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Supervisor(s): Georgios Triantafyllidis

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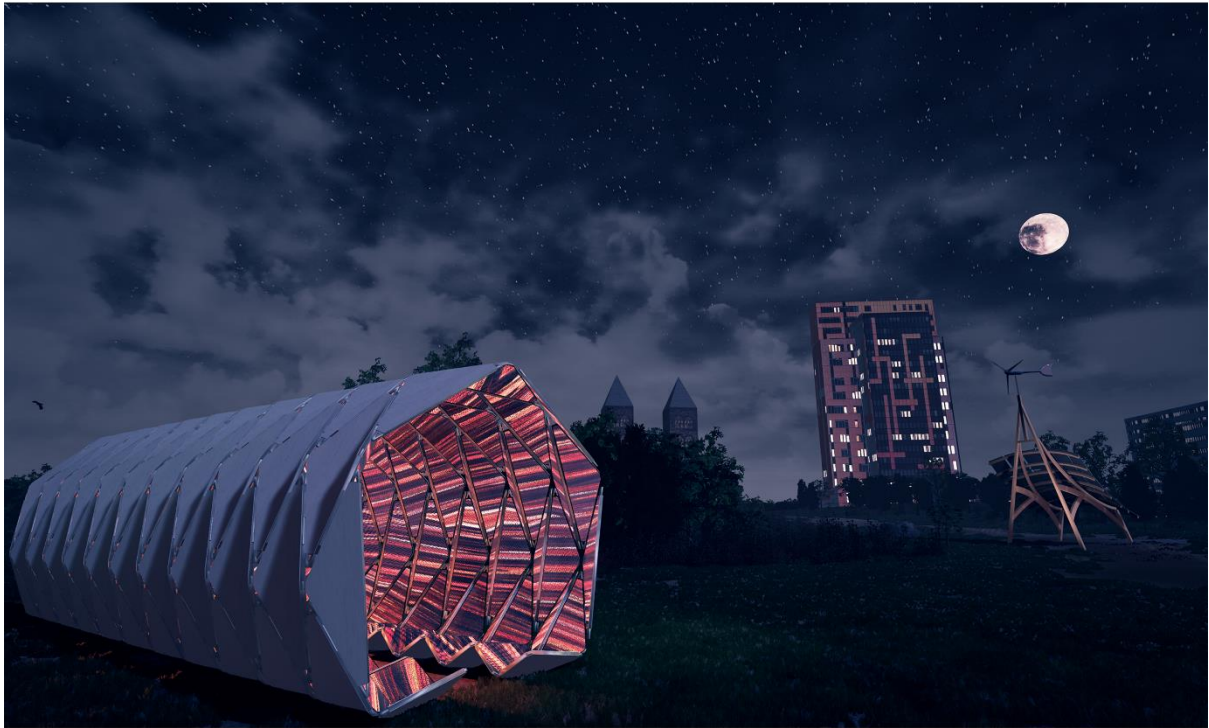**Members:** Emmanouil Xylakis

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Abstract:

This thesis investigates the process of integrating VR technologies in supporting the process of designing and hosting interactive lighting installations. Specifically, how visual immersion through digital means can create spatial awareness, without the need of physical presence, thus facilitating the fluency of the lighting design process. The motivation for this study lies in exploring new methods and techniques which can support the process of designing with light. This study attempts to set up and follow a design methodology that builds upon an existing design approach with light. The project brighter Brunnshög is used as a case study illustrating how a method such as this can be integrated. Additionally, by the end of this thesis a virtual installation will be delivered, that utilizes VR technology during its development as well as its execution.

Master's Thesis in Lighting Design

Department of Architecture, Design and Media Technology

Virtual Environments as a conceptual facilitator for Lighting Design
The case study of Brighter Brunnshög

Author: Emmanouil Xylakis

Supervisor: Georgios Triantafyllidis

Preface

It has been a long and fruitful journey leading to the completion of yet another project that I was fortunate enough to be part of. A two-year long journey that gave me the chance to explore a world completely strange to me and I am being thankful for this. For completing this project, I want to thank family and friends for their support that constantly kept me going. I would like to also thank my university colleagues and supervisor that were constantly triggering my curiosity and were motivating me in reading and learning about the fascinating world of real and "unreal" lighting. Yet another important lesson in always being curious on how things work and a constant reminder to myself to always question, wonder, doubt and finally that "I only know one thing and that is that I know nothing". For all the people that I had the luck of working with and moved me you have my greatest appreciation.

Manolis

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1. Introduction

This thesis investigates the process of integrating VR technologies in supporting the process of designing and hosting interactive lighting installations. Specifically, how visual immersion through digital means can create spatial awareness, without the need of physical presence, thus facilitating the fluency of the lighting design process. The motivation for this study lies in exploring new methods and techniques which can support the process of designing with light. This study attempts to set up and follow a design methodology that builds upon an existing design approach with light. The project brighter Brunnshög is used as a case study illustrating how a method such as this can be integrated. Additionally, by the end of this thesis a virtual installation will be delivered, that utilizes VR technology during its development as well as its execution.

The project used has the requirements that relate to lighting design and interaction so the methodology proposed here relates to not only designing a spatial experience but also meaningful ways of interacting with it. The design process model proposed by Hansen et al [1] guides the overall development and is used to explain how a technology such as this can be implemented.

2. Motivation

Virtual Reality, a technology driven mainly by the Entertainment and Video-games Industries started making its bold appearance in fields beyond that and Architecture, Engineering and Construction is not an exemption. It has already started taking its place amongst other communication tools, like 2d renderings or animations but a substantial work is still missing on its potential beyond these areas. This study will explore the use of VR technology for more than a tool of communication but also as a tool to support design processes and experimentations when working with lighting.

With the availability of "VR editors" [2] [3] (transfer of software environment into the HMD interface) amongst popular game engines and affordability of HMDs, more and more designers realized the ease of involving an approach such as this in their workflow. This thesis tries to explore and introduce an approach in designing outdoor lighting installations and in parallel using it as the host for the actual experience.

3. The Project and Problem Statement

3.1. Initial problem statement

Since the dawn of digital prototyping, designers, engineers, architects, manufacturers and professionals from all types of design industries were seeking to push digitization of as many steps of the design process as they could. Mainly for reasons such as sustainability, costs, testing and experimentation in lab environments, simulating and predicting possible flaws, improving collaboration and communication. So, we realize that there is always a need for improving the current state of design but does lighting design fall under that category? Can we use Virtual Environments(VEs) to assist us in the process of working with light and if yes what is the knowledge required and what are the challenges that we are going to face down that road?

Initial Problem Statement

"To what extent can Digital Prototyping assist the design process of working with light?"

3.2. The Project

Lighting Metropolis Initiative

The case project in this investigation, is part of the Lighting Metropolis initiative. Lighting Metropolis is the first decisive step in realizing a vision for Greater Copenhagen as the world's leading Living Lab for smart urban lighting. The aim is to strengthen the significant role lighting can play in supporting safety, accessibility, identity, health, and education for people in cities. A second Lighting Metropolis target is to facilitate and support the Greater Copenhagen region by tapping into the significant growth potential of these areas as they expand globally and exponentially [4].

Brunnshög

The currently developed area of Brunnshög, hosts two world-renowned research facilities, MAX IV and the currently under-construction facility of ESS (European Spallation Source) that is located on the northeastern side of the city of Lund.

When Brunnshög is fully developed in 30 years, 40 000 people will call this area their home and work space. The municipality of Lund has set high goals for the district; *"it will be a European model for sustainable urban planning and a regional destination for recreation"*.

Figure 1:The area of Brunnshög

Brighter Brunnshög

Brighter Brunnshög, is the first stage of an urban development project in Lund, Sweden, aiming to integrate residents into the development of their area, and spread the word of a new science city and its research centers. This project is conducted under the Lighting Metropolis [4] umbrella, in cooperation with Lund Kommune and Lighting Design in Aalborg University, and funded by Kraftringen.

Purpose

*"The purpose of Brighter Brunnshög is to **help drawing attention to the area** as a sustainable and smart neighborhood, and to **raise its attractiveness** even before settlement is complete – **using light installations**!"*

What we want to solve

"Since Brunnshög is only partially built up and furthermore consists largely of fields or construction sites, the area's attractiveness is rather low and it only has a few visitors. Also, the public awareness of the area's sustainable aspects is low. Kraftringen's aim is to install semi-permanent lighting solutions adjacent to the first construction site in order to make people interested in the area. By making people curious about the area and what is going to be built there, the hope is to make them enjoy the land even before it has become established. If this succeeds, it will benefit those living nearby and be a step on the way to make Brunnshög into a regional destination for recreation." [5]

Figure 2: The vision for future Brunnshög

3.3.Final Problem Statement

Initially the project started with the idea to design and build a physical lighting installation that would be integrated in the present environment and that would, as mentioned above, spread the word of the new science village of Brunnshög and raise the attractiveness of the area. Due to reasons such as lack of funds, personnel and manufacturing experts, affordable means in realizing the vision of the project had to be found.

In the past decade VR and AR (Augmented Reality) experiences have been successfully used for multiple purposes other than the entertainment or videos games industry. Experiences that are used as an Informative tool or related to Education, Design and Architecture but also more importantly for spatial cognition research. Basically, *the ability to create a spatial knowledge,* through stereoscopic interfaces and VR technology, *without the need for being present*, is a strong point and something worth considering when designing for spaces.

