidade de informações que pode ser simplificada em pequenos textos, diagramas, tabelas, matrizes, links que orientam de forma prática e os relacionam com os outros padrões formando um microssistema para o projeto. Cada padrão vai apresentar parâmetros qualitativos ou quantitativos, indicativos de seu bom funcionamento, que serão avaliados pelos projetistas, se aquele padrão se enquadra ou não dentro das suas possibilidades.

Os padrões desenvolvidos por Alexander et al. (1977) seguiam uma lógica de apresentação típica em seu livro (Fig. 4) que também foi seguida em partes por (Mehaffy et al., 2018). Em "Uma Linguagem de Padrões" primeiramente é apresentado o número, nome e asteriscos de confiabilidade do padrão. Em sequência, em alguns aparece uma foto que ilustra numa situação real e depois aparecem textos, sobre os padrões de maior abrangência. Na sequência há um parágrafo que resume a sua problemática, depois um texto das características, restrições e relações com alguns padrões são detalhadas. Depois um texto com a solução para o problema e alguns apresentam ainda diagramas resumo. E por último, padrões de menor abrangência, que também estabelecem relações com ele.

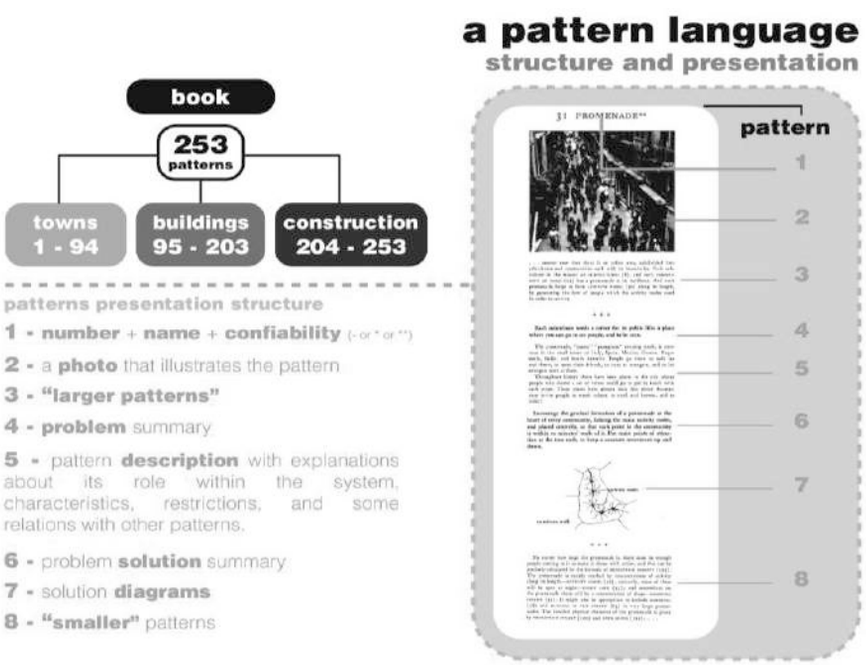

Figura 4. Estrutura de "Uma linguagem dos padrões". Fonte: Sousa et al. (2020)

A estrutura do livro "Urban Elements" de (Fun et al., 2018) apresenta os padrões numa forma mais simplificada (Fig. 2), números, padrões relacionados, nome e diagrama. Na sequência aparece um texto resumo, uma matriz da escala de intervenção, um "script" com uma base de regras, "inputs" e "outputs" e por fim as referências. A apresentação breve dos padrões do Urban Elements nos levam a algumas críticas feitas à apresentação de Alexander et al. (1977). Vaz (2011) aponta que alguns padrões contém até nove páginas, o que dificulta a manipulação do todo, tão importante para a ideia de rede, sistema.

A estrutura dos padrões (Fig. 5) proposta para o protótipo de sistema em questão buscou dividir as informações de maneira clara, a fim de ser o mais operacional possível, uma caixa com ferramentas práticas e explícitas no momento de projetar. Na barra inicial aparece o nome, diagrama e número do padrão na cor da classe a qual pertence, juntamente com os padrões que se relacionam com ele, sejam de comportamento, processo ou elementos.

Figura 5. Estrutura dos padrões. Fonte: Autor, 2022.

Na sequência um texto explicativo com fotos e imagens ilustrativas discorre sobre aquele padrão de forma breve e sintética, pois caso o projetista queira se aprofundar ele pode acessar as referências ou links na parte inferior. Logo abaixo das relações aparecem os atributos, que foram definidos anteriormente nas classes e vem delimitado dentro de cada padrão. Os atributos vão ser a base para primeira seleção dos padrões, identificando se ele se encaixa ou não naquela realidade de projeto. Depois aparecem parâmetros qualitativos e quantitativos, com regras aplicáveis e por último, links de arquivos ou *softwares opensource* que podem ser disponibilizados.

3 Resultados

A partir da definição da estrutura das classes e dos padrões foi possível obter uma primeira lista de padrões desenvolvidos a fim de formar um sistema, com seis padrões para cada classe (Fig.6). A lista inicial teve como base revisão bibliográfica em andamento e estudo anterior de análise de recorrências de padrões em diferentes sistemas aplicáveis a pequenos espaços públicos (Sousa & Paio, 2020). Cada um destes padrões apresenta internamente a estrutura apresentada na metodologia, com as cores de sua classe, seus atributos específicos e os textos, diagramas, fotos e parâmetros atribuídos a cada um deles, com suas as respectivas relações.

Figura 6. Padrões desenvolvidos e sistema. Fonte: Autor, 2022.

Cada projetista chegará no seu próprio sistema a partir da seleção dos padrões que se enquadram dentro da realidade de projeto, por meio da análise dos atributos das classes. A apresentação radial do sistema possibilita visualizar com facilidade os padrões mais conectados (Lima, 2013). Os padrões mais conectados, com mais relações vão exercer um papel maior na dinâmica dos comportamentos no espaço público, na importância dentro do processo de concepção e na materialização dos elementos arquitetônico, que podem inclusive formar elementos conjuntos.

4 Discussões e Considerações

Embasar um sistema de padrões no pensamento sistêmico, estrutura o processo de projeto a partir de novos paradigmas de complexidade, instabilidade e intersubjetividade que buscam respostas mais adequadas para as novas realidades contemporâneas, assim como padrões que incorporam tecnologias digitais. Novas demandas contemporâneas surgem também da necessidade de trazer os cidadãos para o centro das discussões do desenho urbano, tanto na participação das pessoas no processos quanto na importância de trabalhar pequenos espaços públicos, com mais proximidade da escala humana ativa e democrática da cidade. As contribuições desta nova abordagem para sistema de padrões, com uma nova proposta de classes e relações, é justamente uma operacionalização dessa forma de projetar complexa, mas de uma maneira prática e visualmente amigável. As projeções futuras para o desenvolvimento desta investigação estão centradas em desenvolver mais a lista de padrões com base num estado da arte aprofundado, desenvolver mais as relações entre os padrões, se haverá atribuição de peso nessas conexões e explorar formas digitais interativas de manipulação do sistema, para além do formato em livro.

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Referências

Alexander, C., Ishikawa, S., & Silverstein, M. (1977). A Pattern Language: Towns, Buildings, Construction (1 edition). Oxford University Press.

Appleyard, D., Gerson, M. S., & Lintell, M. (1981). Livable Streets. University of California Press.

Burns, M. (2020). New Life in Public Squares. Routledge.

Burry, M. (2020). Better to Make a Good Future than Predict a Bad One. Architectural Design. Special Issue: Urban Futures: Designing the Digitalised City, 90(3), 6–13. https://doi.org/10.1002/ad.2561

Dijk, H., Hocks, B., Revier, E., Klaarenbeek, J., & Hezemans, K. (2015). Healthy Urbanisation. POSAD. http://posadspatialstrategies.com/projects/gezonde-verstedelijking/?lang=en

Dresch, A., Lacerda, D. P., & Jr, J. A. V. A. (2015). Design Science Research: A Method for Science and Technology Advancement. Springer International Publishing. https://doi.org/10.1007/978-3-319-07374-3

Fun, S. L., Christiaanse, K., Cairns, S., Richthofen, A. von, Leyk, D., Knecht, K., Miao, Y., & König, R. (2018). Urban Elements: Advanced Studies in Urban Design. https://doi.org/10.3929/ethz-b-000270354

Jacobs, J. (1961). The Death and Life of American Cities.

Latour, B. (2007). Reassembling the Social: An Introduction to Actor-Network-Theory (1st Edition). Oxford University Press.

Lefebvre, H. (2004). O direito à cidade. Centauro.

Lima, M. (2013). Visual Complexity: Mapping Patterns of Information: (1a edição). Princeton Architectural Press.

Lynch, K. (1960). The Image of the City. MIT Press.

McGrath, B., & Marshall, V. (2009). New Patterns in Urban Design. Architectural Design, 79(6), 48–53. https://doi.org/10.1002/ad.978

Mehaffy, M., Kryazheva, Y., Rudd, A., & Salingaros, N. (2018). A Pattern Language for Growing Regions: Places, Networks, Processes. A Collection of 80 Patterns for a New Generation of Urban Challenges.

Morin, E. (2015). Introdução ao pensamento complexo (5a edição). Editora Sulina.

Naciff, Y. D. das N. (2019). O pensamento sistêmico em análises urbanas: Uma perspectiva para o problema da segregação socioespacial nas cidades. arq.urb, 24, 1–18. https://doi.org/10.37916/arq.urb.vi24.21

ONU, N. U. (2017). Nova Agenda Urbana. https://habitat3.org/the-new-urban-agenda/

OOPEAA. (2019). Seinäjoki Vision and Toolbox book.

Pissourios, I. A., & Lagopoulos, A. P. (2017). The Classification of Urban Uses. Urban Science, 1(3), 26. https://doi.org/10.3390/urbansci1030026

Sbarra, M. H. (2021). Bruno latour e o uso da cartografia de controvérsias em arquitetura: Reconectando teoria e prática no ensino de arquitetura na contemporaneidade. PIXO - Revista de Arquitetura, Cidade e Contemporaneidade, 5(16), Article 16. https://doi.org/10.15210/pixo.v5i16.19402

Simon, H. A. (1996). The Sciences of the Artificial. MIT Press.

Sousa, M., Mônaco, D., Martínez, A., & Souza, D. (2020). The operationalization of “A Pattern Language” by using network analysis tools. Blucher Design Proceedings, 8(4), 128–136. https://www.proceedings.blucher.com.br/article-details/the-operationalization-of-a-pattern-language-by-using-network-analysis-tools-35363

Sousa, M., & Paio, A. (2020). Pattern-driven Design for Small Public Spaces—An analysis of pattern books and toolboxes. Proceedings of the 38th eCAADe Conference - Volume 2, TU Berlin, Berlin, Germany, 16-18 September 2020, pp. 491-498.http://papers.cumincad.org/cgi-bin/works/201520+dave=2:/Show?ecaade2020_498

Vasconcellos, M. J. E. D. (2018). Pensamento Sistêmico. O Novo Paradigma da Ciência (11/11/2020-2a. reimpressão edição). Papirus Editora.

Venturi, R. (1966). Complexity and contradiction in architecture (1a edição). Graham Foundation.

Whyte, W. H. (1980). The Social Life Of Small Urban Spaces. Project for Public Spaces Inc.

Design, Nature and Ecosystems: Sustainable Design

Experimenting with Generative Algorithmic Design using Bamboo

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Abstract. This article arises as an analysis of the practical group work carried out in the course within the framework of our Master's Degree in Architecture, and seeks to comprehend and expand on the logic and dynamics that underlie the digital paradigm and the incorporation of algorithmic practices as possible design generators (Centro de Integración Digital [CID], 2022). By quantitatively and experimentally delving into the knowledge acquired in the course, we integrate the experience of parametric design from a scientific point of view through a process of searching for and solving problems. Our team explored the possibilities that generative algorithmic design offers us when working with a natural material namely bamboo, as a contribution to the mix between digital and bio-sustainable materials. Exploring the approach that digitalization offers us as designers and the role that we are called to play as architects of this time.

Keywords: digital architecture with bamboo, parametric approach to design, experimentation with digital design, creating generative algorithm

1 Introducción

En medio de la sucesión de giros digitales los arquitectos nos enfrentamos a muchos retos, entre los cuales los vertiginosos cambios tecnológicos, la gran necesidad de innovar y la presión por la mejora continua en el rendimiento de los edificios están generando un cambio o un desplazamiento de paradigma en la arquitectura con la adopción del diseño basado en BIM (Aksamija, 2016). Asistimos a una búsqueda o redescubrimiento de nuestras capacidades para vincularnos con el diseño a través de aspectos multidisciplinares y de herramientas muy tecnificadas, o también por lo totalmente opuesto, a través de las manos y la producción *low tech*.

En los cursos de posgrado se generan espacios donde con el "juego" y la "experimentación" se puede profundizar en la tecnología de diseño digital y, en

nuestro caso de estudio, experimentar con la combinación de lo digital con materiales más artesanales o vernáculos como el bambú rollizo sin procesar.

El diseño paramétrico asistido por computadora ha abierto las puertas a la experimentación con las formas, permitiendo la exploración integral de nuevas posibilidades estéticas condicionadas por aspectos variables y de acuerdo con los parámetros que establezca el material y el diseñador. Con estas herramientas se podrían lograr diseños inteligentes y/o responsivos, capaces de adaptarse a diferentes contextos con la habilidad de brindar respuesta a problemas específicos y soluciones al alcance de todos (Navarrete, 2014).

El bambú para la construcción acoplado a un desarrollo tecnológico sostenible y amigable con el planeta puede reemplazar o disminuir el uso de materiales convencionales como el acero y el cemento, abriendo el abanico de posibilidades para la construcción y reduciendo el gran impacto que la industria genera. "Nos brinda importantes beneficios [...] menor tiempo de ejecución, confort, diseño, seguridad, menor inversión, durabilidad; todos estos en comparación a los materiales más usados en el sector construcción" (Gómez *et al*., 2020). Además, el bambú nos puede brindar soluciones prácticas frente al cambio climático y es capaz de darnos estrategias de mitigación, adaptación, restauración del medio ambiente apoyando a la vida mediante la creación de medios de subsistencia sostenibles (INBAR, 2014). Es ventajosa, entonces, su inclusión como material apto para la construcción.

Según Fernandes, Fontana, Laurino, Casañas y Vila (2012), es un material eficiente estructuralmente, y lo describen así:

“[...] sus cualidades de ligereza, resistencia y economía de las estructuras, compuestas por barras longitudinales comprimidas o traccionadas y articuladas en sus extremos o entrelazadas formando superficies curvas o alabeadas [...] se presentan como idóneas para su aplicación en programas temporales o itinerantes y para la rápida solución de espacios habitables en situaciones de emergencia, sin necesidad de la intervención de mano de obra especializada en su proceso de montaje".

El ejercicio propuesto por el curso tuvo como objetivo pensar y desarrollar un algoritmo proyectual que pudiera materializarse en una serie de modelos con las tecnologías disponibles en el laboratorio (Centro de Integración Digital [CID], 2022). El objetivo buscado en el trabajo es el de profundizar de forma cuantitativa y experimental en los conocimientos adquiridos en el curso Informática Aplicada a la Arquitectura, en el marco de la Maestría en Arquitectura en su encuadre tecnológico, a través de la exploración con las tecnologías digitales para la generación de diseños con materiales naturales. Asimismo, explorar el rol que debemos desempeñar como diseñadores/arquitectos ante la propuesta planteada, reflexionando sobre los efectos que las nuevas herramientas tienen sobre el proceso compositivo.

Según A. Tedeschi, como se citó en Massimiano, 2015, en el diseño paramétrico, la forma no sería definida ni definitiva *a priori*, la cual no surge del gusto del arquitecto ni de la aplicación simplista del silogismo forma-función. Esto nos permitiría mantener un alto grado de apertura a los cambios externos,

tanto por parte del proyecto como del diseñador, ya que la forma sería una incógnita (concepto formulado por Sergio Musmeci), que permanecería oculta durante las etapas iniciales de configuración de parámetros y componentes para luego ser revelada al diseñador solo al final del proceso. Así, se cambia la relación entre el diseñador y su creación, que implica una imprevisibilidad ante el resultado final, donde el proceso se convierte en lo fundamental.

2 Metodología

El objetivo del curso fue introducirnos al pensamiento computacional. El ejercicio presentado en este trabajo resume las propuestas de profundización e intenta un acercamiento consciente al diseño paramétrico. La metodología utilizada abarca tres fases.

En la fase inicial se abordó una investigación de carácter exploratorio. La estrategia aplicada consistió en sistematizar el conocimiento actual con relación al diseño digital o paramétrico y del bambú como material para la construcción.

La segunda fase de la investigación se realizó por experimentación proyectual y su posterior materialización de prototipos mediante impresora 3D. En nuestra investigación se utilizó el método experimental como un conjunto de técnicas para adquirir conocimientos y para corregir e integrar estudios previos.

Para la resolución del problema planteado utilizamos la metodología propuesta por el método del *machine learning* (ML) (Kelleher *et al.*, 2015), aplicado a nuestra área de trabajo. Este método propone seis pasos como proceso de análisis y de resolución de problemas:

1. Comprensión del problema enfrentado	*Understanding the matter*
2. Comprensión de los datos	*Data understanding*
3. Preparación de los datos	*Data preparation*
4. Modelado digital	*Modeling*
5. Evaluación	*Evaluation*
6. Modelado 3D	*Deployment*

El primer punto fue desarrollado en la primera parte del trabajo llamada investigación exploratoria, con un proceso de sistematización de los conocimientos y de reflexión activa.

Los puntos siguientes se esquematizan en las figuras a continuación.

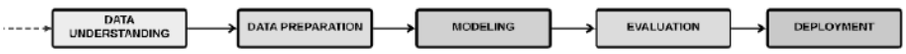

Figura 1. Proceso de análisis de proyectos con metodología de *machine learning*

En base a la metodología del ML se construye el flujograma de trabajo para nuestra propuesta.

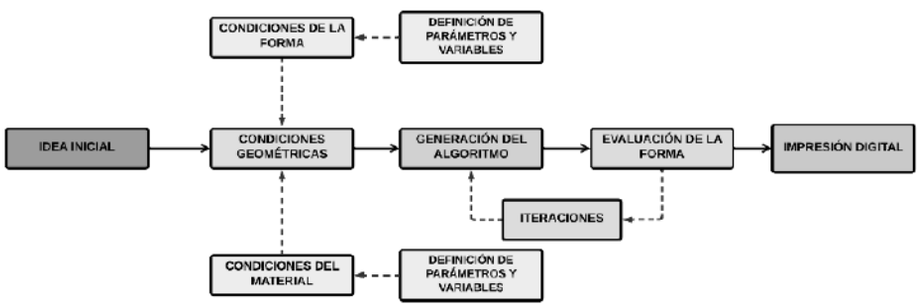

Figura 2. Flujo de trabajo propuesto

Se desarrolló en grupo un “algoritmo” con los programas Rhinoceros y Grasshopper para el diseño de una cubierta formada por una malla poligonal 3D cuya estructura de soporte la conforman uniones impresas y barras de bambú.

El ejercicio nos permitió acercarnos a la definición de las formas manejando las variables de manera independiente, al poseer incidencia directa en las distancias, la formalización de los nudos, los diámetros del bambú utilizados y demás condicionantes tanto de la forma como del material.

En la última fase se realizó el análisis de la información obtenida mediante el enfoque metodológico propuesto, la investigación exploratoria y la experimentación proyectual.

Luego, se extrajeron conclusiones y reflexiones sobre lo experimentado.

3 Resultados

El trabajo práctico se realizó en grupo, en el que se definió generar mediante la exploración de las formas una cubierta cuya estructura resistente involucrara el bambú. El diseño inicial buscado fue una cubierta con una geometría totalmente parametrizable y una estructura de soporte conformada por una malla poligonal 3D de barras de bambú juntadas con elementos "uniones", cuyo diseño también fuera variable según otros parámetros que se desprenderían del diseño elegido para el nodo o unión.

3.1 Definición de parámetros y variables

Una vez definido el resultado final buscado, nos centramos en diseñar el proceso en el cual nos adentraríamos. En la búsqueda de la estructuración de las relaciones entre los parámetros que definen los elementos objeto de diseño y el vínculo que existe entre ellos. De esta manera, controlando las variables y las propiedades que pueden ser modificadas, pudimos verificar los resultados en tiempo real con el objetivo de optimizar el resultado final. El resultado obtenido es, en general, responsivo a las condiciones establecidas previamente, generando un algoritmo con el cual pudimos explorar la forma y adaptar el diseño a las condiciones del material con el que decidimos trabajar.

Al considerar el material bambú, nos planteamos las siguientes interrogantes:

¿Cuáles son los parámetros limitantes en el diseño con bambú?
¿Cómo trabajar con materiales naturales?

Las interrogantes que nos planteó el tipo de estructura elegida fueron las siguientes:

¿Cuáles parámetros son decisivos para la forma buscada?
¿Existen limitaciones en la forma estructural?

En cuanto al diseño del conector o unión entre las barras de bambú, nos preguntamos:

¿Cómo trabaja estructuralmente un nodo?
¿Cuál es el sistema o tipo de unión que mejor se adapta a nuestros requerimientos?

3.2 Condicionantes para la definición de la forma. Conocer la forma

Las mallas espaciales son entramados de barras dispuestas en las tres direcciones del espacio, que soportan y transmiten esfuerzos de tracción o de compresión, nunca flexión. Derivan del principio de triangulación de las celosías planas. A. Graham Bell fue un pionero en el estudio y utilización de las mallas en el ámbito de la ingeniería aeronáutica, hacia 1900 realizó una torre tetraédrica para conseguir mayor resistencia con el menor peso. Asimismo, Buckminster Fuller fue pionero en introducir las mallas al ámbito arquitectónico, creando mallas espaciales geodésicas de grandes dimensiones.

Las mallas espaciales se clasifican en dos grandes grupos según la cantidad de capas que las forman. En primer lugar, están las mallas compuestas por una sola capa, son delgadas y, tal como las membranas, obtienen su resistencia a través de su geometría espacial. Por otro lado, las mallas conformadas por dos o más capas que se generan añadiendo unidades espaciales en diagonal formando poliedros o por uniones en planos verticales. Estas en su conjunto presentan resistencia a la flexión, por lo que no necesitan curvarse (Basset, s. f.).

La malla elegida para el trabajo está formada por dos capas paralelas entre sí, las cuales conforman tridimensionalmente figuras pentaédricas de base cuadrangular, donde la malla superior es mayor que la inferior, generándose así una malla octaédrica.

Para la materialización de la malla 3D se utiliza el componente SpaceTruss1.

Una condicionante de diseño de las mallas doble capa es la relación entre el espesor y la luz, que suele ser entre 1/18 y 1/25 (Basset, s. f.). Otros autores establecen la relación del espesor de la malla entre el largo del módulo de la misma, tal que se encuentre entre 0.5 y 1. Especifican que para relaciones inferiores se provocarían esfuerzos excesivos en las barras diagonales y, para relaciones mayores a 1, la excesiva esbeltez provocaría esfuerzos de pandeo muy grandes (Cavia, 1993). Estas proporciones son a modo orientativo, ya que las dimensiones finales de la malla se deben desprender del cálculo estructural, que en este caso de estudio no se aborda.

Los elementos componentes de la malla son las barras y los nudos. Las barras son, por lo general, realizadas por elementos huecos para aligerar el peso conservando el momento de inercia alto. Los nodos deben ser, en teoría, completamente articulados para permitir el libre giro.

Para la unión entre nodo y barra, se utilizan diversos conectores dependiendo de los materiales utilizados, el sistema elegido y la estética buscada. Pueden ser abrazaderas, espigas, vástagos, clavijas o varillas roscadas, también hay sistemas que permiten el ensamble de la barra en el nodo.

La superficie base a la que se adapta la malla octaédrica se definió como totalmente parametrizable. Se determinó que los datos de entrada definieran el espaciado de los puntos de la curva generatriz de la superficie, y las alturas de dicha curva y del punto inicial. La curvatura en el eje z se puede variar

mediante un control deslizante multidimensional. El resultado final es la definición de la superficie, y las divisiones generadas paramétricamente en los ejes R y V.

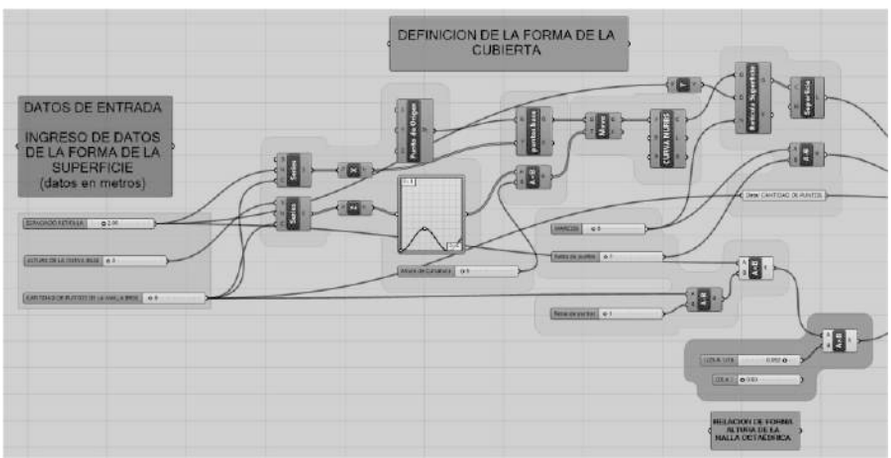

Figura 3. Definición de la forma. Fuente: Palma *et al*., 2022.

3.3 Condicionantes que nos presenta el material

Las limitaciones que encontramos con el bambú surgen de las características del material desarrollado en la información sistematizada en el trabajo.

Una vez definida la especie de bambú que se utilizaría en la estructura, se relevaron sus características geométricas para poder definir de qué sector de la planta obtendremos el material para realizar nuestras barras, su diámetro externo, el ancho de su pared y la distancia promedio entre nudos. Elegimos los tramos más rectos del sector de la basa y verificamos cuál era la longitud máxima utilizable que podíamos encontrar. Estas son las condiciones de ingreso, datos que debimos recabar e ingresar al algoritmo.

La especie de bambú elegida para realizar el trabajo grupal fue *Bambusa tuldoides*, una especie naturalizada en este territorio nacional que puede alcanzar entre 6 y 10 m de altura y su diámetro varía entre 2 y 5 cm. El sector entrenudo puede medir entre 25 y 40 cm de largo. Sus propiedades estructurales son buenas, mejor aún que las de maderas como el pino y el eucalipto, con una densidad estimada de 860 kg/m^3, según Fernandes *et al*. (2012).

Los ejemplares utilizados para realizar el trabajo fueron cortados con una edad entre 2 y 3 años. Se eligieron los sectores de la basa de la caña que poseía un largo total de 4 m. El diámetro medio en la basa alcanzó 2,6 cm, y el espesor promedio de la pared del culmo, 7 mm. Estos datos se ingresaron en el algoritmo.

Con relación a su resistencia mecánica, como en este trabajo no abordamos el cálculo estructural, asumimos que el material que elegimos posee características aptas para el uso estructural.

Los largos de cada barra son uno de los condicionantes del diseño que debe verificarse, ya que la especie de bambú y la edad de corte de los ejemplares obtenidos determinan los tamaños de barra máximos a manejar en la estructura. En el algoritmo se listó el largo de cada tramo. La información obtenida en primera instancia responde a los largos entre eje y eje de nodo. Esta información fácilmente, al ser procesada, puede brindar los datos necesarios para definir si los parámetros de dimensiones que se manejan deberían ser ajustados o no.

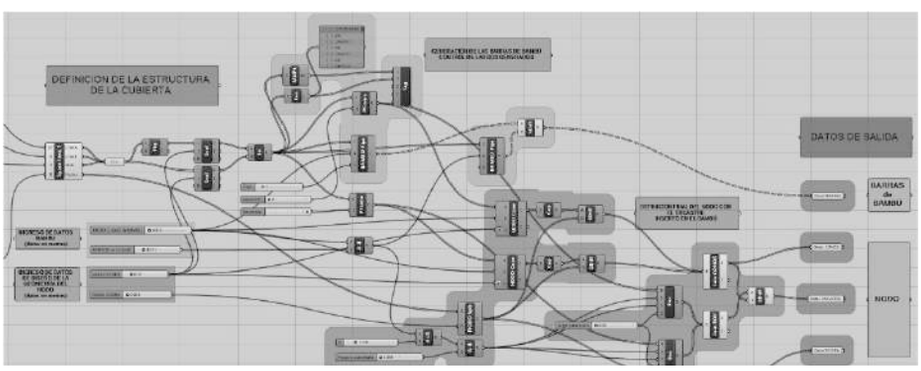

Figura 4. Definición de la estructura de la cubierta. Fuente: Palma *et al.*, 2022.

Para la confección del nodo, consideramos un diseño simple que pudiera realizarse en impresión 3D y que la unión con el material respondiese a las características de la especie utilizada cuyos datos fueron introducidos en el algoritmo. El método de unión entre el bambú y el nodo se efectuó mediante la introducción de una planchuela del nodo dentro del culmo de bambú y su cementado.

3.4 Resultado logrado

El algoritmo final generado fue el resultado de la inclusión de las variables encontradas, que surgen del estudio del material, de las condicionantes de la forma de la estructura buscada y de la definición de las relaciones entre ellas. Esto nos llevó a entender las lógicas de funcionamiento del pensamiento computacional y las lógicas propias del *software* utilizado, y cómo son afectados cada uno de los parámetros al introducir variaciones, sobre todo al

considerar las características particulares de un material natural que afectan el resultado final.

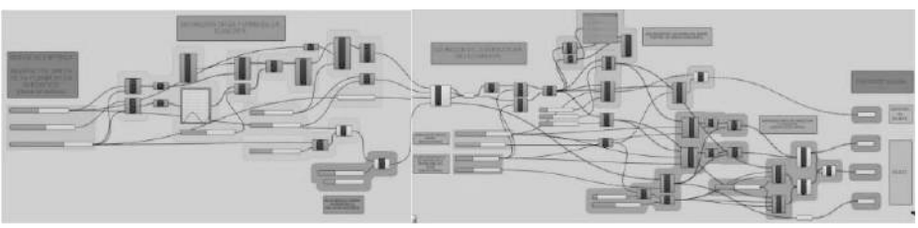

Figura 5. Algoritmo final. Fuente: Palma *et al*., 2022.

Figura 6. Cubierta. Resultado final. Fuente: Palma *et al*., 2022.

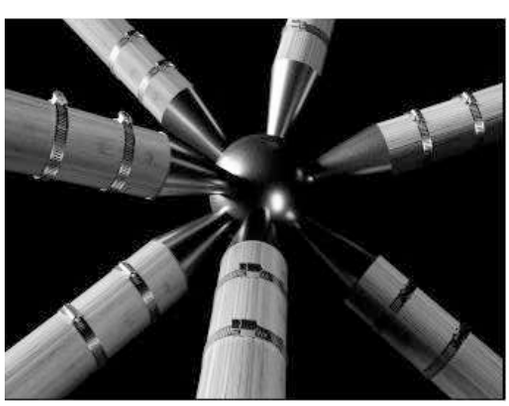

Figura 7. El nodo. Fuente: Palma *et al*., 2022.

Luego de llegar a la definición de lo buscado, se realizaron impresiones digitales de los nodos para generar una maqueta de un sector de la estructura y una maqueta a escala 1:1 de uno de los nodos. Al ser una cubierta curva, la

variabilidad entre los nodos era relevante. La serie de impresiones realizadas en el Centro de Integración Digital (CID) de la Facultad de Arquitectura, Diseño y Urbanismo llevaron a realizar ajustes en el algoritmo hasta obtener el final deseado.

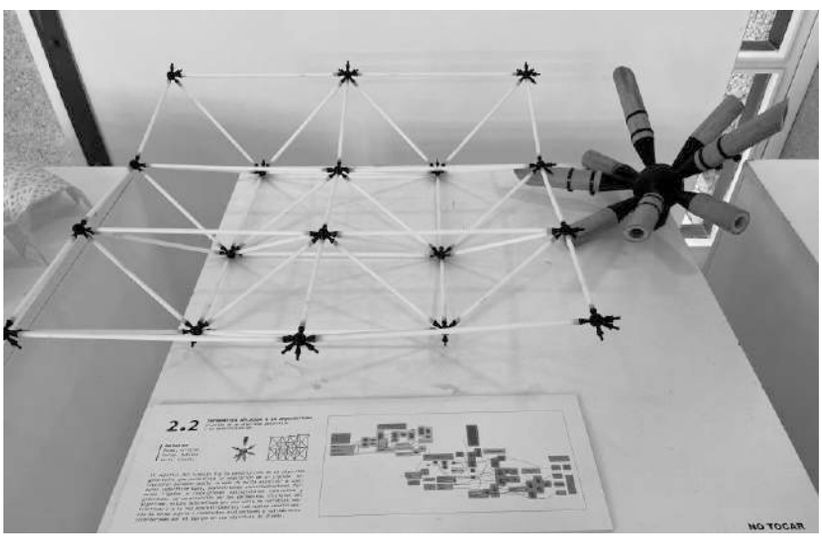

Figura 8. Presentación del trabajo grupal en exposición CID Abierto, agosto de 2022

3.5 Discusión

Lo obtenido en el ejercicio experimental nos resultó muy significativo, en el sentido en que logramos verificar que, a través de la práctica y la investigación, es posible obtener conocimientos prácticos sobre la arquitectura paramétrica o digital, profundizando en los desafíos y las oportunidades que nos puede brindar. Se pudo constatar que la disponibilidad de información y de herramientas existentes en la red facilita materializar diseños con complejidades antes no pensadas, abriendo un vasto campo para el diseño arquitectónico y colaborativo.

Descubrimos que el bambú como material, sustentable y biodisponible surge como un material perfecto para la experimentación con estructuras constituidas por celosías. Además, el diseño algorítmico proporciona espacio para la variabilidad del bambú y para cambios de diseño, incluso durante la construcción, a través de la modificación en el ingreso de variables en la configuración digital (Osmond *et al*., 2022). Esta hibridación que generó el diseño digital a través de un material natural requirió profundizar en el conocimiento y estudio de las distintas especies de bambú, sus características particulares y específicas y su comportamiento estructural. Entendimos que la

comprensión de las geometrías utilizadas y los materiales es imperativa a la hora de diseñar, ya que, conociendo las condicionantes y sus relaciones, la definición del resultado puede ser correctamente ajustada en la producción digital de las formas y a su materialización, a través de la impresión con tecnología digital 3D. Esto siendo siempre el objetivo final buscado en cada proyecto el diseño de un sistema de relaciones entre los diferentes elementos que lo componen, expandiendo así nuestro modo de operar como arquitectos/diseñadores.

Ahora bien, estos giros digitales nos plantean un nuevo lenguaje desde donde podremos repensar y desarrollar nuestro rol de diseñadores/arquitectos. Observamos que el acto de diseñar muta de canales para desarrollarse ahora desde lo cibernético procesando modelos analíticos mediante el análisis de datos. Esto lo debemos recibir y percibir como una expansión de nuestras capacidades y de nuestra responsabilidad. El arquitecto debe asumir ahora su nuevo rol aprendiendo a controlar la tecnología, a manejarla, a aprovecharla, integrando los procesos de iteración y juego y asumiendo que las restricciones no son obstáculos, sino motores del propio diseño.

El diseño a través del juego nos ayuda a la automatización del pensamiento computacional, a la elaboración mediante las retroalimentaciones iterativas y los procesos de análisis y de resolución de problemas. Podremos trascender la mera búsqueda de la complejidad espacial para adoptar lo multidisciplinario que puede ser nuestro trabajo como diseñadores. Con ello, podremos acercarnos digitalmente a las tradiciones artesanales, a materiales con características variables, al diseño que maneja a favor la variabilidad y que contribuye a la sostenibilidad de nuestro entorno, generando experiencias más ricas y diversas, y así llevar a la arquitectura más allá de los límites impuestos anteriormente.

El diseño se abre, se expande, el arquitecto adquiere el rol de sistematizador de conocimientos buscando lo performativo por sobre lo meramente gráfico representativo.

Por ello, nos compete ahora interpelarnos, definir el rol que queremos desempeñar en esta época digital y signada por el cambio climático y la escasez de recursos renovables.

Se abre ante nosotros un vasto universo por explorar.

Debemos tomar partido en esta nueva forma de pensar la arquitectura, ya no más entendida en términos mecánicos, sino en términos cibernéticos y sistémicos, tal como Ortega (2017) expone, para convertirnos en diseñadores totales.

Referencias

Aksamija, A. (2016). *Integrating Innovation in Architecture. Design, Methods and Technology for Progressive Practice and Research*. Chichester: John Wiley & Sons.

Basset, L. (s. f.). *Mallas espaciales*. Escuela Técnica Superior de Arquitectura Universitat Politècnica. https://riunet.upv.es/bitstream/handle/10251/16498/Mallas%20espaciales.pdf?sequence=3

Cavia, P. (1993). Las mallas espaciales y su aplicación en cubiertas de grandes luces. *Revista de Edificación*, 7-15. https://core.ac.uk/download/pdf/83568427.pdf

Centro de Integración Digital (CID). (2022). *Informática Aplicada a la Arquitectura* [Presentación del curso]. https://eva.fadu.edu.uy/pluginfile.php/144821/mod_resource/content/3/2106_10%20IAA%20Presentaci%C3%B3n%20del%20curso.pdf

Centro de Integración Digital (CID). (2022). *Informática Aplicada a la Arquitectura* [Presentación del ejercicio final]. https://eva.fadu.edu.uy/pluginfile.php/146840 /mod_resource/content/1/Presentacio%CC%81n%20del%20ejercicio%20de%20cierre.pdf

Fernandes, C., Fontana, J. J., Laurino, P., Casañas, V. & Vila, V. (2012). *Estructuras livianas. Como respuesta a programas temporales diseñadas con materiales sustentables*. Comisión Sectorial de Investigación Científica (CSIC) de la Universidad de la República.

Gómez, H., Rodríguez, S. & Ramal, R. (2020). El bambú: una solución ecológica sustentable como material de construcción. *Revista Científica Institucional Tzhoecoen*, *12*(2), 253-262. https://revistas.uss.edu.pe/index.php/tzh/article/view/1264

International Bamboo and Rattan Organization (INBAR). (2014). *El bambú: un recurso estratégico para que los países reduzcan los efectos del cambio climático. Informe síntesis de políticas*. https://www.inbar.int/resources/inbar_publications/informe-de-sintesis-de-politicas-1-el-bambu-un-recurso-estrategico-para-que-los-paises-reduzcan-los-efectos-del-cambio-climatico spanish/#:~:text=Si%20se%20reconoce%20como%20un,sobre%20millones%20de%20com

Kelleher, J., Mac Namee, B. & D'Arcy, A. (2015). *Fundamentals of Machine Learning for predictive data analytics*. The MIT Press.

Massimiano, L. (2015). L'approccio parametrico alla progettazione: strumenti e implicazioni metodologiche. La Ricerca Che Cambia, Atti Della Conferenza Del Convegno Nazionale Dei Dottorati Italiani Dell'Architettura, Della Pianificazione, Del Design, a Cura Di L. Fabian, M. Marzo.

Navarrete, S. (setiembre de 2014). Diseño paramétrico. El gran desafío del siglo XXI. *Cuadernos del Centro de Estudios en Diseño y Comunicación*, *49*, 63-72. doi: https://doi.org/10.18682/cdc.vi49

Osmond, J., Stamm, J. & Vahanvati, M. (2022). *Applying design tools for full-culm bamboo. International Conference on Non-conventional Materials and Technologies (Nocmat 2022)*. Pittsburgh. 10.5281/zenodo.6856269

Ortega, L. (2017). *El diseñador total*. Puente Editores.

Palma, C., Porley, N. & Varin, C. (2022). Malla espacial adaptativa, algoritmo para estructuras paramétricas. Trabajo no publicado.

Design, Nature and Ecosystems: Building Performance

Mediating Heat and Light: a Visualization-based Tool for the Analysis and Development of Dynamic Shading Control Protocols

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Abstract. Operating Dynamic Shading Systems (DSS) is often an ill-defined task since it requires pondering design criteria that are often at odds with each other, e.g., visual comfort and building energy-efficiency. This work proposes a co-simulation approach to efficiently analyze the impact of controlling DSS in the daylight and the energy performance of indoor spaces to address this difficulty. The proposed workflow uses advanced daylight and building energy simulation tools to enable comprehensive comparative analyses by post-processing simulation output through queryable visualizations. Additionally, the approach allows designers to create or refine DSS control strategies by manipulating visualizations of hourly DSS operation schedules. The authors tested the workflow in designing and controlling a DSS in three different climates: a temperate, a hot, and a very cold climate. The proposed approach delivered valuable insights about the complex tradeoffs that emerge from controlling DSS.

Keywords: Building Performance, Solar Heat Gain, Visual Comfort, Building Operation

1 Introduction

Previous research has shown a significant impact of windows on buildings' heating and cooling demand (Grynning et al., 2013). Hence, it has been suggested that the application of external shading elements has a critical role in reducing buildings' cooling loads and controlling solar gains in buildings (Nielsen et al., 2011). Moreover, shading elements can potentially optimize daylight performance and ensure visual comfort in indoor spaces (Konstantzos et al., 2015), particularly Dynamic Shading Systems (DSS). DSS are shading systems composed by moveable parts that are controlled either directly by a building occupant or an intelligent system in response to different environmental stimuli in favor of comfort and energy efficiency (Al-Obaidi et al., 2019). Thus,

DSS can effectively improve buildings' energy efficiency as well as occupants' comfort by means of controlling daylight (i.e., providing adequate illuminance levels and avoiding glare) and solar radiation in an efficient manner. However, designing and controlling DSS is difficult as it involves design criteria that are often at odds with each other, such as energy-efficiency and visual comfort. Currently DSS control protocols either aims towards energy efficiency in buildings (Huo et al., 2021) or the mitigation of visual discomfort (Luo et al., 2020). Hence, little research has been done on assessing the impact of operating DSS using standard shading control schemes for visual comfort (IESNA, 2012) in building energy performance and vice-versa. The lack of research on this topic is related either to the difficulty of spatially computing visual discomfort or conducting onerous lab or field studies. The subsequent section discusses exemplary instances of related work to this research field.

1.1 Related Work

The work of Tschakrow and Hellwig (2015) is one of the few that thoroughly analyzed the trade-offs between energy and daylight in DSS control optimization. However, the research focused solely on schools during summer and used limited predictive methods to assess visual comfort. De Vries et al. (2019) studied sensor selection for a sun-tracking control strategy for indoor roller blinds via a case study. The suggested strategy considered both daylight and energy performance and resulted in an overall improvement of building energy-efficiency. Recent developments in daylighting simulation (Jones and Reinhart, 2019) allowed the quick prediction of advanced glare metrics (i.e., Daylight Glare Probability), therefore facilitating the study of controlling DSS using either building energy performance or visual comfort criteria.