The chapters that follow present several cases of successful VR applications in those fields and the tools that were involved behind these processes. This research resulted into transferring the whole experience of the Lighting Installation into the digital, meaning that in the case of Brighter Brunnshög, VR technology will be used as the main tool for designing but also for hosting it.

Therefore, we can assume that the goal of this study is twofold. Firstly, to follow and explore the process of designing a lighting installation by using VR tools. Secondly to recreate the experience of interacting with a Lighting Installation and familiarize users with the area of

Brunnshög. With the above being said, the initial problem statement can be reformulated as such:

"To what extent can VR technology be involved during the <u>design process</u> and <u>execution</u> of an interactive lighting installation that has the aim of familiarizing and involving a local community to its forthcoming urban development. "

4. Literature Review

The present chapter presents chosen literature in the fields of Virtual and Augmented realities. Initially a classification of the different systems is being presented and subsequently cases and tools involved in the process.

4.1. Defining Mixed Reality Systems

In their book "Understanding Virtual Reality, 2002" [6] William R. Sherman and Alan B. Craig defined four key elements that every successful VR system should be focusing on. Although technology in that field has evolved tremendously in the past decade and a lot has changed in the way virtual environments are being used, these elements still play an important role for the development of a VR system. These key elements are: the virtual world (the content), immersion, interactivity, feedback and participants.

The Virtual World or else the content generated by the computer system to be experienced by the viewer. The element of Immersion relates to the ability of the system to provide a full or partial level of captivation to the audience. Interactivity is focusing on the different ways that a participant can interact with the content thus providing a truthful and meaningful experience. Sensory Feedback is related to the output and mainly which of our senses are being engaged in the process.

By combining these elements Sherman and Craig came to the following definition of Virtual Reality.

"Virtual reality a medium composed of interactive computer simulations that sense the participant's position and actions and replace or augment that feedback to one or more senses, giving the feeling of being mentally immersed or present in the simulation."

4.2. Taxonomy of Systems

The definition of the term Mixed Reality can be traced back in 1994 where Paul Milgram and Fumio Kishino in their study "*A taxonomy of Mixed Reality Visual Displays*" [7] came up with the *Milgram Continuum* in their effort to classify different mixed reality displays. This was the first study to mention the term *mixed realities* in the context of Computer Generated Graphics and since then this has been one of the most cited articles in the field of Virtual Reality. Milgram and Kishino defined mixed reality as: "a subclass of VR technologies that involves the merging of real and virtual worlds" and is placed along the Reality- Vitality Continuum.
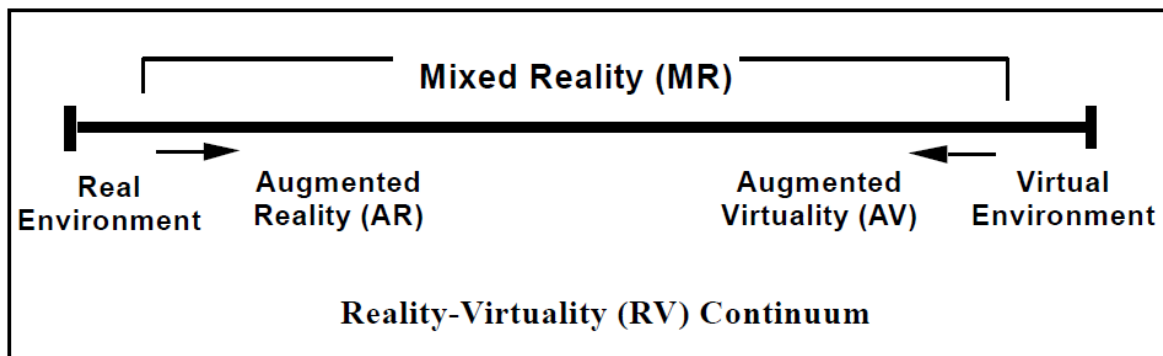
Figure 3: The Milgram Continuum

The Milgram Continuum places mixed reality technologies at the length of a continues line representing their connection to either a **real or purely artificial/virtual environment**. In that specific study, Virtual Environments are described as the environments that fully immerse the participant into a **fully synthetic world**, that may or may not mimic the properties of a real world. On the other hand, Mixed realities systems, involve systems neither purely synthetic nor completely real. Augmented Reality(AR) and Augmented Virtuality(AV) experiences fall under that category. AR systems, or else mentioned by the author "non-immersive/partially-immersive, monitor based", overlay computer generated imagery (virtual content) on top of real/live or stored content. AV systems, are synthetic environments that introduce/overlay real elements into it.

In M.A. Muhanna's study [9], she proposed a taxonomy method that is built upon two factors: **type of technology** and **level of immersion**. If a system requires "special hardware" for its input or output. E.x. Head Mounted Display, this would be then described as Enhanced and Basic if there is no special equipment involved (conventional flat monitors).

Further on systems vary in their level of immersion, regarding the captivation of the participant, as either partially or fully Immersive. Thus, according to Muhanna, technologies that can be defined as fully immersive are HMD based or Room Based that are either vehicle simulations or C.A.V.E.s and partially immersive AR specs or wall projectors that use or augment physical surroundings.
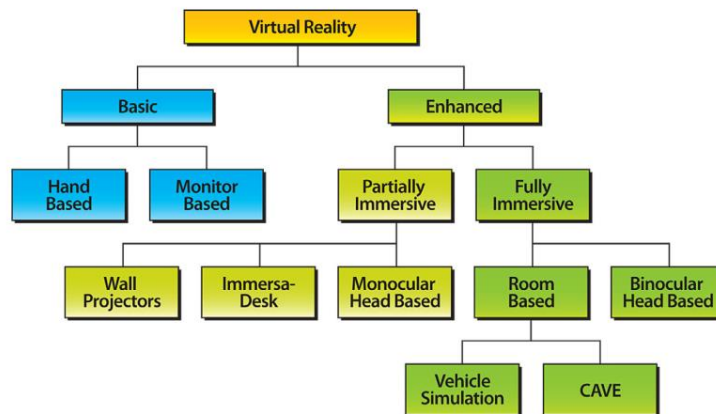
Figure 4: Muhanna's Taxonomy System

Azuma (1997) [10] in his paper defines the three main characteristics of AR: the combination of synthetic and real objects, their appearance interactively and in real-time and the alignment between them.

4.3. Virtual Reality and Augmented Reality Examples and Applications

In the sections above we defined and categorized mixed reality systems, based on existing research and presented the main commercial tools that are currently being utilized. In this section, we are exposing existing research and example applications that make use of this technology. The work that is being presented here focuses mainly on how VR and AR is being used as a design, testing, analysis and communication tool.

A good example of how VR technology is being utilized in architecture firms is New York-based IRISVR. IRISVR allows users to design and present their ideas with the use of real-time features and has been used successfully in a few projects including the expansion of Site Santa Fe Contemporary Arts Center [12].

Another example of how testing and analytics can be used successfully within a VR environment is from the company InsiteVR. They developed a tool that gathered data during user walkthroughs and exported three-dimensional heatmaps representing time spent focusing on areas of the design. "*InstiteVR suggests that the software could be used to improve wayfinding strategies for large buildings such as hospitals, airports and other public spaces. The effectiveness of signs can be accurately measured by how long it takes viewers to find them, and how often they are lead to their intended destination*" [13].
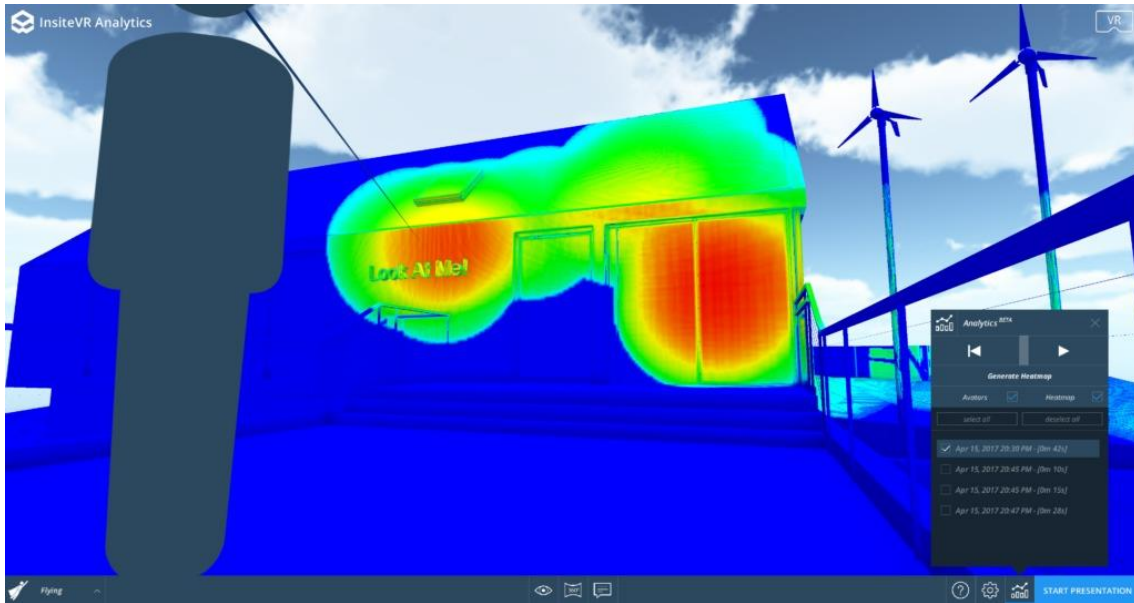
Figure 5: InsiteVR's VR analytics

Portman et al. in their 2015 study [14] and based on Pittman's 1992 research [15] reviewed a series of work that has already been done with VR in the fields of Architecture, Landscape Architecture and Environmental planning and explored the possibility of its involvement in these areas as part of the design and development process. As also the authors mention in their study, fields with significant human intervention, like architecture, could benefit a lot by using these tools as compared to landscape architecture where natural systems are an essential part, thus complicating VR integration. On top of this, the participatory domain which is being utilized by this technology, can offer great advantages in all these design fields allowing a collaborative engagement with the project and a slightly different work process that involves a "testing - instant feedback" method. This type of methodology is being analyzed further in the next chapter.