Moreover, in current standards, guidelines, and codes related to the visual domain, shading control schemas for visual comfort are commonly included. For example, the LM-83 standard (IESNA, 2012) includes DSS operation protocols in the calculation of Spatial Daylight Autonomy (sDA) and Annual Sun Exposure (ASE). The control protocol, known as the 2% rule, determines that a DSS should be deployed if 2% of the occupied area receives ≥1000 lux caused by direct beam (direct sunlight). In most standards related to the thermal domain, DSS control is provided in a rather marginal manner. Typically, minimum and maximum thresholds are related to solar radiation (W/m2), illuminance levels (lux), temperature (°C/°F), and cooling load rates (W or kW).

Current building simulation tools, such as ClimateStudio, use DSS control schemes defined in sustainable rating systems, like BREEAM and LEEDv4. Such control schemes are based on international daylight standards and norms, e.g., EN 17037 (CEN, 2021) and LM-83 (IESNA, 2012). For example, in LEEDv4, ClimateStudio applies the 2% rule as a default for DSS operation. Regarding building energy software, there is no embedded control protocols for DSS, leaving up to the energy modeler their definition.

1.2 Research Goals

Given the lack of integration between DSS control schemes designed either for daylight or energy-efficiency, this study aims to: (i) observe in which conditions current shading protocols conflict, and (ii) develop a computational approach that supports designers to examine the impact of DSS control schemes on daylight and building energy performance and specify custom DSS operation protocols. To that end, the proposed approach aims to assess the DSS impact on daylight and building energy performance via on-demand visualizations.

2 Methodology

This work imparted two phases: (i) development of the proposed design and analysis framework, and (ii) framework application. In the first phase, we developed and implement a framework for assessing the annual energy and daylight performance of DSS through a range of queryable visualizations. The second phase emulated a potential use of the framework and reflects on the complex tradeoffs between daylight and thermal performance of buildings while specifying DSS control protocols.

2.1 Design and Analysis Framework

The framework combines whole building energy simulation with climate-based daylight analysis in a seamless modeling and analysis workflow for the Rhino/Grasshopper Computer-Aided Design ecosystem. The framework implementation integrates ClimateStudio and Honeybee, popular front ends to Radiance (LBNL, 2022) and EnergyPlus (DOE, 2022), as well as custom-tailored Python programs that extend their modeling and visualization capabilities. The framework articulates four modules: the modeling, simulation, visualization, and control schedule design modules.

In the modeling module, the user describes the space to be analyzed, i.e., the geometry and the optical and thermal properties of static building elements and DSS. The user can either manually or parametrically model all design components. This module is supported by different ClimateStudio and Honeybee functionalities and a custom-developed program that interfaces with Radiance's *genblinds* and *genbsdf* routines to generate bidirectional scattering distribution functions (BSDF) to parametrically describe DSS based on venetian blinds. The BSDF describe how light is transmitted and scattered by the DSS.

The simulation module processes the previously described model to automatically simulate the annual daylight and energy performance of three scenarios: (i) baseline, i.e., without any DSS, (ii) the daylight-based (Db) shade control, where a control strategy solely based on daylight criteria controls the DSS, and (iii) the thermal-based (Tb) shade control, which applies thermal criteria to control operable shades. Although the user can specify the Db and

Tb control protocols, the default Db shade control applies the 2% rule defined in LM-83-12 standard (IESNA, 2012). Regarding the Tb shade control, the default protocol deploys shades whenever the incident irradiance in the window group is above 200 W/m^2, and there is a significant cooling load rate (0.5 KW). EnergyPlus and Radiance support the calculations performed in this module.

The visualization module enables users to compare simulation results through bar charts and paired queryable hourly heatmaps. The bar charts compare the annual performance of the different scenarios using different energy end-uses, sDA, and ASE results. They also report on mismatch events (i.e., hours where the different control strategies diverge) and their type. Additionally, users can request, pair, and stack hourly heatmaps of several output data on demand including: (i) hourly cooling and heating loads, (ii) windows transmitted irradiance, (iii) shades operation schedule, and (iv) labeled mismatch events.

Finally, the control schedule design module allows designers to specify alternative control schedules for the modeled DSS. This module supports the development of control strategies either from scratch or by editing Db or Tb shade controls. After prompting the new schedule, the framework assesses its impact on energy and daylight performance using modules 2 and 3.

2.2 Framework Application

We tested the proposed analysis and design workflow in a simple south-facing test cell in three locations: (i) Oakland, a warm/temperate climate, (ii) Phoenix, a hot climate, and (iii) Umeå, a very cold climate. In each location, we tested three blind angles in an equally spaced venetian blind DSS: (i) Tilt 0°, (ii) Tilt 30°, and Tilt 60°. The tilt angle follows the WINDOW software convention, where 0° is perpendicular to the window and positive tilts are in the counter-clock direction. The slats' depth and spacing are 0.1m.

Figure 1 and Table 1 describe the test cell's optical and thermal properties. The optical properties of the different surfaces are fixed. However, the assumed thermal transmittance (U-value) changes depending on location by following the ASHRAE guidelines for mass construction types in different ASHRAE climate zones. Hence, for Oakland, we assigned the construction assemblies for climate zone 3 (warm), for Phoenix, the ones specified for climate zone 2 (hot), and for Umeå, the ones recommended for the most similar ASHRAE climate zone, 7 (very cold).

Concerning building energy simulations, the test cell consists of a single thermal zone that uses an ideal loads air system as its heating, ventilation, and air conditioning (HVAC) system. The cooling thermostat was set to 24°C while the heating to 21°C. Regarding the annual climate-based daylight simulations, the illuminance threshold for sDA calculations is 300 lux. The design criteria for sDA and ASE is sDA ≥ 50% and ASE ≤ 20% of the occupied area. All simulations used hourly data of each location's typical meteorological year

(TMY) file. The shade control protocols were the default ones described in the previous section.

The framework's application imparted two stages. The first stage compared overall data on energy, daylight, and divergency of shade operation modes. Based on the discussion of the first stage results, the second stage entailed a thorough hourly comparison. The pairing of queryable heatmaps supported such comparison, detailed analysis, and even the hypothetical development of new control schedules for the proposed DSS in this stage.

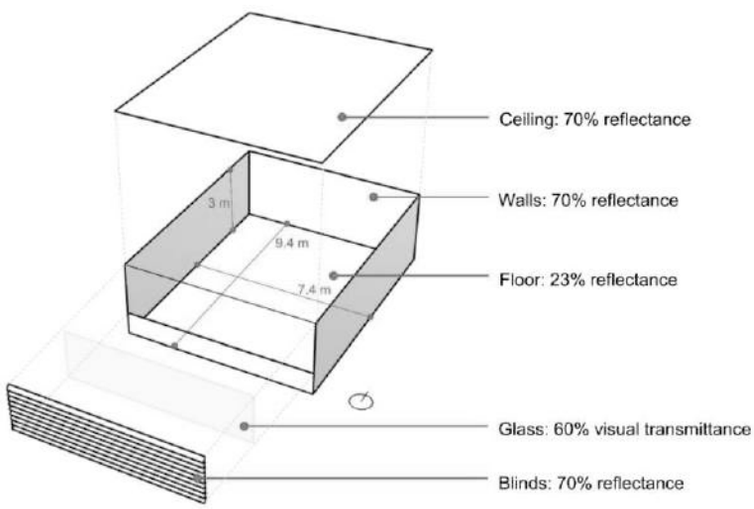

Figure 1. Exploded axonometric of the south-facing test cell labelled with surfaces optical properties (i.e., reflectance and visual transmittance) for all locations.

Table 1. U-values for external wall, roof, glass, and floor.

Location	U-values in ($W.m^{-2}.K^{-1}$)			
	Ext. wall	U_{roof}	U_{glass}	U_{floor}
Oakland, CA	0.60	0.21	1.66	0.52
Phoenix, AZ	0.76	0.21		
Umeå, Sweden	0.37	0.15		

3 Results

This section presents the results of the two stages of our framework application. All the results are further discussed in the discussion section.

3.1 First Stage of Application

The following compares different combinations of tilt angles and DSS control protocols, i.e., scenarios, per location. Figures 2, 4, and 6 provide an overview of annual energy consumption, sDA, and ASE with and without DSS deployment. Figures 3, 4, and 7 measure the percentage of change in different energy end-uses of each scenario relative to the base case.

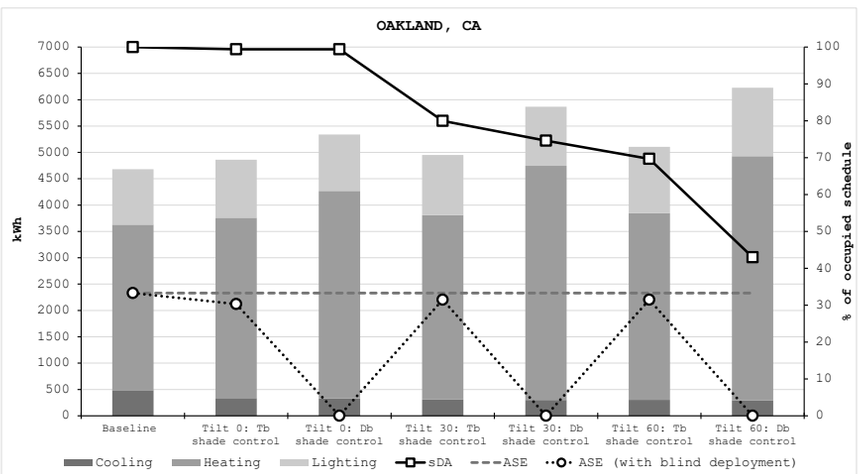

Figure 2. Energy loads per end-use (kWh), sDA, and ASE (with and without blind deployment) measured in percentage of occupied schedule for each shading strategy in Oakland, CA.

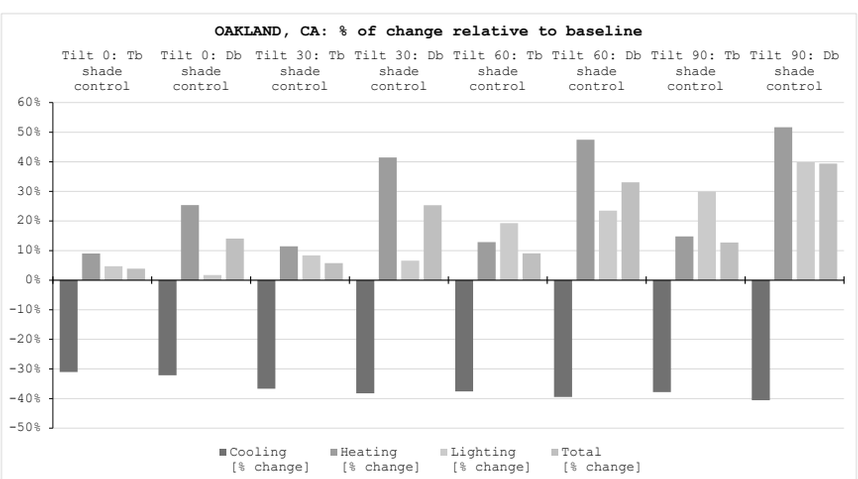

Figure 3. Percentage of change in relation to the baseline scenario for each shading strategy in Oakland, CA.

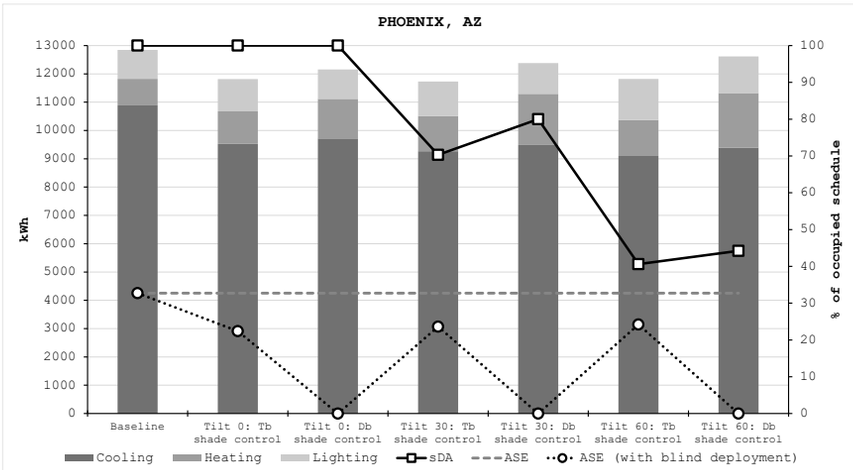

Figure 4. Energy loads per end-use (kWh), sDA, and ASE (with and without blind deployment) measured in percentage of occupied schedule for each shading strategy in Phoenix, AZ.

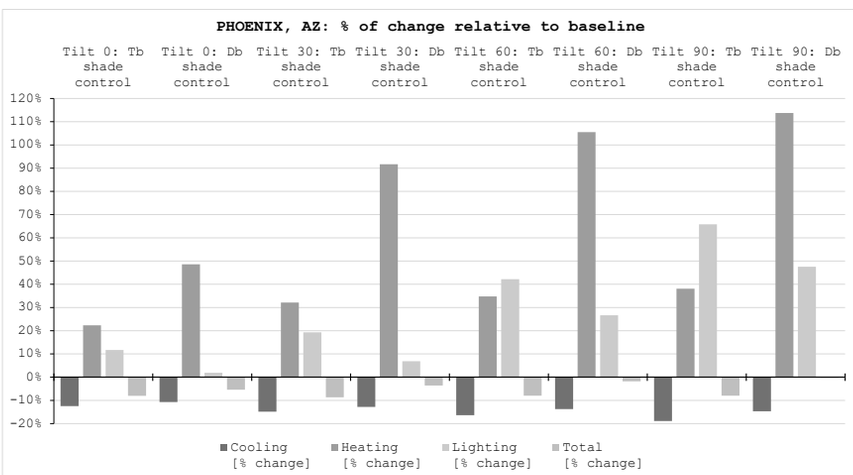

Figure 5. Percentage of change in relation to the baseline scenario for each shading strategy in Phoenix, AZ.

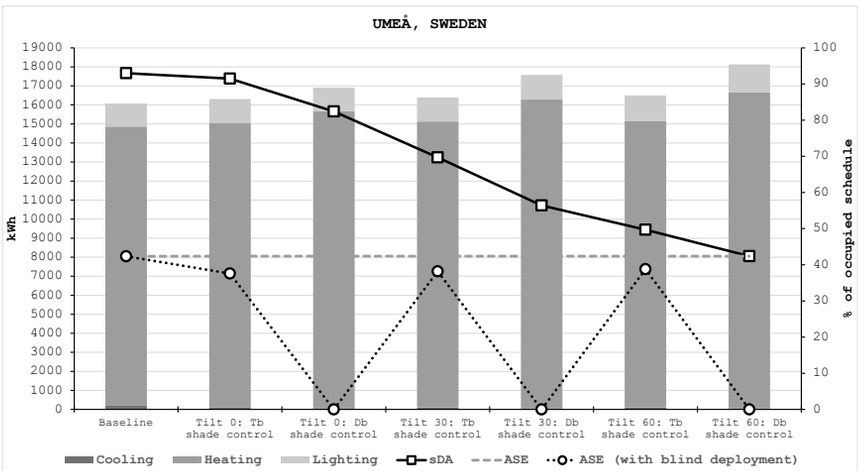

Figure 6. Energy loads per end-use (kWh), sDA, and ASE (with and without blind deployment) measured in percentage of occupied schedule for each shading strategy in Umeå, Sweden.

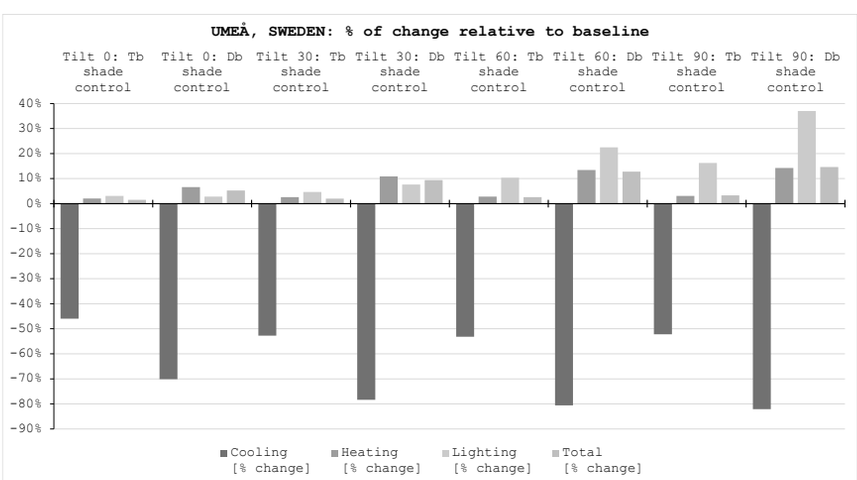

Figure 7. Percentage of change in relation to the baseline scenario for each shading strategy in Umeå, Sweden.

Figures 8 and 9 measure the misalignment of Db and Tb DSS control strategies for the following selected tilts: 0° for Oakland and Umeå, and 30° for Phoenix. Tilt selection was based on their performance, as argued in the discussion section. Figure 8 plots absolute and relative mismatching events, i.e., hours when the two control protocols diverge. Figure 9 maps the mismatching events into four categories: (1) Db shade protocols blocks useful solar heat gains (SHG), (2) Tb shade control blocks view, (3) Tb shade control

potentially allows visual discomfort, and (4) Db shade control allows unwanted SHG.

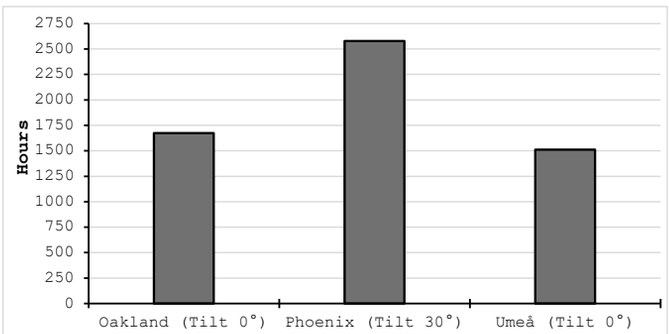

Figure 8. Total number of mismatching control events.

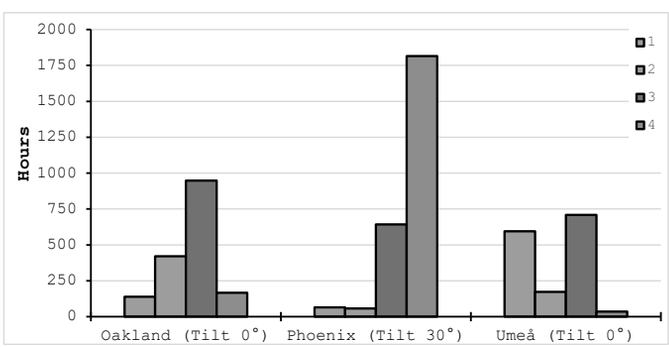

Figure 9. Distribution of mismatching control events type. The mismatching events legend key is as follows: 0 – no mismatch, 1 – Db shade control blocks useful SHG, 2 – Tb shade control blocks view, 3 – Tb shade control potentially allows visual discomfort, 4 – Db shade control allows unwanted SHG.

3.2 Second Stage of Application

Based on the information provided by the previous charts, users could use the framework to perform detailed hourly-based analysis. Due to space constraints, we only present the results of Umeå since it is the location where the Tb and Db shade control strategies are most conflicting. Figure 10 stacks three queryable heatmaps. The top two display the Tb and Db operation schedules, while the bottom one shows the mismatch of the above schedules. Figure 11 shows how the user can use the information provided by Figure 10 to improve one of the control strategies, in this case, the Db one, by prompting periods to be excluded or added. Compared with the Db control scheme, the new control schedule reduced the total annual heating load by 2.5% and overall energy consumption by 2% while maintaining acceptable sDA and ASE levels.

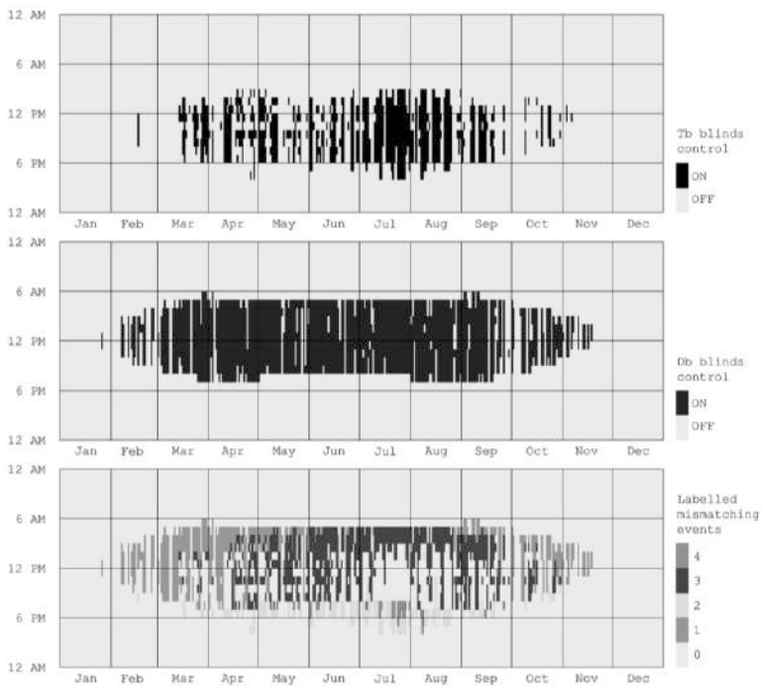

Figure 10. Hourly analysis of Tb and Db shade control strategies and their mismatching event type for Umeå, Sweden. The mismatching events legend key is as in Figure 9.

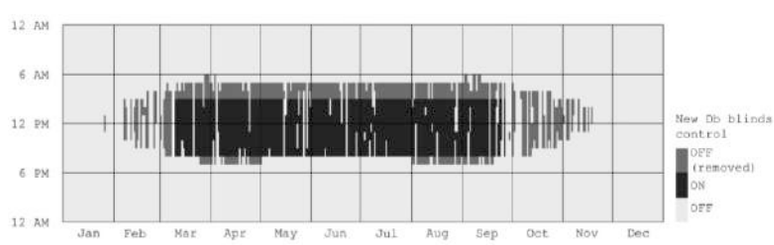

Figure 11. New shade control schedule designed for Umeå based on the Db shade control strategy derived for the same location.

4 Discussion

Figures 2 through 7 provide critical information about the most appropriated tilt angle for each location. The figures show that the DSS deployment using the Db and Tb control protocols significantly reduces cooling loads in all locations. Nevertheless, in Oakland and Umeå, such reduction does not offset the resulting increase in heating loads (Figures 2, 3, 6, and 7). Therefore, using

DSS for visual comfort purposes should impact as little as possible overall building energy performance. In the case of Oakland and Umeå, DSS with a blind tilt of 0° are the ones that least impact energy performance while yielding acceptable ASE and sDA scores. Figures 4 and 5 show that DSS deployment always results in overall energy reduction in Phoenix. Figure 5 indicates that the DSS with a blind tilt of 30° yields the most significant potential for energy savings in Phoenix. Hence, for Oakland and Umeå, the selected DSS blind tilt was 0°, while in Phoenix, it was 30°.

After selecting DSS' blind tilts, the proposed workflow compared the Tb and the Db control strategies to assess the benefits and limitations of using one over the other. Figure 8 shows that the two control strategies diverge in many hours. In Phoenix, using the Db control strategy would significantly increase cooling loads due to the admission of unwanted SHG (Figures 4, 5, and 9). An hourly analysis would show that most mismatching events occur during the cooling season when the sun altitude is higher and seldom causes visual discomfort. Thus, the designer could custom tailor a control strategy that adjusts the Db schedule to deploy the DSS only in the morning and evening summer hours. If we conduct an hourly analysis in Oakland, it is possible to reach to a similar conclusion (Figure 9).

In Umeå, the mismatch is due mainly to two competing factors: harvesting SHG and minimizing visual discomfort (Figure 9). In fact, the Db and Tb control strategies are often at odds mostly because the Db control strategy blocks SHG, which would reduce heating loads, while Tb allows it. Unfortunately, the hours of useful SHG yield a high potential for visual discomfort. Figure 10 presents the hourly comparative analysis of the two control strategies for this location. It shows several potential periods where the Db control strategy could allow the admittance of SHG to reduce heating loads with minimal impact on visual comfort. Such periods include the early hours of the annual occupied schedule, the period of October through December, and January through early March. Figure 11 illustrates the use of the proposed workflow to redefine the Db control schedule by excluding such periods. Compared with the original Db control scheme, the new DSS control strategy for Umeå reduced by 2.5% annual heating loads and by 2% the overall building energy consumption while scoring an sDA of 88% and maintaining an ASE < 20%.

5 Conclusion

This paper presents a new approach based on co-simulation for efficiently analyzing the tradeoffs of controlling DSS either for daylight or energy conservation in buildings. The application of the system shows that it can automatically simulate the daylight and energy performance of different DSS control strategies and provide useful on-demand visualizations to support analysis and design processes. The queryable visualizations inform about the

convergence and divergence of diverse DSS operation modes, their causes, and potential opportunities for better integration. The framework can also be used to create or refine DSS control schedules. Future work will expand the approach by including annual DGP and testing it in more complex examples.

References

Al-Obaidi,K. M., & Al-Marasni, S. W. (2019). Dynamic shading systems: A review of design parameters, platforms and evaluation strategies. *Automation in Construction, 102,* 195-216. https://doi.org/10.1016/j.autcon.2019.01.014

De Vries, S., Loonen, R., & Hensen, J. (2019). Sensor Selection and Control Strategy Development Support for Automated Solar Shading Systems Using Building Performance Simulation. *Proceedings of BS2019, Rome, Italy*, 4855–4862.

CEN. (2021). *EN 17037:2018+A1:2021 Daylight in buildings*.

DOE. (2022). EnergyPlus (version 9.6). https://energyplus.net/

Grynning, S., Gustavsen, A., Time, B., & Jelle, B. P. (2013). Windows in the buildings of tomorrow: Energy losers or energy gainers? *Energy and Buildings*, *61*, 185–192. https://doi.org/10.1016/j.enbuild.2013.02.029

Huo, H., Xu, W., Li, A., Lv, Y., & Liu, C. (2021). Analysis and optimization of external venetian blind shading for nearly zero-energy buildings in different climate regions of China. *Solar Energy*, *223*, 54–71. https://doi.org/10.1016/j.solener.2021.05.046

IESNA. (2012). *LM-83-12 IES Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE)*. New York, NY, USA: IESNA Lighting Measurement. ISBN: 978-0-87995-272-3

Jones, N. L., & Reinhart, C. F. (2019). Effects of real-time simulation feedback on design for visual comfort. *Journal of Building Performance Simulation*, *12*(3), 343–361. https://doi.org/10.1080/19401493.2018.1449889

Konstantzos, I., Tzempelikos, A., & Chan, Y.-C. (2015). Experimental and simulation analysis of daylight glare probability in offices with dynamic window shades. *Building and Environment*, *87*, 244–254. https://doi.org/10.1016/j.buildenv.2015.02.007

Luo, Z., Sun, C., & Dong, Q. (2020). A daylight-linked shading strategy for automated blinds based on model-based control and Radial Basis Function (RBF) optimization. *Building and Environment*, *177*, 106854. https://doi.org/10.1016/j.buildenv.2020.106854

Nielsen, M. V., Svendsen, S., & Jensen, L. B. (2011). Quantifying the potential of automated dynamic solar shading in office buildings through integrated simulations of energy and daylight. *Solar Energy*, *85*(5), 757–768. https://doi.org/10.1016/j.solener.2011.01.010

LBNL. (2022). Radiance (version 5.4 a). http://radsite.lbl.gov/

Tschakrow, E., & Hellwig, R. T. (2015). *Comparison of control strategies of venetian blinds regarding visual and thermal comfort in summer in classrooms.* Healthy Buildings Conference Europe, 18-20 May 2015, Eindhoven, The Netherlands. Loomans, M. et al. (Eds.).

The Effects of Vertical Growth: Struggles for the Right to Solar Access in Residential Areas. The case of Concepción, Chile

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Abstract. In Chile, the neoliberal economic model has intensified the densification process with few restrictions, giving rise to a prolific construction of high-rise multi-family buildings in low-density areas. The study uses a case of a high-rise housing complex that contrasts with local typologies and breaks the human scale in a traditional neighborhood (i. e., one story continues façade). The impact of shadow projections on its neighboring houses is calculated and duration according to the solar sun path. In addition, the effect on daylight availability in the residential units of the towers is analyzed. The results show that the tower's complex projects shade the neighborhood for up to 200 m in winter. Also, a tower's space daylighting autonomy decreases by 11% because of the shades of its neighboring towers. It reflects how this form of high-rise housing affects a fundamental right: the right to the sun in its forms of radiation for passive heating in a heating-demanding climate zone and the potential for daylight harvesting for its own residential units.

Keywords: design, nature and ecosystems, shadow cones, high-rise residential, daylight, simulation

1 Introducción

En el contexto de crecimiento y transformación de las ciudades contemporáneas, surge la búsqueda de nuevas formas de desarrollo que aseguren la viabilidad urbana. Frente a estos nuevos requerimientos, aparece la ciudad compacta o densificada, cuyos beneficios se relacionan con la viabilidad del modelo desde el diseño de las viviendas con mayor densificación de habitantes versus menor ocupación de suelo (Cárdenas *et al*., 2016). Ahora bien, al momento de buscar una vía de desarrollo urbano, es necesario también considerar aspectos sostenibles, que, además de asegurar el acceso a la vivienda, contemplen aspectos de confort, climatización y eficiencia energética (Gómez & Mesa, 2017).

En este sentido, la importancia de la luz y la energía obtenidas del sol es determinante en la calidad de vida urbana, ya que guarda relación con diferentes elementos que van desde lo energético hasta lo sanitario: por un lado, la energía obtenida a través del sol, de manera activa o pasiva, incide en la habitabilidad, climatización e iluminación de los espacios interiores y exteriores, mientras que la mera disposición del recurso solar incide y regula procesos biológicos como el ciclo circadiano, además de facilitar la orientación espacio-temporal (García, 2012; Gómez & Mesa, 2017). Frente a este panorama, y reconociendo tales virtudes, Ralph Knowles propone el concepto de *solar envelope* o envolvente solar: un constructo basado en la trayectoria solar que busca asegurar condiciones mínimas de asoleamiento para las construcciones, así como impedir que estas proyecten obstrucciones sobre los edificios adyacentes (Knowles, 2003). Sumado a esto, aparece el concepto de *acceso solar,* parámetro definido como la captación de energía solar en la morfología urbana para fines energéticos, pasivos o activos (Cárdenas-Jirón & Chang, 2019).

Por otro lado, el desarrollo proyectual en Chile se encuentra regulado por distintas normativas referidas a alturas y distanciamientos, principalmente. Si bien, a mediados del siglo XX, se estipulaba un mínimo de dos horas de iluminación natural, en el día más corto del año, para espacios habitables (Ministerio de Obras Públicas y Vías de Comunicación, 1949), este decreto fue derogado y reemplazado por la Ordenanza General de Urbanismo y Construcciones. Esta reconoce la relevancia del acceso a la luz solar al estipular que cada espacio habitable debe contar con una ventana que permita su asoleamiento (MINVU, 2020) y, para asegurar esta condición, la misma Ordenanza establece distanciamientos mínimos, ángulos de rasantes y alturas máximas para las edificaciones en altura, en función de su ubicación y del cálculo de las sombras proyectadas sobre las construcciones contiguas durante los equinoccios (MINVU, 2020). Cabe destacar, sin embargo, que, si bien la normativa aplica de manera general sobre el territorio, cada zona puede también evaluar su aplicación según el plan regulador y las proyecciones de desarrollo de cada ciudad.

Con respecto a esto, Cárdenas y Uribe (2012) señalan que, si bien la norma urbanística reconoce la relevancia del asoleamiento, esta presenta eslabones pendientes que no aseguran el derecho solar frente a las dinámicas proyectuales inmobiliarias, resultando insuficientes desde la metodología, que no considera, por ejemplo, la dinámica de las trayectorias solares, los casos durante solsticios y la incidencia de las obstrucciones solares en el espacio público. Además, los autores reconocen la importancia del acceso solar en un contexto de búsqueda de fuentes energéticas renovables y sostenibilidad.

Frente a este fenómeno, durante los últimos años se han llevado a cabo estudios en el contexto nacional, especialmente en Santiago de Chile,

destacando el caso de la comuna de Estación Central, donde Inzulza *et al*. (2017) analizan la vulneración del acceso solar en el marco de procesos de verticalización mediante el estudio de los conos de sombra, complementado con la aplicación de entrevistas a los residentes.

Ahora bien, el estudio del impacto asociado a las obstrucciones solares generadas por los edificios ya descritos resulta especialmente relevante en esta ciudad, caracterizada por su clima de lluvias y nieblas abundantes, relacionadas con la cercanía con cuerpos de agua como el río Bío-Bío, lagunas y humedales. Ya en 1960, Roberto Goycoolea, precursor del Plan Regulador de 1960, promovía estudios de asoleamiento previos al desarrollo de edificios de gran envergadura, justificados en el entendimiento de la ciudad como una urbe de complejas condiciones de armonía en la vida urbana debido al carácter húmedo del clima (Muñoz, 1995). Esto conlleva la necesidad de implementar modelos de planificación más estrictos, que garanticen el acceso solar para asegurar los beneficios energéticos asociados al asoleamiento, sean estos activos o pasivos.

Finalmente, Pérez *et al*. (2019) desarrollan un estudio del caso Barrio Condell, uno de los barrios tradicionales de la ciudad, abordando el fenómeno de la verticalización como consecuencia del desarrollo de las políticas de ciudad neoliberal. A través de entrevistas, llega a diagnosticar la problemática del desarrollo de edificios residenciales en altura, con respecto al acceso solar: “Opino que nos sentimos aplastados, nos quitan el sol” (p. 13), “La humedad me afecta porque no me pega el sol en toda la tarde. Entonces el frío es fuerte, uno que no estaba acostumbrado, que tenía solcito para secar la ropa en el patio, claro que afecta” (p. 13). Con esto, abre la oportunidad de ahondar en la vulneración al acceso solar en el marco comunal.

1.1 Metodología

Se aproxima el estudio del fenómeno con métodos mixtos. Se describe un conjunto de viviendas en altura como caso estudio y se cuantifican sus impactos en el contexto inmediato y dentro de sí mismo. Se recopiló información de parámetros morfológicos y planimétricos del conjunto para calcular los impactos mediante *software* de modelación y simulación.

El caso estudio es un conjunto residencial en altura construido en 2015 en un lote de forma triangular de 9000 m^2, aproximadamente. El complejo consta de 4 torres de 18 pisos más 2 subterráneos cada una, siendo los edificios de mayor altura en el sector (figura 1). El espacio circundante es un área residencial de baja densidad, incluyendo equipamiento educacional y de salud. Una característica del conjunto es que las torres se encuentran muy próximas entre sí. Además, el conjunto cuenta con espacios colectivos y áreas verdes de uso privado con incidencia de las sombras. En un estudio previo, se

identificó la falta de asoleamiento en algunas de las unidades habitacionales, producto de las sombras desplegadas por el mismo conjunto en un periodo definido entre enero y junio (Vergara, 2015). El presente estudio complementa dichos resultados con el estudio del efecto de estas sombras en otras fechas relevantes (solsticio de verano y equinoccio de primavera) y ahonda en los efectos de dichas obstrucciones solares.

Figura 1. Vista del conjunto residencial de torres y su contexto inmediato

El primer objetivo fue establecer parámetros y relaciones entre las variables morfológicas de las construcciones en altura y el impacto solar generado en su contexto inmediato de viviendas unifamiliares y equipamiento. En detalle, se plantea el levantamiento de los datos planimétricos y cartográficos tanto del conjunto como de su contexto, con un alcance aproximado de una manzana a la redonda, con el fin de levantar un modelo 3D representativo de los edificios mediante la herramienta Sketchup (Trimble, 2022). Se analiza el tamaño, trayectoria y despliegue de las obstrucciones solares generadas a través de la herramienta de simulación Sun Path (Marsh, 2022) para los solsticios y equinoccios. De esta manera, se observa el despliegue, la proyección de sombra en su mínima y máxima extensión, correspondiendo a situaciones de verano e invierno, respectivamente.

En segunda instancia, el impacto de las sombras entre torres a las unidades al interior del conjunto se realizó simulando las unidades en la parte más baja (piso 2), media (piso 9) y alta (piso 18). Se modelaron dos de las cuatro torres, una en situación de borde (torres A) y la otra interior (torre B) con impacto de sombras en sus dos fachadas. A través de la simulación vía Sefaira (Trimble, 2022), se simulan las unidades habitacionales de esos pisos, exceptuando circulaciones interiores y *shafts*, de manera que se obtiene el detalle de las condiciones lumínicas interiores solo de los departamentos.

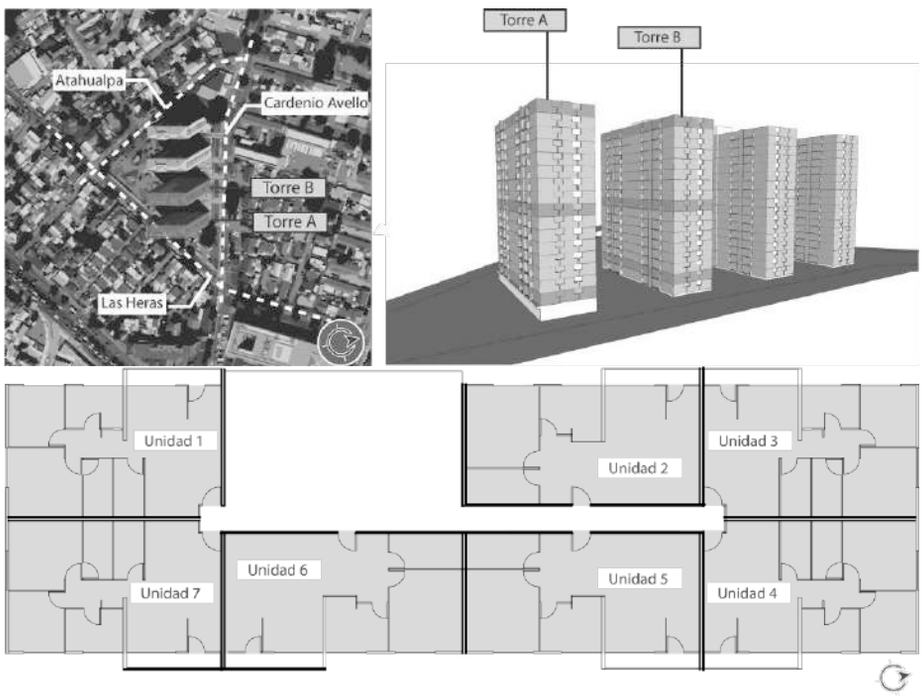


Figura 2. Vista en planta del conjunto residencial de torres y su contexto inmediato (izquierda), y modelos identificando las torres A y B (derecha). Planta tipo (abajo)

Se realiza un análisis comparativo de la situación real con la situación hipotética sin obstrucciones, de manera que se cuantifique el impacto de las sombras intertorres, representado en dos métricas de análisis: autonomía de iluminación natural (Spatial Daylight Autonomy [sDA]) y la exposición de solar anual (Annual Sunlight Exposure [ASE]). sDA describe cuándo un espacio recibe suficiente iluminación natural, específicamente el porcentaje de la superficie que recibe, al menos 300 lux, el 50% anual de las horas de ocupación típicas. ASE describe cuándo un espacio recibe mucha luz directa que pueda causar incomodidad visual (problemas de encandilamiento); específicamente, mide el porcentaje de la superficie que recibe, al menos 1000 lux, 250 de las horas de ocupación por año. Los niveles de autonomía (sDA) se alcanzarían con un mínimo del 50%, mientras que los de ASE con un máximo del 10%.

2 Resultados

2.1 Conos de sombra en el contexto inmediato

El cono de sombra generado por las torres abarca aproximadamente 50 000 m^2 (cinco veces el área del predio que las contiene). En los horarios que alcanzan una mayor longitud, los conos se extienden aproximadamente hasta en 130 m en verano y 200 m en invierno.

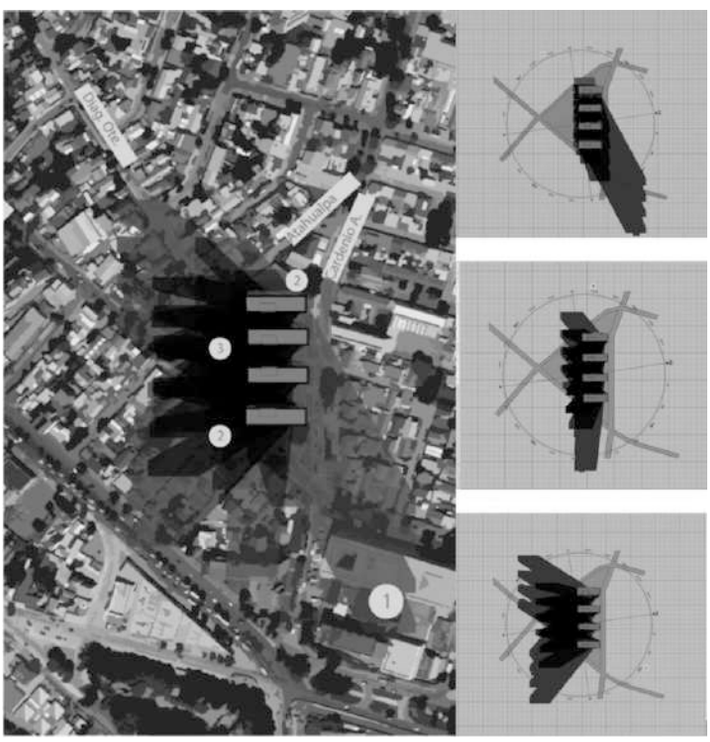


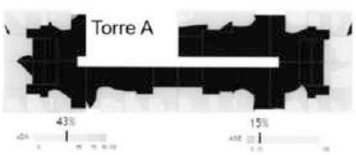
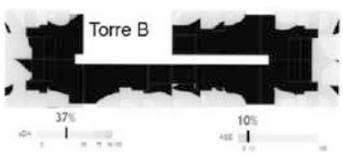
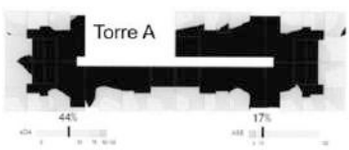
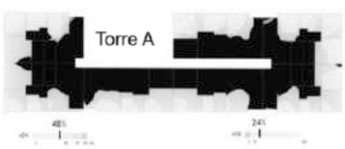
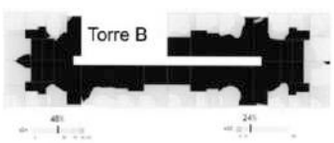
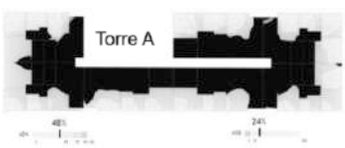
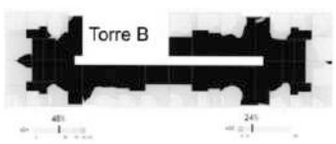
Figura 3. Estudio de conos de sombra, elaborado mediante la herramienta *online* Sun Path. Se realiza un conglomerado de los resultados arrojados por dicha herramienta entre las 9 y 18 horas, en intervalos de 90 minutos, para el solsticio de verano, equinoccio, y solsticio de invierno, respectivamente.

Las sombras recaen sobre (1) equipamiento de salud (hospital); (2) equipamientos educacionales (una escuela de lenguaje y una escuela básica); (3) tres calles circundantes, áreas públicas y recreativas correspondientes al área verde propia del condominio; (4) viviendas unifamiliares de las cuadras circundantes; y (5) unidades de departamentos afectadas por las obstrucciones debido a su proximidad entre sí. En cuanto a espacios residenciales, las sombras recaen sobre 456 viviendas, de las cuales 363 pertenecen al mismo conjunto habitacional.

2.2 Iluminación natural

Los resultados del desempeño de iluminación natural de las torres para la situación actual (real) y la hipotética (sin torre vecina) son ilustrados en la tabla 1. Se observa que la situación hipotética es igual a la de los pisos superiores en ambas torres. Esto debido a que aquellos pisos no se ven afectados por obstrucciones. La torre A ve disminuido su sDA hasta 5% en pisos inferiores por la influencia de la torre vecina. La torre B ve reducido su SDA en 11% en pisos inferiores por la sombra producida por sus dos torres vecinas.

Tabla 1. Resultados de sDA y ASE para los pisos 2, 9 y 18 de las torres A y B (situación real) y situación hipotética (igual a piso 18 de ambas torres), basados en análisis de Sefaira

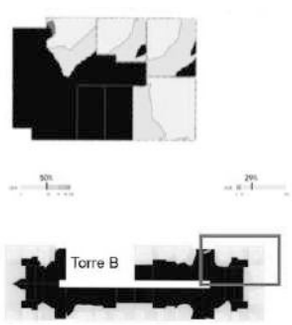
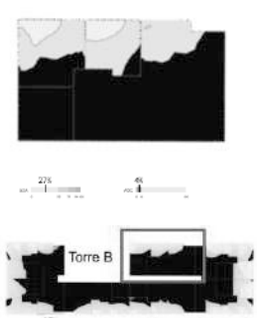
	Situación real, torre A	sDA	ASE	Situación real, torre B	sDA	ASE
Piso 2		43%	15%		37%	10%
Piso 9		44%	17%		40%	14%
Piso 18		48%	24%		48%	24%
	Situación hipotética (sin torres vecinas)	**sDA**	**ASE**	**Situación hipotética** (sin torres vecinas)	**sDA**	**ASE**
		48%	24%		48%	24%

Underlit / baja iluminación Overlit/sobre iluminación

En una segunda instancia, se identifican las unidades residenciales que presentan el mejor y peor desempeño en cuanto a autonomía de iluminación

natural, las cuales se encuentran en el piso más alto y el más bajo, respectivamente. La tabla 2 ilustra unidades representativas de ello. Con orientación norte, en los pisos más altos, se encuentran las unidades que tienen el nivel más cercano a la autonomía de luz natural, en este caso la unidad 3 del piso 18, con sDA del 50%, aunque con un ASE dle 29%. La unidad de orientación poniente en el piso más bajo (unidad 2, piso 2) resultó con sDA del 27% y ASE del 4%.

Tabla 2. sDA y ASE para las dos unidades residenciales de las torres en estudio, basados en situación actual y resultados del análisis lumínico en Sefaira en una síntesis anual

Mejor autonomía [Unidad 3, piso 18]	**sDA**	**ASE**	**Peor autonomía** [Unidad 2, piso 2]	**SDA**	**ASE**
	50%	29%		27%	4%

Underlit / baja iluminación Overlit/sobre iluminación

3 Discusión

El cono de sombra del conjunto de torres sobre su contexto inmediato afecta el acceso solar de 456 viviendas, así como del equipamiento de salud y educacional. Esto resulta especialmente preocupante, considerando los beneficios del sol asociados a la salud y regulación de ciclos biológicos y de bienestar. Además, se produce una privación al acceso a la radiación solar para calefacción pasiva, control de la humedad al interior de las viviendas, secado de ropa o simplemente acceso a vitamina D, además de sus implicancias en iluminación natural. Finalmente, el cono de sombra implica la pérdida energética activa al bloquear la radiación solar sobre algunos paneles solares ya existentes en techumbres. La afección alcanza su mayor despliegue en los meses de invierno, periodo donde el acceso a los beneficios solares resulta más preciado.

En cuanto a las condiciones lumínicas de los pisos analizados, se pueden observar diferencias en la autonomía de iluminación (sDA) de entre 1 y 8 puntos porcentuales. Los pisos superiores de las torres tienen igual desempeño que el caso hipotético al no ser afectados por los conos de sombra. Estos alcanzan un sDA del 48% (22% debajo del mínimo) y un ASE del 24% (14 puntos porcentuales sobre el máximo). Se puede estimar que la pérdida de autonomía en los pisos afectados es 8 puntos porcentuales a la mitad de la torre (piso 9) y en 11 puntos porcentuales en el piso más afectado por las sombras (piso 2). Si bien las sombras contribuyen al exceso de iluminación, el piso en su conjunto aún se encuentra sobre los niveles máximos, debido a la falta de un adecuado control lumínico de las unidades orientadas al norte. Se podría deducir con ello que hay potencialmente sobrecalentamiento en dichas situaciones.

Además, se refuerza que los departamentos ubicados hacia el centro de la torre (unidades 2, 5 y 6), y especialmente mirando hacia los edificios contiguos, son los más afectados por las sombras desplegadas, con autonomías menores, lo cual se traduce en mayor dependencia a la iluminación artificial y, consecuentemente, consumo eléctrico.

En lo relativo a la exposición solar anual (ASE), los resultados muestran que la obstrucción generada por las torres contiguas ejerce el control de la exposición a la luz directa. Esto ocurre a costo de la autonomía de iluminación solar y el consecuente acceso a radiación solar directa. En este sentido, si bien Cárdenas (2016) refuerza la idea de que las obstrucciones solares no necesariamente son negativas, al ayudar a controlar situaciones de sobreiluminación en los espacios habitables, el hecho de que esta especie de “control solar” generado por los edificios en altura sea permanente e inamovible ocasiona más problemas que beneficios. En este sentido, el problema de la sobreiluminación de los espacios podría ser controlado a través de un diseño de fachada eficiente que permita tamizar la luz natural, más allá de bloquearla completamente.

Finalmente, las unidades identificadas con el mejor y peor desempeño en cuanto a la autonomía de iluminación se encuentran en el piso más alto y el más bajo, respectivamente. Las unidades con orientación norte, en los pisos más altos, tienen el nivel más cercano a la autonomía de luz natural con el 50%, aún están con un ASE del 29%, 19 puntos porcentuales sobre el máximo. En este caso, el exceso de iluminación podría ser controlado por sistemas de control en fachada. La unidad con el peor desempeño de autonomía resultó con un sDA del 27%, 23 puntos porcentuales bajo el mínimo debido a la obstrucción de la torre vecina, aunque esta le provee del control para exceso de iluminación con ASE del 4%. En estos casos, no hay posibilidades de

mejorar las condiciones por tratamientos de fachadas, al existir un bloqueo exterior producido por las torres vecinas.

4 Conclusión

Este estudio explora el alcance y las consecuencias de la verticalización en relación con el acceso solar e iluminación natural. El análisis del caso de estudio resulta emblemático, pues sus características de emplazamiento y morfología se han reiterado en varias ciudades del país. Puntualmente, el análisis de proyección de sombra y el estudio de su despliegue han permitido concluir que los perjuicios en el acceso solar no se limitan solo al espacio circundante, como las viviendas de menor altura y el equipamiento a su alrededor, sino que también generan obstrucciones y privaciones de los beneficios solares dentro del mismo conjunto habitacional y sus áreas verdes.

Respecto a las condiciones lumínicas al interior del conjunto, se determinó que ninguna de las unidades analizadas alcanza ni la autonomía con luz de día ni el confort asociado al exceso de iluminación. Si bien las torres vecinas pueden favorecer al control de la exposición a la luz solar evitando problemas de deslumbramiento, esto no constituye una solución apropiada; ya que, de todas maneras, ninguna de las unidades logra alcanzar los niveles de autonomía de iluminación. Esto implica que muchas de las unidades dependerían de la iluminación artificial, creando un costo energético que podría haber sido evitable.

El diagnóstico de estas problemáticas, tanto al interior como al exterior del condominio refuerza la necesidad de replantear la forma en que crecen las ciudades, en un contexto de búsqueda de vías sostenibles, donde la densificación pueda ser desarrollada más consciente y planificadamente. Además, resulta imperativo desarrollar nuevas regulaciones que complementen las normativas asociadas al asoleamiento, y reconozcan de manera efectiva la importancia del acceso solar y la captación de este recurso. En este sentido, es contraproducente el hecho de fomentar, a través de discursos y financiamientos, la integración de colectores solares, junto con la necesidad de reducir el consumo energético (y, por consiguiente, reducir la huella de carbono), mientras no se entreguen garantías mínimas de acceso al sol.

Este diagnóstico, sin embargo, abre otras interrogantes que podrían trabajarse en estudios futuros, en especial la radiación solar afectada tanto fuera como al interior de las torres, el costo monetario que significa la dependencia a la luz artificial y consumo energético, así como el alcance en términos de confort interior no solo relativo a la iluminación, sino también

integrando confort higrotérmico y aspectos cualitativos como la percepción de las personas.

Referencias

Cárdenas, L. & Uribe, P. (2012). Acceso solar a las edificaciones. El eslabón pendiente en la norma urbanística chilena sobre la actividad proyectual. *Revista de Urbanismo*, *26*, 21-41. https://revistaurbanismo.uchile.cl/index.php /RU/article/view/20922

Cárdenas, L., Vásquez, J. & Zamorano, J. & Acevedo, C. (2016). Explorando luz solar en modelos de desarrollo inmobiliario. Aplicaciones en cinco ciudades chilenas. *Revista de Urbanismo*, *34*, 158-173. http://dx.doi.org/10.5354/0717-5051.2016.40394

García, F. (2012). Densificación con criterios de soleamiento. Un método gráfico para el cálculo de áreas adecuadas para nueva edificación en entornos construidos en el caso de Zabalgana en Vitoria-Gasteiz. Trabajo presentado en el 11.° Congreso Nacional del Medio Ambiente. España. https://repositorio.upct.es/bitstream/hand le/10317/3108/dcs.pdf?sequen ce=1&isAllowed=y

Gómez, J. & Mesa, A. (2017). Determinación de densidades urbanas sostenibles en base a metodología relativa al acceso solar: caso área metropolitana de Mendoza, Argentina. *Revista de Urbanismo*, *36*, 131-145. http://dx.doi.org/10.5354/0717-5051.2017.44367

Inzulza, J., Vargas, K. & Wolff, C. (2017). Acceso solar: un derecho urbano para la calidad de vida vulnerado desde la gentrificación contemporánea. El caso de la comuna de Estación Central, Chile. *Revista 180*, *39*, 1-15. http://www.revista180.udp.cl/index.php/revista180/article/view/283

Knowles, R. (2003). The solar envelope: its meaning for energy and buildings. *Energy and buildings*, *35*, 15-25. https://doi.org/10.1016/S0378-7788(02)00076-2

Marsh, A. (2022). 3D Sun Path. Plataforma virtual. http://andrewmarsh.com/a pps/staging/sunpath3d.html

Ministerio de Obras Públicas y Vías de Comunicación. (1949). Decreto 884. Reemplaza Ordenanza General de Construcciones. Ministerio de Obras Públicas y Vías de Comunicación. Chile. http://bcn.cl/317yz

MINVU. (2020). Ordenanza General de Urbanismo y Construcciones. Ministerio de Vivienda y Urbanismo. Chile. https://www.minvu.cl/wp-content/uploads/2019 /05/OGUC-Junio-2020-D.S.-N°32-D.O.-13-06-2020

Muñoz, M. (1995). El plan regulador de Concepción - 1960. *Arquitecturas del Sur*, *12*, 22-28. http://revistas.ubiobio.cl/index.php/AS/article/view/937

Pérez, L., González, G., Villouta, D., Pagola, L. & Ávila, C. (2019). Procesos de reestructuración y verticalización en el Centro de Concepción: Barrio Condell. *Revista de Urbanismo*, *41*, 1-17. http://dx.doi.org/10.5354/0717-5051.2019.53926

Trimble. (2022). Sefaira for Sketchup. Extensión de *software*. https://www.sketchup.com/es/product s/sefaira

Vergara, D. (2015). *Estudio de sombra en edificación habitacional de altura en Concepción para comprobar la factibilidad de la ordenanza en ámbito de iluminación*. Seminario de Arquitectura. Facultad de Arquitectura, Urbanismo y Geografía. Universidad de Concepción.

The effect of façade curvature and surrounding building heights on pedestrian-level wind speeds in the City of London

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Abstract. This paper analyses the effect of façade curvature with varying the surrounding building heights on pedestrian-level wind speeds and comfort for walking, using computational fluid dynamics. The case study focuses on 20 Fenchurch Street site in London as several complaints have risen in relation to high wind speeds, the cause of which is not thoroughly understood. The results of the simulation revealed that although the increase of surrounding building heights reduces overall pedestrian-level wind speeds for both curved existing and cuboid building, façade curvature impacts differently on winds, compared to the cuboid. Isolated curved and cuboid building would perform similarly with the exception of the northwest corner. However, introducing the existing surrounding buildings, the curved façade geometry would create larger area of walking discomfort compared to the cuboid geometry. When the height of the surrounding buildings is increased, both buildings would perform similarly with minor aerodynamic advantage to the curved-façade.

Keywords: Building Performance, Wind Microclimate, Tall Building, Surroundings, Pedestrian-level Wind Speeds.

1 Introduction

The previous literature and research of building aerodynamics did not explain the impact of curved façades on pedestrian-level winds (PLW). Many studies provided information about the relation of building geometry to PLW and comfort such as Druenen et al. (2019), Shirzadi and Tomingaga (2021) which investigated the effect of building geometry on PLW speeds and comfort. However, these studies were carried out with the perpendicular building façades. Moreover, Zhang et al. (2020) investigated the impact of a tall building on PLW comfort with an urban-like setting. They provided fundamental understanding of the influence of tall buildings on PLW comfort, however, the

simplified urban form was not representative of the complicated urban configurations in a real physical world. Furthermore, several studies replicated real urban conditions (Kubota et al., 2008; Tsichritzis & Nikolopoulou, 2019). They showed the relationship between urban parameters (plan area ratio and façade area ratio) and winds, however, the parameters were quite generalised and could not provide information as to which building geometry caused wind accelerations at pedestrian level. To address some of the limitations of previous studies, this paper has assessed the effect of façade curvature with surrounding building heights on PLW speeds and comfort for walking in a real urban condition. As walking is a main trip method, being recorded as the highest number of trips (5.5 – 6.7 million) from 2000 to 2018 among others (cycle, car, bus, underground, rail, etc.) in Greater London, according to Mayor of London (2019), this study focused on wind comfort for walking.

Computational Fluid Dynamics (CFD) simulations were used to run four conditions: 1) Isolated building, 2) Real urban context with the existing surrounding buildings, and 3) A building surrounded by the same existing buildings with increased height up to 50% and 4) 100% of the target building. South-westerly wind direction (225°) was the input as it is the prevailing wind direction for London with a probability of 26.5% in winter. As this study focuses on PLW comfort, wind speed is considered as the main environmental parameter that is relevant to the mechanical effect of winds. Two parameters, the average and threshold wind speed ratio for walking comfort, were represented to assess the effect of façade curvature and surrounding building heights on PLW speeds.

2 Methodology

2.1 Computational Setup

The CFD simulations were carried out using OpenFOAM (v.9) software. Reynolds-averaged simulation with the k-ϵ realizable turbulent model was implemented with the semi-implicit method for pressure-linked equations algorithm. Computational domain was setup in an octagonal shape (Figure 1).

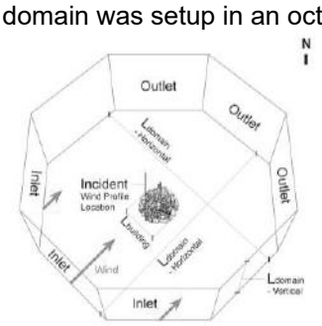
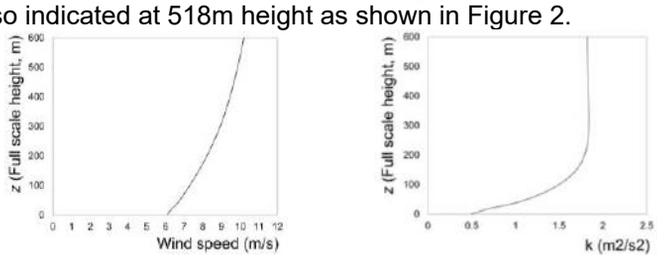


Figure 1. Computational domain

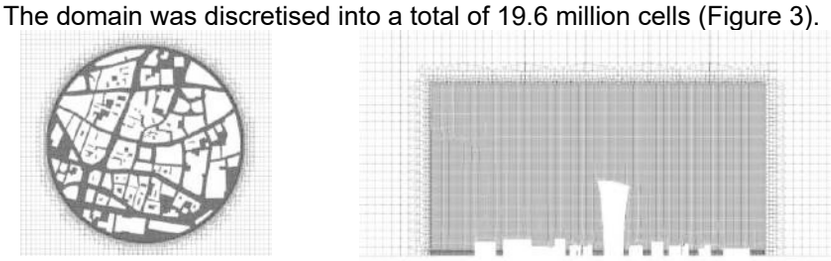
In order to avoid artificial acceleration by blockage due to computational walls, the dimensions of the domain were setup with a directional blockage ratio that is less than 3% (Blocken, 2015). An atmospheric boundary layer profile was setup as an inlet with aerodynamic roughness length (Z_0) of 2m (Wieringa, 1992) reference height (Z_∞) is 518m (Davenport, 1963), and reference wind speed (U_∞) is 10 m/s based on the best practice standards of external aerodynamic studies. From the empty domain, the profiles of wind speed and turbulent kinetic energy (k) at the incident location (refer to Figure 1) are represented in Figure 2. The reference wind speed, U_∞ from the inlet maintained its shape with potential flow reaching 10m/s (rounded to the nearest ones) is also indicated at 518m height as shown in Figure 2.



a. Wind speed profile b. Kinetic energy (k) profile

Figure 2. The profiles of wind speed (a), and kinetic energy profile (b) at the incident location at an empty computational domain

The domain was discretised into a total of 19.6 million cells (Figure 3).



Plan View Section View

Figure 3. Structural mesh

The CFD results were validated against wind tunnel measurements made by Architectural Institute of Japan (Yoshie et al., 2007) and on-site monitoring with a mobile weather station.

2.2 Test Geometries and Urban Forms

To analyse the effect of building heights on pedestrian-level wind speeds, three-dimensional computational models were setup as follows:

1) An isolated building condition with the existing (convex/concave) and a cuboid target building as shown in Figure 4. This simulation will serve as the baseline without the influence of surrounding buildings characterize the pure aerodynamic performance of each geometry.

2) The existing and cuboid target building with the existing urban context of CoL (see Figure 5).
3) The existing and cuboid building with increased surrounding building height to 50% (see Figure 6) and 100% of the target building (see Figure 7).

Figure 4. Existing (left) and cuboid target building (right)

Figure 5. Existing (left) and cuboid target building (right) with existing surrounding buildings

Figure 6. Existing (left) and cuboid target building (right) with surrounding buildings at 50% height

Figure 7. Existing (left) and cuboid target building (right) with surrounding buildings at 100% height (bottom)

As this study focuses on the effect of buildings height on PLW speeds, detailed parts of the buildings, such as canopies, podiums, and roof shapes were simplified for the scope of this study.

2.3 Buildings and Urban Configuration Performance Analysis Technique

To assess the wind speed at pedestrian level areas surrounding the main building, five zones were chosen as shown in Figure 8.

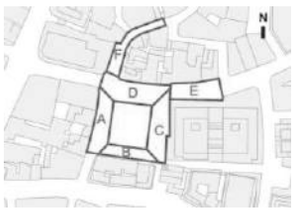


Figure 8. Analysis zones A – F

All wind speeds are represented as ratios (U) in accordant with Equation 1:

$$U = \frac{U_0}{U_\infty} \quad (1)$$

U_0 (m/s) is defined as the local wind speed at 1.5m above ground level and U_∞ is the reference wind speed, 10 m/s at 518m above ground level.

2.4 Average (U_{ave}) and threshold wind speed ratio for walking (U_{tw})

To assess U, two parameters were used, the average (U_{ave}) and the area (%) that exceeds threshold wind speed ratio for walking (U_{tw}). U_{ave} is the mean value of U at 1.5m above ground level. U_{tw} is defined as the threshold of U that can cause discomfort for walking. For this study, U_{tw} is quantified using the Weibull distribution obtained from the City of London (CoL) wind microclimate guidelines (City of London and RWDI, 2019).

The 36 Weibull parameters obtained from the CoL guidelines were initially converted to 8 for this study (see Table 1) where parameters *p, c,* and *k* are the probability, scale and shape factors respectively. It should be noted that this study shown in the present paper is a part of a larger investigation that assess a building and the urban form on all 8 wind directions instead of 36 directions, hence the conversion was made.

Table 1. Weibull parameters in winter for 8 wind direction (45° increments)

Direction	N	NE	E	SE	S	SW	W	NW
p	0.081	0.094	0.086	0.064	0.134	0.265	0.193	0.087
c	4.73	6.01	6.40	5.23	6.65	7.60	6.75	5.24
k	1.54	1.93	2.02	1.97	1.83	2.00	1.72	1.61

Moreover, to calculate U_{tw} for this study, the equation for PLW comfort (2) was used:

$$f(x) = P \cdot e^{-\left(\frac{x}{U_{tw} \cdot 1.42 \cdot c}\right)^k} \quad (2)$$

Where $f(x)$ is the probability of exceedance for the season, x is wind speed threshold value for the activity. Since this study is concerned with walking that is when 8 m/s mean velocity exceeds 5% of the time, it is considered uncomfortable according to the CoL Guidelines. Therefore, $f(x)$ is capped to 0.05 (i.e. 5%) and x is 8 (m/s). U is wind speed ratio (refer to Equation 1), 1.42 is the reference height scale factor that is interpolated in accordance with the CoL Guidelines to match the reference height (518m) used in the simulations. Note that $f(x)$ is the sum of probability considering all wind directions (i.e. all 8

angles). However, this study focuses on the prevailing SW wind direction only and therefore should the probability exceed 5% it would indicate discomfort without testing other angles. The contribution of other angles would increase the probability and worsen the comfort which is important in more detailed investigations. When the parameters for SW in Table 1 are substituted into Equation 2, and the equation is solved for U_{tw} would therefore be:

$$U_{tw} = 8 \cdot (1.42 \cdot 7.60 \cdot \sqrt{-\log_e \frac{0.05}{0.265}})^{-1} \quad (3)$$

Hence, 0.57 (rounded to the nearest hundredth) is U_{tw} that can cause walking discomfort from one wind direction.

3 Results

3.1 Average wind speed ratio (U_{ave}) and PLW patterns

The average wind speed ratio (U_{ave}) for zones A – F are represented in Figures 9. In the isolated tall building condition, overall U_{ave} of the existing and cuboid buildings show similar values. However, at zone A, U_{ave} of the existing building is slightly higher than the cuboid building.

Figure 10 shows the contours of wind speed ratio (U) at 1.5m above ground level. Higher U appears to occupy a larger area of zone A for the existing building due to the convex façade compared to the cuboid. In addition, a larger wake occurs in zones B and C for the existing building than the cuboid (Figure 10). These variations in velocities are due to the western convex façade of the existing building which pushes the fast-moving air slightly farther to the north west direction than the cuboid thus creating a larger wake.

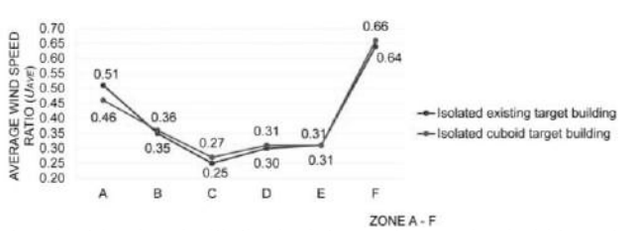


Figure 9. U_{ave} at pedestrian level with the isolate existing and cuboid target building

Figure 10. U at pedestrian level by an isolated existing and cuboid building

With the existing surrounding buildings introduced, the existing target building accelerated the wind marginally more than the cuboid building at zones A (the westerly frontal area), C, D and F (the wake area of the buildings) (Figure 11).

The underlining accelerations at the corners remained visible at zones C and D for both the existing and cuboid buildings (Figure 12). These accelerations were due to the convex angle of the western façade of the existing target building which created a narrower channel for the wind thereby causing higher corner acceleration with a stronger venturi effect than the cuboid (where the channel remained uniform). The curvature of the south façade of the existing target building also caused a stronger flow separation at the south-eastern corner creating a longer stream of higher-speed winds at zone C than the cuboid building.

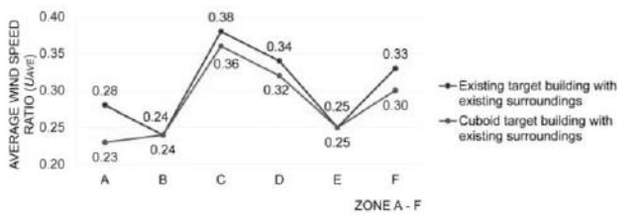


Figure 11. U_{ave} at pedestrian level with the existing and cuboid target building with existing surrounding buildings

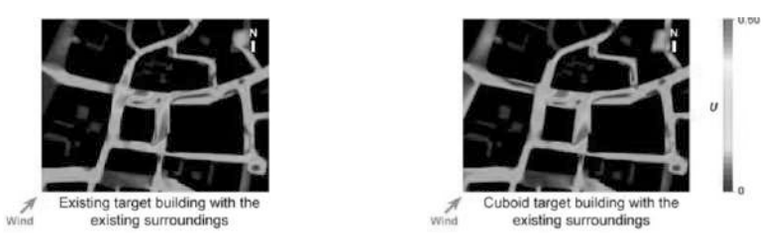


Figure 12. U at pedestrian level in existing and cuboid target building with existing surrounding buildings

When target buildings were surrounded by buildings of 50% height, the wind speed became higher for the cuboid compared to the existing target building at B, D, E, and F although at zone B and E the differences of wind speed were minor between the two buildings (Figure 13). At zone A, the wind speed was slightly higher for the existing target building compared to the cuboid.

Figure 14 shows the velocity contours for the 50% height case. Due to the increase in surrounding buildings height to 50% of the target building, the fast-moving wind flows above buildings to the west of the target reducing the amount of high speed winds reaching pedestrian level. Thereby, the venturi effect minimised compared to the existing case condition where the surrounding buildings were shorter (see Figure 12). Moreover, the convex geometry in the direction of the flow is more streamlined with lesser frontal area facing the wind direction compared to the cuboid. As such less wind is being channelled to

pedestrian level to the west of the target building. This effect is, however, reversed on the southern façade as the flow separates at the south-eastern corner and interacts with the western elevation of the building to the east before accelerating to ground level.

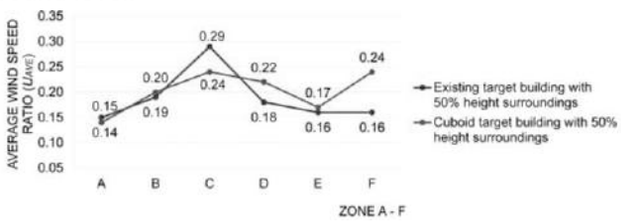


Figure 13. U_{ave} at pedestrian level with the existing and cuboid target building surrounded by 50% height buildings

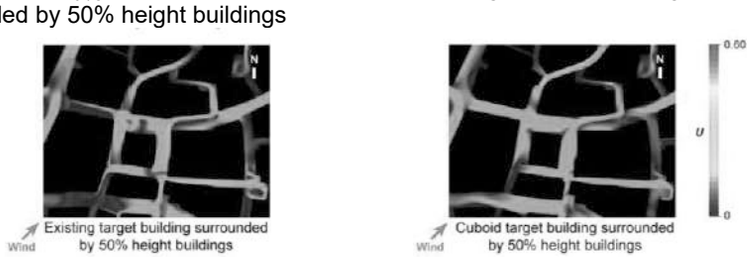


Figure 14. U at pedestrian level with existing and cuboid target building surrounded by 50% height buildings

When the surrounding buildings are the same height of the existing building (160m tall), overall, the cuboid-shaped tall building would generate slightly faster winds at pedestrian level, except for zone F (Figure 15).

Looking at the U patterns at pedestrian level shown in Figure 16, the sheltering effect provided by the surroundings would reduce the overall wind speed. As the overall wind speed decreases, both geometries generated similar flow pattern at zones A to F. However, the cuboid building generates slightly higher-speed winds than the existing target building as the upper part of the target building (defined by the convex shape at the east and west) reduced the amount of high wind speeds from moving down to pedestrian level in comparison to the cuboid.

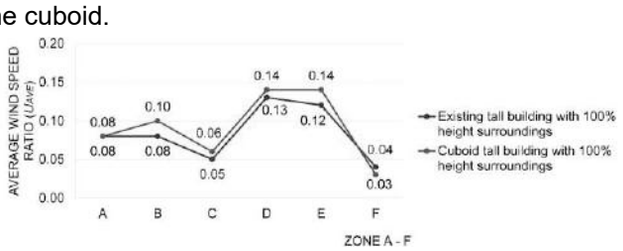


Figure 15. U_{ave} at pedestrian level with the existing and cuboid target building surrounded by 100% height buildings

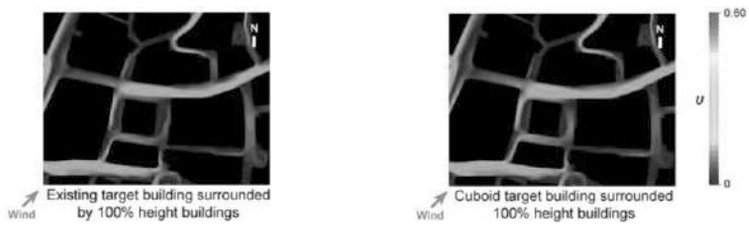


Figure 16. U at pedestrian level with existing and cuboid target building surrounded by 100% height buildings

Figure 17 shows the summary of results, representing the relationship between façade curvature of a target building with surrounding building heights and PLW speeds. It shows the trends that as the heights of surrounding buildings become taller (without the surroundings, with the existing, 50%, and 100% height surroundings), the overall wind speeds decreased over the zone A – F, except for zone C and D between the isolated and existing surrounding conditions. From this trend, however, the curved existing and cuboid target building generated the different wind speeds as follows: 1) In the isolated condition, the existing target building performed marginally better than the cuboid at B, C, D, E, and F with generating slightly lower-wind speeds. 2) With the existing surroundings, the cuboid worked better at A, C, D, and F. 3) With the surrounding buildings at 50% height of the target building, the existing target building would be favourable to a slight extent than the cuboid at B, D, E, and F. 4) With the surrounding height of 100% of the target building: the existing target building had minor advantages with creating slightly lower-moving flows than the cuboid at B, C, D, and E.

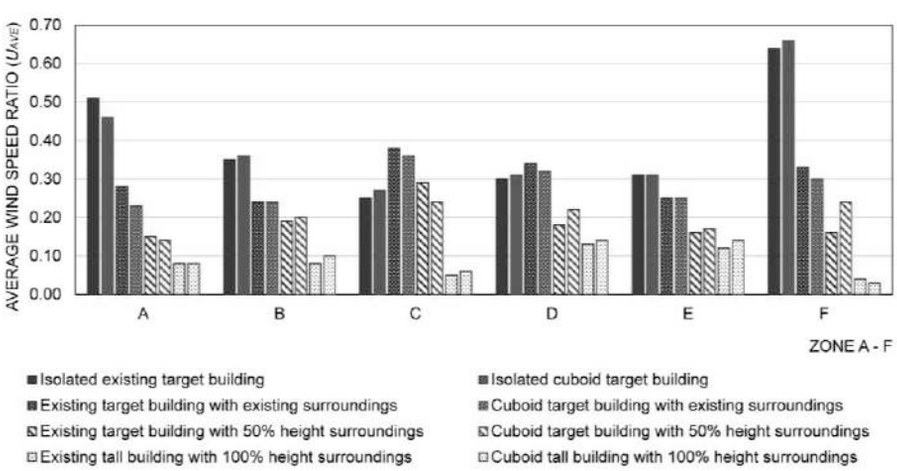


Figure 17. The summary of the results showing the relationship between façade curvature with the surrounding building heights and U_{ave} at 1.5m above ground level of zone A - F

3.2 Threshold U for walking discomfort (U_{tw})

Figure 18 indicate the walking discomfort zone for each tested building in isolation. At the northwest corner, the existing building generates a larger walking discomfort zone in comparison to the cuboid. This is because the convex angle of the west façade creates higher wind speeds than the perpendicular angle. However, the concave angle of the south façade of the existing building performed similarly to the perpendicular angle of the cuboid, having similar discomfort zone. The free shear area of both buildings show similar patterns.

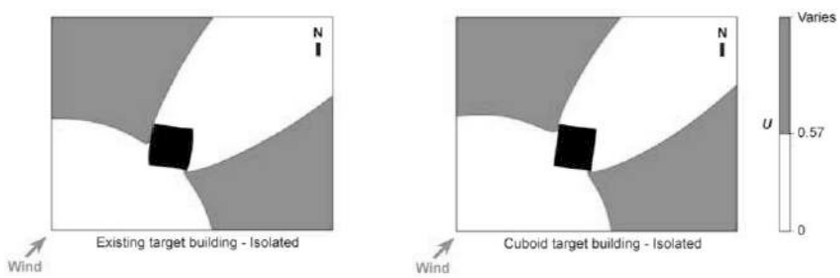


Figure 18. Areas over U_{tw} (0.57) with the existing (left) and cuboid (right) target building in the isolated condition

Introducing existing surroundings created different areas of walking discomfort between the existing and cuboid target building (see Figure 19). Overall, the walking discomfort areas decreased in comparison to the isolated condition. However, the cuboid performed better, inducing the smaller area of walking discomfort.

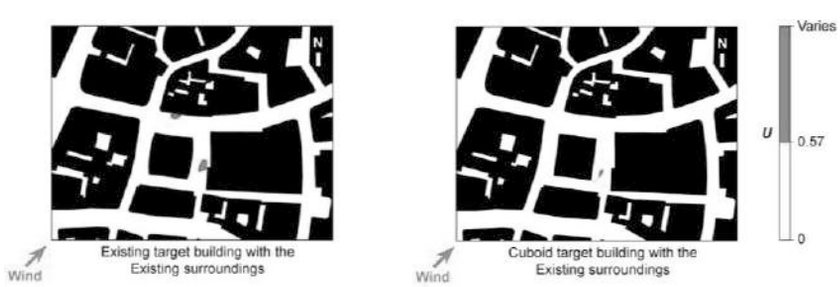


Figure 19. Areas over U_{tw} (0.57) with the existing (left) and cuboid (right) target building with the existing surroundings

When the height of the surrounding buildings is 50% and 100% of the existing building, all discomfort zones are eliminated.

4 Conclusions and Contributions

This paper presents the effect of façade curvature with surrounding building heights on pedestrian-level winds by CFD simulations. The summary of new findings are as follows: although overall PLW speeds are decreased as the surrounding building heights become taller, the existing and cuboid target building generate different PLW speeds, based on the curvature of building facades. In the isolated condition, the existing target building performs marginally better than the cuboid as the convex façade rather pushes away the fast-moving winds and creates larger wake zones. When the existing surrounding buildings are introduced, the cuboid works better. This is because the curvature of the existing target building causes higher corner acceleration due to the stronger venturi effect at the north west corner, and the longer stream of higher-speed winds at the south-eastern corner because of the flow separation than the cuboid. As the heights of surrounding buildings become 50% height of the target building, the venturi effects are minimised due to the overflow of the fast moving winds, compared to the existing condition. The curved existing target building would be slightly favourable than the cuboid. This is because the convex facade at the west side makes the frontal area to be reduced in comparison to the cuboid, and thereby, less winds were channelled. But this effect is reversed at the south façade as the flow separation occurred at the south-eastern corner. When the surrounding buildings are the same height as the existing building, the existing target building shows minor advantage because the convex façades make less amount of fast-moving winds to reach to the pedestrian level. Thus, slightly lower-speed winds occurs compared to the cuboid.

Examining the effect of façade curvature with surrounding building heights on wind comfort for walking, in the isolated building condition, the convex geometry of the existing target building at the west side generates larger discomfort zone than the cuboid. With the existing surroundings, the cuboid worked better, creating less area of discomfort zone for walking than the existing target building. As the surrounding building heights become 50% and 100% of the target building, discomfort zones are eliminated.

Whilst this paper focused on the CoL, as the study examined the interactions between façade curvature and surrounding building heights, it is relevant to the building in the other cities, in particular, of which urban forms are not in grid layouts but in curvy shapes and close proximities. The investigations in this paper is a part of the study that covers the wind effects, affected by various geometries of an isolated building (cuboid, pyramid, constant, and inconstant-angled facades) and the tall buildings in an urban context.

References

Blocken, B. (2015). Computational Fluid Dynamics for urban physics: Importance, scales, possibilities, limitations and ten tips and tricks towards accurate and reliable

simulations. Building and Environment, 91, 219-245. https://doi.org/10.1016/j.buildenv.2015.02.015

City of London and RWDI. (October 1, 2019). City of London Wind Microclimate Guidelines. Retrieved February 1, 2021, from https://www.cityoflondon.gov.uk/assets/Services-Environment/wind-microclimate-guidelines.pdf

Davenport, A. G. (1963). The relationship of wind structure to wind loading. Wind effects on buildings and structures conference (pp. 54-111). National Physical Laboratory. Retrieved September 13, 2022, from https://www.aivc.org/resource/relationship-wind-structure-wind-loading

Druenen, T.V., Hooff, T.V., Montazeri, H., & Blocken B. (2019). CFD evaluation of building geometry modifications to reduce pedestrian-level wind speed. Build. Environ., 163 (106293). https://doi:10.1016/j.buildenv.2019.106293

Kubota, T., Miura, M., Tominaga, Y., & Mochida, A. (2008). Wind tunnel tests on the relationship between building density and pedestrian-level wind velocity: Development of guidelines for realizing acceptable wind environment in residential neighborhoods. Building and Environment, 43 (10), 1699-1708. https://doi.org/10.1016/j.buildenv.2007.10.015

Mayor of London. (2019). Travel in London, Report 12. Retrieved February 8, 2022, from https://content.tfl.gov.uk/travel-in-london-report-12.pdf

Shirzadi, M. & Tominaga, Y. (2021). Multi-fidelity shape optimization methodology for pedestrian-level wind environment. Build. Environ., 204 (108076). https://doi:10.1016/j.buildenv.2021.108076

The OpenFOAM Foundation. (2022). OpenFOAM (version 9) [Computer software]. https://openfoam.org/version/9/

Tsichritzis, L. & Nikolopoulou, M. (2019). The effect of building height and façade area ratio on pedestrian wind comfort of London. Journal of Wind Engineering & Industrial Aerodynamics, 191, 63-75. https://doi.org/10.1016/j.jweia.2019.05.021

Yoshie, R., Mochida, A., Tominaga Y., Kataoka, H., Harimoto, K., Nozu, T., & Shirasawa, T. (2007). Cooperative project for CFD prediction of pedestrian wind environment in the Architectural Institute of Japan. Journal of Wind Engineering and Industrial Aerodynamics, 95, 1551-1578. https://doi.org/10.1016/j.jweia.2007.0

Wieringa, J. (1992). Updating the Davenport roughness classification. Journal of Wind Engineering and Industrial Aerodynamics, 41, 1-3, 357-368. https://doi.org/10.1016/0167-6105(92)90434-C

Zhang, X., Weerasuriya, A.U., Zhang, X., Tse, K.T., Lu, B., Li, C.Y., & Liu, C. (2020). Pedestrian wind comfort near a super-tall building with various configurations in an urban-like setting. BUILD SIMUL, 13, 1385-1408. https://doi.org/10.1007/s12273-020-0658-6

Design, Nature and Ecosystems: Bio-Inspired Design

Biodigital Product Design Through Additive Fabrication Technologies: Stool Project

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Abstract. Designers and architects have widely used references from nature for their projects; bioinformed design has had a significant evolution in recent decades, largely thanks to digital technologies advantages, especially digital fabrication and parametric software. This text presents the process of design, experimentation and materialization of a stool based on three-dimensional patterns extracted from nature. The project followed this methodological sequence (1) Selection of biological referents (2) Morphologic synthesis (3) Compression test (4) Analysis of thicknesses and stress (5) Fabrication of 1:1 scale prototype through Fused Deposition Modelling technology -FDM- (6) User testing (7) Conclusions and improvement proposal. The 1:1 scale prototype fabrication process presented various challenges in terms of dimensions, printing times and costs. Finally, the prototype demonstrated that it is possible to materialize functional and resistant objects through FDM; the proposed goals were achieved in the context of a valuable experience, as a result of a transdisciplinary collaboration.

Keywords: biomimicry, biodigital design, parametric design, additive fabrication technologies, fused deposition modelling technology

1 Introducción

Profesionales de las disciplinas proyectuales han usado ampliamente referentes de la naturaleza para sus propuestas de diseño. La denominación biónica fue introducida por el doctor coronel Jack E. Steele en 1960 en una investigación comparativa entre los sistemas naturales y sintéticos en la United Air Force de los Estados Unidos (Villamil & Otálvaro, 2019). Benyus y García (2012) definen la biomimética como una ciencia que estudia los modelos de la naturaleza para resolver problemas humanos con una aproximación sistémica. El diseño y la arquitectura biodigital emergen de una fusión entre las tecnologías digitales y las posibilidades de lo biológico, uniendo una variedad de conceptos como la naturaleza, los algoritmos, la cibernética, la genética y las matemáticas (Estévez, 2020).