Figure 6: Portman's instant feedback exemplar

In the case of "Project Anywhere" [16] C. Miltiadis saw VR's and AR's potential in the embedment of the design and more specifically in Architecture. He developed a AR prototype system, running on an iPhone, allowing basic capabilities of object creation, scaling, coloring, movement and all this supported by a fully immersive and collaborative friendly environment.

A mobile app developed by the Austrian company Codeflugel, had the goal of informing locals on the forthcoming development of the Argos project in Gratz, Austria [17]. The Argos project was an effort by Zaha Hadid Architects to add a contemporary architectural accent in the midst of the founding facades of Graz's Old Town. Through the application, users would get a glimpse of the future building, through the use of 360 panorama rendered stills having both views from outside and inside.

Figure 7: ARGOS AR Application

The examples presented above was a way to be familiarized on how VR and AR technology has been used recently as a tool in different steps of the design process, either as a design and experimentation or assessment tool but also to communicate upcoming projects or development of an area. The number of projects using these tools as purely communication is significantly larger than examples that practice them in design. The main reasons behind the lack of work in these areas are: slightly different methodology approach of testing – feedback, unfamiliarity with recent technology, tools and methods by designers, need for specialized hardware and slight increase in budget requirements. On the other hand, the availability of low cost systems is out there and designers are already using them both for VR and AR.

4.4. Interfaces, Displays and Technologies

Virtual Reality Technologies

Head mounted Displays or else HMDs, are currently the main interface between the user and the virtual environment in VR applications. Two main types of widely used HMDs can we distinguish, one offering a more portable, static and lightweight experiences and another more realistic, highly interactive, heavyweight and of course less affordable. The former is usually being executed in portable devices such as smartphones that with the help of a stereoscopic viewer can immerse the user into digital environment. This category offers a more portable approach enabling users to experience spaces just by viewing it in 360 degrees. The most Popular devices in these two categories are: HTC's VIVE, Oculus Rift, Samsung's GearVR.

Augmented Reality Technologies

Augmented reality displays come in two main forms. One head based and screen based. As disgusted also in earlier chapters AR systems relate to alignment of virtual content on top of existing and thus are being defined as partially immersive and have different goals than VR applications.

Figure 8: VR & AR Interfaces

C.A.V.E Systems Technologies

Cave systems include mainly the use of multiple projectors (usually more than two) in order to achieve immersion through peripheral vision, via projected content on walls in an existing space. Navigation is being handled by a single person with the use of a controller.

Figure 9: CAVE system

source: http://www.visbox.com/

5. Approach and Methodology

The design process within VR is based on the architectural experiment design model [1], was based on current demands for a transdisciplinary approach. In this study, the architectural experiment design model is named the model of lighting design experiment (LDE) as it has been developed for designing with light in architecture. The approach is based on a linear or else one directional procedure where the feedback between creation, adjustment and re-creation is either non-existent, more cumbersome or slower and less dynamic in nature. By contrast, the constant feedback in VR requires the designers within the virtual workplace to have the ability to instantly and simultaneously process results and feed these back into the design itself. The virtual environment which approximates the real world enables designers to work with their spatial perception gained within this method. Based on these conditions; fast and constant communication between software, real time workflow, and spatial experience, this study explores how LDE can be optimized by the use of VR.

This Virtual environment requires designers to take on the responsibility of learning due to the complex relationship between the input and output during the design development. As it provides opportunities for self-directed learning and self-assessment [19], problem based learning (PBL) [20] is used as a guideline in VR for optimizing the LDE design process into the multi-dimensional learning and developing design process.

5.1. Design Process in the Architectural Experiments

Since the concept of the project penetrates different domains, the design process is driven by the model of lighting design experiment (LDE), the latter of which is a theoretical proposal of how to design with light as a multi-dimensional design element by integrating scientific, technical and creative approaches to light through 5 linear steps. Drawing from the work briefly outlined in the preceding section, the theoretical framework has been developed on how research traditions can be integrated in transdisciplinary practice, and are illustrated in the model for architectural experiments (Fig.10 left).

The feedback loops in its structure result in a stepwise process of adjustments and readjustments. As such each step synthesizes and integrates the data from different fields into the single project. These loops result in an irreversible trend whereby alterations are not undone. The design model structure consists of five steps:

1) Transfer-Image and ask, 2) Translate - Explore and propose, 3) Transform – Link and construct 4) Test and explain - evaluation 5) Share and learn, and this sequence happens in a loop-like fashion.

The model attempts to resolve the question of how the knowledge of different disciplines can be thoroughly integrated into the design process, create innovative solutions and generate new knowledge. This works not only as a tool for integrating knowledge from different domains but also a guideline for a procedure in designing effectively.

5.2. Design Process by integrating VR technology

Designing light with the use of virtual environments differs from designing in a physical environment since we are dealing with a space where tangible objects are simulated. In other words, designing in VR means basically creating an entire virtual environment including lighting, and calculate the relationship of all the graphical components in the scene. This critical difference implies the necessity of new design methodologies and new knowledge fields and mainly on light phenomenology and how does this translate to the engine's language.

The three main factors in VR are defined in terms of real time rendering, flexibility and spatial experience. These factors critically affect the traditional design approach, and can be used to validate the design phases with light in VR.
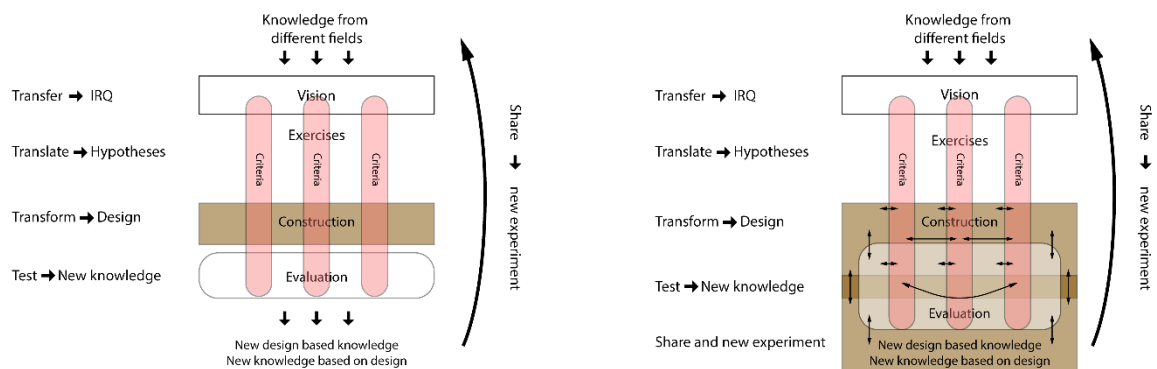

Figure 10: Methodologies Diagram (left)within LDE (right)within VR

With the latest advancements in virtual environments, Computer hardware now can approximate quite truthfully real-world conditions. [21] The highly advanced stereoscopic visual output and the sensor technology of HMD enables designers to use their spatial sense for lighting. The application of LDE in VR, therefore, implies its adaptation, as many aspects within VR fundamentally change the nature of design and workflow.

In VR, the flexibility between VR engaged software (game engine) and protocols has been the subject of study which explains its relevance. The research on VR applications has established several VR conditions, such as flexible integration of VR interfaces and external software, ease-of-use, lowering the learning curve and empowering end-users. [22]

5.2.1. Working with Real-Time game engines

As VR relies on the flexibility and freedom which is adjustable depending on the programs involved, these elements have been developed to be well-compatible with each other, and allow for constant feedback due to instant communication.

Generated geometry from this external software can be imported and adjusted within "a host graphics engine", and as such be expanded greatly. This system directly influences the way LDE can be applied.

More specifically, steps 3 to 5 in LDE; transform - test and explain - share and learn, are engaged more complexly, and the boundary between steps slightly fade. Further, feedback between the steps is continuous and results in a model where the order of elements is less restricted and more interchangeable.

As indicated by Hardiess "VR is highly controllable and makes procedures repeatable with respect to the design of the environment and the way of interacting with it." Figure 10(right) outlines the multidimensional(or else non-linear) communication between the different elements of the model. This model highlights the complex and strong ties of steps 3 to 5. The design, test and evaluation keep repeating and not strictly in the same order, during the design progress.