Como una idea integradora, Iouguina *et al*. (2014) proponen el concepto de disciplinas bioinformadas, agrupando a todos los enfoques de diseño basados en la naturaleza para resolver problemas del ser humano con resultados sostenibles o no. A un nivel más específico, Gebeshuber y Drack (2008) diferencian dos enfoques para la biomimética: por analogía y por inducción. El método por analogía arranca desde el problema del ser humano para buscar referentes en la naturaleza y, finalmente, transfiere sus características a través de productos o sistemas. El método por inducción empieza desde el estudio de un fenómeno o sistema natural para después buscar aplicaciones en el mundo artificial. Pedersen Zari (2007) propone tres niveles de complejidad para estudiar referentes de la naturaleza: organismo, comportamiento y ecosistema. El diseño bioinformado ha tenido una evolución significativa en las últimas décadas, en gran medida gracias a las tecnologías digitales, en especial la fabricación digital aditiva y los *softwares* paramétrico-asociativos. La fabricación digital aditiva permite materializar geometrías complejas, un alto nivel de precisión, materialización de ensambles armados, multimaterialidad; esta tecnología, además, ha inspirado un movimiento de proyectistas y fabricantes con el objetivo de democratizar el diseño y la fabricación (Gao *et al.,* 2015). Ford, Despeisse y Viljakainen (2015) afirman que permite realizar diseños personalizados; la fabricación aditiva facilita la traducción del modelo digital a formas concretas, incluidos prototipos y productos finales (Scheeren & Sperling, 2020). Con estos antecedentes se propuso un proyecto orientado a diseñar una serie de objetos bajo las premisas de lo biodigital, destacando las posibilidades de las tecnologías de fabricación digital aditiva y diseño paramétrico para materializar morfologías de la naturaleza. En este texto se presenta el proceso de diseño, experimentación y materialización de un taburete basado en patrones tridimensionales extraídos de la naturaleza.

2 Metodología

Se propuso un proyecto con una aproximación transdiciplinaria, un método empírico-experimental, combinación de herramientas analógicas y digitales, y el uso de análisis cuantitativos. Desde el diseño basado en la naturaleza, se utilizó el enfoque por inducción (Gebeshuber & Drack, 2008) y el uso de referentes a nivel de organismos (Pedersen Zari, 2007). Como se puede ver en la figura 1, se realizó la siguiente secuencia metodológica: (1) búsqueda y selección de referentes en la naturaleza, (2) síntesis morfológica y parametrización, (3) materialización de probetas y ensayos de compresión, (4) análisis digital de espesores y *stress*, (5) materialización del prototipo escala 1:1, (6) validaciones, (7) conclusiones y propuesta de mejora.

Figura 1. Secuencia metodológica

Se buscaron referentes biológicos con presencia en diferentes entornos, que cumplieran los requerimientos de ser patrones morfológicos y a la vez de crecimiento tridimensional, con características geométricas diferentes entre sí y factibilidad para ser aplicados al objeto de destino (asiento). Como se puede ver en la figura 2, los patrones elegidos fueron crecimiento diferencial, ramificaciones y el diagrama de Voronoi.

Figura 2. Referentes de la naturaleza, de izquierda a derecha: crecimiento diferencial, ramificaciones y diagrama de Voronoi. Fuente: Imagen de la derecha extraída de Evolo, 2022.

El diagrama de Voronoi es un patrón morfológico que se puede encontrar en diferentes organismos, a escala micro y macro; el patrón Voronoi elegido es de tipo tridimensional y se encuentra a nivel microscópico en huesos, una estructura ligera y eficiente estructuralmente porque posee más volumen en las zonas que requiere un mayor esfuerzo mecánico, en las zonas de menor esfuerzo tiene un volumen reducido o está vacío. Las ramificaciones en plantas y árboles dan soporte estructural al organismo, permiten obtener una máxima exposición al sol y distribuir nutrientes; arrancan desde un tronco, a partir de este se bifurcan diferentes ramas en ángulos que en general varían

entre 75° y 90°. El crecimiento diferencial se presenta en el reino vegetal y corales (animales denominados pólipos o zooides). Su crecimiento no homogéneo se debe a la estructura no uniforme de la composición de los materiales o el transporte intercelular. Las limitaciones físicas en las paredes celulares obligan a las células adyacentes a deformarse de manera coordinada generando morfologías complejas e irregulares. Posteriormente se hizo el proceso de abstracción y parametrización en Grasshopper; se integraron estas morfologías a un volumen cilíndrico base de 420 mm de altura y 300 mm de diámetro, que corresponden a las dimensiones del objeto final. En las figuras 3, 4, 5 y 6, se pueden ver los algoritmos y los tres modelos resultantes.

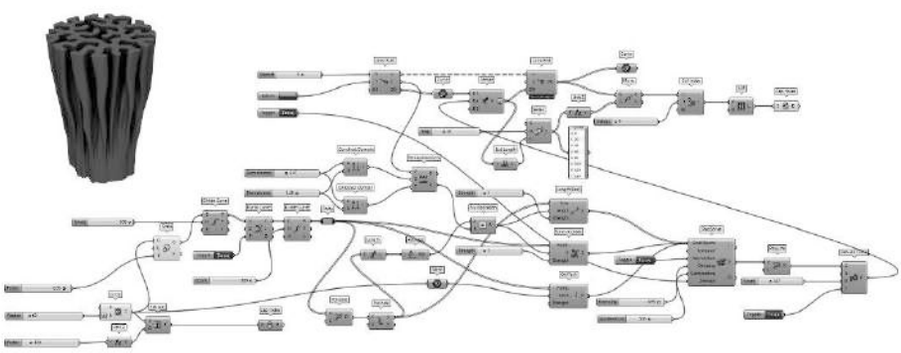

Figura 3. Algoritmo del patrón de crecimiento diferencial

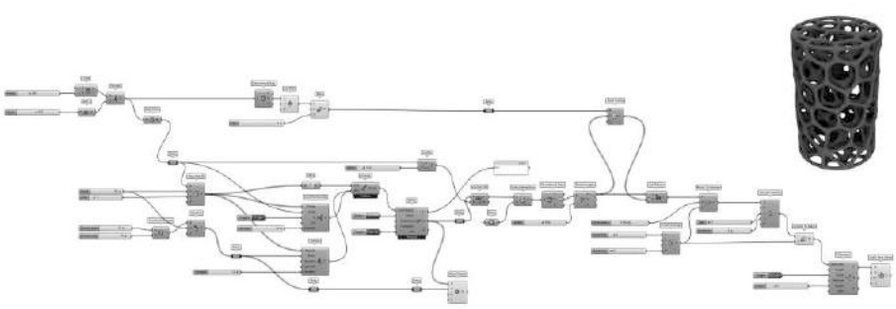

Figura 4. Algoritmo del diagrama de Voronoi

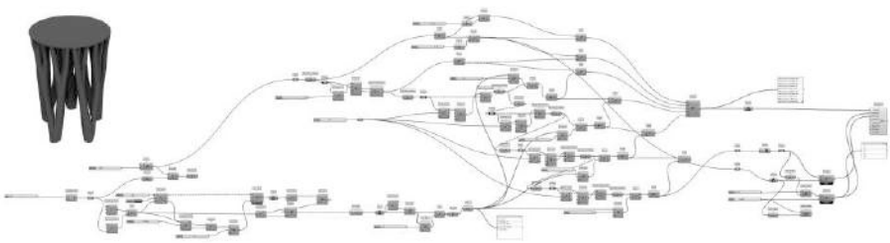

Figura 5. Algoritmo del patrón de ramificación

Figura 6. Aplicación de patrones morfológicos de la naturaleza en la geometría base

Para las pruebas de esfuerzo se consideraron varios parámetros y conceptos como la fórmula esfuerzo y deformación, esfuerzo máximo específico, dimensiones de la probeta, parámetros de impresión. Se decidió hacer la prueba de compresión, ya que este sería el principal esfuerzo al cual será sometido el objeto final. Más abajo se puede ver la fórmula de esfuerzo y deformación (1) y de esfuerzo máximo específico (2).

$$E = \frac{F}{A} \tag{1}$$

$$\frac{\text{Maximum Stress}}{\text{Masa (peso)}} = \text{Esfuerzo máximo específico} \tag{2}$$

Ahora, debido a que las morfologías de las secciones horizontales de cada probeta son diferentes, fue necesario definir una sección transversal horizontal promedio para hacer los cálculos de esfuerzo. Esta sección promedio se calculó con cinco secciones transversales por cada probeta a través de un algoritmo hecho en Grasshopper. En las figuras 7 y 8 se puede ver el algoritmo y la aplicación en una de las probetas.

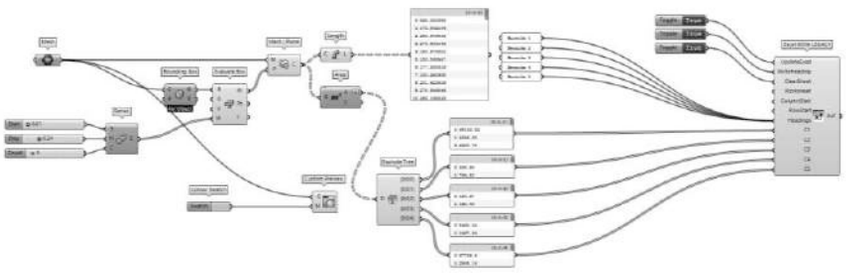

Figura 7. Algoritmo para el cálculo de las secciones transversales promedio

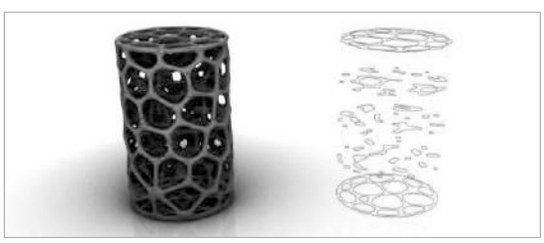

Figura 8. Secciones transversales de la probeta correspondientes al patrón de Voronoi en Grasshopper

Se diseñaron cuatro probetas de 120 mm de altura y 60 mm de diámetro, una probeta cilíndrica y las tres probetas con las morfologías extraídas de la naturaleza. Las probetas se materializaron a través de la tecnología Fused Deposition Modelling (FMD) con la impresora Creality 3D Ender-3, el material usado fue Polylactic Acid (PLA) construidos en la empresa Polymasters (figura 9). La pieza cilíndrica permitió hacer una caracterización de ese tipo de probetas con el material y proceso elegidos; en la tabla 1 se pueden ver los parámetros de impresión de las probetas.

Figura 9. Probetas de PLA, tecnología FDM

Tabla 1. Parámetros de impresión para probetas

Parámetros de impresión	
Impresora	Creality 3D Ender-3
Tecnología	FDM
Diámetro de boquilla	0,4 mm
Altura de capa	0,28 mm
Espesor de pared	0,8
Recuento de línea de pared	2 líneas
Densidad de relleno	40%
Velocidad	50 mm/seg

Fuente: Polymasters, 2022

Las pruebas de compresión se hicieron en la Universidad Pontificia Bolivariana en Medellín, Colombia. Se usó una máquina de ensayos universal Instron modelo 5582, acoplada con una celda de carga de 100 kN. El ensayo se ejecutó a una velocidad de 2 mm/min. Ver figuras desde la 10 a la 13.

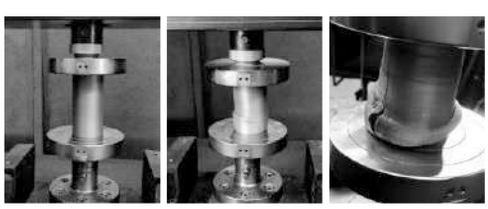

Figura 10. Prueba de esfuerzo a compresión, probeta cilíndrica

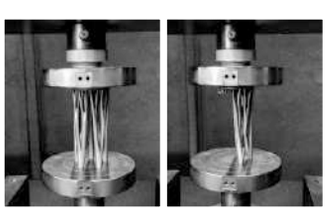

Figura 11. Prueba de esfuerzo a compresión, probeta con patrón de ramificación

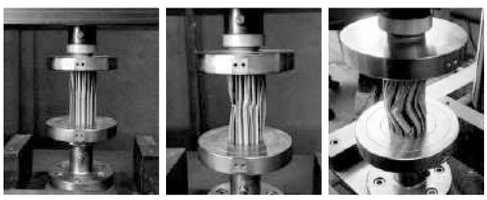

Figura 12. Prueba de esfuerzo a compresión, probeta con patrón de crecimiento diferencial

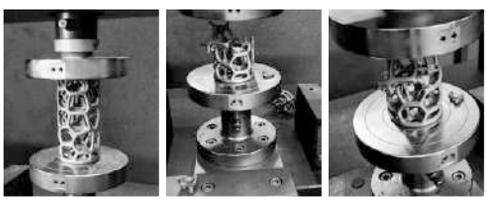

Figura 13. Prueba de esfuerzo a compresión, probeta con diagrama de Voronoi

Para el prototipo escala 1:1 se planeó imprimir las tres propuestas, pero no fue posible por tiempos y costos. Se elige el modelo con el diagrama de Voronoi; aunque ese patrón ya es muy conocido, es el que ofrece mayores desafíos debido a su morfología compleja. Se hicieron análisis de elementos finitos en el *software* Inventor (figura 14) y se imprimieron partes del prototipo con diferentes diámetros de la estructura; según estos análisis se decidió usar un espesor de 10 mm para la fabricación del prototipo.

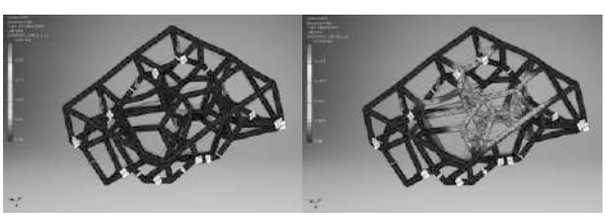

Figura 14. Análisis Von Misses Stress y desplazamiento

La materialización del prototipo escala 1:1 presentó diversos desafíos en cuanto a dimensiones, tiempos de impresión y costos. Para lograr los objetivos planteados, se hizo una alianza con la empresa Polymasters de Medellín, Colombia. Se trabajó con la impresora Artillery Sidewinder X2; fue necesario dividir el modelo en cuatro partes y se trabajó con el *software* Ultimaker Cura para definir los parámetros de impresión. En la tabla 2 se pueden ver los parámetros de impresión y, en la figura 15, el proceso constructivo.

Tabla 2. Parámetros de impresión para prototipo escala 1:1

Parámetros de impresión	
Impresora	Artillery Sidewinder X2
Tecnología	FDM
Diámetro de boquilla	0,8 mm
Altura de capa	0,4
Espesor de pared	2,4 mm
Recuento de línea de pared	3
Densidad de relleno	15%
Velocidad	45 mm/seg

Fuente: Polymasters, 2022

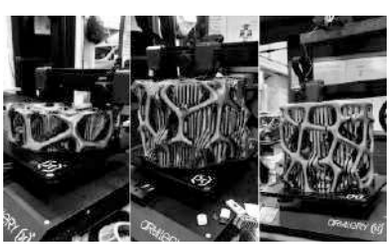

Figura 15. Proceso constructivo prototipo escala 1:1

3 Resultados

3.1 Pruebas de esfuerzo a compresión

En las tablas 3 y 4 y en la figura 16, se aprecia que la pobreta con patrón de ramificación fue la que tuvo la mayor resistencia específica (2.60 MPa/g), seguida de la pobreta con el patrón Voronoi (0.24 Mpa/g), luego la probeta con patrón de crecimiento diferencial (0.21 Mpa/g) y por último el cilindro fue el

que tuvo menor resistencia específica (0.13 MPa/g). La pobreta con patrón de ramificación tuvo la mayor resistencia específica y además presentó un comportamiento más rígido y menor peso (56 g); por el contrario, la probeta cilíndrica (la que tuvo menor resistencia específica) fue la que tuvo mayor tendencia a la deformación y mayor peso (171g).

Tabla 3. Información general de las probetas

	Etiqueta de la probeta	**Diámetro equivalente (mm)**	**Área (mm^2)**	**Longitud (mm)**	**Masa (g)**
1	Cilindro	60,00	2827,43	120,00	171,00
2	Voronoi	18,14	258,56	125,54	79,00
3	Ramificación	6,24	30,58	120,82	56,00
4	Crecimiento diferencial	41,95	1381,85	120,23	128,00
Media		31,58	1124,61	121,65	108,50
Desviación estándar		24,07	1279,68	2,62	51,36

Tabla 4. Cargas y esfuerzos de las probetas

	Maximun Load (kgf)	**Maximum Stress (MPa)**	**Módulo (Automática) (MPa)**	**Esfuerzo máximo específico (MPa/g)**
1	< -6424.67	> 22.28	908.88	0.13
2	< -493.21	> 18.71	811.30	0.24
3	< -454.25	> 145.67	15218.70	2.60
4	< -3811.56	> 27.05	1289.01	0.21
Media	-2795.90	53.43	4556.97	0.79
Desviación estándar	2885.90	61.59	7110.81	1.21

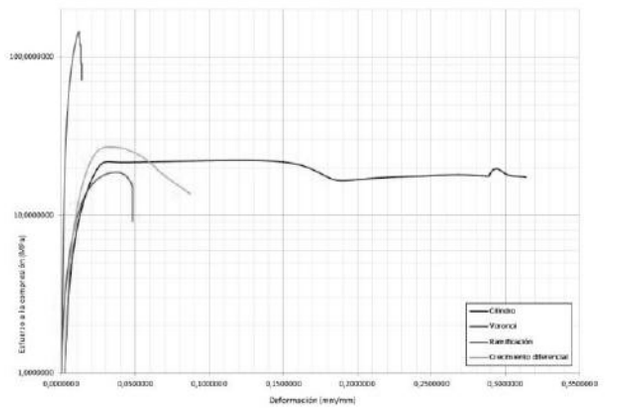

Figura 16. Gráfico comparativo de esfuerzo y deformación, resultado de la prueba de compresión de las probetas.

3.2 Prototipo y validaciones

En la figura 17 se puede ver el prototipo escala 1:1 y algunas validaciones, el prototipo mide 420 mm de altura y 300 mm de diámetro, pesa 3.3 kg, el material es PLA y tardó 10.7 días en el proceso de impresión, construido en la empresa Polymasters. Se hicieron validaciones con diez personas, y a través de entrevistas semiestructuradas se pudo conocer su apreciación. Dijeron que tiene una apariencia atractiva, aunque luce frágil se siente sólido al sentarse, es resistente y las dimensiones son adecuadas, aunque la rigidez del material no lo hace cómodo para un uso prolongado.

Figura 17. Prototipo escala 1:1 y algunas validaciones

4 Discusión

El uso de referentes de la naturaleza fue un aporte y con resultados impredecibles; en el caso de las probetas, el patrón más ligero fue el que tuvo la resistencia específica más alta (ramificaciones); esta información puede ser útil para futuros proyectos. Se comprobó que es posible materializar a través de FDM objetos funcionales con morfologías complejas, resistentes y con una definición adecuada; respecto al prototipo, no es viable comercialmente por los extensos tiempos de impresión y su alto costo, pero se abre la oportunidad de integrar el uso de técnicas convencionales de manufactura. Fue muy importante la prueba y error, un proceso de aprendizaje constante. A futuro se espera materializar los tres modelos, integrar el uso de herramientas digitales de optimización topológica y otras que mejoren el desempeño estructural.

Agradecimientos. Agradecemos a nuestras familias, a la Universidad Pontificia Bolivariana y a la empresa Polymasters de Medellín, Colombia.

Referencias

Benyus, M. & García, A. (2012). *Biomímesis: innovaciones inspiradas por la naturaleza*. Tusquets.

Ford, S., Despeisse, M. & Viljakainen, A. (2015). Extending Product Life Through Additive Manufacturing: The Sustainability Implications. *Global Cleaner Production and Consumption Conference*, *December*, 1-4.

Gao, W., Zhang, Y., Ramanujan, D., Ramani, K., Chen, Y., Williams, C. B., Wang, C. C. L., Shin, Y. C., Zhang, S. & Zavattieri, P. D. (2015). The status, challenges, and future of additive manufacturing in engineering. *CAD Computer Aided Design*, *69*, 65-89. https://doi.org/10.1016/j.cad.2015.04.001

Gebeshuber, I. C. & Drack, M. (2008). An Attempt to Reveal Synergies between Biology and Mechanical Engineering. *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, *222*(7), 1281-1287. https://doi.org/10.1243/09544062JMES890

Iouguina, A., Dawson, J. W., Hallgrimsson, B. & Smart, G. (2014). Biologically Informed Disciplines: A Comparative Analysis of Bionics, Biomimetics, Biomimicry, and Bioinspiration Among Others. *International Journal of Design and Nature and Ecodynamics*, *9*(3), 197-205. https://doi.org/10.2495/DNE-V9-N3-197-205

Pedersen, M. (1-3 de junio de 2007). Biomimetic approaches to architecture. Poster presented at the Toronto Sustainable Building Conference 07, Toronto, Canadá.

Scheeren, R. & Sperling, D. M. (2020). *Flexible multi-scalar system: 3D printing of modular components for adaptable tensioned structures*. XXIV International Conference of the Iberoamerican Society of Digital Graphics, *8*(4), 371-376. https://doi.org/10.5151/sigradi2020-51

Villamil, B. & Otálvaro, V. (2019). *Biónica y biomímesis en el diseño de productos: modelos de aplicación* (1.ª ed.). Universidad del Valle.

Performative Accessories in Multispecies Design: Enhancing Humidity Levels for Plants with 3D-printed Biomimetic Structures

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Abstract. The paper moves the design debate from human-centered toward posthuman design, discussing how designers can use a strategy based on Multispecies Ethnography and Participatory Design, considering nonhuman agents to create efficient designs. To illustrate this, it describes a project of 3D-printed biomimetic structures for plants that enhances humidity levels in internal environments. The project methodology started by analyzing the ideal humidity for indoor plants and humans, which is between 40% to 50%. Subsequently, a biomimicry study was done to understand how to generate a cooler indoor microclimate using passive strategies and how to create an effective interlocking system to connect structures. 3D-printed structures as supports for water droplets were designed according to their performance and placed in different arrangements around the plant itself. The structures were tested, and humidity levels increased by approximately 13%. The paper discusses the resultant evidence-based design and a new approach to mass customization.

Keywords: Bio-Inspired Design, Multispecies Design, Biomimicry, 3D printing, Humidity Control.

1 Introduction

For more than three decades, the human-centered discourse has dominated design. However, due to the repercussions of technology and environmental transitions, designers are currently compelled to work on complicated socio-technical systems (Forlano, 2017). The study moves the design debate from human-centered (Norman, 2013) to posthuman design (Forlano, 2017), which considers human and nonhuman agents. It asks how designers may use multispecies techniques (De Ruiter et al., 2005) and Participatory Design (Simonsen and Robertson, 2012) to develop efficient projects.

The paper offers a posthuman interpretation of the term "user," moving away from anthropocentrism and toward biocentrism (Lanza and Berman, 2010). It analyses examples of new design methodologies that emphasize the growing rhetoric of post-humanism (Braidotti, 2013) and proposes that nonhuman lifeforms be included as participants in design research, either as informants and co-designers or as users. To illustrate this, it describes a project that started in an academic course and involved designing a set of "accessories" for plants. The work extends traditional understandings of the "user" to nonhumans and examines the field of action for modern design practitioners, making it a novel contribution to the profession.

The project methodology started with a study based on Multispecies Ethnography and Participatory Design (Gatto and McCardle, 2019) with the observation of discoloration and brown-colored tips of certain leaves caused by a lack of humidity (Iowa State University, n.d). The relationship between indoor plants, humans, and humidity levels was studied, and the ideal humidity levels found between these two species are from 40% to 50% (Koster, 2016; Young, 2020).

Next, a study on biomimicry (Benyus, 2002) was done to better understand how to generate a cooler indoor microclimate using a sustainable passive strategy (Khelil and Zemmouri, 2018) without relying on electricity and how the structures could be connected effectively using the same material. Three biomimicry case studies, the Darkling beetles (AskNature, n.d), Warka Tower (AskNature, 2017), and Birds Feather Interlocking Systems (AskNature, 2018), were used as examples to design the geometry of the structures for better efficiency. 3D-printed biomimetic structures as supports for water droplets were designed. These design decisions became beneficial and evolved according to their performance. The structures can be combined and arranged in different ways around the plant as architectural elements staged around the individual plant specimen. These arrangements were important because they allowed for an evidence-based design tuned for maximum performance and plant health. Humidity levels of the structures were measured using an in-door hygrometer, Inkbird ITH-20, and it was noticed that they increased by approximately 13%.

The paper discusses the resultant evidence-based design and a new approach to mass customization. The findings pointed us to a deeper understanding relative to nonhuman design, ergonomics, humidity control, and design performance to gain insight into desirable nonhuman situations.

2 Posthuman Design and Multispecies Theory

The conventional dualistic systems of natural and artificial, human and animal, and human and machine are blurring due to technological developments. They emphasize nonhumans' new kinds of agency in the world, whether it's environmental or technological. A growing body of social theory has sprung around concepts aimed at making sense of this blurring of lines and

introducing hybrid, non-dual, relational modes of thinking (Forlano, 2017). This paper focuses on one of these hybrid modes of thinking, specifically the posthuman, for a design approach that significantly increases our awareness of the numerous agencies, dependencies, entanglements, and linkages arising from current design challenges and questions (Forlano, 2017).

The human-centered design methodology is a practice where designers focus on human needs (Norman, 2013). However, humankind is just one of many variables that shape our environments, and its agency is constituted through relational processes rather than predetermined (Gatto and McCardle, 2019). As design moves into the social sector and deals with issues in complex socio-technical systems, it's critical to change this approach to a broader one, such as a posthuman design, considering human and nonhuman actors. The work being done in post-humanist and post-anthropocentric disciplines argue that we should start thinking of manufactured systems as networks that encompass a variety of living creatures and the agency structures that act in and around them to better understand our planet's transitions.

Moreover, design does not have to be seen as an affirmative discipline but rather as a process-oriented analytical tool. One area open to investigation is re-interpreting man's connections with other species and the environment, proposing future multispecies cohabitation scenarios. To experience multispecies worlds to understand environmental issues, designers must get familiar with numerous techniques designed to be more than just a set of procedures but also distinctive ways of behaving, thinking, and experiencing (Gatto and McCardle, 2019).

The term "multispecies" was first mentioned in the fields of biology and ecological sciences more than a decade ago to describe patterns of co-construction of environmental niches and wildlife management (De Ruiter et al., 2005). Its fairly recent introduction into the study of anthropology has allowed for new interpretations of the concept, helping us reevaluate how nonhuman agents interact with design and associated processes. It also broadens the definition of sustainability because tackling environmental problems from nonhuman viewpoints can produce different results from those predicted by technocentric approaches (Gatto and McCardle, 2019).

The paper proposes a design that engages human and plant perspectives to create a multispecies reading of the concept of humidity in interior spaces.

3 Theoretical Underpinnings for Methodology

3.1 Multispecies Ethnography and Participatory Design

Ethnographic research is a design process that uses observational and interview methods to understand better the people who will utilize the developed products. The fundamental hypothesis is that a detailed

understanding of people's lives, habits, motivations, and challenges might lead to better proposals or, at the least, more pertinent design suggestions. Long-term immersion in their subjects' lives, including participation in their everyday activities, is a hallmark of anthropologists and ethnographers. They engage in various actions, such as observing, taking pictures, recording, making notes, and conducting interviews. Based on these activities, they generate theories, texts, and publications to demonstrate their academic credibility (Nova, 2016). Designers utilize this information and ethnographic tools to create original concepts, develop ideas, and implement them (Van Dijk, 2012).

However, beyond standard ethnographic research, this project was based on Multispecies Ethnography, a more-than-human perspective on the ethnographic study gaining traction in anthropology and related fields. In this context, the terms “interdependent” and “inseparable” are used to characterize work that acknowledges the interconnection and inseparability of people and other living things, striving to expand the scope of ethnography beyond the limitations of the human experience (Münster, 2015). Multispecies ethnographers are starting to trace genes, cells, and organisms through landscapes and seascapes to learn how elements of Homo sapiens are producing becomings in the bodies of other species, as well as the converse. (Hayward and Kelley, 2010). Differently from Multispecies Ethnography, the research location for this project was not an open field; the chosen place was an indoor environment, inside a house, because that is where daily interaction of nonhumans and humans occurs.

The concept of multispecies offers new perspectives on how nonhuman individuals fit into the design and its related practices. Participation in design can be interpreted as a dialogue between many users (Lawson, 2005), but things can get complicated when participants aren't actual people. Before we can accept the agency of other-than-humans, we must first experiment with design solutions that can help us hear what other-than-humans want to "say" and, considering that, come up with alternatives to our social, cultural, and economic models (Gatto and McCardle, 2019). The primary focus of participatory design study and practice is on human participants. Nonhumans, however, can also participate in the design process and significantly influence how it is carried out.

The paper expands on that idea and analyzes indoor plants' ergonomics, the ideal conditions for them to thrive, their relation to humans, and how plants and people establish a mutualistic relationship in a win-win scenario. Ideal humidity levels are essential for both species to survive; therefore, improving one will surely benefit the other. The theory holds that co-performance (Kuijer and Giaccardi, 2018) promotes greater cooperation among humans, nonhumans, and the environment while allowing both species to thrive. Lovelock extends this idea by posing the earth as a self-regulating entity (Lovelock, 2016).

3.2 Biomimicry Strategies

The discoloration on certain leaves, caused by a lack of humidity in specific conditions (Iowa State University, n.d) and the research on the ideal humidity levels for plants and humans led to the idea of creating 3D-printed structures for plants that would generate a cooler microclimate in internal environments.

Another step involved biomimicry research (Benyus, 2002) to better understand how water could increase the humidity of indoor environments through a sustainable passive strategy (Khelil and Zemmouri, 2018) and how to create a performative interlocking system to connect structures with the same material.

The first two biomimicry case studies were related to how nature collects and retains water. The first one was the Darkling beetles of the Namib desert. To survive, some species of these beetles include unique points and bumps in their wing scales that aid in water collection. Water droplets occur as air condenses on the tips, which run off the bumps and into the beetle's mouth (AskNature, n.d.). The second one was the Warka Tower, a biomimetic project inspired by the beetle that similarly gathers atmospheric water vapor from rain, fog, or dew which condenses on the polyester mesh's cool surface, generating droplets of liquid water that flow down into a reservoir at the structure's bottom (AskNature, 2017).

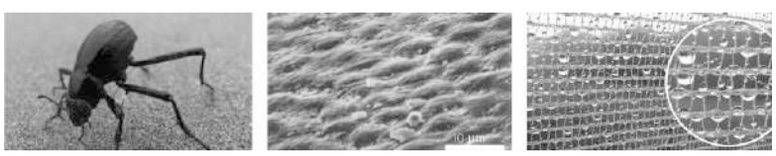

Figure 1. Darkling Beetle, scanning electron micrograph of the textured surface of the Darkling beetle's overwing; atmospheric water vapor condensed on the Warka Tower mesh's surface. Source: https://asknature.org

The third biomimicry case study was the Birds Feather Interlocking Systems in which filaments of birds' feathers connect with interlocking hooks and work as a "natural" zipper. A feather's central shaft has approximately a hundred filaments on either side, each fringed by a hundred smaller filaments called barbules. The birds comb with their beak the disarranged feather's filaments, which are pressed together. The barbules' hooks reengage like the teeth of a zip-fastener, restoring a smooth and continuous surface (AskNature, 2018). These three biomimicry case studies were considered for the shape and geometry design of the structures for better performance.

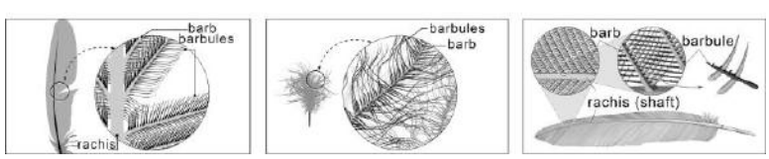

Figure 2. Feathers' interlocking. Source: Mya Thompson, 2014; Brittanica, n.d.

4 Methodology

The project methodology started with a study based on Multispecies Ethnography, analyzing the discoloration on certain leaves of indoor plants caused by a lack of humidity in specific conditions (Iowa State University, n.d). Many humans and nonhumans suffer from low humidity levels, especially in dry climates. So, the relationship between indoor plants, humans, and humidity levels was studied. The ideal humidity levels for humans are between 30% to 50% (Koster, 2016), and for indoor plants are from 40% to 60% (Young, 2020). There is an overlap of ideal humidity conditions for both species, indoor plants and humans, between 40% to 50%. When designing to enhance one's performance related to humidity levels, the other will automatically increase, following the concept of co-performance (Kuijer and Giaccardi, 2018). This research led to the idea of creating 3D-printed structures for plants that would generate a cooler microclimate in internal environments that could benefit nonhumans and humans.

Figure 3. Discoloration on indoor plants' leaves. Source: Krystal Slagle, 2022.

Also, in this project, the idea of accessory or adornment (Maykut, 2014) became relevant, extending to nonhumans the same care and attention that people have when interacting with their bodies, as well as Participatory Design (Simonsen and Robertson, 2012) to be conscious of how ergonomics perform when designing for nonhuman bodies and enhanced efficiency.

The design of the structures started with decisions on the external shape that had to be easy to compose but also strong not to bend or break. Considering that the triangular shape, and its derivations, are stronger than the rectangular shape, and they can fold in a non-orthogonal way, the external shape was designed as arrangements of triangles. One method Buckminster Fuller would describe the differences in strength between the rectangle and the triangle is to apply pressure on each. The rectangle would fold up and become unstable, but the triangle can withstand the pressure and is far more rigid–in fact, it is twice as strong–than the rectangle (Buckminster Fuller Institute, n.d.)

In parallel, textures were studied based on the Darkling beetles (AskNature, n.d.) and Warka Tower (AskNature, 2017) to understand how water droplets could be stored within a mesh. However, the 3D-printed biomimetic structures wouldn't harvest water from the air, unlike the previously mentioned examples. The proposed structures would serve as supports to accommodate and store

sprayed water, creating a cooler microclimate for indoor plants, the main users, and humans. An object that would interact greatly with the plant should be made of natural or biodegradable materials. In this case, compostable bioplastic, PLA, was used and water. Also, they should be lightweight, have a system to connect, and grip different steam sizes to better adjust to the plant's ergonomics. They were 3D-printed as flat structures and later folded for efficient storage and transport, like origami.

Parametric definitions were generated using Rhinoceros and Grasshopper. Different meshes were tested, calibrating the pattern and the layering. The initial approach used sinusoidal wave patterns in a 2.5D configuration, with overlapping and non-overlapping layers. The cases with overlapping layers responded better, storing water in-between the waves due to surface tension. Other meshes with 1, 2, and 3 layers of 3D-printed PLA were tested, and the one that performed better was the two-layered one. The one-layered mesh was not enough to store a good amount of water droplets, and the three-layered one, although it could hold more water droplets, was not malleable and quite heavy (Figs. 4 and 5).

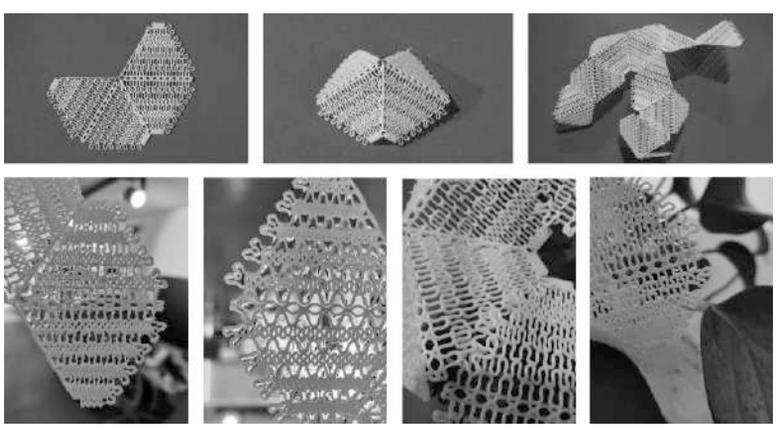

Figure 4. Initial structures: flat, bent, connected with others; structure with water; a close-up of the structures' interlocking system; and the structures arranged on a plant.

The second approach evolved the pattern to a 3D configuration using a calibration between the toolpath geometry and the extrusion parameters. In this case, water is stored as droplets in the three-dimensional structure, and the one-layered performed better than the others (Fig. 5). The one-layer 3D configuration is enough to store a good amount of water, maintaining its lightweight and strength. The two- and three-layered ones were not malleable and quite heavy. Therefore, the chosen mesh for the final structures was the one-layer 3D configuration – P4-1 (Fig. 6).

Throughout the process, it was important to use sprayed water because, in dry climates, people already spray indoor plants' leaves with it, so it is a standard and interesting procedure that helps the two species bond. In this

case, the only difference would be that the water retained would be enhanced using these structures.

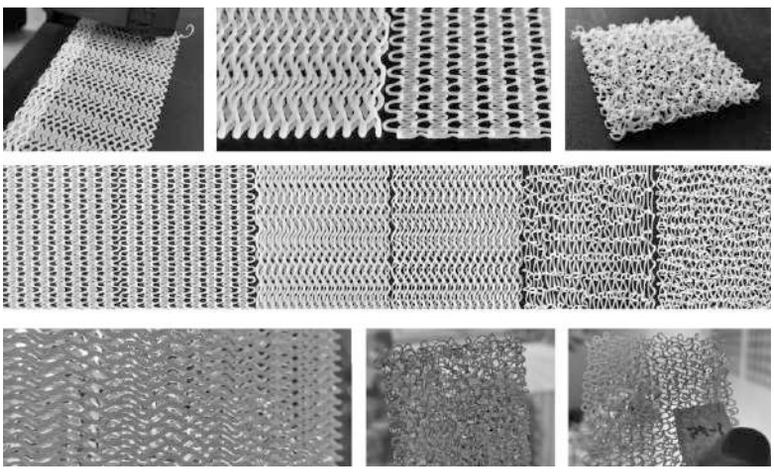

Figure 5. Meshes with 2.5D and 3D configuration.

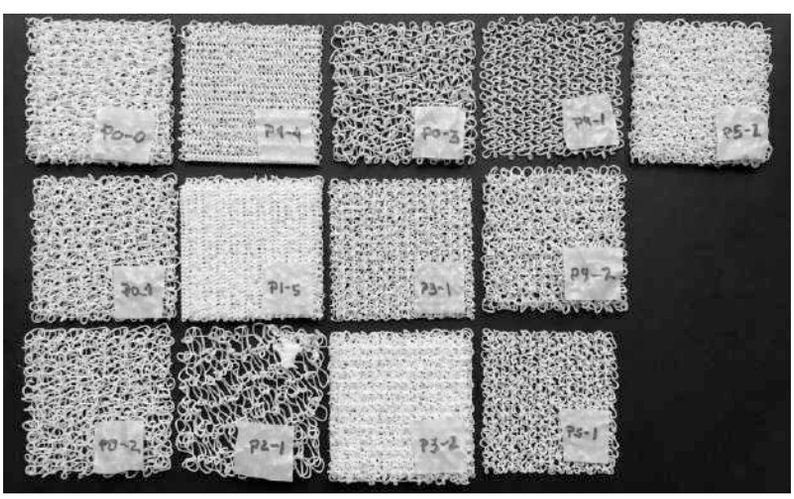

Figure 6. Meshes with 3D configuration. The one that performed better and therefore was chosen for the final structure was the P4-1.

Observing that the mesh had undulations on the outer part, which could be used to join the structures, it was decided that there wouldn't be different typologies but just one that would allow multiple connections. For that, the undulations on its outer part were exaggerated to make the interlocking system more stable, and another biomimicry strategy was applied related to the Birds Feather Interlocking Systems (AskNature, 2018). The interlocking systems of

the structures were designed according to a fractal-like organization and configured according to their performance and grip-ability to the plant's stem. An open-ended possibility of combinations was created using an interlocking system of a standard module without using another material.

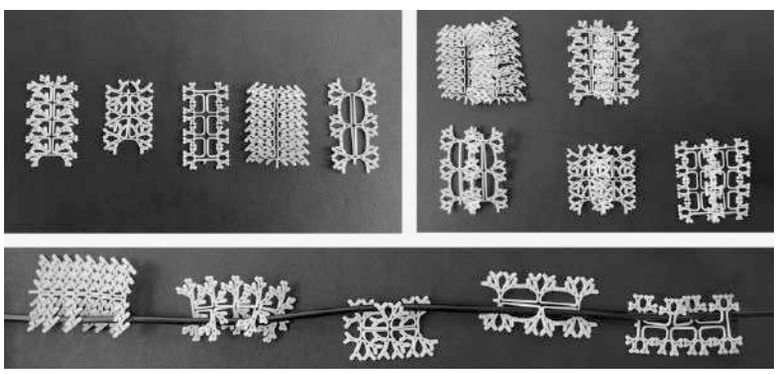

Figure 7. Interlocking systems designed according to a fractal-like organization and configured according to their performance and grip-ability to the plant's stem. The one that performed better and was chosen for the final structure is the one in the middle on the first photo and the end on the second and third.

After the tests above, the structure's design was simplified to a rhombus formed by two triangles rather than four. The structures were 3D-printed in two sizes to fit better with plants' different types and body parts: a bigger one with approximately 10 cm x 7 cm and a smaller one of about 8cm x 6cm.

Also, the joint connecting the two triangles of the structure was part of the sinusoidal weaving strategy of the pattern in the initial tests. That generated geometrical continuity, but it was difficult to bend, and, in some cases, it broke, compromising the system's stability. On the structure using the 3D mesh, the joint was modified to a square wave to facilitate the bending in different directions. In the final configuration, the distance between the triangles was reduced to enhance stability and continuity between the modules (Fig. 8).

Next, 30 structures of the bigger size and 25 of the small ones, 55 in total, were arranged around a plant in an indoor environment that didn't receive direct sunlight to prevent the evaporation of the water embedded in them. The structures were combined and arranged in different ways around the plant itself, as an architectural element to be staged around the individual plant specimen and according to how much weight the plant could support in each part, culminating in different performative qualities. These arrangements were important because they allowed for an evidence-based design tuned for maximum performance and plant health. The plant with the structures was put inside a cardboard box to measure the humidity level with an in-door hygrometer.

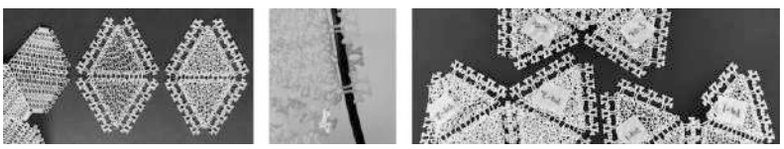

Figure 8. Different joint types and sizes; test for the grip-ability to the plant's stem, structures with different meshes. The one that performed better and was chosen for the final structure was the P4-1.

5 Results, Discussion and Conclusion

The structures were placed inside a white cardboard box to measure the humidity level with a standard in-door hygrometer, Inkbird ITH-20. The initial humidity level was 42%, and after water was sprayed on them, the humidity level increased to 55%. When this last step was repeated with the structures arranged around a plant, the humidity level changed to 63% because the plant helps to retain the water droplets. As indoor plants need humidity levels from 40% to 60% (Young, 2020), the structures provided quite an effective change in humidity. Since plants can co-exist in indoor environments, contributing to different humidity levels, the concept of co-performance (Kuijer and Giaccardi, 2018) expands our sense of inter-dependence with other species, helping each other to regulate beneficial conditions.