Imported models interact much faster in the game engines as these enable rendering of the visual asset and allow interactions in real time and in a highly realistic manner. In addition, body position, pointing direction, and exploration movements can be measured with high precision in real time via the sensors that are part of the interfaces involved.

5.2.2. Spatial experience in the design process of light

The spatial aspects of VR have been highlighted and considered the strongest point of the vision of VR in different industries and as such the human experience is based on spatial environment. Regarding the spatial experience factor of VR, Hardness outlined that firstly "manipulations of the environment, of viewpoints or metrics of the virtual space (e.g., physical inconsistencies or non-Euclidean metrics), and of interactions with the virtual reality are possible *in real time*."

Secondly, "different sensory modalities related to spatial perception can be tested selectively and can be brought into competition with one another in order to estimate their relative contributions for a given task." Lastly, "virtual reality enables the measurement of spatial behavior in large-scale environments also under real walking conditions (e.g., treadmill or walking sphere)." For these reasons VR has been proposed as a more cost effective and safer replacement of physical projects which might be inappropriate or impossible to be realized due to inaccessibility, cost, security issues.

Besides the aforementioned impact on user experience, the spatial conditions in VR equally affect the method of the design process itself. More specifically, it enables designers to experience the light while they are creating the scene. In this process, the field of perception moves constantly between 2D flat screens and the virtual workplace.

This temporal and spatial approximation of the real world is relatively precise, and enables designers to propose lighting scenarios based on real situations. However, VR requires the designers to react almost instantaneously to its constant feedback during the design, and at the same time the designers are expected to exploit this flexibility and freedom with absolute control through blueprints and script coding. In addition, this real-time testing-feedback requires the lighting designers to either obtain more broad and precise knowledge about other fields integrated in the project or, as Haan [23] commented, that for the development of VR applications, there is a need to closely collaborate with relevant domain experts.

5.2.3. Prototyping in VR

The reasons behind the use of prototyping during the development of a product or a service is to test, validate and predict designs before moving to implementation stages. A prototype may replicate just one portion of a design. It may create the look of the object without its functionality, or the functionality without the look. A fully functional prototype is a full-scale working model of the final product [24].

Prototypes in the field of Architecture and Engineering can be either physical or virtual, and each of those would yield different knowledge and output to the designer/developer and are being chosen accordingly. For the same project, the simultaneous existence of both can happen and will be answering different types of questions.

6. Development

6.1. Analysis and field research

The Area and People of Brunnshög

The initial analysis happened at an earlier stage of the project yielding information such as activities of the locals, area demographics, views and interests based on questionnaires.

Main activities taking place in the area of Brunnshög include: allotment farming that are being used for vegetable or herb growth by locals, educational trips by schools to introduce younger generations to nature and lastly used as a nature getaway from the city of Lund for walks and short trips.

People inhabiting the surrounding rural area of Brunnshög are mainly farmers but slowly new residents choose to move there as they are being involved with either the closely located research facilities or universities surrounding the city of Lund.

Data collected from the interviews revealed extend interests in topics such as: energy efficiency, quality of life, outdoor activities, such as horse-back riding and jockeying and finally new and innovative technologies and mobile applications.

The study "Interactive Lighting Art-design Installations as a Stimulus for Public Ownership over Urban Development - Brighter Brunnshög" [25], which served as the basis for this thesis presents in detail all the work that was done prior to VR involvement. There more can be read about the field research, the procedure of conducting the interviews and the initial design steps in regard to the Installation.

6.2. Design, Prototyping and Testing

Prototyping with room-scale VR

Physical mockups helped establishing the physical shape of the tunnel installation and enabled idea generation and details around its form. Once the design for the construction was finalized, taking that further into the Virtual Environment, would help gain an understanding of the installation within its space(Brunnshög) and experiment with features such as lighting, materials, tunnel motions and interactions.

With the room-scale VR technique, a physical space was chosen according to the physical dimensions of an active area of the tunnel [26]. This step is important in simulating the experience of walking inside the tunnel and creating a sense of scale assisting both design process but also recreating the experience of the installation to the user.
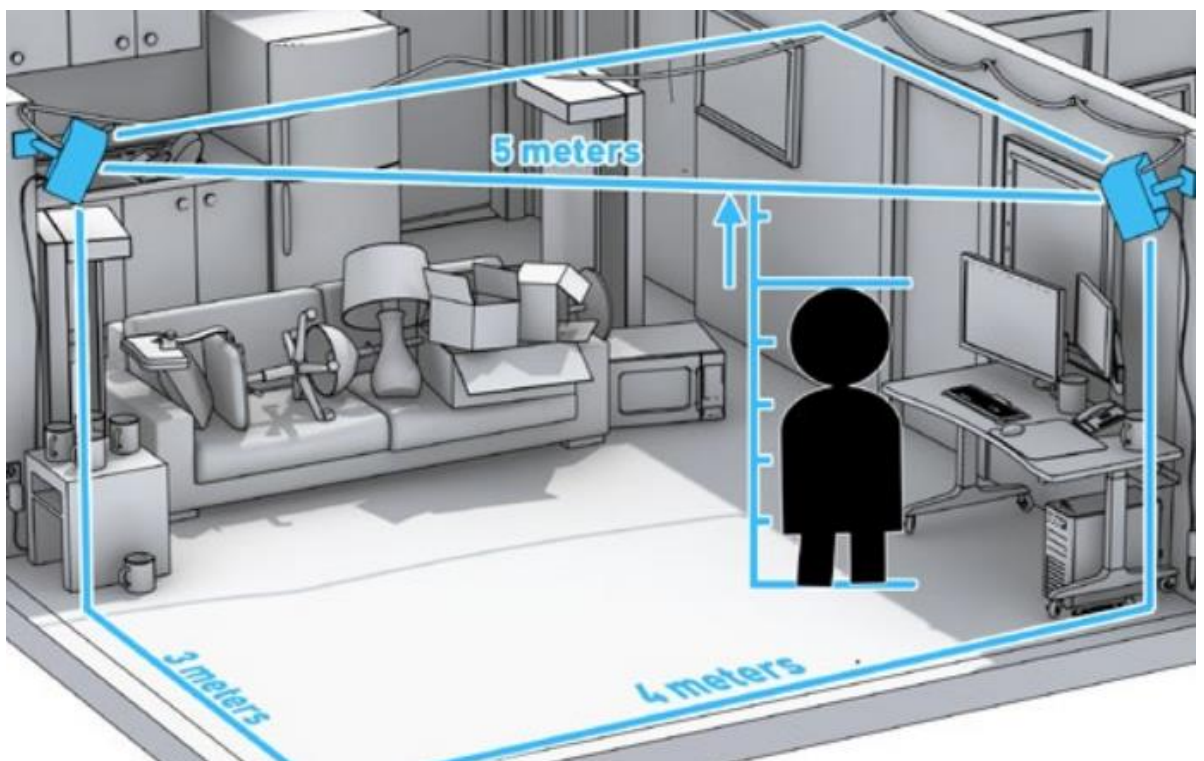

Figure 11: Room Scale VR

Image source: https://medium.com/

Choice of tools relied on factors such as ease of integrating external interfaces, availability of material and documentations, and size of community around them. Thus, as the main platform for running the simulations, the game engine Unreal Engine 4(UE4) was chosen and as a HMD interface, HTC VIVE.

The main features that were being developed in that engine were: Lighting design and calculations, dynamic material creation and editing, landscape and foliage generation, interaction scripting and sensor integration and testing.

3d modeling software blender and Mc Neel's Rhinoceros were being used to digitally model the tunnel installation as well as the different landmarks that were imported later in the engine. UV maps and light maps were generated externally from the engine in blender and then assigned in their different channels in the engine. Lastly texture creation and editing was taking place in Adobe's Photoshop. Flow diagram bellow illustrates the work process between the software involved. An example scenario of this work process could be:

1st step: Modeling geometry and generating UV maps for texturing and Light maps in Blender.

2nd step: According to the scales of the modeled geometry and its UVs the textures are being created in Photoshop and later on assigned as a diffuse or albedo map back in blender.

3rd step: Exporting all the layers as an fbx file will result in retaining all data for import in the engine

4th step: Once imported successfully in the engine, material attributes (reflectivity, translucency, etc.) are being configured, lighting is being placed and adjusted (lux, color temperature, angles) and interactivity scenarios are scripted and compiled.

5th step: Running all calculations in the engine for all static/dynamic lighting, materials attributes and Global illumination before the execution of the application.