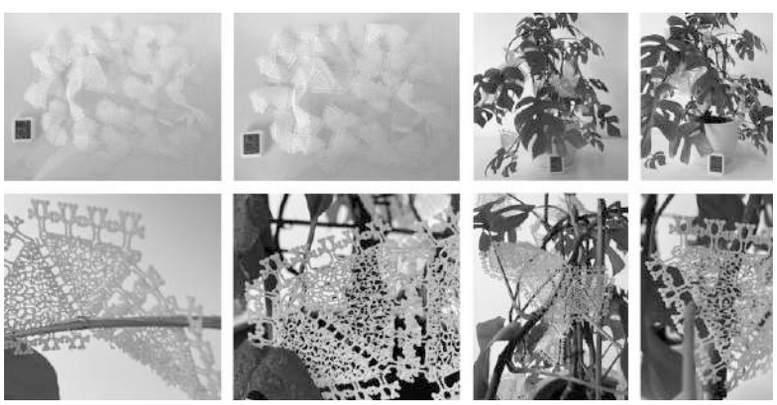

Figure 9. Structures without water (42% of humidity) and with spayed water (55% of humidity); structures arranged around a plant without water (42% of humidity) and with sprayed water (63% of humidity); structures arranged around a plant and close-ups.

This paper advances the design discussion toward post-humanism, which considers human and nonhuman agents, the last typically disregarded in design procedures. To gain insight into desired nonhuman settings, it starts with an interdisciplinary discussion that links recent research in nonhuman design, ergonomics, design performance, and ideal indoor humidity levels. It also

details the development of a project of "accessories" for plants that culminated with 3D-printed biomimetic structures as support water droplets, placed in various patterns around a plant to increase humidity levels in indoor environments. The findings reveal that just the structures without the plant increased humidity by approximately 13% and with the plant by 21%. The results imply that considering nonhuman actors can lead to different design proposals and a mutualistic relationship scenario based on the concept of co-performance.

The paper creates a new approach for working with plants as nonhuman actors and recognizing the potential of "other-than-human" capabilities, making a fresh addition by extending conventional understandings of the "user" to nonhumans and linking it with 3D printing and mass customization. It explores the evidence-based design that resulted and the environmental ideals we want our society to embrace, with implications for future design rules and practice.

6 Reference

AskNature (2017). Lightweight Water Collection System Inspired by Darkling Beetles: Warka Water. Retrieved July 02, 2022, from https://asknature.org/innovation/lightweight-water-collection-system-inspired-by-darkling-beetles/

AskNature (2018). Feather Parts Reattach, Birds. Retrieved July 02, 2022, from https://asknature.org/strategy/feather-parts-reattach/

AskNature (n.d.). The Beetles That Drink Water from Air: Darkling beetles. Retrieved July 02, 2022, from https://asknature.org/strategy/water-vapor-harvesting/

Benyus, J. M. (2002). Biomimicry: Innovation Inspired by Nature. (First ed.). Harper Perennial.

Braidotti, R. (2013). The Posthuman. (First ed.). Polity Press.

Buckminster Fuller Institute (n.d.) Geodesic Domes. Buckminster Fuller Institute. Retrieved July 02, 2022, from https://www.bfi.org/about-fuller/geodesic-domes/

De Ruiter, P., … Moore, J. C. (2005). Multispecies Assemblages, Ecosystem Development and Environmental Change. In: De Ruiter, P., … Moore, J. (Eds.), Dynamic Food Webs: Multispecies Assemblages, Ecosystem Development and Environmental Change, Vol.3, Academic Press.

Forlano, L. (2017). Posthumanism and Design. She Ji: The Journal of Design, Economics, and Innovation, 3(1),16-29. https://doi.org/10.1016/j.sheji.2017.08.001

Gatto, G., & McCardle, J.R. (2019). Multispecies Design and Ethnographic Practice: Following Other-Than-Humans as a Mode of Exploring Environmental Issues. Sustainability, 11(18), 1-18. https://doi.org/10.3390/su11185032

Iowa State University (n.d). Why does my houseplant have brown leaf tips and edges? Retrieved July 02, 2022, from https://hortnews.extension.iastate.edu/faq/why-does-my-houseplant-have-brown-leaf-tips-and-edges

Khelil, S., & Zemmouri N. (2018). Biomimetic: a new strategy for a passive sustainable ventilationsystem design in hot and arid regions. Int. J. Environ. Sci. Technol., 16, 2821–2830. https://doi.org/10.1007/s13762-018-2168-y

Kirksey, E. (2014). The Multispecies Salon. (First ed.). Duke University Press Books.

Kirksey, E, & Helmreich, S. (2010). The Emergence of Multispecies Ethnography. Cultural Anthropology, 25(4), 545–576. https://doi.org/10.1111/j.1548-1360.2010.01069.x

Koster, L. (Feb 2016, February 16). Indoor humidity and your family's health. Retrieved July 02, 2022, from https://www.nationalasthma.org.au/news/2016/indoor-humidity

Kuijer. L., & Giaccardi, E. (2018). Co-performance: Conceptualizing the Role of Artificial Agency in the Design of Everyday Life. In CHI 2018: Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems, 125, (pp.1–13). Palais des Congrès de Montréal. https://doi.org/10.1145/3173574.3173699

Lanza, R., & Berman, B. (2010). Biocentrism: How Life and Consciousness are the Keys to Understanding the True Nature of the Universe. (First ed.). BenBella Books.

Lawson, B. (2005). How Designers Think: The Design Process Demystified. (Forth ed.). Architectural Press.

Locke, P., & Muenster, U. (2015). Multispecies Ethnography. Multispecies Ethnography - Anthropology - Oxford Bibliographies. doi: 10.1093/OBO/9780199766567-0130

Lovelock J. (2016). Gaia: A New Look at Life on Earth. (Illustrated ed.). Oxford University Press.

Maykut, C. (2014). Concept Analysis: The Clarification of Body Adornment. International Journal of Caring Sciences, 7(2), 406-414. https://www.academia.edu/28182404

Nova N., & Léchot-Hirt L. (2016). Beyond Design Ethnography: How Designers Practice Ethnographic Research. (First ed.). Provinces Press.

Norman, D. (2013). The Design of Everyday Things. (Second ed.). Basic Books.

Simonsen, J., & Robertson, T. (2012). Routledge International Handbook of Participatory Design. (First ed.). Routledge.

Van Dijk, G. (2012). Design ethnography: Taking inspiration from everyday life. In Stickdorn M., (2012). This is Service Design Thinking: Basics, Tools, Cases. (First ed.). Wiley.

Young, A (2020). Humidity for house plants. Royal Horticultural Society. Retrieved July 02, 2022, from https://www.youtube.com/watch?v=dAYzmZTrTCc

SynBio-Design: Building new infrastructures and territories with Synthetic Biology

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Abstract. Which kind of imagination do we need for the future of our planet? In the past 150 years, we have completely transformed our biosphere. Today we have arrived at points of no return in global warming! The temperature of the Arctic Ocean will increase by 3-5°C by mid-century. This will lead to disastrous ocean acidification, sea-level rise, and worst of all the thawing of the permafrost that will release 1 trillion tons of carbon dioxide into the atmosphere. In this paper, we argue that building with biology will be the most important force to transform our planet. Since 2006, Synthetic Biology (SynBio) has surfaced as the fastest-growing technology in human history. SynBio involves emerging techniques that allow us to design, edit, and engineer all kinds of living organisms. In this paper, we elaborate on its potential development in growing infrastructures and its impacts on architectural thinking.

Keywords: Synthetic Biology, Bio-Architecture, Climate Change, Biotechnology, Architecture.

1 Our Biosphere after 150 years

In the past 150 years, we completely transformed our planet. Today human industrial processes determine most living organisms and ecological systems in the world. We have fully manufactured a world for our controlled fauna and us. If we look at mammals by weight on earth, humans are 36% of the mammals, 60% are our livestock and just only 4% are wild mammals (a number that has continued to decline every decade).

After 150 years, our industrialized world is unveiling its horror. The latest reports from the Intergovernmental Panel on Climate Change (IPCC) and the United Nations Environmental Program (UNEP) show that we are quickly arriving at points of no return in the warming of the Arctic Ocean (UNEP, 2019). This will inevitably lead to disastrous ocean acidification, sea-level rise, and worst of all the thawing of the permafrost (Schoolmeester, 2019). The permafrost has

sequestered underneath its ice sheet one trillion tons of carbon dioxide and methane that will be gradually released into the atmosphere. Thus, carbon “emission reduction” efforts are necessary but are certainly insufficient. We quickly need to pivot into “negative emissions” visions that will allow us to develop carbon removal at a massive scale (Masson-Delmotte, 2018).

1.1 Climate Change is a Deep Crisis of Imagination

When we architects propose ways to mitigate climate change we tend to go back to just slightly improved industrial technologies with which we created the emergency. We are in a deep crisis of imagination!
In this paper, we propose that biology is a much more sophisticated platform to transform our planet. We provide a summary of how our concepts of biology have changed and how we have moved into a new era of biotechnology. But we also argue that this new era is not only about new material technology but also needs a new spatial imagination at the planetary scale.

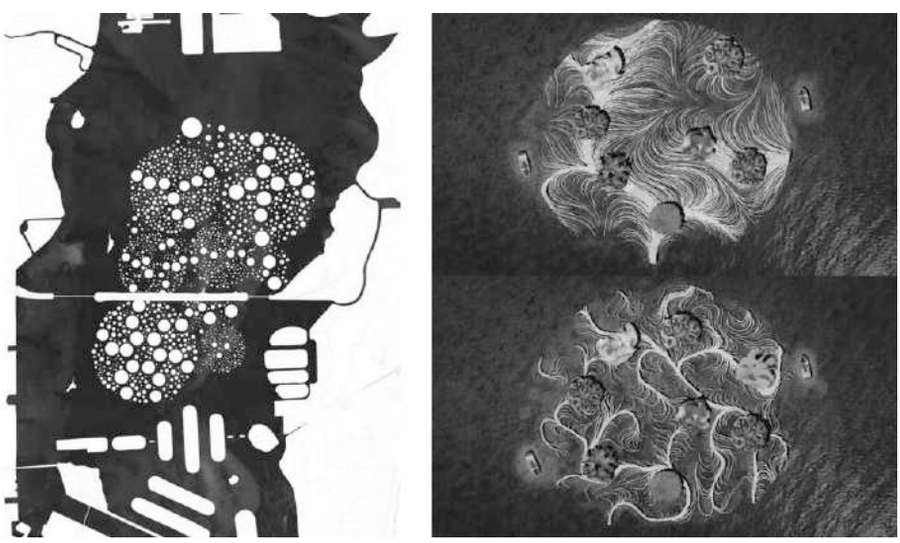

Figure 1. The proposal envisions a series of islands that grow in Biscayne Bay by reengineering cyanobacteria. A biological circuitry allows cyanobacteria to capture carbon dioxide in the water via photosynthesis and transforms it into finely layered rock material. The process is similar to the living stromatolites that were abundant in the Precambrian age. Cyanobacteria created the earth’s atmosphere. Left image: Site plan, Design 7-8 Studio, 2018. Right image: a project by Daniela Romero & Solange Salinas (Alfredo Andia Design 8 Studio, FIU, Fall 2019).

1.2 Nature and Biology

Nature has been an evolving concept! The field of biology of the 1800s emerged from the voyages of authors such as Charles Darwin and Alfred Wallace did into the practically untouched nature during that period. By the 1900s, biological studies began to move away from travels and into labs that began to study life principles. The discovery of the “DNA structure and function” in the 1950s was a major breakthrough in lab biology. By the last decade of the 20th century, the genetic branch of biology began to gather traction as DNA reading (DNA sequencing) and DNA writing (DNA synthesis) expertise accelerated.

1.3 Programmable Biology: Synthetic Biology (SynBio)

Since 2006, Synthetic Biology (SynBio), the field dedicated to finding ways to rewrite or recode biology has surfaced as the fastest-growing technology in human history. SynBio involves emerging techniques that allow us to design, edit, and engineer all kinds of living organisms. Today we can manufacture molecule by molecule: lab-grown meat, bio-grown leather, milk, wood, plants that do not need fertilizer, fuels, fragrances, fabrics, novel pharmaceuticals, mRNA vaccines, and even age-reversal techniques. Synthetic Biology was officially born in 2006, but it is growing by a factor of 10 times per year, by comparison, computer technology has been rising by a factor of 1.5 times per year (Church 2014).

Figure 2. An emergent fragile habitat in Stilsville, Florida, that grows with different strategies such as curl noise, recursive growth, and DNA plexus. The project reflects on the spectrum of fragility in which we could nurture our SynBio habitats. Project by

Bryan de la Cruz and Juan Moreno (Alfredo Andia Master Project Studio, FIU, Spring 2021).

2 SynBio in the Construction Industry

We think there are two generations of possible tactics for the future of SynBio in construction. An emerging number of startups are developing lab-grown products that aim to replace existing materials. However, we think that the real potential of SynBio will involve soon a more advanced narrative of engineered living materials that will allow infrastructures to grow locally around the world.

2.1 First Generation: Lab-Grown Materials

A rapidly growing number of lab-grown materials are surfacing today. BioMASON is using a Bacillus strain to facilitate the formation of calcium carbonate that creates bricks from sand at room temperature. Companies such as Ecovative and MycoWorks use fungal mycelium to create bricks, walls, and wall insulation materials. Lingrove uses plant-based fibers and resin to create lab-made wood. Wooddoo makes transparent wood. Moreover, others like Modernmeadow, Tomtex, and Vitrolansinc made lab-grown leather. These approaches have the potential to affect the processes of building today without altering significantly design and construction delivery. In our studio work, we think that there is a huge value in pursuing first generation projects, but, at the rate the technology is developing, we think that these are temporary visions.

2.2 Second Generation: Engineered Living Materials (ELM)

A more advanced vision for SynBio in construction is to engineer new living materials from cells, bacteria, fungi, biological seeds, or the orchestrated growth of multiple organisms in an accelerated timeframe. ELM become a funded research program at DARPA in 2016 with a particular vision stated as: “imagine that instead of shipping finished materials, we can ship precursors and rapidly grow them on site using local resources. And, since the materials will be alive, they will be able to respond to changes in their environment and heal themselves in response to damage” (Darpa, 2016). Several authors have developed wide-ranging reviews and taxonomy that summarize projects in this novel direction (Nguyen, 2018; Gilbert, 2018; and Srubar, 2020). We believe that soon this second generation of SynBio technologies will challenge the design of human spaces. We could imagine a future in which SynBio producers could deliver bio-ingredients and ecosystems to a specific site from which we can grow and make our habitats.

3 SynBio-Design Projects

Which type of human spaces we can generate with these new methods? In the following pages, we describe the themes we have developed in several studios.

3.1 Carbon stabilization Infrastructures: Reengineering Cyanobacteria

As stated above, the UNEP and IPPC reports state that the only way out of climate change is through new carbon removal methods. Which organism naturally removes carbon dioxide from our planet today? 100% of the oxygen on earth is a biological product. The earth did not have an oxygenated atmosphere until photosynthetic cyanobacteria emerged between 3.5 to 2.5 billion years ago. These bacteria transform Carbon Dioxide (CO2) and water (H2O) into sugars that are used for energy and as a byproduct of the photosynthesis processes Cyanobacteria releases oxygen (O2) into the air. Even today, 100% of the oxygen all living organisms breathe comes from cyanobacteria or descendant organisms: such as cyanobacteria in our oceans, and in plants and tree species that absorbed cyanobacteria via endosymbiotic evolution. Cyanobacteria life forms in the sea (such as the Prochlorococcus, algae, and oceanic plankton) are responsible for between 50-to-80% of the oxygen production on the planet.

Cyanobacteria, when they die, can create living rocks in the ocean like the stromatolites that were abundant in the Precambrian age. A lab led by Wil Srubar at the University of Colorado Boulder has already created a bio-concrete, using “synechococcus” cyanobacteria (Heveran, 2020). This bio-concrete grows and reproduces at an exponential rate. They were able to keep alive the cyanobacteria for 30 days. For example, if you create a brick with this biomaterial and you divide it into smaller parts while the cyanobacteria are alive, each part is capable of growing back again into a new whole brick in hours.

By re-designing a biological circuitry with cyanobacteria in shallow waters. We could capture excess CO2 from the atmosphere and create entire new islands and buildings from cyanobacteria bio-cement in just days. The only thing we need is water and redesigned cyanobacteria. In Figure 1 we envision a series of islands that grow by themselves using re-engineered cyanobacteria in the shallow waters of the Biscayne Bay, in Miami, FL, which is usually just 3-to-5 ft. deep.

3.2 Sea-Level Stabilization towers

In the work of our studio, we imagine how we can grow large bio-infrastructures that can absorb and retain seawater like sponges and cactus. We could grow with SynBio these desalinization towers all over the world (figure 3). These Bio-towers could absorb excess seawater from the melting ice sheets and glaciers

to the point that we could stabilize sea level rise. We could control and reshape our current coastal areas and these sponge towers can contain bioreactors and all kinds of infrastructures from which we can obtain food, energy, and raw materials, locally.

The Miami desalinization tower project is an infrastructure that could absorb about 6 million cubic feet of seawater. The growth of the design is based on voxels of calcium carbonate that arrange in Semper knot structural formations as a byproduct of cyanobacteria circuitry. These sponge towers could be a sea-level stabilization strategy for the planet. The ocean surface area is about 1,680 million sf. If we calculate that sea-level rise will be around 6 feet by 2100, the earth will gain around 10,800 million cubic feet of seawater volume. If we could gradually grow 1500 of these infrastructures around the world, that could absorb the extra seawater, we could maintain the sea level we have today.

Figure 3. Desalinization, absorption, and retention tower proposal for Miami Biscayne Bay proposal that follows the process of growth via aggregation through a Semper's knot weight distribution. Project by Renzo Lopez (Alfredo Andia Design 8 Studio, FIU, Spring 2018).

3.3 Bio-fibrous structures

A series of fibrous-based skin habitats were developed based on the ability of fibrous infrastructures to capture CO2 from the air. The fibrous structures can be injected with synthetic micro-fluidics like the ones developed at the Max-Plank Institute and increase carbon sequestration 100 times more than using the same tree volume.

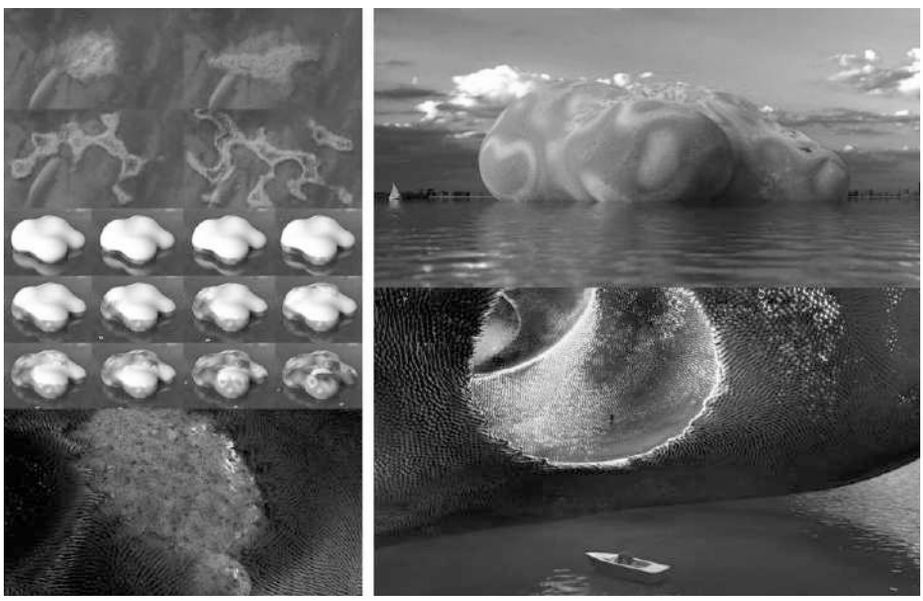

Figure 4. This project is an island/concert hall that grows from the shallow Biscayne Bay. Project by Carmen Alvarez and Steve Rivera (Alfredo Andia Design 8, FIU, Spring 2021).

Figure 4 depicts an island/concert hall that grows from the shallow Biscayne Bay via a metaball structural formation. The surface is covered by synthetic biological fibrous organisms that capture CO2, fuels energy, and provides changing illumination to the structure. The fibrous skin is an advanced version of the glowing nanobionics plants developed at Strano Research Group at MIT.

3.4 Bio-foods and the form of food

Plant-based food and lab-grown meat has been one of the earlier successes of synthetic biology. Companies such as Impossible Foods, the Not Co., or Ecovative are creating products that imitate and replace current products. Some companies are even creating scaffoldings that simulate the texture of steaks, bacon or egg. However, if we can transform proteins into any taste or shape why does food in our near future has to look like our old burgers, bacon, or steaks? Why vegetables cannot have the crunchy taste of pizza or the consistency and smoothness of marshmallows?

As we enter into this new era, we will have to redefine our design territories. A new freedom of forms will imply that food could have not only any shape, any texture, or consistency but also addresses its politics. In our studios, we have

worked on eatable buildings. Buildings with bio-surfaces with engineered bacteria that could clean dirt, eat toxins, and detect any pathogens.

Figure 5. Left images: SynBio habitats in the artic offer both bioengineered food and refuge for explorers. It also is designed to provide nourishment for wild mammals, such as polar bears, that encounter longer periods of starvation due to climate change every year. Project by Jessica Milton and Karen Quezada (Alfredo Andia Master Project Studio, FIU, Spring 2021). Right images: Visceral creatures are habitats that are covered with synthetic fibers that perform photosynthesis. They are capable of capturing carbon dioxide at around 100 times more efficiently than trees. The project is based on research from the Max-Plank Institute that combined synthetic biology with micro-fluidics. Project by Aldo Escobar and Kathryn Leblanc (Alfredo Andia Design 8, FIU, Spring 2021).

Food is also a critical issue for a large number of species on our planet, especially for the dwindling number of mammals in the Arctic. In figure 5 we developed a project for the Arctic Polar Bears, which are encountering increasing food supply shortages and are increasingly resorting to cannibalism to survive. In this project, we propose habitats for Arctic explorers that also could have bio-reactors that could synthetically produce food for Polo Bear. As the devastations of climate change unfolds and we enter into a bio-technological era, a new human-animal relationship.

3.5 Bio-String structures

Spider silk is one of the strongest materials on earth. It is stronger than steel and more resistant than Kevlar. There is an increasing number of startups, such as Spiber Inc., that are already growing synthetic spider silk in their labs and are being used in products developed by Adidas and North Face. When will synthetic spider silk move into architecture? In the history of art, design, and

architecture, we have a very limited experience with string structures.

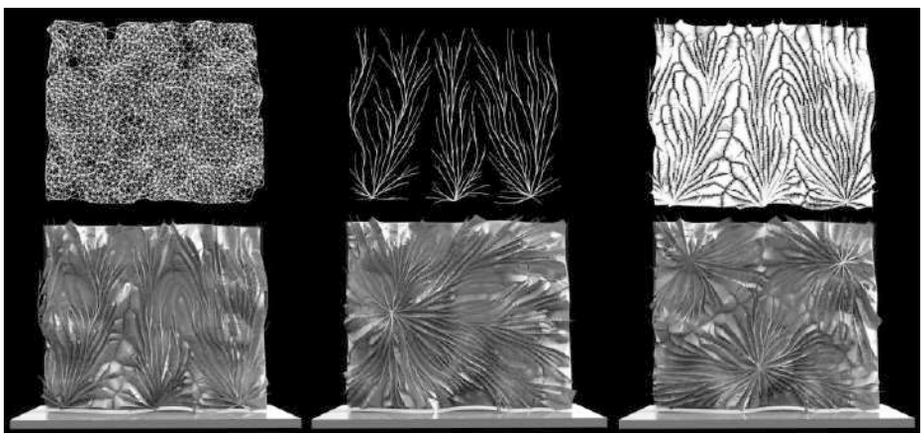

Figure 6. This façade uses a process of growth based on the shortest path logic using sting structure. Project by Maria Perez and Richard Salinas (Alfredo Andia Master Project Studio, FIU, Spring 2021).

Figure 7. Stages of growth of a string structure using reaction diffusion. Project by Maria Perez and Richard Salinas (Alfredo Andia Master Project Studio, FIU, Spring 2021).

In our studios, we studied synthetic spider silk piping structures and enclosure/façade systems. Figure 6 shows the experiment of string structures

in a façade. The growth process allows for the emergence of continuous channels that are able to collect, transport, and store nutrients within the wall. Figure 7 show the work using reaction-diffusion and noise offset to structure string-based forms for architectural settings.

3.6 Programmable Bio-matter

“Programmable matter” is a term used in computer science to describe a material that can be programmed by digital code. It is perhaps the most advanced vision on the computing field could affect the analog world. It is often imagined to be made of tiny robots (smaller than sand). Projects named Claytronics, M-blocks, Computronium are the early version of this grandiose vision.

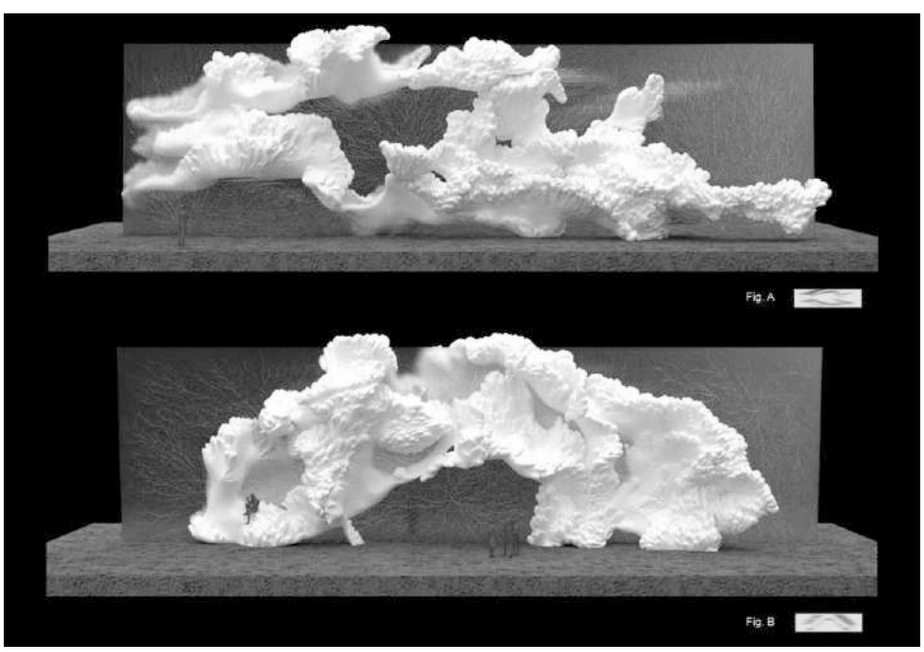

Figure 8. Programmable Bio-Matter. A series of walls designed to react to stiffness and solar radiation levels and wind forces of the site. Project by Maria Perez and Richard Salinas (Alfredo Andia Master Project Studio, FIU, Spring 2021).

However, biology is a much more sophisticated way to alter matter than traditional computing. All living organisms are made of programmed biological matter. For example, the broken antlers of a Dear is an organ that can regrow almost an inch per day and knows exactly when to stop. Therefore, in our studios we imagine that in the future we could have a kind of generic bio-matter, a highly intelligent biological entity that is made of living cells, that can bio-compute, store, retrieve and process data encoded in its DNA (figure 8).

We experimented with bio-matter that uses form-finding workflows using recursive growth. A group studied façades that use recursive growth bio-matter that propagates by two conditions: solar radiation and structural stiffness (figure 8). Other students have used the bio-matter to grow skin structures over a scaffolding that was made from fast a growing shrubs that later dissolves.
We have also explored a growing bio-matter organism that could develop catenoid formations. Catenoid structures would allow bio-matter to develop spatial materialization from a single plane that twist as it grows. This project was based by research of artificially produced cells at The Technical University of Munich that demonstrated how cells could communicate, which in a more advanced version could also lead shape control (Dupin, 2019).

4 Conclusion: SynBio Zeitgeist

Every major innovative period comes with a design paradox. Generally, we are unable to imagine the new! The design of the new usually has strong references to the immediate past. For example, when automobiles first emerged, they resembled their direct predecessor, the horse carriage. However, over time, the car evolved and every one or two decades the automobile reinvented itself following a particular zeitgeist, or the spirit of its time. In the 1950s followed the curves of planes and today, as we face an era of irreversible climate change, electric car projects from companies like Tesla, Lucid and Nio are transforming once more our vision of what is car mobility. Similarly, the first generation of SynBio products (2006-to-2021) has been highly concerned with developing a viable industrialized biology. For example in the food industry, one of the biggest success story has introduced viable plant-based meats that sell in most cities in the United States today.

But we ask: are we really going to remain in this new biological era eating SynBio foods that resemble our old burgers or bacon? Can we redesign our foods beyond that? In architecture, we are also trapped in this paradox. Will our architectural design imagination in this new era be reduced to just replacing elements of our contemporary buildings and cities? In our work, we propose that the final zeitgeist of a SynBio era will be how we weave our bodies in “pure experiences” with our biosphere (in the epistemic notion of experience inaugurated by philosophers William James and Kitaro Nishida). Imagination is critical!

References

UNEP. (2019). Temperature rise is ‘locked-in’ for the coming decades in the Arctic. UN Environment, Press release: Nairobi, March 13, 2019. Retrieved May 30, 2021, from: https://www.unep.org/news-and-stories/press-release/temperature-rise-locked-coming-decades-arctic

Schoolmeester, T., Gjerdi, H. L., Crump, J., Alfthan, B., Fabres, J., Johnsen, K., & Baker, E. (2019). Global linkages—A graphic look at the changing Arctic. Nairobi and Arendal: UN Environment and GRIDArendal.

Masson-Delmotte, V., Zhai, P., Pörtner, H. O., Roberts, D., Skea, J., Shukla, P. R., & Waterfield, T. (2018). Global warming of 1.5 C. Intergovernmental Panel on Climate Change (IPCC).

Heveran, C. M., Williams, S. L., Qiu, J., Artier, J., Hubler, M. H., Cook, S. M., ... & Srubar III, W. V. (2020). Biomineralization and successive regeneration of engineered living building materials. Matter, 2(2), 481-494.

Church, G. M., & Regis, E. (2014). Regenesis: how synthetic biology will reinvent nature and ourselves. Basic Books.

Roosth, S. (2017). Synthetic: How life got made. University of Chicago Press.

Ginsberg, A. D., Calvert, J., Schyfter, P., Endy, D., & Elfick, A. (2017). Synthetic aesthetics: investigating synthetic biology's designs on nature. MIT press.

DARPA. (2016). Living Structural Materials Could Open New Horizons for Engineers and Architects. Retrieved May 30, 2021,

Nguyen, P. Q., Courchesne, N. M. D., Duraj-Thatte, A., Praveschotinunt, P., & Joshi, N. S. (2018). Engineered living materials: prospects and challenges for using biological systems to direct the assembly of smart materials. Advanced Materials, 30(19),

Gilbert, C., & Ellis, T. (2018). Biological engineered living materials: growing functional materials with genetically programmable properties. ACS synthetic biology, 8(1)

Srubar III, W. V. (2020). Engineered living materials: taxonomies and emerging trends. Trends in Biotechnology.

Dupin, A., & Simmel, F. C. (2019). Signalling and differentiation in emulsion-based multi-compartmentalized in vitro gene circuits. Nature chemistry, 11(1), 32-39

Biodigital Product Design Through Additive Fabrication Technologies: Beer Tap Handles Project

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Abstract. Biomimicry is a new transdisciplinary science that studies the models of nature to solve human problems with a systemic approach; design based on nature has had a significant evolution in recent decades thanks to digital technologies advantage, especially digital fabrication and parametric software. This text presents the process of design, experimentation and fabrication of beer tap handles series based on morphological patterns from nature. The project followed this methodological sequence (1) Design problem (2) Selection of biological referents (3) Morphologic synthesis (4) Analysis of thicknesses and stress (5) Detailed design (6) Fabrication of 1:1 scale prototype through Fused Deposition Modelling technology -FDM- (7) User testing (8) Conclusions and improvement proposal. The digital design and fabrication process were effective, the prototypes worked and reached the project goals, the users perceived that the beer tap handles are comfortable, functional and have an attractive appearance.

Keywords: biomimicry, bio-informed disciplines, parametric design, additive fabrication technologies, fused deposition modelling technology

1 Introducción

La evolución ha generado organismos con patrones morfológicos y características extraordinarias que permiten protegerlos de depredadores y sobrevivir en entornos adversos; estas propiedades únicas han llamado la atención de investigadores y proyectistas que han buscado comprender estas estructuras para usarlas en la solución de problemas del ser humano (Tee *et al*., 2021). Benyus (2012) define la biomimética como una nueva ciencia transdisciplinaria que estudia los modelos de la naturaleza para resolver problemas con una visión sistémica. Gebeshuber y Drack (2008) diferencian dos enfoques para la biomimética, por analogía y por inducción. El método por analogía arranca desde el problema del ser humano para buscar soluciones en la naturaleza y, luego, transferirlas. El método por inducción empieza desde el

estudio de un fenómeno o sistema natural para después buscar aplicaciones en el mundo artificial. Pedersen Zari (2007) propone tres niveles para estudiar referentes de la naturaleza: organismo, comportamiento y ecosistema.

El diseño basado en la naturaleza ha tenido una evolución significativa en las últimas décadas, en gran parte gracias a las tecnologías de fabricación digital aditiva y el uso de *softwares* paramétricos. A través de la fabricación digital aditiva, es posible materializar geometrías complejas, alto nivel de precisión, construir ensambles ya armados, multimaterialidad; esta tecnología ha inspirado un movimiento de proyectistas y fabricantes a democratizar el diseño y la fabricación (Gao *et al*., 2015). Attaran (2017) asevera que la fabricación digital aditiva es altamente innovadora, abre nuevas oportunidades y posibilidades para las empresas, agiliza significativamente los métodos de fabricación, y los consumidores pueden convertirse en microfabricantes. La impresión 3D tiene la capacidad de eliminar el costo adicional y desafíos técnicos asociados con la fabricación de sistemas y estructuras complejas (Tee *et al*., 2021). En el diseño paramétrico, a diferencia de los métodos digitales convencionales, en lugar de dibujar una forma específica para cada elemento, se diseña un sistema de reglas y ecuaciones algorítmicas dinámicas, un conjunto de principios codificados capaces de originar una familia de objetos posibles y variables (Orciuoli, 2011). En este contexto, emerge la idea de arquitectura biodigital y genética; el profesor Estévez (2020) plantea que *inteligencia natural* e *inteligencia artificial*, *bioaprendizaje*, *biofabricación* y *fabricación digital* son palabras clave que dan forma a la nube de lo biodigital, una fusión entre biológico y digital.

Con estos antecedentes se propuso un proyecto orientado a diseñar una serie de objetos basados en el concepto de lo biodigital, destacando las posibilidades de las tecnologías de fabricación digital aditiva y *softwares* paramétricos para materializar morfologías de la naturaleza. En este texto se presenta el proceso de diseño, parametrización y fabricación de una serie de asas para cerveza del barril con una morfología basada en patrones geométricos extraídos de la naturaleza, proyecto situado en un contexto local.

2 Metodología

Se propone un proyecto con un enfoque empírico-experimental, se destaca el uso de herramientas digitales y métodos de análisis mixto, combinando aproximaciones cuantitativas y cualitativas. Desde el diseño basado en la naturaleza, se usa el enfoque por analogía basado en Gebeshuber y Drack (2008) y el uso de referentes a nivel de organismos según Pedersen Zari (2007). Como se puede ver en la figura 1, se desarrolló la siguiente secuencia metodológica: (1) definición del problema, (2) selección de referentes en la naturaleza, (3) abstracción morfológica y parametrización, (4) análisis de espesores y *stress*, (5) diseño detallado de las propuestas, (6) materialización de prototipos escala 1:1, (7) validaciones, y (8) conclusiones y propuestas de mejora.

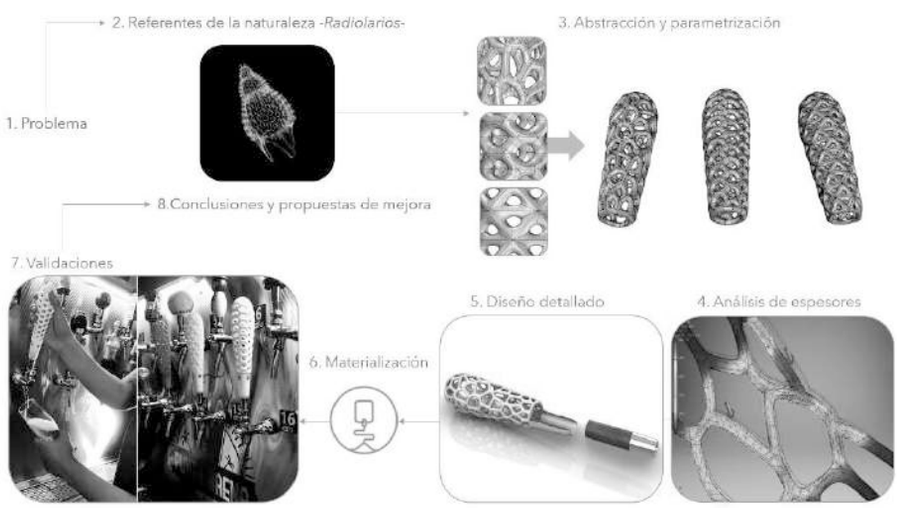

Figura 1. Secuencia metodológica del proyecto. Fuente: imágenes de radiolarios de Drews (2015) a través de Creative Commons 2.0; las demás corresponden al esquema del autor, 2022.

Al inicio se definió el problema junto al dueño y a los trabajadores del bar Punta Arena, en Medellín, Colombia. El objetivo fue el rediseño de manijas para cerveza de barril, se usó un modelo existente como referencia. Ver figura 2.

Figura 2. Asa convencional usada como referencia

Los requerimientos se organizaron en torno a cuatro áreas: de uso, funcionalidad, estético-comunicativa, materiales y fabricación. En la tabla 1 se puede ver una síntesis de requerimientos.

Tabla 1. Requerimientos por áreas

Área	**Requerimientos**
Uso/interacción	Comodidad, uso para diferentes usuarios, ligereza, fácil limpieza
Funcionalidad	Resistencia, ligereza, ensamble seguro, durabilidad
Materiales y fabricación	Materialización de formas complejas, alta precisión, material resistente al uso y a la humedad
Estético comunicativo	Apariencia fiable, llamativa y diferente a lo conocido

Se eligieron como referentes los radiolarios. Son parte de la familia de los protistas ameboides, suelen ser unicelulares y habitan el océano como zooplancton. Se caracterizan por tener esqueletos minerales, generalmente de sílice y con diferentes patrones morfológicos, gracias a ello resisten en forma homogénea las presiones del agua. Ver figura 3.

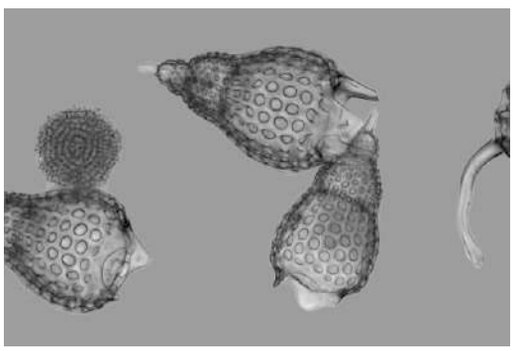

Figura 3. Referentes naturales utilizados: radiolarios. Fuente: Fox (2010) a través de Creative Commons 2.0.

Tomando en cuenta los requerimientos, se diseñó una geometría base para integrar los patrones basados en la naturaleza. Se amplió el tamaño del asa, la morfología es totalmente curva y simétrica. En la figura 4 se puede ver una comparación dimensional entre el modelo existente (referencia) y la propuesta en su geometría base.

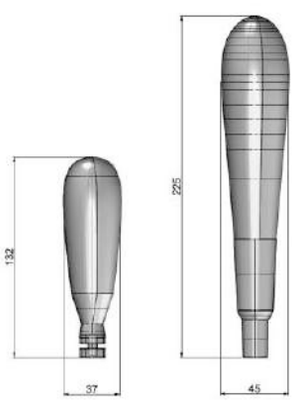

Figura 4. Comparación dimensional entre el modelo existente a la izquierda y la propuesta en su geometría base

Luego, se hizo el proceso de abstracción morfológica y parametrización. En las figuras 5, 6 y 7, se pueden ver los algoritmos hechos en Grasshopper en el entorno del *software* Rhinoceros. Esto permitió hacer ajustes dinámicos y asociativos en las morfologías según los requerimientos.

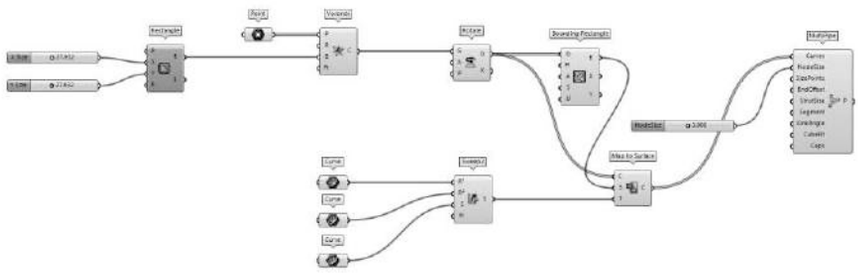

Figura 5. Algoritmo de patrón Voronoi basado en radiolarios

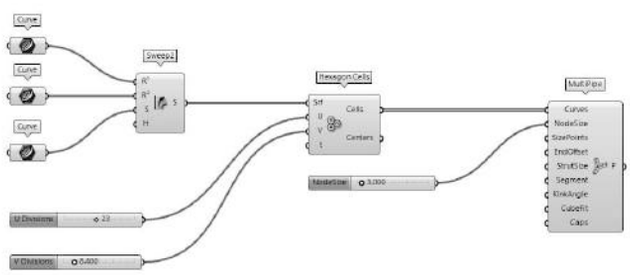

Figura 6. Algoritmo de patrón hexagonal basado en radiolarios

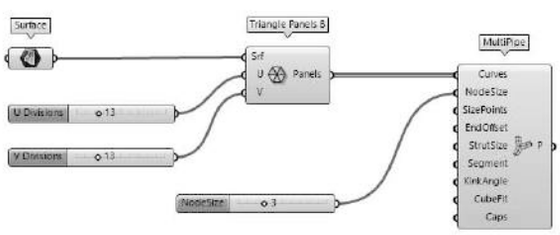

Figura 7. Algoritmo de patrón triangular basado en radiolarios

Posteriormente se hizo el diseño detallado en Rhinoceros. Para la materialización, se selecciona la tecnología Fused Deposition Modelling (FDM) poque permite fabricar piezas funcionales; se elige el material polimérico acrilonitrilo butadieno estireno (ABS) porque tiene una resistencia adecuada a esfuerzos mecánicos, durabilidad y hay una amplia variedad de colores; y se usa la impresora Tumaker Voladora NX Dual. En la tabla 2 se pueden ver los parámetros de impresión empleados.