6th step: Running the application and viewing it in the HMD while all dynamic scenarios are being executed. In this process, we receive instant feedback on all dynamic elements leading back to the engine for re-adjustments.
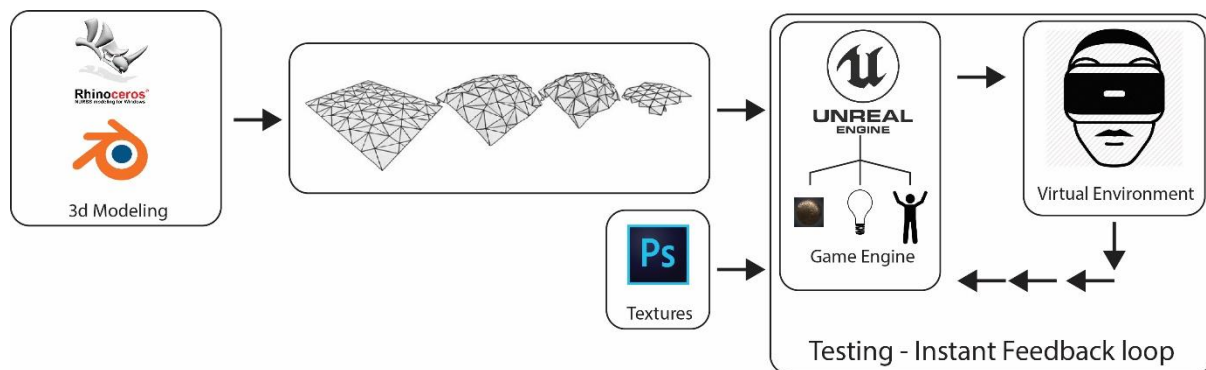

Figure 12: process flow diagram

6.2.1. Construction ("the Physical")

As mention in earlier chapters the design process of the tunnel didn't include any VR intervention and was realized by using physical and CAD prototypes. Criteria such as installation placement within the site, flexibility and interactions were used as guidelines of the "Stimulus for Public Ownership over Urban Development" [20] that eventually resulted in realizing its final form.
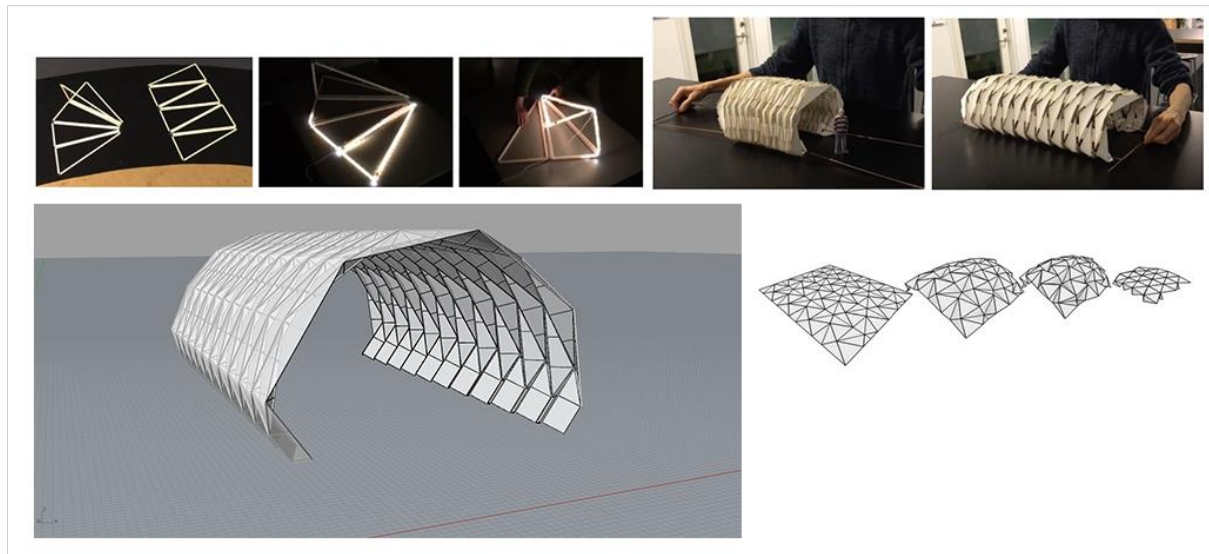

Figure 13: Prototyping for Construction

"Look, feel and motion" are the next steps in the process and by involving a real-time engine would assist in simulating and testing different lighting scenarios with the different materials.

6.2.2. Materials and Lighting

Material Creation

Working with materials as part of a virtual prototyping process, can be quite demanding and time consuming if the techniques applied are not fully understood. The rules that designers and developers work in order to create their materials are more or less the same, regardless of which software tools they use to build them in. A model commonly being used when working with "digital" materials is the Physically Based shading model[27] that consists of 4 properties that that have control over the materials general behavior to light and appearance and their range is from 0 to 1.

Those are:

- Base Color has control over the overall color of the Material and is defined by a 3vector value controlling its RGB.
- Roughness input controls how rough the material or smooth a material is. A rougher material will scatter light in more directions than a smooth material. Roughness of 0 results in a completely smooth/mirror-like material and of 1 in a matte/diffuse type.
- Metallic input literally controls how "metal-like" the surface will be thus nonmetals have Metallic values of 0 and metals have Metallic values of 1
- Specular is in control over the scale of specularity for non-metallic objects and mainly has control over the Index of Refraction.

Figure 14: Example, Top: Charcoal, fresh concrete, worn asphalt. Bottom: Copper, iron, gold, aluminum, silver, nickel, titanium

(Image source: https://docs.unrealengine.com/latest/INT/Engine/Rendering/Materials/PhysicallyBased/index.html#hable)

Configuring these 4 parameters, experimentations around types of glass, aluminum and ground were tried out by combining those with the different lighting scenarios.

Creating brushed aluminum material for the outer faces of the tunnels relied on tweaking the parameters of roughness and metallic in the material editor and on top of this an aluminum map creating a more realistic effect.

For creating glass and translucent polycarbonate plastic for the interior of the installation during test phase, material parameters translucency and specularity were adjusted to create the desired effect.

Regarding the Lighting for the tunnel several ideas were tried out in UE4 but three of them were standing out and are being analyzed further on in the following chapters.

Tunnel Lighting Design tests 1 (LED strips with and without translucent screens)

The first design scenario for the lighting was to recreate LED strips that are being placed within the profiles of the structure. A common technique being used for lighting installations that usually aims in enhancing the shape of a structure by creating contrast between the "skeleton", the profile emitting light and the rest of the surfaces that are being either un light, transparent or hollow.

A direction such as this creates an abstractness and unclear interpretation of a narrative while at the same time leaves great room to focus on the tunnel shape. Motion through the play of intensities between the individual "LED modules" could create a certain organic interest and strengthen depth perception within the tunnel.
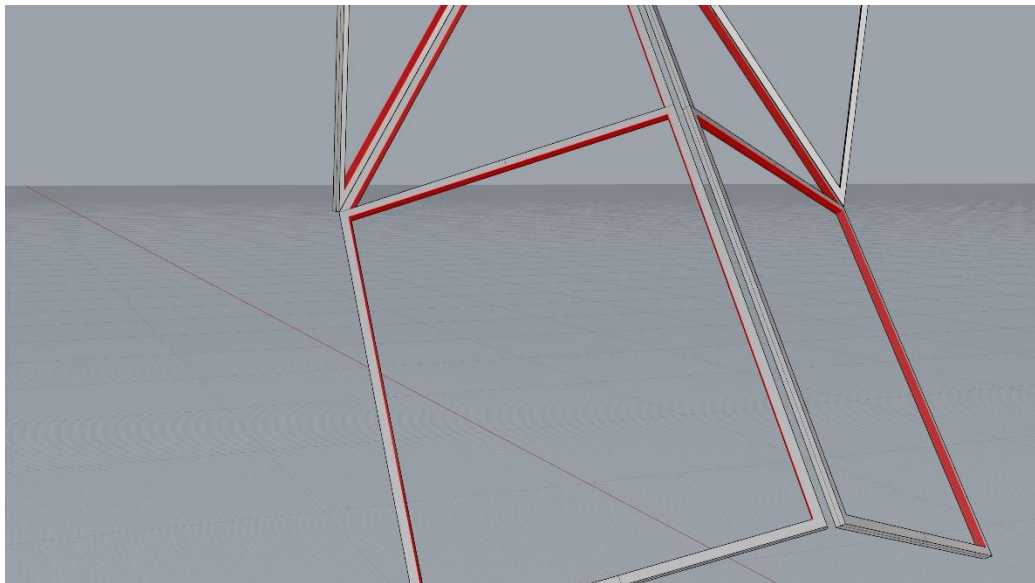

Figure 15: LED Placement

The LED strips design was simulated and tested inside the Engine by combining two main materials for the tunnels screens. The first material resembled a semi-transparent material similar to frosted glass or polycarbonate plastic. The goal for this was for the screens no to function as an obscuring element but to allow for the outer surrounding to be experienced as well. The second one was created by having in mind a matte material like fabric and that meant to achieve the opposite effect and that is to create a sense of a cave-like feeling within the tunnel. Figures bellow illustrates the different output.
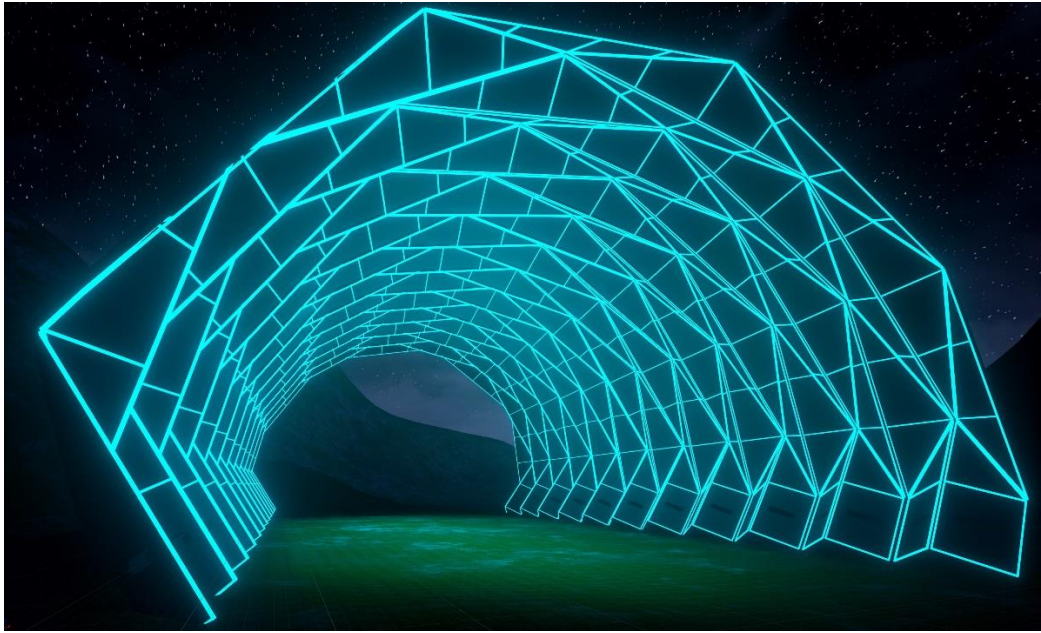
Figure 16: LED test no Transparency
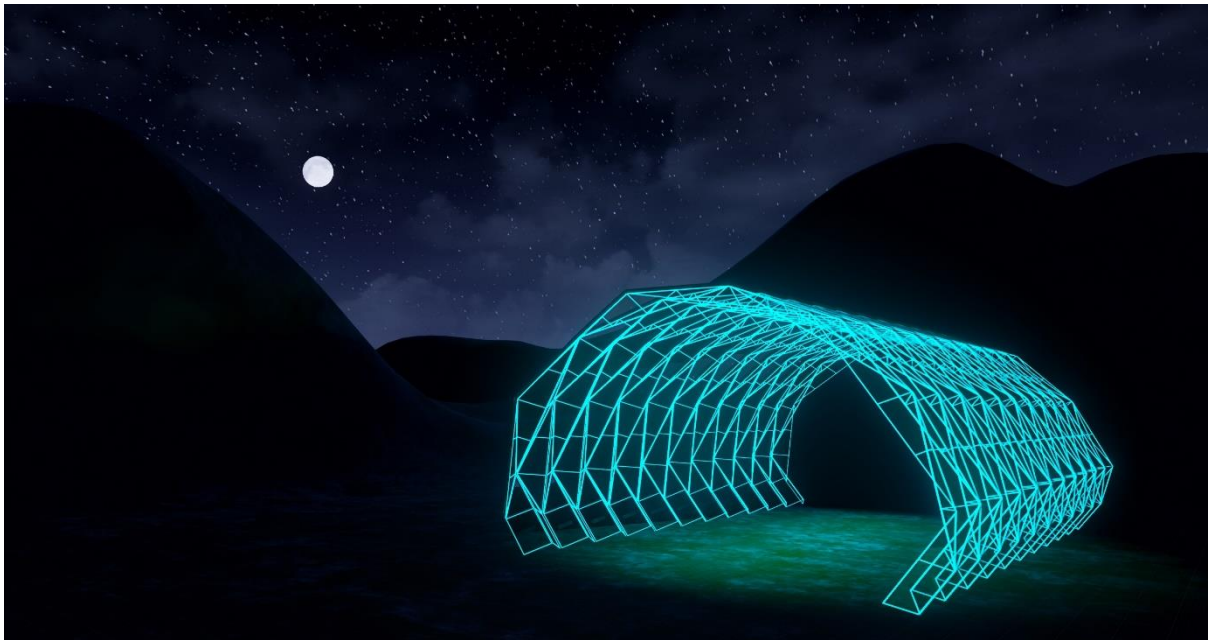
Figure 17: LED test with Transparency

Tunnel Lighting Design Test 2 (Media screens)

The second Design Scenario aims towards a more direct communication with the Installation resembling LED media screens to be placed within the tunnel screen surfaces. This scenario has a different approach in that it requires content creation to be viewed and have the ability of interacting with through alteration or manipulation by users. Unlike with the aforementioned scenarios this requires an effort towards designing a concept around the content and does not focus on material properties and simulating those. This design aims through a clearer message, allowing multiple possibilities for content interaction but having a difficulty to be integrated in a natural environment such as the one we are dealing with. Previous scenarios included a more integratable solution, one that could easily be perceived as more natural since the tunnel structure didn't obscure the surrounding environment but merely to augmenting it.


Figure 18: Media Screens test

Tunnel Lighting Design Test 3 (Lighting the outer faces)

The Lighting experimentations for the outer face of the tunnel was meant to "put the tunnel on the map", meaning that considering the night scenery simulated in the engine, the installation had to be perceived and noticed from a significant distance. Different positions, intensities and angles of spotlight luminaires were tried facing the outer faces of the tunnel. The final experiment resulted in a scenario were 4 spotlights with different temperatures distribute light evenly across its sides. Figure 19 illustrates position and luminaire angles.
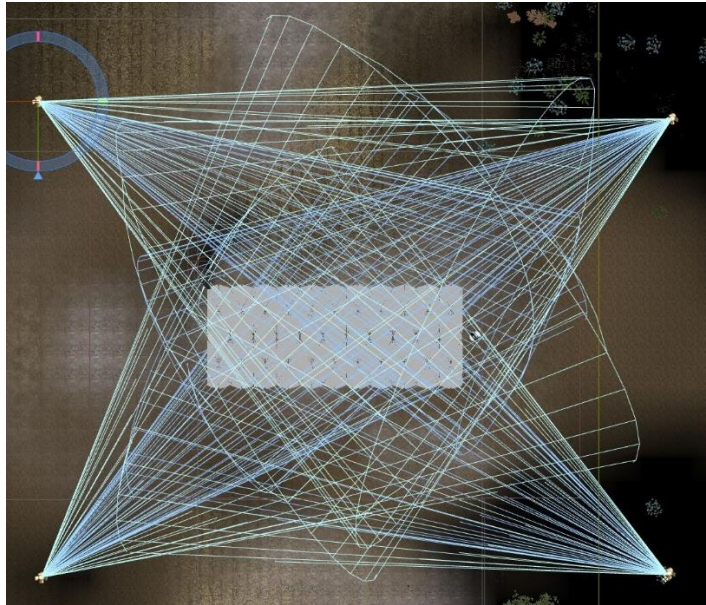
Figure 19: Outer luminaires positions and angles

Two luminaires per side with a cone angle of approx. 30 degrees that emit two different types of colored lighting. The result is the change of reflected color according to the viewing angle of the user. When user approaches the tunnel structure coming from the south he would get a colder color while coming from the north he/she would experience a bright yellow color. Approaching from the sides of the crossroads, these colors come together and mix in the center of the sides. Other than the color play, we wanted to create an emphasis on the matte aluminum material which the screens were made of.
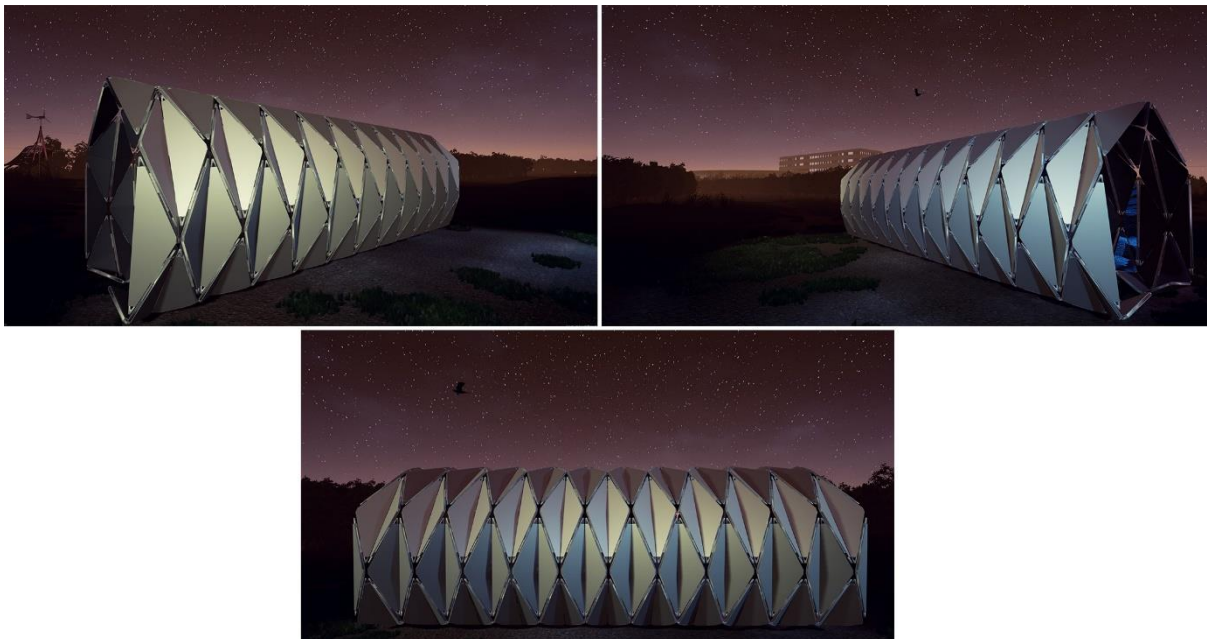
Figure 20: Result of outer Lighting

The final design for the interior lighting was based on the experiments based on test 3. During the experiments for each test possible interactions were tried out. Working this approach enabled this methodology of testing-instant feedback loop during this process of experimentation.