Tabla 2. Parámetros para impresión 3D

Parámetros de impresión	
Impresora	Tumaker Voladora NX Dual
Tecnología	FDM
Diámetro de boquilla	0,4 mm
Altura de capa	0,15
Espesor de pared	2 mm
Recuento de línea de pared	5
Densidad de relleno	40%
Velocidad	2700 mm/seg

Fuente: Empresa EQ3D, 2022

Finalmente, se instalaron los tres prototipos funcionales y se usaron para atender clientes reales. Se hizo una entrevista semiestructurada al dueño del local y a los tres trabajadores.

3 Resultados

3.1 Síntesis morfológica y parametrización

En las figuras 8 y 9, se pueden ver los resultados del proceso de parametrización morfológica y la aplicación de patrones en la geometría base.

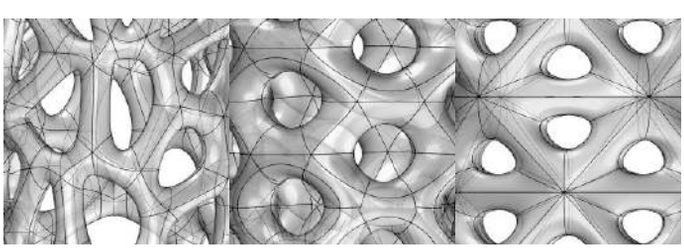

Figura 8. Patrones morfológicos basados en radiolarios

Figura 9. Aplicación de patrones morfológicos parametrizados en la geometría base, conformando una estructura hueca

3.2 Análisis de espesores y *stress*

Se hicieron análisis de elementos finitos en el *software* Inventor (figura 10) y se imprimieron partes del prototipo con diferentes diámetros en la rejilla; según estos análisis de decidió usar un diámetro de tres milímetros en la rejilla.

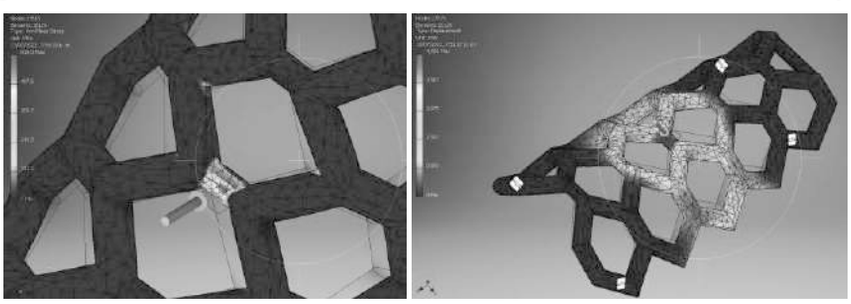

Figura 10. Análisis de *stress* Von Misses y desplazamiento, patrón hexagonal

3.3 Propuesta final y diseño detallado

Para las propuestas se consideraron todos los requerimientos. Se amplió el tamaño del asa, la morfología es totalmente curva y simétrica. Esto permitirá que sean cómodas, lo usen personas con tamaños de manos diferentes, ya sean zurdos o derechos. Aumentar el largo reduce el esfuerzo, debido a que a mayor distancia se origina un torque menor. La morfología hueca y los patrones basados en la naturaleza la hacen más ligera. Esto junto con un espesor adecuado puede generar la resistencia requerida ante esfuerzos. El sistema

de ensamble consideró tornillos desde cinco ejes diferentes, lo cual asegura fiabilidad en su uso. En la figura 11 se puede observar un corte parcial en la etapa de diseño detallado.

Figura 11. Corte parcial en la etapa de diseño detallado, *software* Rhinoceros

3.4 Fabricación de prototipos funcionales

Los prototipos se materializaron a través de la tecnología FDM y el polímero ABS en la empresa EQ3D, en Medellín, Colombia. Los tiempos de impresión fueron de 20 horas para el diagrama de Voronoi, 15 horas para el patrón hexagonal y 7 horas para las geometrías triangulares (figuras 12, 13 y 14).

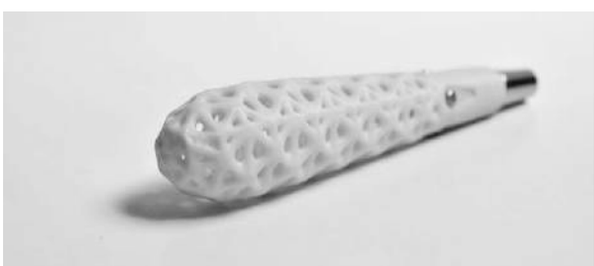

Figura 12. Prototipo funcional basado en un patrón triangular

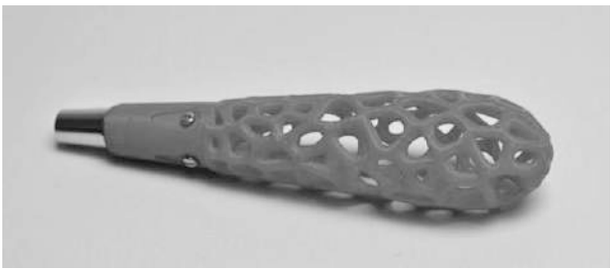

Figura 13. Prototipo funcional basado en el diagrama de Voronoi

Figura 14. Prototipo funcional basado en un patrón hexagonal

3.5 Validaciones

En las figuras 15 y 16, se pueden ver los prototipos funcionales instalados y las validaciones de uso. Las asas se han usado durante seis meses.

Figura 15. Serie *Radiolaria* instalada en el local

Figura 16. Validaciones de uso

Se hizo una entrevista semiestructurada de diez preguntas al dueño y a los tres empleados del bar. En síntesis, consideraron que las manijas son de apariencia llamativa y atractiva, cómodas de usar y fáciles de lavar, al ejercer fuerza se sienten robustas. El aumento de tamaño fue acertado porque lo pudieron usar diferentes tipos de personas. Se utilizaron con un esfuerzo menor respecto a las manijas convencionales; según la zona de dónde se manipulen, se puede servir con mayor velocidad (más arriba) o menor velocidad (más abajo). Esto último es muy útil para cervezas con más espuma. Después de seis meses de uso, no han identificado aspectos a mejorar; de todos modos, sería interesante hacer propuestas con espesores más delgados y disminuir levemente el tamaño para que sean más livianas y reducir los tiempos de impresión.

4 Discusión

Ha sido valioso desarrollar productos basados en la naturaleza para un contexto real. El uso de referentes de la naturaleza fue un aporte funcional y estético; el diseño paramétrico ha facilitado la generación y transformación morfológica, ayudando a cumplir los requerimientos en un tiempo razonable; se demostró que la tecnología FDM permite materializar productos reales, funcionales, con alta definición y precisión, con amplias ventajas respecto a las tecnologías convencionales. Algunas desventajas de esta tecnología son los extensos tiempos de impresión, sumados a la extracción de soportes que en algunos casos fue lento y complejo. Los métodos usados pueden ser útiles para otros proyectos similares. Finalmente, esta experiencia evidencia la importancia de transferir los conocimientos de las investigaciones académicas al medio profesional y en un contexto local.

Agradecimientos. Agradezco a mi familia en Chile y Colombia, a la Universidad Pontificia Bolivariana, a la empresa EQ3D y al bar Punta Arena de Medellín, Colombia; gracias a la colaboración de todos ellos ha sido posible realizar esta investigación, me motiva a seguir haciendo proyectos a futuro para crecer en lo personal y profesional.

Referencias

Attaran, M. (2017). The rise of 3-D printing: The advantages of additive manufacturing over traditional manufacturing. *Business Horizons*, *60*(5), 677-688. https://doi.org/10.1016/j.bushor.2017.05.011

Benyus, M. & García, A. (2012). *Biomímesis: innovaciones inspiradas por la naturaleza*. Tusquets.

Drews, A. (2015). 160x magnified, stacked image, bright field (negative image). Fundort / Site: Barbados (sediment sample). Alter / Age: fossil (Middle Eocene to Oligocene) Präparation. [Microfoto]. https://es.wikipedia.org/wiki/Radiolaria#/media/Archivo:Radiolarian_-_Podocyrtis_(Lampterium)_mitra_Ehrenberg_-_160x.jpg

Estévez, A. (2020). *4th International Conference for Biodigital Architecture & Genetics*; 1st ed.). Bubok Publishing. https://www.bubok.es/autores/biodigital?fbclid=IwAR2n2ey4uYtxStxWHd93GBKGGqZgX2k-oe8pH6VrnieyrmkVv-3dKbzI0w4

Fox, F. (2010). Radiolarian protozoan, order Nassellaria, subphylum Radiolaria. [Microfoto]. https://es.wikipedia.org/wiki/Radiolaria#/media/Archivo:Mikrofoto.de-Radiolarien-3.jpg.

Gao, W., Zhang, Y., Ramanujan, D., Ramani, K., Chen, Y., Williams, C. B., Wang, C. C. L., Shin, Y. C., Zhang, S. & Zavattieri, P. D. (2015). The Status, Challenges, and Future of Additive Manufacturing in Engineering. *CAD Computer Aided Design*, *69*, 65-89. https://doi.org/10.1016/j.cad.2015.04.001

Gebeshuber, I. C. & Drack, M. (2008). An Attempt to Reveal Synergies between Biology and Mechanical Engineering. *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, *222*(7), 1281-1287. https://doi.org/10.1243/09544062JMES890

Orciuoli, A. (2011). La enseñanza de la fabricación digital aplicada a la arquitectura: diseño y producción en la era de la información. ESARQ, UIC, Barcelona.

Biomimetic Approaches to Architecture. Poster presented at the Toronto Sustainable Building Conference 7, Toronto, Canadá.

Tee, Y. L., Maconachie, T., Pille, P., Leary, M. Do, T. & Tran, P. (2021). From Nature to Additive Manufacturing: Biomimicry of Porcupine Quill. *Materials and Design*, *210*, 110041. https://doi.org/10.1016/j.matdes.2021.110041

Biodigital Jewelry Through Parametric Design and Additive Fabrication Technologies

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Abstract. Traditional jewelry is the result of knowledge that have been inherited from generation to generation, a traditional activity focused on the skills and manual dexterity of the artisan. In recent decades, a new paradigm for jewelry has emerged thanks to the integration of parametric design and digital additive fabrication technologies. A design project was proposed, aimed to create a series of jewels connecting nature, emotions, and digital technologies. The following methodological sequence was carried out (1) Selection of referents from nature (2) Design concept (3) Parameterized morphological synthesis (4) Morphological explorations (5) Detailed design (6) Materialization through additive fabrication technologies (7) User testing and emotional evaluation (8) Conclusions and improvement proposal. People perceived that the proposals were based on nature, there was a tendency towards positive emotions, such as fascination, desire, pride and hope. Finally, the methods used can be used in other design projects.

Keywords: bio-inspired design, biophilic design, parametric design, digital fabrication technologies, additive fabrication technologies

1 Introducción

La joyería convencional es el resultado de conocimientos y experiencias que se han transmitido de generación en generación, una actividad tradicional centrada en las habilidades y destreza manual del artesano. En las últimas décadas, luego de un proceso de transición entre el uso de técnicas convencionales y tecnologías digitales, emerge un nuevo paradigma para la joyería gracias a la integración del diseño paramétrico y la fabricación digital aditiva. El diseño paramétrico ha impulsado un notable crecimiento en diferentes campos del diseño, incluyendo a la joyería; permite desarrollar geometrías complejas, explorar un amplio rango de posibilidades, superando a los sistemas CAD (Computer Aided Design) convencionales. Solo modificando los *inputs* se originan variaciones en el resultado o conjunto de resultados del algoritmo. Estas transformaciones se pueden ver en un flujo de

datos explícito (Demarco *et al*., 2020). La fabricación digital aditiva, comúnmente conocida como impresión 3D, se caracteriza por construir piezas a través de la adición de capas horizontales a través de diferentes técnicas y materiales. Tiene amplias ventajas, tales como fabricar piezas que no son posibles a través de otros procesos: piezas poliméricas sin moldes, un alto grado de precisión, ensambles ya armados, entre otras posibilidades (Bertacchini *et al*., 2021). La impresión 3D ha tenido un impacto significativo en el proceso de fabricación de joyas, optimizando los tiempos y la productividad, fortaleciendo la producción en serie y personalizada, permitiendo la materialización de piezas complejas que no serían posibles de realizar a mano, mejorando la calidad en definición de detalles entre muchas otras posibilidades (Humberto & Trujillo, 2016). Ejemplos de joyería paramétrica a nivel internacional son las propuestas de Zaha Hadid, Nervous System, Growth objects, Studio Seed y Generative Ways.

Por otra parte, surge la biofilia definida como la inclinación humana para vincularse con la naturaleza, fundamental para la salud física, mental y el bienestar (Wilson, 1986; Kellert & Wilson, 1993; Kellert, 1997; Kellert, 2012). Esta tendencia a relacionarnos con la naturaleza se origina desde una función adaptativa y de supervivencia que llevamos en los genes gracias a nuestros antepasados, que pasaron años inmersos en el medio natural, observando, sintiendo y aprendiendo (Kellert & Calabrese, 2015). El diseño biofílico es la manera de materializar la biofilia y obtener resultados como productos, sistemas, espacios y experiencias; según Kellert y Calabrese (2015), hay tres tipos de experiencias con la naturaleza: directa, indirecta y con el espacio y lugar. El diseño biofílico se conecta con el concepto emergente de diseño positivo, la evolución del término diseño emocional. El enfoque conocido como diseño emocional fue establecido a partir de la primera conferencia internacional Design & Emotions, en 1999 en los Países Bajos; esta aproximación buscaba el desarrollo de productos más significativos y conectados con sus usuarios, utilizando las emociones desencadenadas en la interacción persona-objeto como mediador para dicho fin. El diseño positivo, en cambio, se ha ido orientando hacia aspectos cada vez más profundos y de largo plazo —al tiempo que más humanos y relevantes—, buscando como fin último el bienestar integral de las personas (Jacob-Dazarola, 2022). Considerando estos antecedentes, se propuso un proyecto orientado a diseñar una serie de joyas basadas en referentes de la naturaleza, aprovechando las ventajas de las tecnologías del diseño paramétrico y la fabricación digital aditiva.

2 Metodología

Se planteó un proyecto con un enfoque empírico-experimental, uso de métodos de análisis cualitativo, con énfasis en el uso de tecnologías digitales para el diseño y materialización. Desde la biofilia se trabajó con una experiencia indirecta con la naturaleza según Kellert y Calabrese (2015), es decir a través de elementos artificiales basados en organismos o sistemas naturales. Como se puede ver en la figura 1, se realizó la siguiente secuencia metodológica: (1) selección de referentes en la naturaleza, (2) concepto de diseño —idea generatriz—, (3) síntesis morfológica parametrizada, (4) exploraciones morfológicas, (5) diseño detallado, (6) materialización a través de tecnologías de fabricación aditiva, (7) validaciones y evaluación emocional, (8) conclusiones y propuestas de reconfiguración.

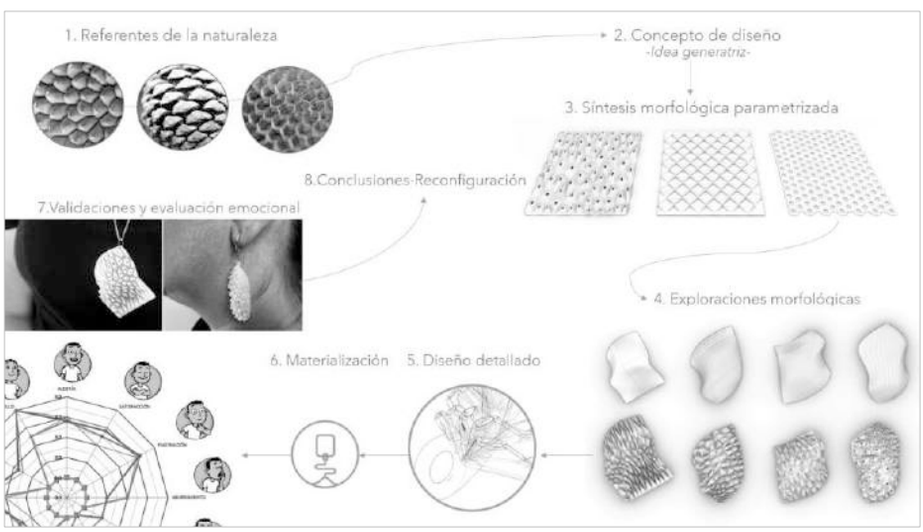

Figura 1. Secuencia metodológica del proyecto.

El proyecto empezó con la búsqueda de referentes en el ámbito de las superficies, pieles y membranas. Se buscaron elementos de diferentes entornos, con morfologías diversas y con patrones modulares; como se puede ver en la figura 2, se eligieron tres referentes: el fruto del *Artocarpus heterophyllus*, el panal de avispas y el porta semilla de la *Pinus pinea.*

Figura 2. Referentes de la naturaleza. Fuente: Gallego y el autor, 2022.

Una vez elegidos los referentes, se definió un concepto de diseño —idea generatriz—, trabajar con superficies complejas y doble curvatura con texturas bioinspiradas. Se decide trabajar en líneas integradas por aretes (aros o pendientes) y un colgante para collar. Esta idea será el eje que definirá el trabajo y exploración en adelante. Como se puede ver en la figura 3, se hizo el proceso de abstracción y parametrización de los patrones morfológicos en Grasshopper, en el entorno del *software* Rhinoceros.

Figura 3. Abstracción y parametrización de patrones

Posteriormente se hicieron diversas exploraciones morfológicas parametrizadas con superficies complejas de doble curvatura. Este tipo de morfologías que están presentes en la naturaleza no obedecen a características estructurales o funcionales para las propuestas, están enfocadas a un planteamiento estético-comunicativo para saber cómo se perciben estas superficies complejas con diferentes texturas bioinspiradas, qué emociones activan y con qué intensidades. En las figuras 4 y 5 se pueden observar las superficies base elegidas. En las figuras 6, 7 y 8 se pueden ver los algoritmos para cada referente, y en las figuras 9 a la 12 se aprecian las tres propuestas de línea.

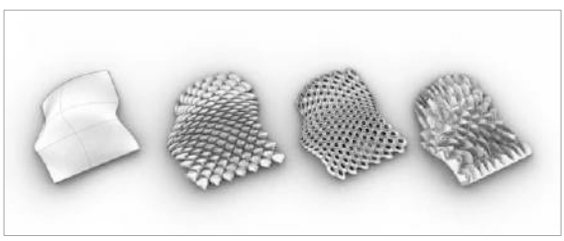

Figura 4. Parametrización para el colgante de collar

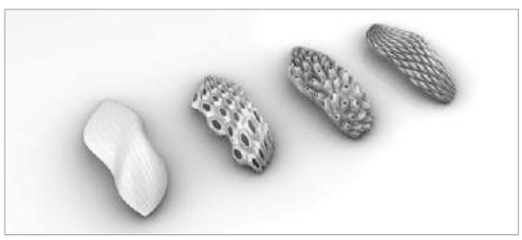

Figura 5. Parametrización para los aretes

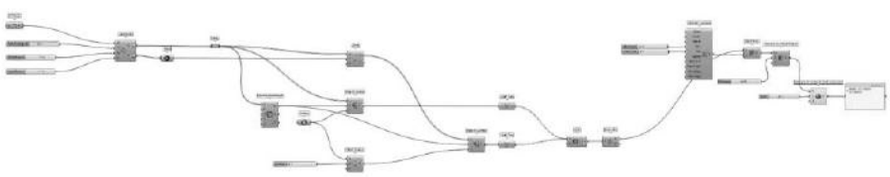

Figura 6. Algoritmo de la línea panal. Fuente: Rabus, 2022.

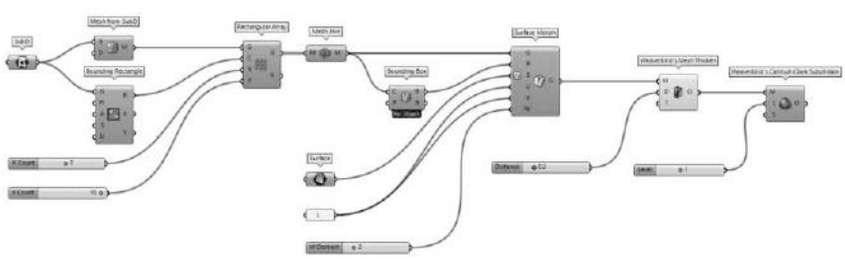

Figura 7. Algoritmo de la línea basada en el porta semilla de la *Pinus pinea*. Fuente: Rabus y el autor, 2022.

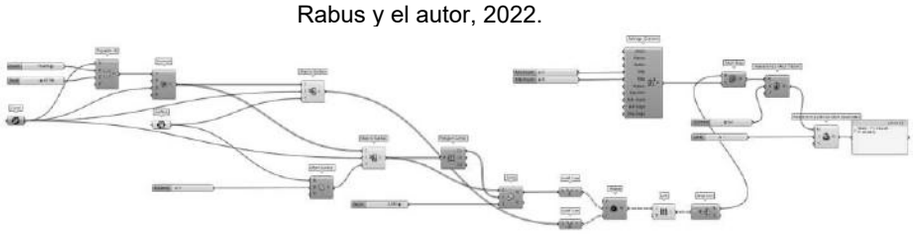

Figura 8. Algoritmo de la línea basada en el fruto del *Artocarpus heterophyllus*. Fuente: Rabus y el autor, 2022.

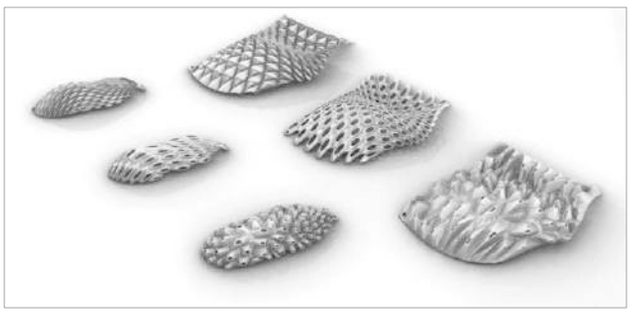

Figura 9. Las tres propuestas de líneas. Fuente: Rabus, 2022.

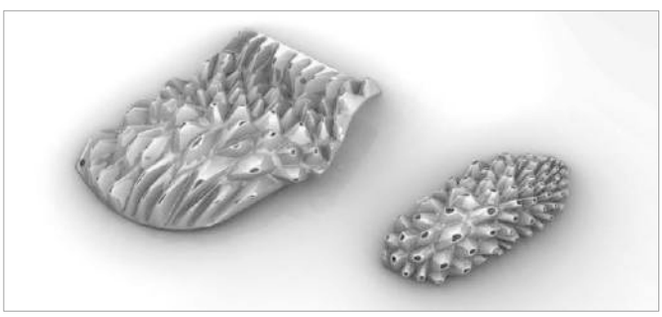

Figura 10. Propuesta de línea 1, basada en el *Artocarpus heterophyllus*, patrón Voronoi. Fuente: Rabus y el autor, 2022.

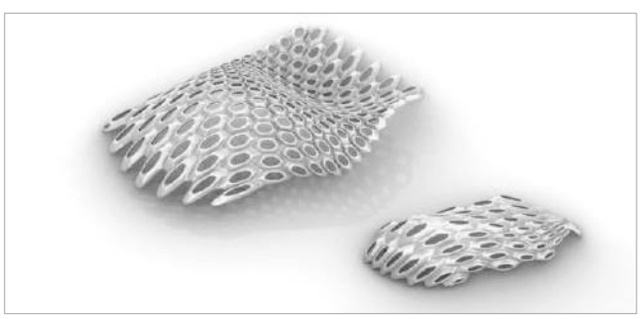

Figura 11. Propuesta de línea 2, basada en panal. Fuente: Rabus y el autor, 2022.

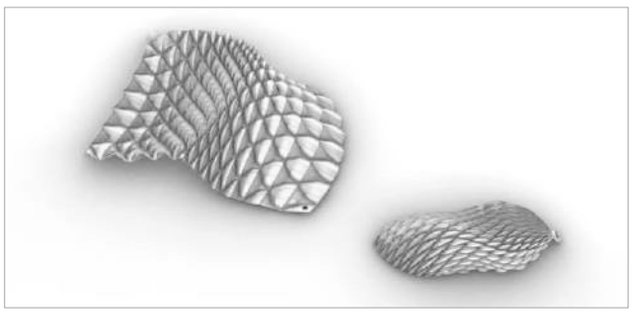

Figura 12. Propuesta de línea 3, basada en el *Pinus pinea*. Fuente: Rabus y el autor, 2022.

Luego se hizo el proceso de diseño detallado de cada una de las piezas en el *software* Rhinoceros. Para materializar las joyas se decidió trabajar con la tecnología Liquid Crystal Display (LCD), esta tecnología permite diseñar piezas muy delgadas, se definió un espesor de 0,2 mm y perforaciones de 1 mm para el anclaje de piezas metálicas. En la tabla 1 se pueden ver los parámetros de impresión.

Tabla 1. Parámetros de impresión

Impresora	UNIZ SLASH 2
Tecnología	LCD
Material	Resina epóxica termocurable color blanco
Resolución de pantalla	4K
Altura de capa	0,1 mm
Tiempo de exposición	4 seg

Se materializaron las tres líneas de joyas, finalmente se hicieron pruebas de uso y una evaluación sobre emociones y percepciones a diez personas, esta actividad consideró tres partes: PrEmo (Emotion Measurement Instrument), diferencial semántico y una entrevista semiestructurada.

3 Resultados

3.1 Prototipos

En las figuras 13 y 14 se pueden ver los prototipos de resina blanca termocurable construidos a través de la tecnología Liquid Crystal Display (LCD).

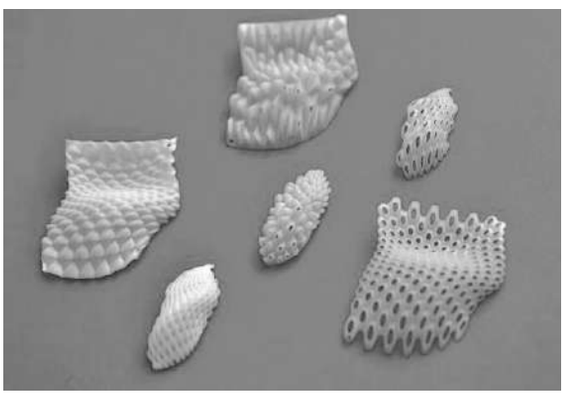

Figura 13. Prototipos de joyas construidos a través de la tecnología LCD

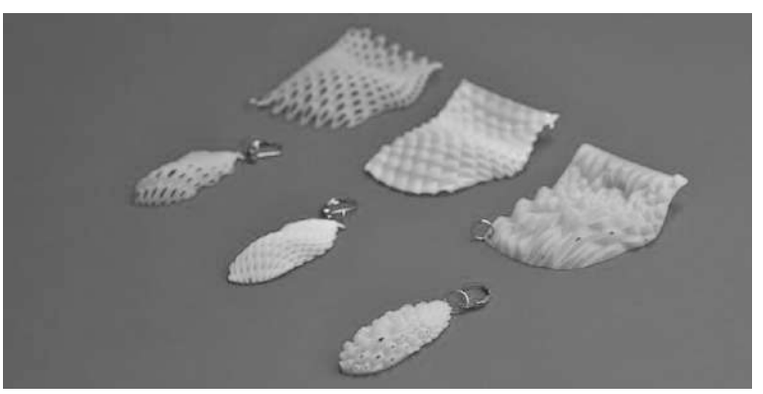

Figura 14. Prototipos de joyas construidos a través de la tecnología LCD con soportes metálicos

3.2 Validaciones de uso

Se hicieron validaciones de uso con una persona que las utilizó durante un día. Se concluye que las piezas son ligeras y resisten, pero es recomendable aumentar el espesor para evitar quebrarlas con algún movimiento brusco o golpe. Las perforaciones de los colgantes (diámetro 1 mm) a veces dificultan insertar las piezas metálicas, entonces se recomienda

agrandarlas. Los tamaños y proporciones de las joyas son adecuados respecto el cuerpo (figura 15).

Figura 15. Fotos de algunas validaciones de uso

3.3 Evaluación perceptual y emocional

Se hizo una evaluación sobre emociones y percepciones a diez personas de Chile, Perú y Colombia. El perfil definido corresponde a mujeres profesionales del diseño, arquitectura o arte. Se define este tipo de personas porque tienen afinidad con el diseño de productos, pueden comprender con mayor facilidad el tipo de preguntas de la evaluación y la interpretación de códigos estético-comunicativos de las propuestas. Esta etapa se dividió en tres partes: PrEmo (Emotion Measurement Instrument), diferencial semántico y una entrevista semiestructurada.

Como se puede ver en la figura 16, el PrEmo evidenció que la línea 1 tiene una tendencia hacia emociones positivas (79,49%) por sobre las negativas (20,51%); entre las positivas se destacan deseo, alegría y satisfacción, y las negativas más importantes fueron miedo, aburrimiento y enfado. En la línea 2 predominaron también las emociones positivas (90,24%) respecto a las negativas (9,76); sobresalen las emociones positivas de orgullo, deseo y satisfacción, las negativas de miedo y aburrimiento. En el caso de línea 3 hay un mayor porcentaje de emociones positivas (94,44%) comparado con las negativas (5,56%); resaltan las emociones positivas de fascinación, deseo y satisfacción, con un bajo índice de emociones negativas. En la figura 17 se puede ver un gráfico comparativo de intensidades de emociones de las tres líneas, se aprecia una preponderancia de las emociones positivas de fascinación, deseo, orgullo y esperanza. La línea 3 fue la que tuvo una mayor inclinación hacia emociones positivas (94,44%) y la línea 1 la que tuvo un mayor porcentaje de emociones negativas (20,51%).

Figura 16. PrEmo: intensidades de emociones de las líneas

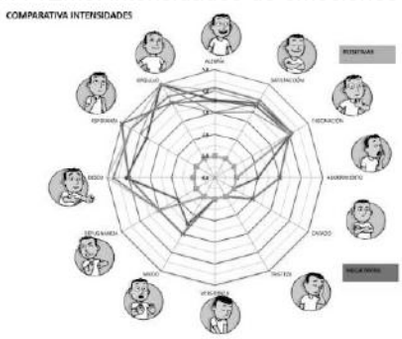

Figura 17. PrEmo: comparativa de intensidades de emociones

Los resultados del diferencial semántico mostraron que el estímulo A (línea 1) se inclinó hacia los conceptos de atractivo, delicado, duro, futurista y complejo. El estímulo B (línea 2) tuvo una tendencia hacia lo atractivo, delicado, duro, futurista, complejo y ligero. Por último, el estímulo C (línea 3) tuvo propensión hacia lo atractivo, valioso, fuerte, blando, futurista y joven. Como se puede ver en la figura 18, la tendencia general del tipo de estímulos del diferencial semántico es hacia las ideas de atractivo, futurista, ligero, joven y pacífico; en el lado de los conceptos opuestos: complejo, inquieto, delicado y blando.

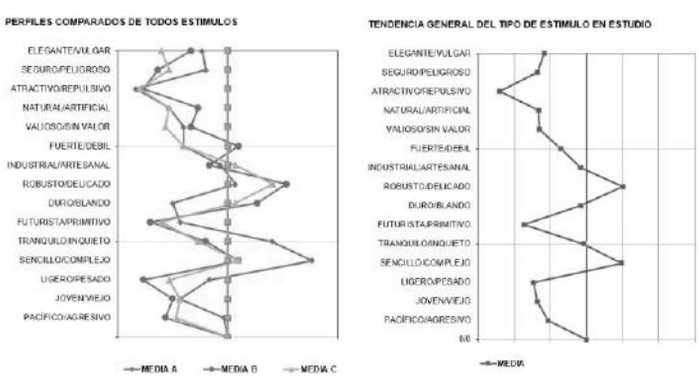

Figura 18. Comparativa y tendencia del diferencial semántico

Al revisar los resultados de las entrevistas semiestructuradas, se puede concluir que se percibe como una propuesta interesante, inusual y diferente a lo existente en el mercado. Un 90% dijo que es una propuesta atractiva, las usarían o regalarían, solo una persona dijo que no le parecieron interesantes, percibió las propuestas como agresivas y delicadas. Un 100% de las entrevistadas reconoce que el diseño fue basado en la naturaleza, gracias a los patrones morfológicos y formas orgánicas en crecimiento dinámico, se relacionó con referentes como conchas, panales, frutas. Un 40% prefirió la línea 3; un 30%, la línea 1; un 20%, la línea 2; y a un 10% no le gustó ninguna (una persona). Algunas participantes sugirieron aplicar diferentes colores para potenciar la propuesta y dar un nombre a cada línea, también les causó curiosidad conocer el proceso de conceptualización y diseño del autor.

4 Discusión

Respecto al uso de tecnologías digitales, efectivamente fueron una ventaja para el proceso de diseño y materialización porque permitieron configurar fácilmente geometrías bioinspiradas con transformaciones dinámicas, materializar morfologías complejas, de alta precisión y espesores extremadamente delgados. Respecto a las percepciones y emociones analizadas en las evaluaciones, es muy interesante que las personas entendieron o interpretaron claramente que se usaron referentes extraídos de la naturaleza, también se identificó una tendencia hacia la percepción de emociones positivas; se destacaron fascinación, deseo, orgullo y esperanza; se dijo que estas joyas son atractivas, interesantes e inusuales. Con esta información se deduce que podría existir una relación directa entre el estímulo (diseño basado en la naturaleza) y la activación de emociones positivas. Sin embargo, en este proyecto aún quedan abiertas muchas preguntas, por ejemplo: ¿exactamente qué rasgos morfológicos otorgan la apariencia de natural o artificial? ¿Qué estímulos específicos activan un mayor nivel de atracción? ¿Qué relación existe entre las formas complejas y el nivel de atracción? ¿Por qué junto con las percepciones positivas subsisten emociones como el miedo o el aburrimiento? Solo por mencionar algunas. Se espera a futuro explorar otro tipo de morfologías de la naturaleza por ejemplo fractales y ramificaciones; ampliar y afinar el tipo de herramientas para medir las emociones y utilizar los resultados obtenidos para hacer modificaciones a las propuestas de diseño. Sería interesante hacer validaciones con personas que no pertenezcan al ámbito de diseño, arquitectura o arte, y contrastar los resultados con la información obtenida en este proyecto. Los resultados y métodos utilizados se pueden aplicar a otras iniciativas de joyería o a otros ámbitos, como calzado, vestuario, mobiliario, entre otros, en un campo emergente y aún en construcción que conecta las propuestas de diseño basado en la naturaleza, las emociones y las tecnologías digitales.

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Referencias

Bertacchini, F., Bilotta, E., Demarco, F., Pantano, P. & Scuro, C. (2021). Multi-objective Optimization and Rapid Prototyping for Jewelry Industry: Methodologies and Case Studies. *International Journal of Advanced Manufacturing Technology*, *112*(9-10), 2943-2959. https://doi.org/10.1007/s00170-020-06469-2

Demarco, F., Bertacchini, F., Scuro, C., Bilotta, E. & Pantano, P. (2020). Algorithms for Jewelry Industry 4.0. En *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics): Vol. 11973 LNCS*. Springer International Publishing. https://doi.org/10.1007/978-3-030-39081-5_37

Humberto, J. & Trujillo, S. (2016). *Lámpsakos*. Universidad Católica Luis Amigó.

Jacob-Dazarola, R. (2022). Diseño y afectividad para fomentar bienestar integral (Vol. 15, Issue 2, pp. 27-68).

Kellert, S. (1997). *Kinship to Mastery: Biophilia in Human Evolution and Development*. Island Press.

Kellert, S. (2012). *Birthright: People and Nature in the Modern World*. Yale University Press.

Kellert, S. R. & Calabrese, E. F. (2015). *The Practice of Biophilic Design*. https://www.biophilic-design.com/

Kellert, S. R. & Wilson, E. O. (1993). *The Biophilia Hypothesis*. Island Press.

Design, Nature and Ecosystems: Living Things

Biocentric Design: Mapping Optimal Environmental Variables for Moss Propagation on Urban Bioreceptive Surfaces

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Abstract. The biocolonisation of urban building surfaces by mosses is a ubiquitous and naturally occurring phenomenon that encapsulates immense ecological value for both current and future challenges of life in cities. The miniature ecosystems facilitated by mosses capture atmospheric pollutants and maintain local biodiversity by providing shelter and nutrients for a highly diverse set of organisms across all kingdoms of life. Early establishment and growth of bryophyte communities appear to be influenced by a dynamic mix of biotic and abiotic factors, while environmental cues modulate physiological responses and biochemical exchanges. A prototype monitoring device was designed to measure carbon dioxide uptake under variable light, humidity, and temperature conditions during a 3-week experiment. By providing a non-destructive tool for understanding and visualising the impact of environmental variables on photosynthetic behaviour, the device contributes to a biocentric design practice, where an organism's ecological needs begin to drive the development of bioreceptive micro-environments.

Keywords: Living things, Bioreceptive design, Moss ecophysiology, Photosynthetic behaviour, Environmental monitoring.

1 Introduction

The practice of Bioreceptive Design challenges the modernist notion of *skin* in architecture by replacing it with a heterogenous Architectural *bark* composed of hybrid mineral-biological assemblages generated through quantitative studies and bio-digital explorations (Cruz & Beckett, 2016). Material porosity, surface macro- and micro-geometry, chemical composition, proximity to sources of diaspores and biochemical interactions between living and non-living material components are known to modulate their bioreceptivity (Guillitte & Dreesen, 1995; Heimans, 1954; Sanmartín et al., 2021). In this

context, building facades have been proposed as potential homes for dynamic multispecies interactions, which have the potential to contribute to green infrastructures by maintaining ecosystem services and urban biodiversity (Watkins et al., 2020). The application of ecological research to architectural design is facilitating a transition towards an *aesthetic of impurity* whereby material-biological interactions and façade ageing are embraced by designers rather than avoided (Cruz, 2021).

Mosses growing autonomously on urban bioreceptive surfaces are part of global cryptogamic covers and play an essential role in carbon sequestration, nutrient cycling and stormwater retention (Anderson et al., 2010; Delgado-Baquerizo et al., 2018; Elbert et al., 2012). During moss development, a range of micro-interactions with substrates and surrounding ecology may influence the development speed and fitness of colonies (Delgado-Baquerizo et al., 2013; Hornschuh et al., 2006; Schauer & Kutschera, 2011). However, the ecophysiological dynamics that enable mosses to develop on vertical building materials such as concrete, brick, stone or wood are not yet fully understood. Photosynthetic rates determine the speed at which mosses grow. However, these are known to be influenced by many factors, including colony morphology (Zotz et al., 2000), humidity (Coe & Sparks, 2014), light conditions (Griffin-Nolan et al., 2018), temperature (Osaki & Nakatsubo, 2021), and carbon dioxide availability (Coe et al., 2012).

Figure 1. Biocolonisation of a brick wall by *Tortula muralis* moss. Source: Alexandra Lăcătușu, 2019

Experiments on the physiological ecology of mosses require a mix of lab-based and field methods. Firstly, understanding how particular parameters influence plant development implies controlling the delivery of a limited number of variable conditions and observing changes in morphology, mass, colour, and gas exchange against control samples (Zotz et al., 2000). In contrast, field experiments consider dynamic environmental changes and

seasonal variations in photosynthetic activity. These span over larger timeframes and often lack detailed data sets that may reveal the dynamic relationship between growth rates and heterogenous weather conditions, day-night dynamics, or site-specific variations in light, temperature and moisture availability (Zotz & Rottenberger, 2001).

Recently, hybrid methods have been developed to pair field and laboratory experiments for tracking succession by bacteria and algae on concrete-based materials (Cruz, 2021; Manso et al., 2014). While some of these included photographic and colorimetric analysis, metagenomic testing and material tests such as porosimetry, it is not yet clear how linking the asynchronous data sets gathered at varying time resolutions and spatial scales can reveal the growth behaviours of studied organisms nor how results from empirical experiments might be re-introduced into an iterative design process.

Echoing planetary and agricultural scale green space monitoring, non-destructive image-based methods for quantifying in-situ moss photosynthesis have already been developed (Pettorelli et al., 2005; Valle et al., 2017). The Normalised Difference Vegetation Index (NDVI) analysis represents one of these methods and was paired with lab tests and colorimetric analysis of reflected light wavelengths to monitor the photosynthetic activity of mosses (Burgheimer et al., 2006; Graham et al., 2006; Young & Reed, 2017).

By combining methods from the fields of bryology, ecology, design and engineering into cross-disciplinary research and design practice, this project aims to create an integrated workflow for introducing the physiological needs of biocrust mosses into bioreceptive design. In this context, this study proposes a hybrid method that includes gas exchange monitoring and image analysis for quantifying photosynthetic performance in bespoke conditions to quantitatively assess the environmental factors that impact the growth of biocrust mosses.

2 Methodology

2.1 Monitoring Device

A small-scale monitoring system for tracking moss growth, health and carbon dynamics was designed and manufactured. Based on research into critical environmental parameters, its purpose was to verify and extract optimal conditions for the growth of the biocrust moss *Syntrichia ruralis*. The prototype closed-loop system contained sensors and a near-infrared image capture module that recorded the photosynthetic activity of the moss specimen by measuring carbon dioxide (CO_2) uptake and oxygen (O_2) production in relation to temperature, humidity, light intensity, and light colour. The monitoring device was placed within a plant growth chamber (CONVIRON, GEN2000 TC) on a 22h-2h day-night cycle at 25-15°C.