Focusing the final lighting design around test 3 meant that a meaningful content related to the project had to be realized. Content that would enable manipulation from the user side while allowing space for informing on the development of the Science Centers. A research on the nature of work that is being done in the ESS and the MAX IV revealed in detail the differences between these two particle accelerators. While one (MAX IV) enables this acceleration in a circular manner (explains the Building's structure) the other ESS facilitates a more of a linear movement of protons thus its structure as well, with accelerator tube length of 602m [27]. The idea upon creating patterns that resembles the motion that the particles do from within an accelerator, others circular (MAX IV) and others linear (ESS).
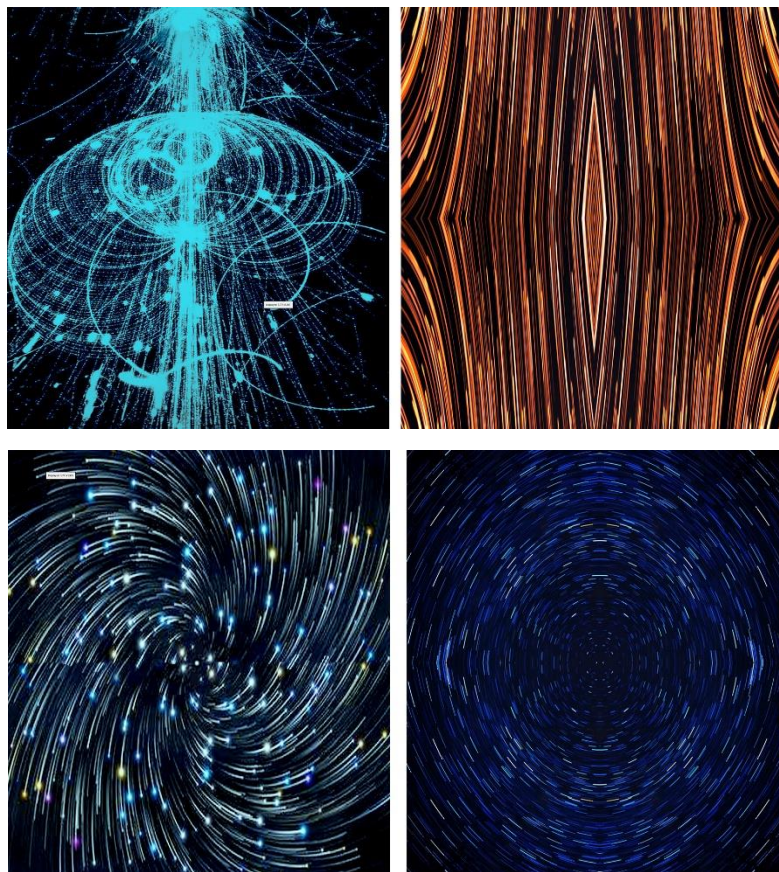

Figure 21: (Top) ESS linear concept, (bottom) MAX IV circular concept

6.2.3. Interactions

Designing the interactions for the experience can be separated in two main areas. One being how users are interacting with the tunnel installation while the other relates to the interactions with the environment around the installation and generally relate to the general experience. Since the whole experience fulfils the project's separate criteria and is not being used only as a host for the lighting installation, it is an essential step to explain how those two main areas relate to the needs of the project.

Designing Interactions for the Installation and Environment

Interacting with the installation is meant to create an intimate sense with the object thus an active scenario of interacting with it had to be realized. Initial thoughts on this were to define two layers, one being more passive and that was meant to enhance the overall experience and adding an extra interest. Quickly it was realized that scenarios such as these would interfere with the experience as it is meant to be understood by participants with different backgrounds, ages and possibly several not having any experience with this type of technology. Since we wanted to create a certain interest around the installation, we didn't want to put the participant in an observer role but one that would give him the role of the designer or creator. The idea for a moving pattern that visualizes particle movements within an accelerator was the first step for the concept of the screens. Making multiple that the user could then apply himself on each tunnel module would result in creating his version of the tunnel. Also by leaving the pattern's color parameter open for manipulation, this would give an extra creative addon to the user. By the end of this the controller, while inside the tunnel, becomes something resembling a "coloring-pen" that enables the user to choose patterns and their color and by "touching" each individual module to "color" them with light! Upon scrolling through the different patterns, a small model of a sphere following the position of the controller informs the user on the pattern currently chosen.

A design such as this promotes the idea of a participatory installation, that the user instead of a viewer, receives a more active role and thus creating feelings of accomplishment and involvement.

Outside the tunnel the controller becomes the main tool for navigation and understanding the surrounding buildings and landmarks that make up the environment. A function of leaping/teleportation was added, that by the press and hold of the trigger button and by pointing it towards a certain direction the user would instantly be transferred once this was released. This was considered an improved scenario of navigation, as compared to having the user navigate with the crosshair, more likely resulting to nausea effects for those that are inexperienced with these kinds of applications. Figure 22 depicts the final result.

Figure 22:(left) navigation system, (right)coloring-pen
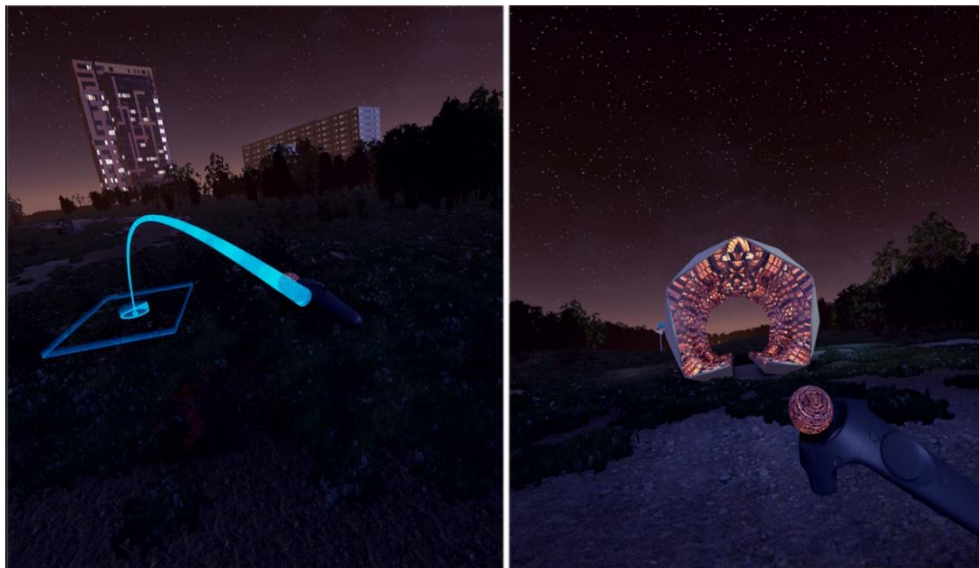
The decision upon using the HTC's controllers as the main mean for interacting with the installation and the environment was made. Several ideas on how to configure exactly its functionality were tried and were tested during evaluation phase. Figure bellow is illustrating the functionalities of the controller.

Figure 23: Application's Controls

credits to Kraftringen

6.2.4. Environment Creation, Landmarks and Interactions

Environment

As mentioned also in the beginning, the goal of this study is to use game engines as a platform for lighting experiments in order to evaluate and test several hypotheses but also to use it as the main host for the entire installation. Therefore, this chapter is dedicated to the development process of external elements such as environment creation and landmarks. The chosen area to be generated inside the engine would cover a size of 500 m^2 and can be viewed in the figure below.
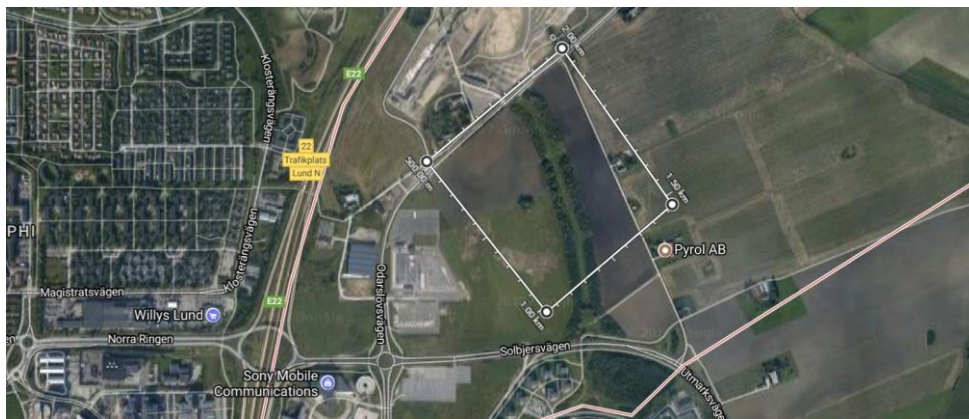
Figure 24: Selected area of Brunnshog

Within the engine now and with the tools that are being provided, the landscape was generated and with the combination of height map data[23], topography was set. Following this the texturing and foliage generation, gave the environment the feeling of being present at the area of Brunnshög. Foliage and trees were mainly found online from freely distributed libraries and edited in the engine for a closer resemblance to our space.

Figure 25: Landscape final result

Buildings and Landmarks

The client's request from the experience, besides the user's familiarization with the science village and the development, was to include certain Landmarks as a way of brand that relates to the city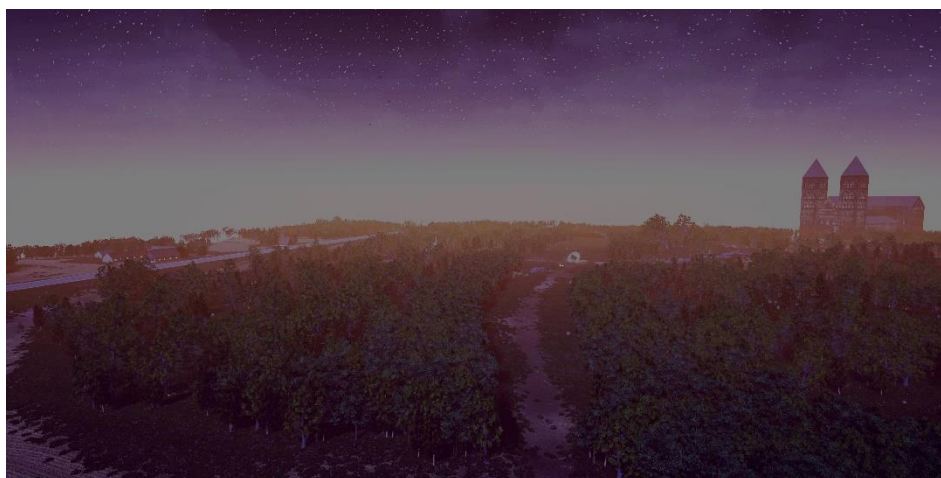 of Lund. Such Landmarks, other than the ESS and the Max IV which are part of the development, are Lund Cathedral [24], Ideon Gateway [25] famous for its innovative design, Lund University Hospital [26] and finally the Giraffe 2.0 [27], a solar powered installation by InnoVentum. Modeling those occurred externally and textured and post processed in the engine.

Figure 26: Lund's Landmarks in the Engine

Lastly, informing participants on the Development of Brunnshog, as well as Lund's Landmarks,

the idea for creating texts in Swedish containing all that information was proposed and well received by the client. Active areas around each Landmark where defined and by the press of the info button on the motion controller, the user would receive a corresponding "info bubble" presenting information about the Landmark and its connection to the city of Lund. Each of these corresponding messages would pop-up on top of the controller and would follow the orientation and position making it easy for each user to adjust the distance to be read.

Figure 27: Implementing Info bubbles

All these added features, from external environment and bubble texts, empowers the installations goal on awareness over the present area as well as the forthcoming development. While the tunnel itself communicates a more abstract message through its patterns, visualizing particle acceleration, spallation processes and motion, the external addons that wrap the whole

experience communicate a more direct message to the participants. All these in the end add up to not only create and awareness but also to encourage participation, involvement and to build a platform for discussions for the local community, municipality and stakeholders.

6.3. Evaluation and Finalizing of the experience

Evaluation

19 users participated in evaluating the experience with varying ages from 25 to their late 60s and most them around the age of mid 40s. The evaluation of the experience was accompanied by questionnaires that were related to Brunnshög and the development of the area (see appendix for detailed description of questionnaire).

The goal of the demonstration/evaluation was to understand how people felt about the experience up that point. Was the experience communicating the points that we wanted to bring forth? Did inexperienced participants had any feelings of dizziness or nausea during the demonstration? Were the controls easily understood and were the text messages clearly read? Could they effortlessly navigate in the virtual environment? These and more had to be considered carefully in order to provide a meaningful and tangible experience.

The approach upon we considered in getting all these answers was with a qualitative observatory method. The procedure for every participant was to firstly explain to them on what the virtual environment is portraying as well as the basic controls of navigation and interaction.

Results of the experience were mostly positive, even by people that had no experience with such technology. None of the participants experienced any sort of nausea while in the VE and the concept was easily perceived and understood by most of them.

Finalizing

Improvements and changes that occurred after the evaluation were:

- Clearer navigation path in the landscape to help orientation
- The use of a single controller rather than two (simplification of controls)
- Changes in info bubbles to improve reading (bigger fonts, color changes, bending of text)
- Feedbacks on actions such as visual, auditory and controller vibrations
- Background music enhancing the atmosphere
- A more interesting concept for the tunnel in regard to screen patterns and gamification of whole interaction concept, resembling a pallet-brush style
- Added fauna and more vegetation to enhance the environment from a more natural perspective

Figure 28: Evaluation of Experience

7. Future Work

Studies and Applications in the field of VR and AR technologies have generated multiple ideas on their usage outside Entertainment and Communication and that was the focus of the present study as well. The recent affordability and access to head mounted displays and interfaces allowed designers and researchers first hand experimentation with these but in environments that belong in the field of gaming industry.

Dedicated environments/software that support real-time technologies and HMD interfaces for the sole purpose of aiding lighting designers and architects in their workflow don't really exist yet. An extended research would yield data on the specific parameters and tools that designers need to have access to when working with virtual reality. This would result in creating a simplified environment, enabling easier embedding in the designer's workflow.

A hypothetical scenario for a software such as this would work something like this: the designer would import all his geometry and materials in the system and by running it he would have access to all basic lighting fixtures and their properties as well as the possibility of importing IES files. While walking virtually inside the simulated space and experiencing it with the help of a HMD interface, he would freely choose fixtures and place them in desirable positions while adjusting their main attributes. While doing this he/she would immediately be accessing his actions and readjust accordingly. By the end of this he would receive relevant information according to his design that could be an average of lux levels on surfaces, luminance ratios and false color imaging according to his/hers material adjustments, energy consumption if the work was done with existing solutions. Once the design/testing phase is done, the material has already been created and adjusted is ready to be presented and communicated further.

Another system that could facilitate the work process of working with light, is an augmented reality environment, that could run through either HoloLens interfaces or smartphone/tablet devices and could present alternative lighting designs on top of the existing space while being present there. This would give the ability to the user/designer to compare existing solutions with those that have been designed and are being proposed instead.

Considering the above we can clearly see the potential of involving mixed realities and virtual content in the design process of working with lighting design. Prototyping and experimenting with such an approach could involve lighting in earlier stages of a project and will assist in a better understanding of the light's complex nature and behavior to our surroundings. Designers are advised to gain an extended knowledge of these tools in order to assist them in their design process and thinking with the goal of achieving optimal solutions and designs. Still we understand that the future for this technology is still unclear and there is a lot of evaluation and trial and error work needed in order for it to shape according to its foreseen potential.

8. Discussion

The topic of the present study was the exploration of designing with light by using a virtual environment. The goal was to document the process with the aim of formulating a possible methodology. An approach such as this comes with great advantages but also with the responsibility of its roles and limits.

Firstly, a strong interdisciplinary approach that combines media technology, computer vision, lighting phenomenology, physics, architecture and design is required by designers that choose to make use of these tools. Working with technology that up till recently was being used in the development of video-games, puts designers in the position of becoming familiar with developer tools and in some cases coding. Regarding what problem is being tackled, the scientific question and tasks needs to be clearly defined from early on, for those are the reasons that will influence *the required degree of realism in a VE*. Higher realism, expects from a designer a strong background in computer generated imagery and computer vision.

Secondly, if the task has been clearly defined and it is clear for what purpose the VE is being used, that is then going to adjust what hardware and what knowledge from the designer is expected. Systems that support full immersion and high degree of realism are quite upscale still, demanding dedicated hardware and special interfaces, but on the other hand less costly solutions could also be the answer. Full immersive and realistic solutions are not always the goal for these applications. When it comes to usage of digital immersion as a conceptual tool, immersion is not the priority.

Thirdly, when it comes to how the design process alters, in that the design steps become more "loose" and the borders between them fade, can create a feeling of uncomforting to designers that are used to a more "strict" flow. It is of great value to comprehend and process the testing-instantaneous feedback, taking place simultaneously in parallel aspects of the project. Better collaboration and communication between involved designers is expected in order for this approach to perform. Because of its nature, many means necessary to empower and encourage that collaboration reside within these tools.

Lastly, how this different workflow and approach can affect the final design is an important matter. While these methods can be categorized as being part of the rapid prototyping process and may introduce lighting design matters earlier in a project, simultaneously can result to a degree of setback when we move to implementation and where physical being involved. Digital prototyping and experimentation process, is a step of its own and can either fit or not, regarding the nature of the project. We must be aware on how we involve VEs, meaning what questions do we need to answer and when? VEs are still a rapid prototyping method and they are here to ensure that our move to the physical would have as less as possible mistakes and that we foresaw as many as possible outcomes. VEs can be a great ally within sustainability, affordability and feasibility goals of forthcoming projects, but of course if utilized in a structural and careful manner.

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