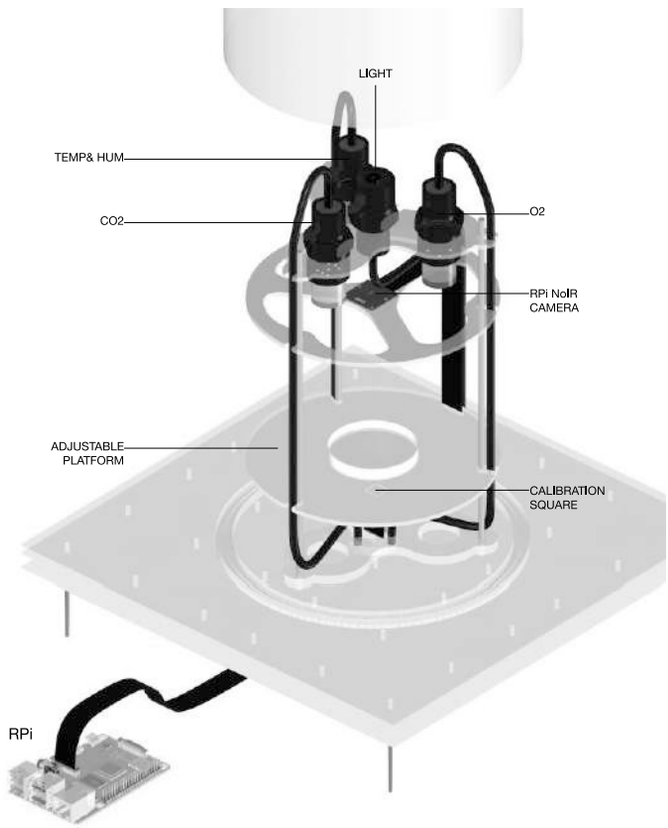

Figure 2. Moss Monitoring Device components. Source: Alexandra Lăcătușu, 2021

2.2 Sample Collection and Preparation

A tuft of *S. ruralis* moss was collected from a concrete surface located next to a riverbank in London (51.560932, -0.043466). Before the experiment, the sample was placed into a petri dish and sprayed with sterile water until saturation. Excess water was discarded, and the specimen was placed at a marked location on the observation platform within the monitoring device. The device was sealed to provide an airtight closed-loop microenvironment for the whole duration of the experiment.

2.3 Sensor Readings

A series of factory-calibrated sensors (EZO series, Atlas Scientific) located within the device recorded CO_2, O_2, air humidity, temperature, dew point and light intensity levels. All sensors were placed at the top level of the device,

facing the sample at approximately 15cm, except for the light intensity and light colour sensor, which faced upwards to capture environmental light levels. Sensor recordings were done at 15-minute intervals throughout the 3-week experiment and recorded on a Raspberry Pi microcontroller.

2.4 Image Capture and NDVI Image Analysis

Image data was captured with a Raspberry Pi NoIR camera at the same 15-minute intervals for complementing sensor readings and measuring the surface area of the studied sample. The absence of an infrared filter on the camera module allowed for reflected infrared light to be recorded and the Normalised Difference Vegetation Index to be calculated (Young & Reed, 2017).

$$NDVI = (NIR - RED)/(NIR + RED) \quad (1)$$

Values range from -1 to 1, and pixels with an index above 0.33 indicate active photosynthetic areas.

2.5 Net Photosynthesis Equation

The basic equation for a closed-loop system was used (Field et al., 1989).

$$An = ((Cf - Cb) * V)/\Delta tL \quad (2)$$

Here Cb is the initial concentration of CO_2, Cf is the final concentration, V is the total volume of air within the chamber, Δt is the time elapsed from the beginning of the experiment until its end, and L is the surface area of the moss sample estimated from image recordings. Final photosynthetic rates were calculated based on chamber CO_2 levels and the estimated sample area at 15-minute intervals and as an absolute cumulative value for the whole experiment duration. All values were expressed as ppm/m^2/s.

3 Results

3.1 Photosynthesis and Respiration

Daytime CO_2 values within the device fluctuated between 150 and 460 ppm during the experiment. A steady decrease in overall CO_2 levels was observed for the first four days, which may show its uptake by moss, followed by an equivalent increase between day 5 and day 8, potentially indicating respiration from moss tissues. Following this period, CO_2 levels went through a plateau phase, stabilising around the value of 300 ppm. An increase in the

initial CO_2 levels within the device followed the plateau phase, indicating higher respiration rates than photosynthesis. For the night cycles, a rhythmic set of spikes in CO_2 levels between 50-80 ppm correlated with a humidity increase from 70% to 100% and a decrease in O_2 levels.

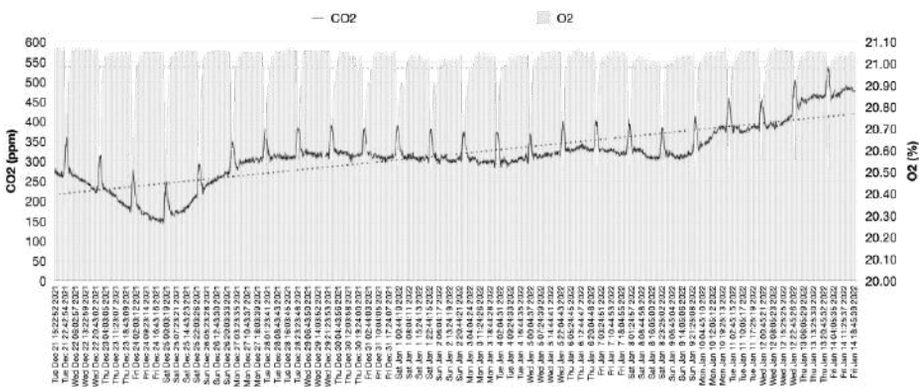

Figure 3. Fluctuations between daytime and night CO_2 and O_2 levels within monitoring device. Source: Alexandra Lăcătușu, 2022

3.2 Photosynthetic Rates

The photosynthetic rate at 15-minute intervals showed substantial variations throughout the experiment, ranging from an average CO_2 gain of 5.84 ppm/m^2/s to a loss of 6.44 ppm/m^2/s. The cumulative rate of -0.1 ppm/m^2/s calculated for the 3-week experiment indicated an overall negative CO_2 balance in the moss sample.

3.3 Environmental Monitoring

Throughout the experiment, there was a clearly defined diurnal pattern in overall environmental conditions, with light and temperature levels influenced by the plant growth chamber's environmental schedule. Temperature levels within the monitoring device oscillated from 15°C during night cycles to just below 30°C during the day. While the lower limit was in line with the chamber's night cycle setpoint, the daytime temperature exceeded it by about 5°C, indicating overheating within the device. In line with the lighting settings of the chamber, the light intensity levels recorded were relatively stable and low, varying between 1.5% and 2.5% of full sun, with the first part of the day characterised by lower values (1500-2000 lux), and higher light intensity for the rest of the day cycle (up to 2500 lux). Daytime air humidity (80%) was recorded at high temperatures (29°C), while sudden drops in temperature (15°C) and light intensity during the night cycle matched drops in air humidity (70%). A rise in humidity above daytime levels was recorded toward the end of each night cycle.

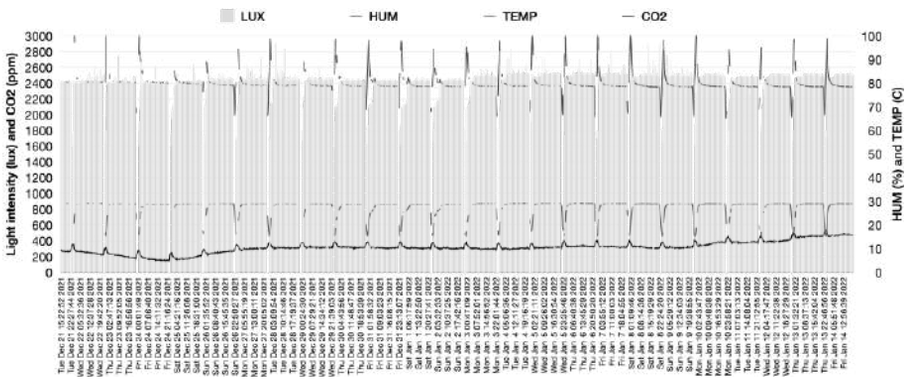

Figure 4. Interaction between environmental parameters and CO_2 levels. Source: Alexandra Lăcătușu, 2022

3.4 NDVI Image Analysis

Results from NDVI analysis show that photosynthetic activity was maintained for longer in the middle of the sample as opposed to its edges. This is indicated by red areas with an NDVI value between 0.66 and 1, while yellow and green areas were the least active, shown by values below 0.66 and 0.33, respectively. Since image data gathered throughout the experiment showed drying and shrinkage of moss starting from the edges of the sample and moving toward the centre, the NDVI pattern shows a correlation between the presence of liquid water and photosynthetic activity.

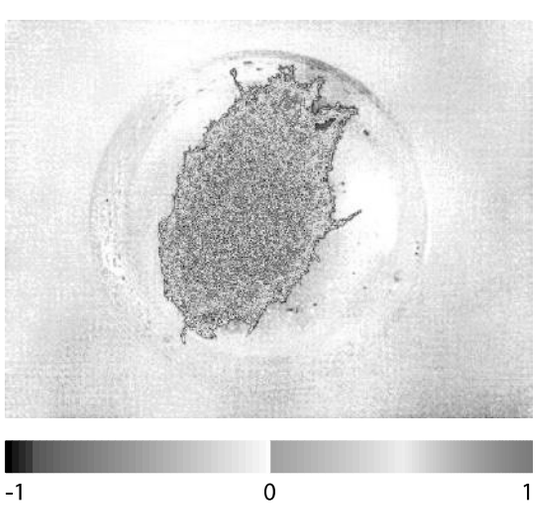

Figure 5. NDVI results for *S. ruralis* moss sample. Colourised pixels represent NDVI values between 0 and 1. Source: Alexandra Lăcătușu, 2022

4 Discussion

The results from this pilot experiment revealed the short and mid-term effects of variable light intensity, temperature, and air humidity on the photosynthetic activity of the selected moss species, *S. ruralis*. The rhythmic day-night cycles, environmental conditions provided by the plant growth chamber, and the single watering event at the beginning of the experiment provided a controlled set of variables for observing patterns in photosynthetic activity. Pairing sensor data and zooming in and out at different time scales within the data set allowed for correlations to be monitored and interpreted against existing literature on how individual variables such as light intensity, temperature, humidity, and CO_2 influence photosynthesis.

4.1 Photosynthetic Behaviour

The most critical factor for photosynthesis in mosses is the presence of water. Studies have shown that the optimal relative water content (RWC) for maximum photosynthetic rates in drought-tolerant moss *S. ruralis* is 40% to 70% (Tuba et al., 1996). Water content above this range causes low CO_2 diffusion through the water pellicle gliding on the leaf surface and inhibiting photosynthesis, while a lower RWC does not fulfil the cell's water potential for the photosynthetic activity to be maintained (Coe & Sparks, 2014). Although the RWC of the sample could not be measured for this experiment, the drying pattern recorded on camera over the 3-week timeframe, paired with NDVI image analysis, data on air humidity and CO_2 levels were sufficient for observing the photosynthetic behaviour of the studied specimen. Following the initial watering, the gradual decrease of CO_2 levels within the chamber over the first four days of the experiment is hypothesised to correlate with increasing photosynthetic rates in the moss. Image data showed surplus water evaporating from the sample, followed by gradually drying of the moss tuft inwards. This pattern was in line with the NDVI analysis showing that dry tissues reflected less infrared light, indicating the reduction of photosynthetic activity within the sample.

Light is observed to be another highly limiting factor for photosynthesis. With few exceptions, the light compensation and saturation points for sun-adapted species are between 1000-2000 lux (Bazzaz et al., 1970) and 10000-30000 lux, respectively (Glime, 2017). In *S. ruralis*, 95% light saturation and maximum photosynthetic rates occur at a photosynthetic photon flux density (PPFD) of 832-935 $\mu m/m^2/s$ and full saturation at >1000 $\mu m/m^2/s$ (Coe & Sparks, 2014; Marschall & Proctor, 2004), the equivalent of about 36000-40000 lux and 43500 lux respectively. In this experiment, daytime lighting levels were just over the compensation point, at about 2.5% of full sunlight (1500-2500 lux).

Insufficient excitation of electrons due to light intensity levels below the compensation point is known to halt photosynthesis and activate dark

respiration processes, causing CO_2 loss from plant tissues and limiting growth (Glime, 2017). As a result, the CO_2 uptake rates recorded for this experiment show the lowest range of photosynthetic capacity for the moss species, which was about 5.84 ppm/m^2/s. The sudden switch from light to darkness was followed by increased levels of CO_2 and humidity within the device, which indicates dark respiration (Zotz et al., 2000).

The optimal temperature levels for *S. ruralis* range between 10 - 20°C, while at temperatures above 25-35°C, the organism's photosynthetic activity becomes inhibited by a series of biochemical, physiological and environmental factors, which include increased respiration rates and the reduction of water availability due to faster evaporation (Coe et al., 2012). The daytime temperature within the monitoring device was around 30°C, exceeding the optimal range for this species and consequently creating unfavourable conditions for photosynthesis.

The photosynthetic performance of *S. ruralis* must be assessed against suboptimal conditions since the negative carbon balance was influenced by the low light intensity paired with high temperature and limited water availability. Due to *in vivo* yearly climatic dynamics, which include irradiance factors, temperature oscillations, and magnitudes and length of rain events, biocrust mosses may not always maintain a positive annual carbon balance (Coe & Sparks, 2014), and the results from this 3-week experiment showed how variations in humidity, light and temperature below or above optimal levels affect the carbon balance of wall-dwelling moss *S. ruralis*. In this context, bioreceptive design projects that seek to sequester CO_2 from urban environments through moss biocolonisation need to include strategies for maintaining environmental conditions within optimal ranges to match the ecophysiological needs of selected species.

4.2 Device optimisation and further research

The environmental variables monitored in this experiment were generated by the plant growth chamber with pre-set schedule and a single watering event, setting a predictable rhythm of photosynthesis. However, temperature, moisture, and lighting conditions vary more widely across days and seasons in the outdoor environment. Introducing wider variations in light intensity, temperature, and water availability would allow for more correlations and a higher resolution in understanding optimal conditions for maximum photosynthetic rates in mosses.

Further calibration of the camera hardware and software enabling automated tracking of total green surface area measurements would allow photosynthetic rates to be calculated in real-time. Script amendments, including automatic NDVI gradient analysis, will generate more accurate results on the photosynthetic potential of different moss species. At the same time, the assessment of relative photosynthetic rates for larger biocolonised

surfaces and different mosses growing *in vivo* could be done remotely (Graham et al., 2006; Young & Reed, 2017).

Data gathered from similar experiments testing other urban moss species may contribute to a standardised model for identifying optimal environmental conditions. This is necessary for identifying and evaluating the potential of other mosses to propagate and thrive on building materials. The designed monitoring device is a prototype tool for simulating the interaction between different *in vivo* environmental variables and the photosynthetic behaviour of cryptogams in dynamic microclimatic settings. This research constitutes a critical step toward a data-driven bioreceptive design practice based on biological experimentation (Cruz & Beckett, 2016), where the needs of particular moss species are captured and analysed through quantitative research, beginning to drive what can be seen as a biocentric approach to both design and material bioreceptivity.

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References

Anderson, M., Lambrinos, J., & Schroll, E. (2010). The potential value of mosses for stormwater management in urban environments. *Urban Ecosystems*, *13*(3), 319–332. https://doi.org/10.1007/s11252-010-0121-z

Bazzaz, F., Paolillo, D., & Jagels, R. (1970). Photosynthesis and Respiration of Forest and Alpine Populations of *Polytrichum juniperinum*. *American Bryological and Lichenological Society*, *73*(3), 579–585.

Burgheimer, J., Wilske, B., Maseyk, K., Karnieli, A., Zaady, E., Yakir, D., & Kesselmeier, J. (2006). Relationships between Normalized Difference Vegetation Index (NDVI) and carbon fluxes of biologic soil crusts assessed by ground measurements. *Journal of Arid Environments*, *64*(4), 651–669. https://doi.org/10.1016/j.jaridenv.2005.06.025

Coe, K. K., Belnap, J., Grote, E. E., & Sparks, J. P. (2012). Physiological ecology of desert biocrust moss following 10 years exposure to elevated CO_2: Evidence for enhanced photosynthetic thermotolerance. *Physiologia Plantarum*, *144*(4), 346–356. https://doi.org/10.1111/j.1399-3054.2012.01566.x

Coe, K. K., & Sparks, J. P. (2014). Physiological Ecology of Dryland Biocrust Mosses. In D. T. Hanson & S. K. Rice (Eds.), *Photosynthesis in Bryophytes and Early Land Plants* (pp. 291–308). Springer. https://doi.org/10.1007/978-94-007-6988-5

Cruz, M. (2021). Design for Ageing Buildings. In L. Duanfang (Ed.), *The Routledge Companion to Contemporary Architectural History* (pp. 384–400). Routledge.

Cruz, M., & Beckett, R. (2016). Bioreceptive design: A novel approach to biodigital materiality. *Architectural Research Quarterly*, *20*(1), 51–64. https://doi.org/10.1017/S1359135516000130

Delgado-Baquerizo, M., Maestre, F. T., Eldridge, D. J., Bowker, M. A., Jeffries, T. C., & Singh, B. K. (2018). Biocrust-forming mosses mitigate the impact of aridity on soil microbial communities in drylands: observational evidence from three continents. *New Phytologist*, *220*(3), 824–835. https://doi.org/10.1111/nph.15120

Delgado-Baquerizo, M., Morillas, L., Maestre, F. T., & Gallardo, A. (2013). Biocrusts control the nitrogen dynamics and microbial functional diversity of semi-arid soils in response to nutrient additions. *Plant and Soil*, *372*(1–2), 643–654. https://doi.org/10.1007/s11104-013-1779-9

Elbert, W., Weber, B., Burrows, S., Steinkamp, J., Büdel, B., Andreae, M. O., & Pöschl, U. (2012). Contribution of cryptogamic covers to the global cycles of carbon and nitrogen. *Nature Geoscience*, *5*(7), 459–462. https://doi.org/10.1038/ngeo1486

Field, C. B., Ball, T. J., & Berry, J. A. (1989). Photosynthesis: Principles and field techniques. In R. W. Pearcy, J. Ehleringer, H. A. Mooney, & P. W. Rundel (Eds.), *Plant Physiological Ecology. Field methods and instrumentation* (pp. 209–253). Chapman and Hall.

Glime, J. (2017). Photosynthesis: The Process. In J. Glime (Ed.), *Bryophyte Ecology, Volume 1: Physiological Ecology* (Vol. 1). Michigan Tech. http://digitalcommons.mtu.edu/bryophyte-ecology/

Graham, E. A., Hamilton, M. P., Mishler, B. D., Rundel, P. W., & Hansen, M. H. (2006). Use of a networked digital camera to estimate net CO2 uptake of a desiccation-tolerant moss. *International Journal of Plant Sciences*, *167*(4), 751–758. https://doi.org/10.1086/503786

Griffin-Nolan, R. J., Zelehowsky, A., Hamilton, J. G., & Melcher, P. J. (2018). Green light drives photosynthesis in mosses. *Journal of Bryology*, *40*(4), 342–349. https://doi.org/10.1080/03736687.2018.1516434

Guillitte, O., & Dreesen, R. (1995). Laboratory chamber studies and petrographical analysis as bioreceptivity assessment tools of building materials. *Science of the Total Environment*, *167*(1–3), 365–374. https://doi.org/10.1016/0048-9697(95)04596-S

Heimans, J. (1954). L' accessibilité, terme nouveau en phytogéographie. *Vegetatio*, *5*(1), 142–146.

Hornschuh, M., Grotha, R., & Kutschera, U. (2006). Moss-associated methylobacteria as phytosymbionts: An experimental study. *Naturwissenschaften*, *93*(10), 480–486. https://doi.org/10.1007/s00114-006-0137-7

Manso, S., De Muynck, W., Segura, I., Aguado, A., Steppe, K., Boon, N., & De Belie, N. (2014). Bioreceptivity evaluation of cementitious materials designed to stimulate biological growth. *Science of the Total Environment*, *481*(1), 232–241. https://doi.org/10.1016/j.scitotenv.2014.02.059

Marschall, M., & Proctor, M. C. F. (2004). Are bryophytes shade plants? Photosynthetic light responses and proportions of chlorophyll a, chlorophyll b and total carotenoids. *Annals of Botany*, *94*(4), 593–603. https://doi.org/10.1093/aob/mch178

Osaki, S., & Nakatsubo, T. (2021). Effects of climate warming on the production of the pioneer moss *Racomitrium japonicum*: seasonal and year-to-year variations. *Journal of Plant Research*, *134*(1), 115–126. https://doi.org/10.1007/s10265-020-01240-w

Pettorelli, N., Vik, J. O., Mysterud, A., Gaillard, J. M., Tucker, C. J., & Stenseth, N. C. (2005). Using the satellite-derived NDVI to assess ecological responses to environmental change. *Trends in Ecology and Evolution*, *20*(9), 503–510. https://doi.org/10.1016/j.tree.2005.05.011

Sanmartín, P., Miller, A. Z., Prieto, B., & Viles, H. A. (2021). Revisiting and reanalysing the concept of bioreceptivity 25 years on. *Science of the Total Environment*, *770*, 145314. https://doi.org/10.1016/j.scitotenv.2021.145314

Schauer, S., & Kutschera, U. (2011). A novel growth-promoting microbe, *Methylobacterium funariae* sp. nov., isolated from the leaf surface of a common moss. *Plant Signaling & Behaviour*, *6*(4), 510–515. https://doi.org/10.4161/psb.6.4.14335

Tuba, Z., Csintalan, Z., & Proctor, M. C. F. (1996). Photosynthetic responses of a moss, *Tortula ruralis, ssp. ruralis*, and the lichens *Cladonia convoluta* and *C. furcata* to water deficit and short periods of desiccation, and their ecophysiological significance: A baseline study at present-day CO_2 concentration. *New Phytologist*, *133*(2), 353–361. https://doi.org/10.1111/j.1469-8137.1996.tb01902.x

Valle, B., Simonneau, T., Boulord, R., Sourd, F., Frisson, T., Ryckewaert, M., Hamard, P., Brichet, N., Dauzat, M., & Christophe, A. (2017). PYM: A new, affordable, image-based method using a Raspberry Pi to phenotype plant leaf area in a wide diversity of environments. *Plant Methods*, *13*(1), 1–17. https://doi.org/10.1186/s13007-017-0248-5

Watkins, H., Robinson, J. M., Breed, M. F., Parker, B., & Weinstein, P. (2020). Microbiome-Inspired Green Infrastructure: A Toolkit for Multidisciplinary Landscape Design. *Trends in Biotechnology*, *xx*(xx), 4–7. https://doi.org/10.1016/j.tibtech.2020.04.009

Young, K. E., & Reed, S. C. (2017). Spectrally monitoring the response of the biocrust moss *Syntrichia caninervis* to altered precipitation regimes. *Scientific Reports*, *7*(July 2016), 1–10. https://doi.org/10.1038/srep41793

Zotz, G., & Rottenberger, S. (2001). Seasonal changes in diel CO_2 exchange of three central European moss species: A one-year field study. *Plant Biology*, *3*(6), 661–669. https://doi.org/10.1055/s-2001-19363

Zotz, G., Schweikert, A., Jetz, W., & Westerman, H. (2000). Water relations and carbon gain are closely related to cushion size in the moss *Grimmia pulvinata*. *New Phytologist*, *148*(1), 59–67. https://doi.org/10.1046/j.1469-8137.2000.00745.x

Other Computations: Digital Craft

Curve folding in Form Generation with Digital Fabrication

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Abstract. The combination of traditional morphological knowledge with digital manufacturing possibilities is fundamental for Design. Understanding how to create unthinkable shapes, when old boundaries are removed, opens generative possibilities for everyday objects. On the other hand, pre-digital knowledge provides conceptual resources to organize this new possibility. This interaction allows critical appropriation to take place. This research aims to incorporate curved folding through laser cutting as a tool to generate new forms, considering the value of pre-digital knowledge and of the benefits of digital fabrication in this area, compared to traditional cutting dies. The analysis of geometric aspects was the initial activity, defining the design variables for two kinds of patterns. Later different laminar materials were tested to determine the advantages and obstacles in each case. Finally, some of the results were implemented in products and verified in instructional activities with Industrial Design undergraduate students.

Keywords: digital craft, morphology, design, curve-folding, materials

1 Introducción

Cuando existe un extenso desarrollo de posibilidades tecnológicas, es fundamental elegir atendiendo a las necesidades locales, con una mirada global. A lo largo de los años, nos hemos apropiado de distintos recursos provenientes de los medios digitales. Al enseñar e investigar en una universidad pública, los fondos siempre han sido limitados. Esta restricción fomentó la diversidad, tanto de plataformas y programas que empleamos como de usos híbridos analógico-digitales. Entendemos también que no se trata de descartar los conocimientos previos, sino de capitalizarlos y reformularlos o ampliarlos a la luz de los avances que permiten nuevas exploraciones.

Como una manera de ejemplificar este modo de trabajo, nos referiremos a la investigación sobre plegado curvo en objetos. Esta tecnología ya estaba disponible con procesos tradicionales (troquelado y corte). Sin embargo, la

dificultad de la construcción de los troqueles limitaba las formas posibles, y su costo requería una cantidad significativa de repeticiones para que fuera viable económicamente. El marcado o el corte discontinuo con corte láser habilitó un gran número de experimentaciones que extendieron los límites de la incorporación de este sistema generativo a las formas de los objetos cotidianos, incorporando también la complejidad de los pliegues curvos como una variable más de diseño. En este proyecto se revisaron los desarrollos teóricos previos para diseñar exploraciones con el propósito de identificar las variables de transformación y su potencia configurativa para contribuir a la elaboración de la forma de los objetos de uso. Asimismo, se exploraron diferentes materiales para detectar la potencialidad y su aporte como recurso de diseño.

1.1 Los antecedentes

Uno de los orígenes del plegado curvo puede rastrearse al doblado de servilletas del siglo XVII (Demaine *et al.*, 2008; Koschitz, 2014), como se aprecia en *Li Tri Trattatti*, de Messer Mattia Giegher (1639). Siglos después, con una mirada centrada en la exploración de la forma y la materia, Josef Albers introduce esta temática en los cursos de la Bauhaus de 1927 y 1928. Algunas producciones de sus estudiantes fueron el origen de distintas investigaciones. Una historia pormenorizada de este recorrido se encuentra en Koschitz (2014), quien, si bien centró su tesis en la obra de Huffman, realiza un atento relevamiento de los antecedentes del plegado curvo. Desde un punto de vista morfogenerativo, se considera de particular interés el trabajo de Huffman, Resch, Demaine, Mitani y Sweeney. A lo largo de los años, desde la producción de diseño industrial, se ha empleado en envases, muebles y diversos productos en distintos materiales como cartulina, plástico y metal. Un caso paradigmático es el del sistema de lámparas creado por Poul Christiansen y fabricado por la empresa Le Klint (s. f.) desde 1971 en láminas plásticas. Estos objetos muestran la complejidad formal que puede lograrse a partir de una lámina rectangular por medio de simples plegados curvos. Productos tan disímiles como cubiertos descartables de Sam Sannia Design (s. f.) del 2007, el equipamiento Flux de 2009 (fluxfurniture.com), el bote plegable de Maarmo Design de 2011 (Etherington, 2011) o la instalación Arum de Zaha Hadid (s. f.) de 2012 evidencian la diversidad de usos, escalas y materiales que aprovechan esta estrategia morfogenerativa.

Es notable el aporte de los medios digitales en estos casos en un rol doble. Una valiosa contribución es en la generación y determinación de formas, en particular aquellas concretadas por módulos diferentes que dan cuenta de las transformaciones. El otro rol se vincula a sus aspectos productivos: desde el corte láser o por agua en materiales tan diversos como papel y metal, la disposición de placas para el aprovechamiento del material y la identificación de piezas distintas por grabado hasta el plegado de metal por robots, entre otras contribuciones.

2 Metodología

En el marco del proyecto UBACyT 20020130200091BA, *Morfología y medios digitales: nuevas posibilidades morfogenerativas y de fabricación*, se estudiaron las alternativas para la producción de formas por medio de plegado curvo, en principio en instancias predigitales, para producir una conceptualización de estas técnicas desde sus posibilidades morfogenerativas. Con el propósito de delimitar el objeto de estudio, nos centramos en los diagramas que consisten en bandas, con pliegues paralelos al lado corto y los radiales, con simetría en su mayor parte y sin costura. Se dejaron de lado las tramas por plegado curvo (Koschitz, 2014) y los plisados por líneas concéntricas cerradas (ampliamente desarrolladas por Demaine *et al*., 2009; y Caigui *et al.*, 2019). También excluimos los plegados con tensión del material curvado y por asociaciones de fragmentos de superficies reflejadas. Estas categorías podrían abordarse en otra instancia. Se seleccionaron dos grupos de patrones, y se produjeron diversas experiencias para definir sus variables. En principio se trabajó a mano y luego se empleó corte láser en diferentes materiales laminares, para explorar los aportes y limitaciones que cada uno brindaba. La conceptualización y su implementación apuntaban al uso del plegado curvo como un recurso más en la generación de formas para el diseño industrial.

3 La investigación

La indagación atravesó diferentes etapas: una vinculada mayormente a la comprensión de las variables de transformación de algunos patrones existentes; otra relacionada con el empleo de diferentes materiales y su implementación en productos.

3.1 Análisis de las configuraciones

Para entender la relación entre las formas planas y sus correlatos tridimensionales, se desarrollaron diferentes modificaciones de los patrones de plegado seleccionados, verificando su influencia en el modelo 3D. Esto puede verse en un diagrama de bandas y en el desarrollo del pasante de investigación Bruno Lai sobre el patrón Bud (https://theiff.org/oexhibits/paper04.html de la Dra. Jeannine Mosely) en la figura 1.

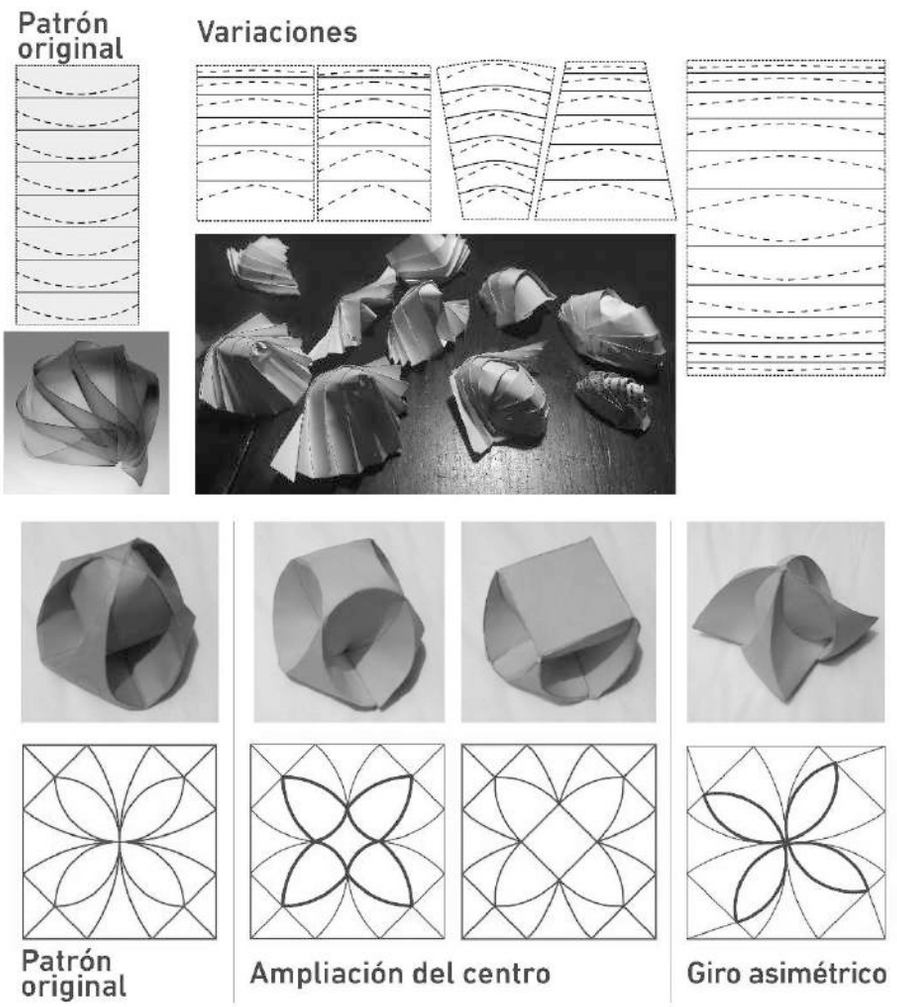

Figura 1. Diagrama original (bandas y radial) y variaciones

3.2 Exploraciones empleando corte láser y diferentes materiales

Una vez detectadas las principales variables de diseño y la relación entre el 2D y 3D, se incorporó el corte láser como herramienta de exploración para incluir diferentes materiales laminares. Cabe aclarar que el Laboratorio de Morfología no cuenta con máquinas de corte láser propias, por esto se trabajó con proveedores externos. En todos los casos, ellos tenían una amplia experiencia en el uso de los equipos y no hubo problema en las soluciones técnicas.

La primera experimentación fue con polipropileno, ya que aportaba la posibilidad de incorporar la variable de transparencia, transluscencia y opacidad. Esta última se lograba por superposición de material como puede verse en el sector superior de la figura 2. Otro aspecto significativo para esta elección fue la resistencia al plegado reiterado que tiene este material. Su baja tasa de fatiga permite doblar las piezas muchas veces sin que se agrieten o rompan. En el sector inferior de la figura 2 se aprecia cómo el punteado no presentó problemas en la superficie y también algunos modos de unión que desarrollamos a partir de las propuestas de Clement Zheng (https://clementzheng.github.io/joinery/). Si bien el *software* es para uniones entre rectas, puede adaptarse a configuraciones curvas. Al ser un material muy resistente, se utilizó esta característica para generar las trabas para mantener la pieza en 3D.

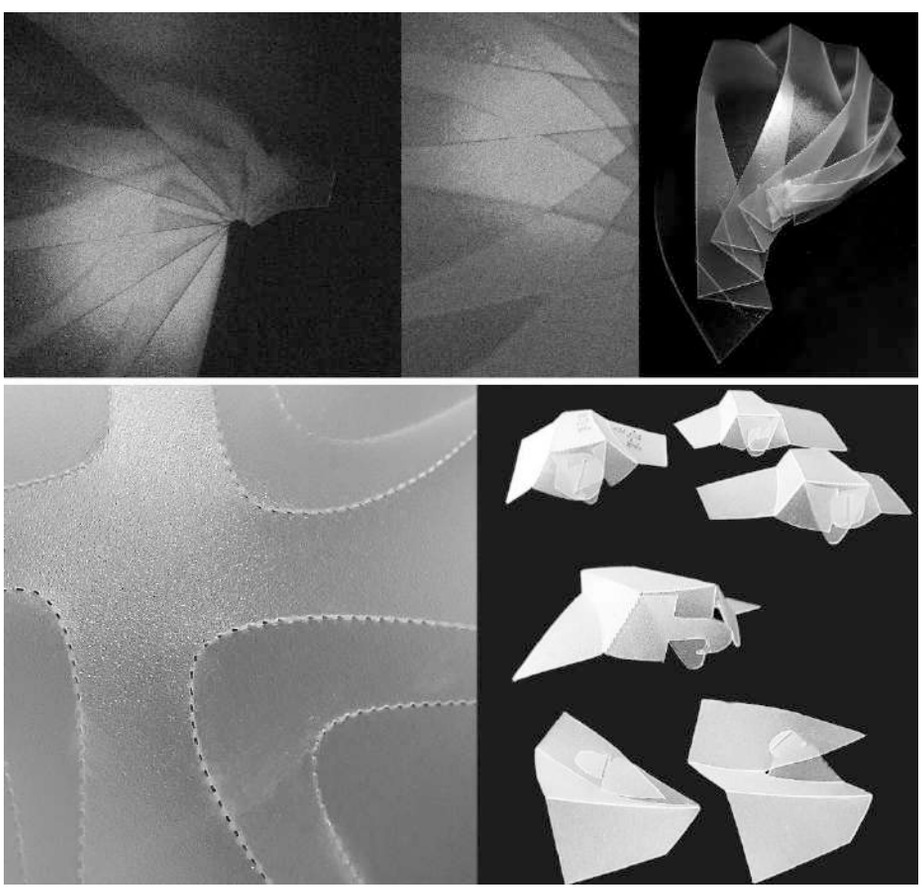

Figura 2. Trasluscencia por superposición en polipropileno. Detalle del punteado con láser y estudio de uniones. Fuente: Muñoz, 2017.

Estas experiencias se trasladaron al diseño de un cloche para un concurso internacional de cocina, Bocuse D´Or, que presentamos en Homo Faber 2.0 (IEHU, 2018). Las piezas finales se fabricaron en polipropileno, pero se realizaron exploraciones muy interesantes con el film de las pantallas led que distorsionan la imagen. No la empleamos porque era muy sensible al quemado, que era inaceptable para el producto. Sin embargo, en la figura 3 se destaca su potencial para otros usos.

Figura 3. Prueba del cloche en film con propiedades ópticas. Fuente: Muñoz, 2017.

Luego, se emplearon cuero y cuerina (o cuero sintético) con un grupo de pasantes de investigación: Leila Linares, Estefanía González Oliva, Santiago Alvarez Troya y Rocío Hochbaum. En estas dos instancias, la flexibilidad del material permitió trabajar con curvados o plegados suavizados. Hay un concepto interesante de *soft folding* (Zhu *et al*., 2013). Si bien es un trabajo diferente, los autores explican la posibilidad de regular la intensidad del plegado, en su caso por la intervención de un *software*, pero también plantean que ese resultado puede lograrse a través del material utilizado.

Figura 4. Algunos resultados de la exploración con cuero y cuerina.
Fuente: Muñoz, 2019.

En nuestra exploración, a partir de uno de los modelos tradicionales de plegado de bandas, realizamos pruebas alternando líneas punteadas y continuas de corte para flexibilizar el material. Las segundas permitieron un curvado más regular. Asimismo, elaboramos una muestra con cuerina de mayor espesor, con un trazado de curvas que alternaban su concavidad y convexidad, dando como resultado el suavizado de los pliegues (figura 4).

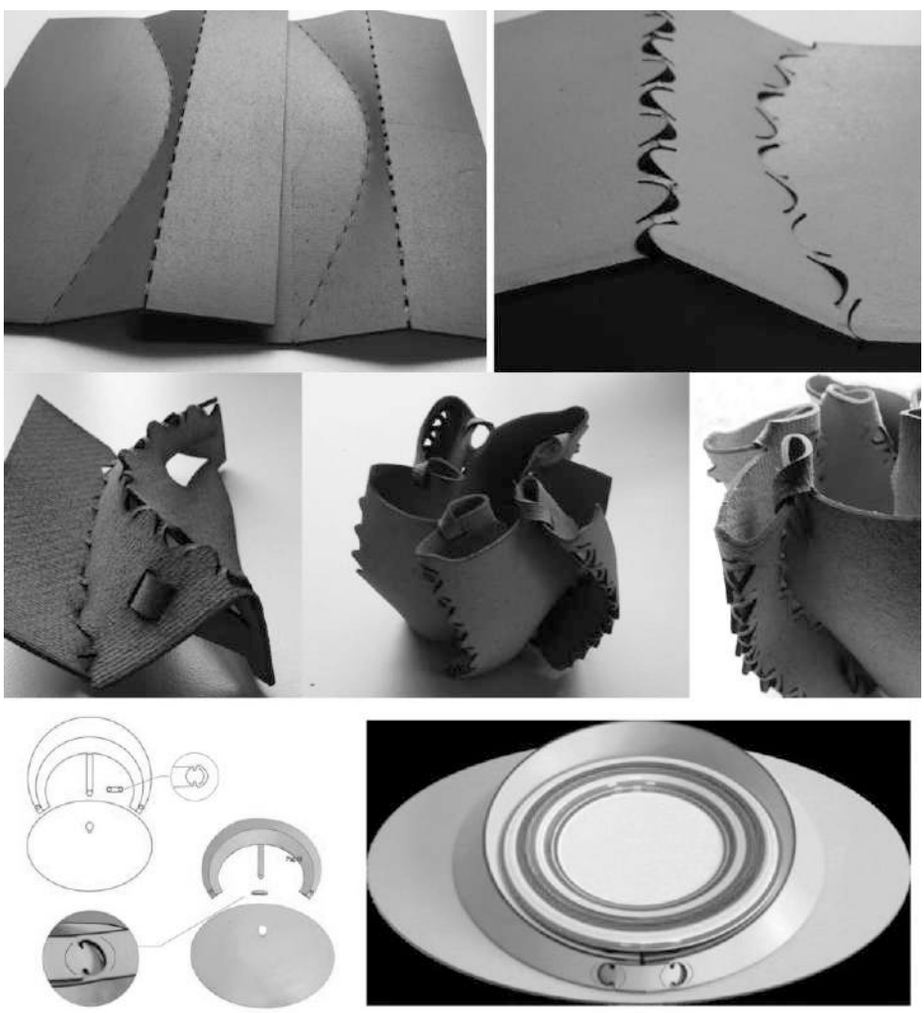

Figura 5. Exploraciones en cuero reconstituido e individual empleando los resultados de la investigación. Fuente: Muñoz, 2019.

Otra experimentación empleó cuero reconstituido (Cueroflex-https://www.cooperativacueroflex.com.ar/#bondedleather). Es un material

aglomerado que contiene 80% de fibras de cuero obtenido de las curtiembres, evocando al cuero natural. Es más rígido que los materiales explorados previamente, y aporta la incorporación de la diferencia de color de sus caras y del espesor como una variable de diseño. Es más quebradizo que el polipropileno, pero flexiona bien al debilitar las zonas de plegado por trazado.

Se realizaron pruebas por punteado y se desarrolló un corte con curvas y contracurvas que colaboraron para liberar las tensiones en curvas más cerradas, al estilo que Industrial Origami emplea en metal para el plegado recto (Chino, 2010). Esto también permite generar líneas de plegado curvo discontinuas, como se aprecia en la figura 5.

En el proyecto de investigación, Analía Sequeira aplicó el plegado curvo en cueroflex, a través de una línea de trazado continuo, para la realización de una ayuda técnica para pacientes que requieren fijar el plato por problemas de motricidad. Este individual podía integrarse a los otros elementos de comida de quienes compartían la mesa sin marcar una diferencia ligada a la discapacidad (figura 5).

4 La transferencia a la enseñanza

Figura 6. Imágenes del taller durante el desarrollo. Fuente: Muñoz, 2019.

La transferencia de los resultados de la investigación se realizó también en la enseñanza. El plegado curvo se incorporó como tema de la asignatura

Morfología 2, de la carrera de Diseño Industrial, FADU, Universidad de Buenos Aires, Argentina, en el curso 2018. Concordamos con Pendelbury (1998) cuando plantea que la práctica es mutable porque cambia con el tiempo y presenta nuevas configuraciones que no pueden ser desconocidas si pretendemos que nuestros raciocinios sean sólidos. Contribuyendo a estos cambios, incorporamos estos nuevos abordajes. Se analizaron las estrategias didácticas propuestas por Koschitz (2014) y se adaptaron a los objetivos del curso.

La práctica involucró a 180 estudiantes organizados en ocho grupos docentes con actividades individuales y grupales. Se alternaron actividades experimentales y analíticas. Los medios empleados por los alumnos fueron también restringidos intencionalmente. Hubo momentos de trabajo sobre maquetas de estudio en papel, otros de dibujo en croquis, otros en CAD y finalmente habilitamos el uso de impresión 3D para las maquetas finales (figura 6). La duración de toda la práctica fue de doce clases, de cuatro horas, una vez por semana. Algunas producciones del proceso de una estudiante, Brenda Pitkowski, se muestran en la figura 7.

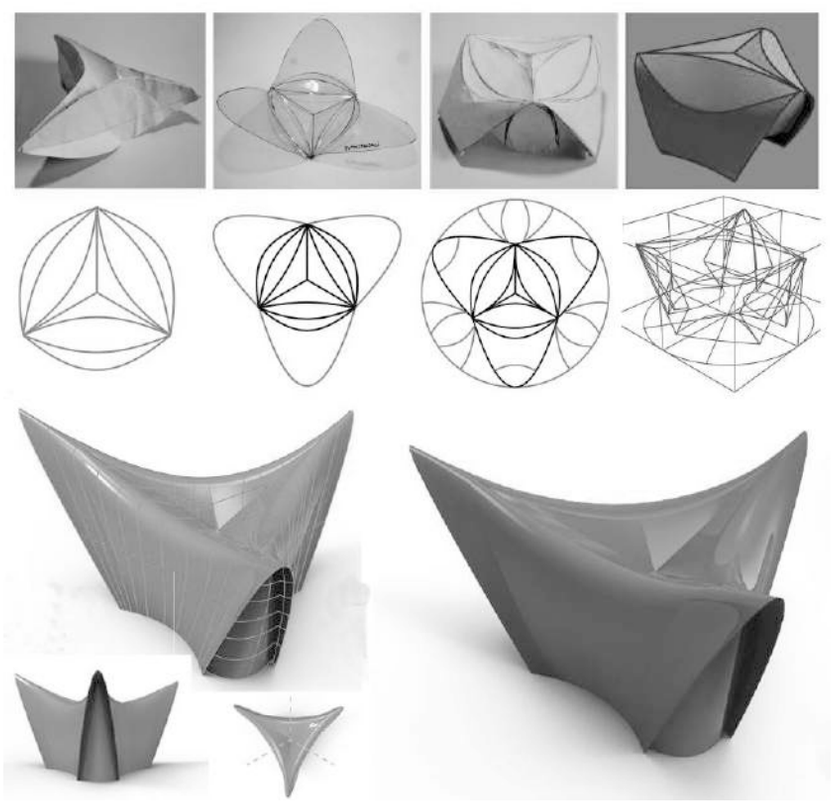

Figura 7. Parte del proceso de una estudiante, Brenda Pitkowski.
Fuente: Muñoz, 2019.

Cabe aclarar que, al no existir un FABLAB en la Facultad, los estudiantes mandaban a cortar su trabajo con proveedores externos. El énfasis se puso en la posibilidad de regular la forma obtenida en la interacción entre el 2D y el 3D, comprendiendo sus lógicas generativas. El plegado curvo no fue un objetivo final, sino una etapa inicial en el diseño de superficies curvas complejas.

La consigna inicial fue la de diseñar una superficie espacial curva a partir de una lámina por medio de las operaciones de corte y plegado curvo. Se brindaron algunas estrategias que los estudiantes combinaron o modificaron para su desarrollo. En esta práctica, la forma era el resultado del trabajo sobre el material, en maquetas. No existía la prefiguración en dibujo, sino que se establecía un diálogo entre las posibilidades generativas de la técnica y el material. Cada propuesta era registrada fotográficamente y organizada en una bitácora que documentaba el progreso. La evolución de las propuestas estaba directamente vinculada al saber, puesto en práctica sobre la materia. La evaluación de lo producido suscitaba nuevas alternativas superadoras. Cada estudiante elaboraba su diseño, pero se discutía en equipos los aspectos positivos de cada uno y se producía un intercambio muy interesante para superar los obstáculos que se encontraban. El desarrollo del estudiante Germán del Campo se observa en la figura 8.

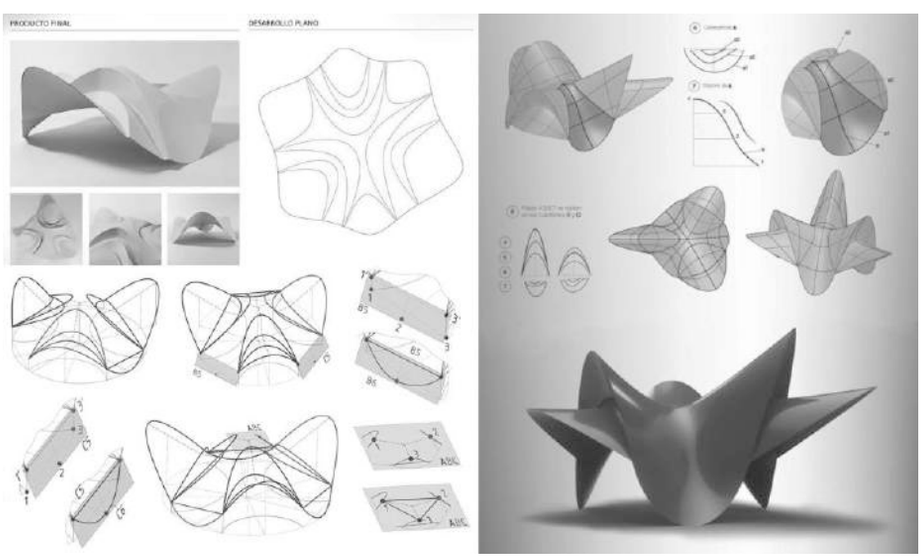

Figura 8. Parte del proceso de un estudiante, Germán del Campo Fuente: Muñoz, 2018.

Debido a la complejidad y a la generación de las formas resultantes, no se realizaron modelados tridimensionales ni dibujos 3D. Se entregaron los modelos tridimensionales y su diagrama productivo, distinguiendo líneas de

corte y plegado. Se recurrió a la notación de los patrones de origami, diferenciando valles y montañas.

En una segunda instancia, se evaluaron las propuestas de cada miembro del equipo y se seleccionó una para continuar. Los estudiantes determinaron la estructura simplificada del diseño preliminar elegido para avanzar en el proyecto y explorar sus alternativas. En esta etapa fue fundamental el empleo de CAD. Cada estudiante usa el *software* que dispone, de modo que la intervención del docente está ligada a las herramientas proyectuales, no a las posibilidades operativas de un programa en particular.

A partir de la estructura cada equipo generó alternativas empleando conceptos de simetría y de continuidad. De esta forma, lo que parecía el producto final es solo un paso en su creación. Por lo general, las primeras propuestas en las prácticas son simétricas. Desarrollos posteriores alteran esa regularidad inicial, definiendo algunos sectores de mayor interés sobre otros y rompiendo parcialmente la uniformidad original. Otro recurso generativo empleado es la posibilidad de reducir la cantidad de caras por continuidad, enfatizando o atenuando las relaciones entre sectores de la forma de origen. Las transformaciones permiten que los estudiantes incorporen la variable identidad/ruptura de una forma, adquiriendo la capacidad de definir equivalencias y diferencias con la configuración de base que definen sus umbrales de reconocimiento.

5 Derivaciones y conclusiones

La posibilidad de marcar el material o de generar líneas de plegado discontinuas con láser permitió la producción de objetos en bajas series y con plegados de mayor complejidad con costos viables. También permitió la exploración del empleo de diferentes materiales laminares, como el polipropileno, que incorpora la propiedad de bisagras “vivas”; o el fieltro y cuero, que brinda la posibilidad de regular las líneas de curvado. En la actualidad estamos realizando pruebas de plegado curvo en metal empleando corte láser.

Si bien existía un extenso desarrollo desde la ingeniería y la matemática, no había una clara conceptualización de este campo, en cuanto a su apertura, sus límites y sus variables para el diseño. Este conocimiento permite incorporar estas formas a la disciplina proyectual, para generar las formas que sintetizan aspectos operativos, tecnológicos y comunicacionales.

Los cambios productivos, a partir de la fabricación digital, amplían las posibilidades de concreción de formas. Sin embargo, la conceptualización morfogenerativa de las formas que habilitan permite una apropiación más potente de estos medios. Su incorporación a la enseñanza propició la verificación de los resultados obtenidos y promueve nuevas preguntas que surgen de la experimentación ampliada al vincularla a objetivos didácticos

proyectuales. Así, la investigación propicia la creación de herramientas y recursos para incorporar posibilidades tecnológicas que lo digital aporta, para sumarlas al diseño de los objetos cotidianos que conforman nuestro hábitat.

Referencias

Caigui, K., Mundilova, K., Rist, F., Wallner, J. & Pottmann, H. (2019). Curve-pleated Structures. *ACM. Association for Computing Machinery, 38*(6). 169:1, 169:13. https://caiguijiang.github.io/publication/2019_siga_curvepleated/

Chino, M. (2010). Sheet Metal Origami cuts Down on Energy, Materials. *Inhabitat*. https://inhabitat.com/sheet-metal-origami-cuts-down-on-energy-materials/

Demaine, E., Demaine, M. & Koschitz, R. D. (2008). Curved Crease Origami. En *Proceedings of Conference: Advances in Architectural Geometry* (pp. 29-32). http://theory.lcs.mit.edu/~edemaine/papers/CurvedCrease_AAG2008/paper.pdf

Demaine, E., Demaine, M., Hart, V., Price, G. & Tachi, T. (2009). *(Non)existence of Pleated Folds: How Paper Folds Between Creases*. https://arxiv.org/pdf/0906.4747.pdf

Etherington, R. (2011). Foldboat by Max Frommeld and Arno Mathies. *De Zeen*. https://www.dezeen.com/2011/09/29/foldboat-by-max-frommeld-and-arno-mathies/

Giegher, M. M. (1639). *Li tre trattati.* Gallica, bibliothèque numérique de la Bibliothèque Nationale de France. https://gallica.bnf.fr/ark:/12148/bpt6k3101729/f5.image?lang=EN

IEHU. (2018). Curved Folding. En R. Scheeren, P. Herrera & D. Sperling (Eds.), *Homo Faber 2.0, Politics of Digital in Latin America* (pp. 66-67). https://tinyurl.com/23p3d7m9

Koschitz, R. D. (2014). Computational design with curved creases: David Huffman's approach to paperfolding. *MIT Libraries*. http://hdl.handle.net/1721.1/93013

Le Klint. (s. f.). Iconic model 172 Sinus turns 50… https://www.leklint.com/en-gb/news/iconic-model-172-sinus-turns-50?Action=1&PID=820

Pendelbury, S. (1998). Razón y relato en la buena práctica docente. En H. McEwan y K. Egan, *La narrativa en la enseñanza, el aprendizaje y la investigación* (pp. 86-108). Amorrortu editores.

Sam Sannia Design (s. f.). Flat Pack. https://www.samsannia.com/works/flat-pack/

Zaha Hadid Architects (s. f.). Arum. Installation and exhibition by Zaha Hadid. https://www.zaha-hadid.com/2012/10/04/autumn-review-arum-installation-and-exhibition-by-zaha-hadid-architects-at-venice-architecture-biennale/

Zhu, L., Igarashi, T. & Mitani, J. (2013). Soft Folding. *Computer Graphics Forum 32*(7), 167-176.

Crafting the Digital: A Pedagogical Design Process in a Digital Era

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Abstract. This paper outlines a methodology defined as crafting the digital, that adds to current craft-based discourse in the digital age. It proposes pedagogy centered on a constant examining of the local design discourse linked to analog local tecniques, tradition and material abundances of the local environment and susteainability in relatión to digital relationships between form, material, and use (load). The paper illustrates a MDA pedagogy used to challenge students to innovate through an iterative experimental design process informed by a hybrid mix in local routes and the use of digital tools.

The key question is how local tradition techniques, abundant local materials and loads could be integrated as datasets into a renewed concept defined as "crafting the digital" a soft modeling and iterative design ´process that further explore a hybrid process that incorporates craftsmanship in a digital era as part of the production process. The results expand the boundary of conventional static and idealized craft as an object result of a cultural process while seeking for an integrated design process linked to local economies as an alternative to global markets. The result is an exploration and convergence of both: analog techniques and digital simulation in a parallel and coexistent contemporary dialectic dialogue.

Keywords: digital-physical, craft, dialectical dialogue, design processes and practices, design pedagogy

1 Introducción

En una era de recursos digitales cada vez más disponibles en el norte global y transferencia de tecnología limitada a los países del sur global, muchos estudiantes y creadores de diseño se encuentran confundidos entre un mundo paradójico lleno de herramientas digitales y al mismo tiempo de limitado acceso a esta tecnología y a su gran potencial. Diversos conceptos binarios tales como desarrollo y subdesarrollo, nuevos métodos contemporáneos en combinación con técnicas tradicionales, son parte de los discursos en las escuelas de arquitectura y diseño.

Esta condición paradójica, al mismo tiempo sienta las bases de un momento muy interesante de discusión e intercambio de conocimiento entre la riqueza de los procesos artesanales tradicionales mexicanos y las nuevas tecnologías digitales. Los practicantes de artesanía/diseño altamente especializados ahora pueden optar por utilizar procesos digitales en su trabajo, ayudándolos a simplificar los procesos de diseño, prototipado y producción. Sin embargo, existe el riesgo de volverse altamente dependiente de la maquinaria en un país de baja innovación tecnológica como México.

Este trabajo sugiere conciliar ambas visiones; a través de un entendimiento pedagógico para vincular la artesanía y las tecnologías digitales. En otras palabras, se argumenta aceptar la riqueza de estos híbridos formados por habilidades tecnológicas tradicionales, y la inclusión de alternativas tecnológicas. De acuerdo con Huang (2013), “se exploran procesos de entrega pragmáticos y restricciones materiales, donde se incorpora el intercambio entre lo hecho a mano, la representación de habilidades locales y la tecnología de lo digitalmente concebido”.

Esta propuesta definida como "artesanear lo digital" no pretende buscar nuevas formas, sino incorporar la comprensión de los métodos tradicionales y contemporáneos que promueven una nueva generación de diseñadores bilingües tecnológicamente. La definición del significado de artesanía contemporánea y sus procesos están evolucionando rápidamente y la incorporación de lo análogo-artesanal y la fabricación-digital se están redefiniendo en respuesta a esta evolución.

1.1 Artesanear lo digital: lo análogo-digital

El proceso pedagógico "artesanear lo digital", a través del trabajo de los estudiantes que se presenta en este artículo, considera esta transición desde el punto de vista de creaciones contemporáneas artesanales no como un objeto o técnica tradicional, sino como una oportunidad de redescubrir e informar nuevos procesos de diseño. Desde la visión de patrimonio, la artesanía u objetos culturales no surgen de un grupo aislado de teóricos o especialistas, sino de la práctica experimental continua a través de todo un grupo de pobladores con un patrimonio común, resolviendo una necesidad vinculada a su ecosistema y economía local (Clausen & Belluschi, 1994).

En otras palabras, en lugar de emplear la artesanía como un concepto romántico o una categoría idealizada, se argumenta que se utiliza el concepto de "artesanear" como un proceso de diseño experimental iterativo para aprender a través del hacer y así enfrentar desafíos de diseño cotidianos. Adamson defiende el uso del oficio como actitud de acercamiento o hábito de acción. En síntesis, “la artesanía no solo existe como un concepto estático, sino en movimiento, es una forma de hacer las cosas, no una clasificación de objetos fijos, técnicas, personas o instituciones. Es una amalgama de principios y prácticas de diseño interrelacionados” (Adamson, 2007).

Desde esta perspectiva, el proceso de "artesanear lo digital" se puede definir como “un proceso de ideación, planificación, habilidad, desarrollo y ejecución cuidadosa y deliberada donde ocurre una negociación constante entre el diseñador y el proceso creativo” (Oxman, 2007). En este proceso, el objeto y las herramientas de transformación no están claramente definidas, sino que informan un proceso iterativo de búsqueda constante que se alinea a nuestra pedagogía con un uso no predeterminado de la tecnología, sino de apoyo experimental. En palabras de Bonsiepe (1985), "artesanear" sería el verbo para transformar un material fuera de los circuitos de la formación oficial. Bonsiepe (2012) lo define como un saber comprendido que no puede ser codificado y no puede ser adquirido mediante métodos discursivos, sino prácticos experimentales.

En el hemisferio norte, se ha impuesto la cultura *maker* del "hacer" y la de *crafter* “artesanear” con incidencia en la educación e incluso del diseño, retomando los ideales del movimiento británico Arts and Crafts de Ruskin y Morris (Garber *et al*., 2018). Sin embargo, la producción artesanal latinoamericana se desarrolla con una habilidad y conocimiento que no está exteriorizada o expuesta de manera explícita, sino encerrada en sus creadores. Por lo anterior es importante documentar los procesos creativos para entender la evolución por ensayo y error entre generaciones. Desde esta perspectiva, "artesanear" como verbo de acción y exploración del conocimiento material; hoy puede proporcionar los cimientos de un proceso de pensamiento dentro del diseño y la producción, y como tal puede dar algunas pistas en la transición a una paradójica era digital emergente (Sennet, 2008).

En resumen, desde la perspectiva "artesanear lo digital", “el diseño puede ser tanto local como global, utilizar la artesanía y la tecnología, vincularse a la tradición y la vida contemporánea” (Schejetnan, 2010). Los desafíos actuales relacionados con la escasez, la emergencia, la resiliencia, la globalización, las pandemias y las limitaciones económicas urgen en interrogar como institución académica los principios establecidos y emergentes en los procesos de diseño de una manera más crítica. Esta claridad es imprescindible para garantizar alternativas dentro del diseño y la fabricación con tecnologías emergentes. En este artículo, se presentan dos proyectos de estudiantes, desarrollados dentro del Lab.Bio de la maestría en Diseño Avanzado, a través de la lente "artesanear lo digital" como proceso de diseño experimental-iterativo.

2 Metodología “artesanear lo digital”

Desde la academia se plantea un ajuste al proceso de diseño convencional utilizado por diseñadores para informar sus procesos en la era digital. Un enfoque con entendimiento ecosistémico que plantea identificar y potencializar las riquezas regionales; el conocimiento local, las técnicas y recursos materiales locales a partir de una exploración continua e iterativa.

Se propone un híbrido metodológico desde las primeras etapas de las decisiones de diseño en donde los procesos artesanales y análogos informan los procesos digitales y viceversa. El uso y la aplicación de herramientas digitales y tecnológicas son informados mediante los procesos análogos; sin embargo, la metodología planteada no se ubica dentro de un proceso lineal. Al contrario, es un proceso fluido y dinámico de continuos ajustes que permite mejorar procesos mediante la articulación y retroalimentación entre las etapas análogas y digitales, y el entendimiento local ecosistémico.

2.1 Entendimiento ecosistémico, democratización tecnológica y el diseño experimental iterativo

Los proyectos se desarrollan bajo tres principios y conceptos teóricos abordados previamente con relación al entendimiento local ecosistémico, democratización tecnológica y el diseño experimental iterativo (Figura 1). El primer principio de entendimiento local ecosistémico se centra en identificar todos los recursos valiosos del sitio; las riquezas locales, tradiciones, conocimiento local, técnicas manuales y las abundancias del contexto con relación a recursos materiales, residuos y desechos derivados de procesos de producción local. Dentro de este principio se plantea el objetivo de lograr un crecimiento local que armonice con la sociedad y el medio ambiente que lo rodea en el cual se inserta desde un inicio el concepto de “diseño situado” para crear productos o servicios bajo una estrecha relación con el territorio identificando oportunidades para nuevas economías que permitan generar diversos beneficios sociales, económicos y ambientales.

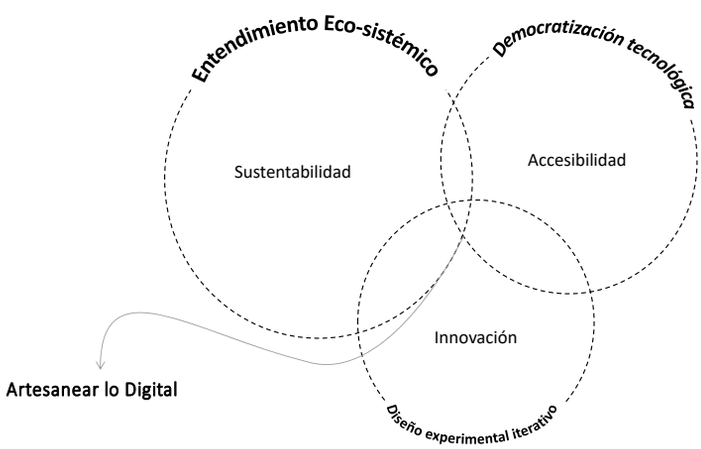

Figura 1. Principios de la metodología "artesanear lo digital"

Dentro del territorio se plantea una visión firme sostenible, insertada desde las primeras etapas del proceso creativo que permita dimensionar los impactos del uso y explotación de materias primas determinando un nuevo paradigma hacia la materialidad de un futuro sustentable.

El segundo principio, democratización tecnológica, hace referencia a la accesibilidad informática y tecnológica partiendo de una selección de herramientas que sean fáciles de conseguir, reparables por el fabricante u operador y asequibles. Bajo dicho principio se sustenta la expresión "vernácula digital" que, de acuerdo con Stevens y Nelson (2014), se encuentra arraigada en las tradiciones prácticas, trata de evitar esta divagación mediante una cuidadosa selección de herramientas. Esta selección no está pensada para impedir el progreso o la creatividad, sino para arraigar la base del trabajo en el presente y no en nociones románticas del futuro. En la era digital actual, las nuevas herramientas digitales deben permitir al diseñador volver a conectar con la naturaleza táctil de los materiales sin caer fácilmente en una utopía digital. Dentro de este principio se resalta la intensa relación que surge entre el creador, el material y la herramienta, y se ejecuta con criterio, cuidado y habilidad (Pye, 1995). De igual forma dentro de este principio se aborda el concepto DIY (*Do it yourself*), hazlo tú mismo, que permite descentralizar los procesos productivos mediante acercamientos y exploraciones directamente desde el creador, lo cual habilita para todos el acceso a la información, así como desarrollar aportaciones propias brindando la oportunidad de mejora continua.

El tercer principio de "diseño experimental iterativo" se centra en la oportunidad de innovar y generar nuevo conocimiento mediante un protocolo riguroso experimental. Dentro de esta etapa se exploran aspectos y características de la materialidad, la forma y la relación con la técnica y herramienta. La definición de procesos y la constante búsqueda de oportunidades para la innovación se construyen principalmente a partir de las siguientes metodologías experimentales consolidadas en el área de diseño: Design Thinking, Material Driven Design Method (MDD) y Form Finding. Se toma como base experiencias y conocimiento previo planteando explorar campos no explorados, identificar vacíos y definir variables que permitan informar los procesos a través de experimentación a prueba y error para ser traducidos a nuevo conocimiento. Como sustento y definición del grado de innovación, se plantean protocolos de evaluación, comportamiento del elemento creado (material, objeto, sistema) y se identifican las posibles aplicaciones.

3 Experimentación: aprender haciendo

El planteamiento metodológico se ilustra a partir de casos de estudio desarrollados como proyectos de investigación elaborados por estudiantes a través del equipo del Lab Bio2.0 (Laboratorio de Biomateriales 2.0) de la MDA

(maestría en Diseño Avanzado, UMSNH) bajo la dirección de los autores. Los proyectos que se presentan permiten valorar de manera crítica el enfoque pedagógico y los procesos e impactos en el proceso de diseño de los estudiantes. Asimismo, permite cuestionar y reajustar los métodos pedagógicos aplicados en centros educativos latinoamericanos, donde el acceso a la alta tecnología es limitada, mediante procesos híbridos analógicos-digitales informados bidireccionalmente y asistidos por herramientas y técnicas de baja tecnología que presentan una alternativa pedagógica que permite incorporar el valor y la riqueza del conocimiento local en la era global-digital.

El modelo pedagógico retoma lecciones importantes planteadas por Oxman (2007), quien resalta bajo el concepto “digital craft” la existencia de un flujo de información recíproco entre el diseñador y el objeto de diseño, el material y el modelo digital, lo analógico y lo digital y los prototipos que en conjunto permiten un rico dominio de potencialidades para los diseñadores. Asimismo, se plantea hacer un cambio de paradigma de una enseñanza “instructiva” hacia un enfoque de aprendizaje “activo” (Vrouwe *et al*., 2015), que permite a los estudiantes desarrollar formas creativas de trabajar con herramientas análogas y digitales a su alcance, así como tomar consideraciones financieras mediante el acceso a materiales abundantes o recuperados y tecnologías democratizadoras.

3.1 Casos de estudio 1: proceso híbrido de fabricación. Tecnología y técnica

El proyecto está enfocado en la exploración, a través de procesos híbridos de fabricación que conjugan la tecnología digital con técnicas artesanales, de un intercambio multidireccional de conocimiento para generar nuevas oportunidades de diseño. Siendo el espectro de la tecnología digital tan amplio y diverso, la técnica artesanal se convierte en una variable dentro de este por medio de una exploración teórico-práctica a través de un proceso no lineal, sobre el conocimiento, procesos y aplicaciones del material dentro de la técnica artesanal aplicada en un taller local de alfarería, para posteriormente buscar el diseño en la experimentación con la tecnología digital; dicho de otro modo, el diseño a través de un proceso gradual por medio de la investigación basada en la práctica con lo que se da un intercambio multidireccional de conocimiento para la generación de nuevas oportunidades de diseño. De manera particular, explora el desarrollo de tecnología análoga como un posible medio de engranaje entre la fabricación digital y la técnica tradicional (Espinoza, 2019).

Los resultados y aportaciones del caso de estudio 1 se sintetizan en las figuras 2, 3, 4 y 5, resaltando los tres principios metodológicos previamente discutidos: entendimiento local ecosistémico, democratización tecnológica y el diseño experimental iterativo.

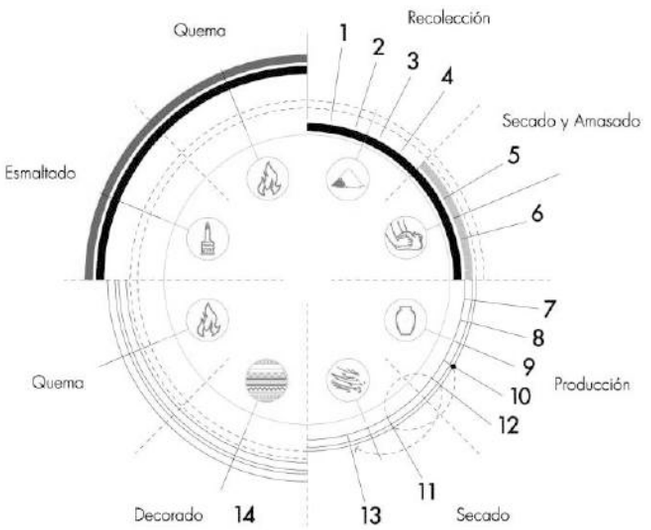

Figura 2. Entendimiento local ecosistémico acercamiento y colaboración con taller local de alfarería. Fuente: Espinoza, 2019.

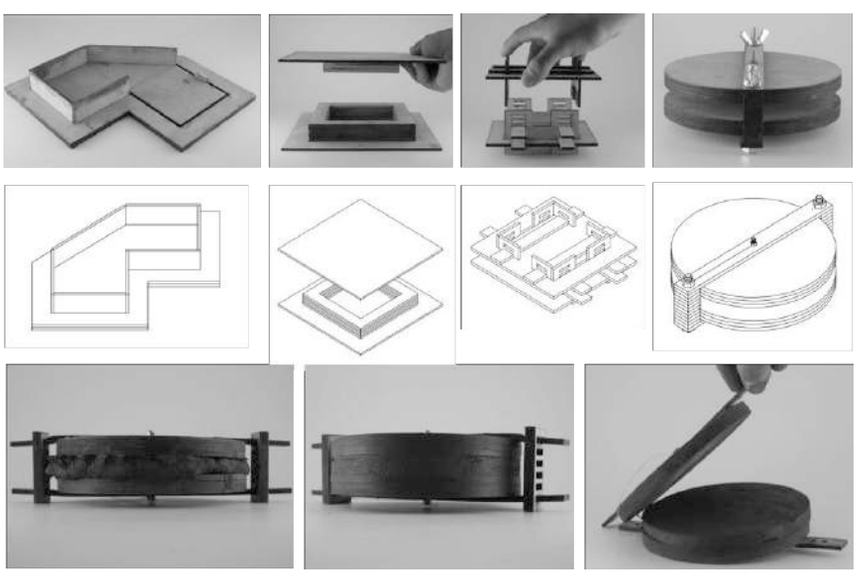

Figura 3. Diseño experimental iterativo. Fuente: Espinoza, 2019.

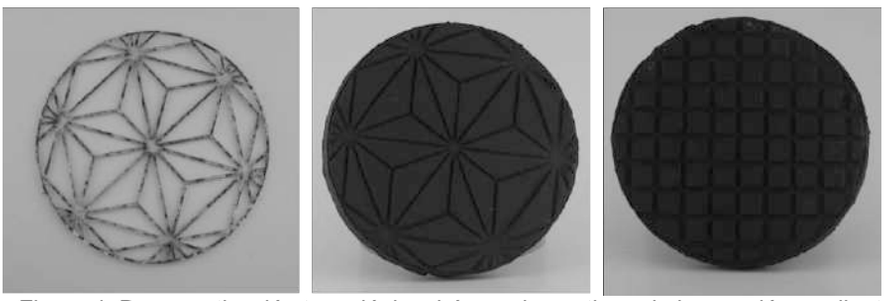

Figura 4. Democratización tecnológica: búsqueda continua de innovación mediante procesos análogos y digitales. Fuente: Espinoza, 2019.

Figura 5. Aplicaciones. Fuente: Espinoza, 2019.

3.2 Casos de estudio 2: transformación material a partir de plantas invasoras

El proyecto identifica múltiples problemas ecosistémicos vinculados al lirio acuático (*Eichhornia crassipes*), planta invasora considerada una de las cien especies más dañinas. Se desarrolla bajo una experimentación continua e iterativa, con la finalidad de aprovechar la abundancia del recurso para nuevas materialidades. Se acompañó de un protocolo experimental de tres etapas denominadas como exploratorio, material y funcional, acotado a la generación de dos líneas materiales, una con cualidades de flexibilidad y otra de rigidez. El resultado generó un material flexible, el cual se desarrolló a partir de encapsular la raíz del lirio acuático en colágeno y glicerina vegetal. Este material tiene características visuales y táctiles semejantes a un cuero, así mismo otro con características rígidas elaborado a partir de los nenúfares secos del lirio acuático acompañado de almidón como aglutinante natural; con él, se pueden generar aglomerados biobasados con cualidades para moldeo sometido a compresión. Ambos materiales cuentan con diversas bondades que los hacen aptos de aplicación, sobre todo en ámbitos de uso moderado

(Alvarez, 2022). De igual forma que en el caso anterior, los resultados y aportaciones del caso de estudio 2 se sintetizan en las figuras 6, 7, 8, 9 y 10, resaltando los tres principios metodológicos previamente discutidos.

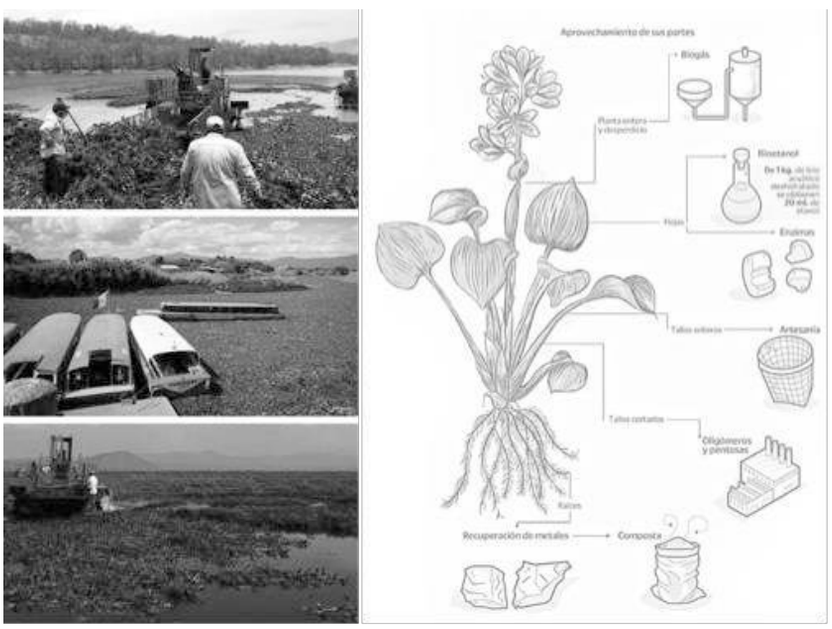

Figura 6. Entendimiento local ecosistémico*:* riquezas locales, tradiciones, conocimiento local, técnicas. Fuente: Álvarez, 2022.

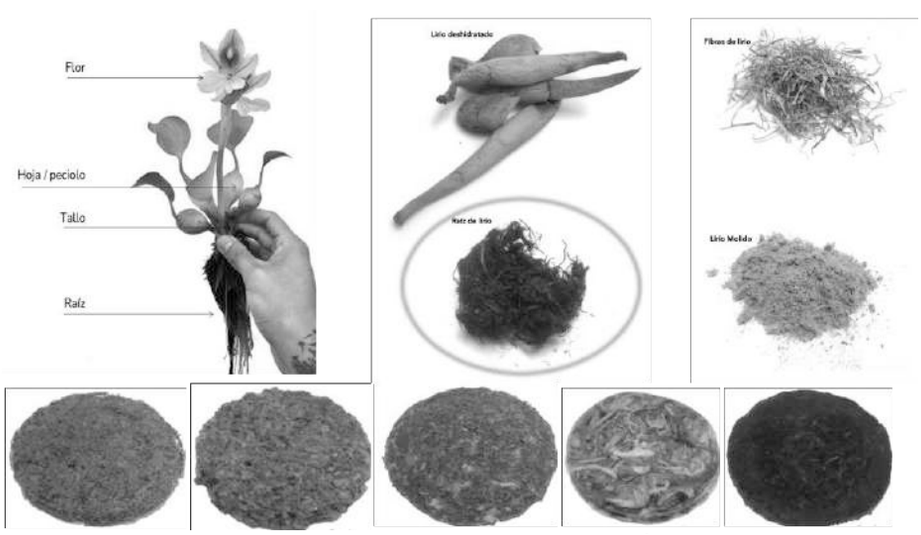

Figura 7. Diseño experimental iterativo. Fuente: Álvarez, 2022.

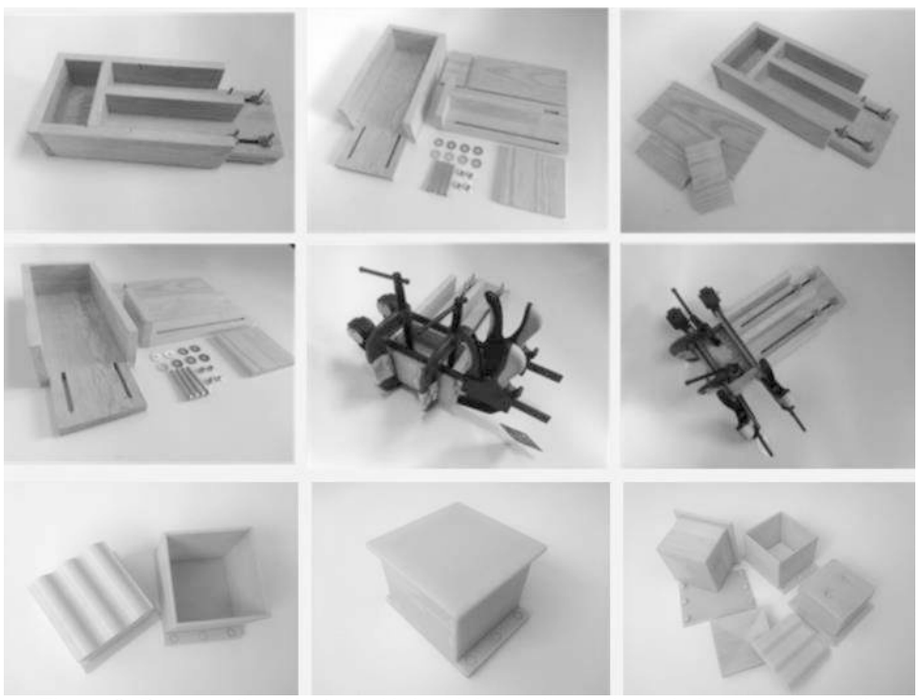

Figura 8. Democratización tecnológica: búsqueda continua de innovación mediante procesos análogos y digitales. Fuente: Álvarez, 2022.

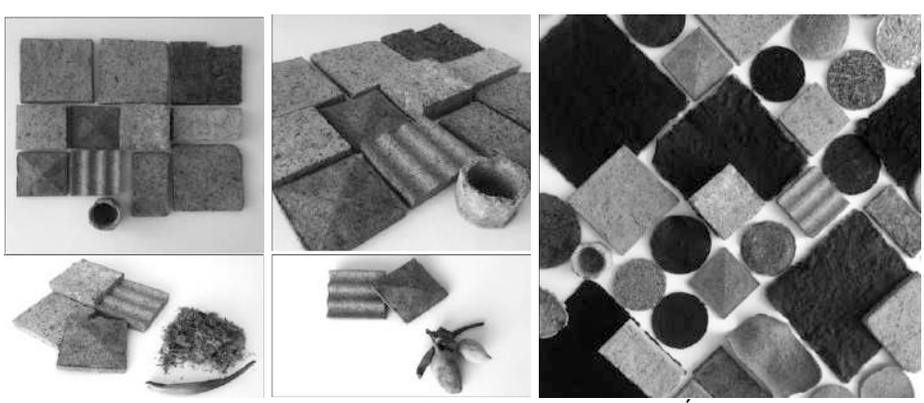

Figura 9. Nuevo biomaterial flexible y rígido. Fuente: Álvarez, 2022.

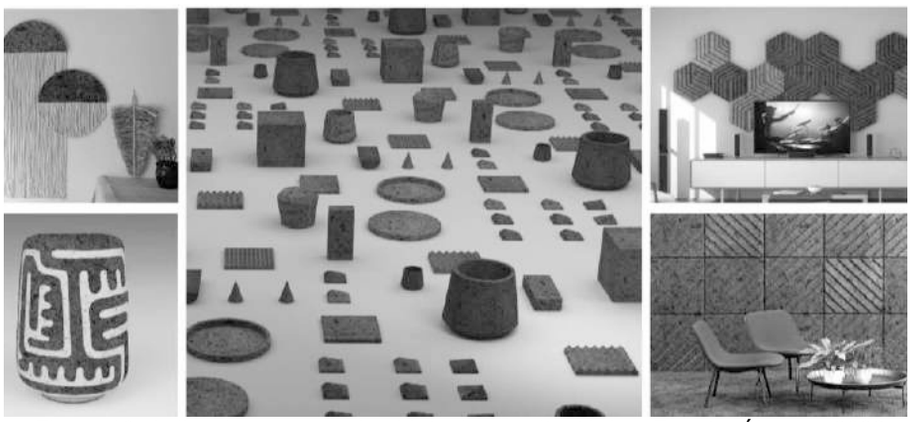

Figura 10. Aplicaciones a escala objetual y arquitectónica. Fuente: Álvarez, 2022.

4 Discusión

El enfoque pedagógico tradicional para informar los procesos de diseño utilizados por diseñadores tiene oportunidades emergentes. Los métodos tradicionales adoptados en las aulas, basados en proveer información o en dar instrucciones, sin tener un entendimiento o exploración pleno del problema, resultan limitados. Para ello, se plantea la metodología expuesta con un enfoque práctico y activo mediante laboratorios de diseño experimental, en los que los alumnos tienen que planificar y realizar sus propias exploraciones, en lugar de seguir ciegamente una guía o un manual con instrucciones. El presente artículo debate los posibles cambios que pueden introducirse en la academia y la práctica profesional como resultado de esta renovada forma de enseñanza y aprendizaje. La investigación a través del saber hacer, titulada "artesanear lo digital", ha sido personalizada por los alumnos de MDA, como diseñadores especialistas, en técnicas que surgen de la exploración iterativa de la materialidad y sus propiedades que permiten un mayor acercamiento al pensamiento de diseño potenciando el proceso sobre el resultado. Aprendiendo de procesos de diseño tradicional en el que se consideran diversos materiales (arcilla y fibra natural en estos dos casos de estudio presentados). El prototipado, fabricación y ensambles interactúan con técnicas locales a escala objetual bajo un entorno de simulación digital y evolucionando en diversas aplicaciones a escala arquitectónica. Esta adaptación gradual y emergente es sostenible dentro de las economías locales, permitiendo exploraciones iterativas de manera directa con prototipos a escala arquitectónica. Por ello, acercarse al diseño a través de "artesanear lo digital" resulta una oportunidad de entender procesos de manera formativa. Esta investigación aporta experiencias que fortalecen la identidad del diseño contemporáneo en la región, proponiendo insumos de experimentación a personas que dirigen programas educativos, laboratorios de fabricación,

talleres cooperativos y políticas de desarrollo a gobiernos locales, con el fin de establecer una sinergia y responsabilidad social entre la academia, las técnicas tradicionales y las abundancias ecosistémicas como alternativa al desarrollo local en tiempos de globalización.

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Referencias

Adamson, G. (2007). *Thinking through* craft. Berg publishers.

Álvarez, J. (2022). *Futuros posibles: transformación material a partir de plantas*. Universidad Michoacana de San Nicolás de Hidalgo, Morelia, México.

Bonsiepe, G. (1985). El diseño de la periferia: debates y experiencias. Editorial Gustavo Gilli.

Bonsiepe, G. (2012). *Design: como prática de projeto*. Blucher.invasoras.

Espinoza, L. (2019). *Proceso híbrido de fabricación, tecnología y técnica*. Universidad Michoacana de San Nicolás de Hidalgo.

Garber, E., Hochtritt, L. & Sharma, M. (Eds.). (2018). *Makers, crafters, educators: Working for cultural change*. Routledge.

Huang, A. (2013). Digital Craft. Acadia 2013. *Adaptative Architecture*. Cambridge Ontario, pp. 52-55.

Iriarte, P. (2018). Digital Craft in Semi-Periphetal Natións. *Acadia 2018. Recalibration on impresition and infidelity*. Ciudad de México, pp. 51-55.

Oxman, N. (2007). Digital Craft: Fabrication-based Design in the Age of Digital Production. *Workshop Proceedings for Ubicomp 2007: International Conference on Ubiquitous Computing*, 534-538.

Pye, D. (1995). *The Nature and Art of Workmanship*. Rev ed, Bethel, CT, Cambium Press.

Sennet, R. (2008). *The Craftman*. Yale University Press.

Shejnan, M. (2015). *Inaugural MDA Conference*. Universidad Michoacana de San Nicolás de Hidalgo.

Stevens, J. & Nelson, R. (2014). *Digital Vernacular: Practicing Architectural Making*.

Vrouwe, I., Luyten, L. & Pak, B. (2015). Teaching and Learning CAAD and CAM in a Fluid Era, eCAADe 2015-33rd Annual Conference.

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