# Introduction to Utzon(x) 2013: Tetraleaf

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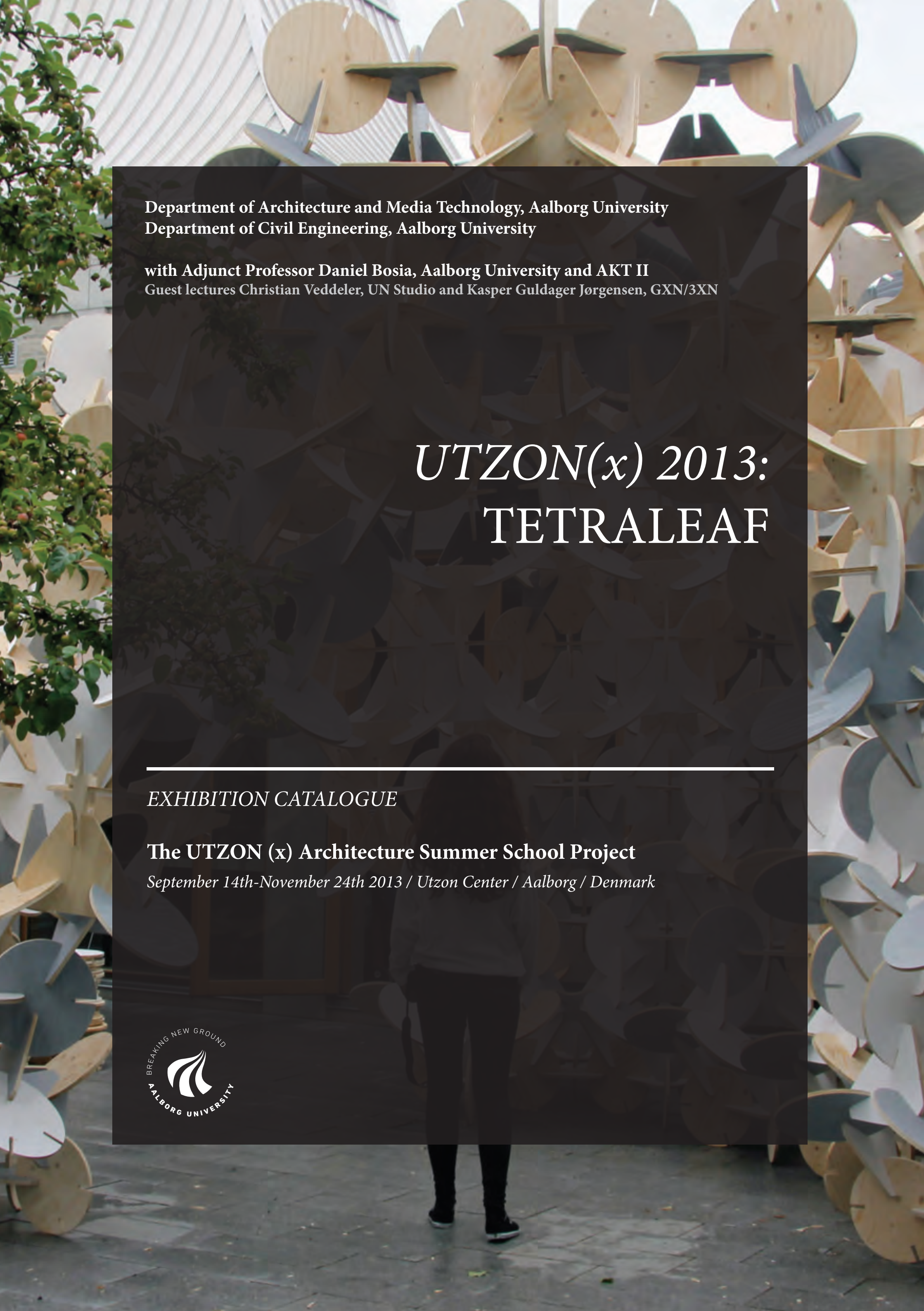


**Department of Architecture and Media Technology, Aalborg University**
**Department of Civil Engineering, Aalborg University**

**with Adjunct Professor Daniel Bosia, Aalborg University and AKT II**
Guest lectures Christian Veddeler, UN Studio and Kasper Guldager Jørgensen, GXN/3XN


# *UTZON(x) 2013:* TETRALEAF

*EXHIBITION CATALOGUE*

**The UTZON (x) Architecture Summer School Project**

*September 14th-November 24th 2013 / Utzon Center / Aalborg / Denmark*

BREAKING NEW GROUND
AALBORG UNIVERSITY

*UTZON(X) 2013:TETRALEAF*
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## *INTRODUCTION TO UTZON(X)*

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Department of Architecture and Media Technology, Denmark

This catalogue shows the project *Utzon(x) 2013: Tetraleaf* which is the outcome of the twelve days summer school in August 2013 at the Utzon Center in Aalborg.

The Utzon(x) project is a co-operation between the Department of Architecture and Media Technology, the Department of Civil Engineering both at Aalborg University and The Utzon Center. The lecture series and Summer School ask academia and practice within architecture and design from around the world for new approaches, methods, models and projects that attempt to construct architecture from the merged platform of architecture and engineering.

Why the (x) in Utzon?
Among the possible ways to reconsider Utzon legacy, one can look at his strategies for variation and repetition in the light of the recent development of computer software, parametric modelling, computational techniques, digital fabrication and their application in architectural design and engineering. The Utzon(x) projects and summer school is a hands-on learning environment, where theoretical knowledge is coupled with physical and practical assignments related to specific design themes. During the two weeks of The Utzon(x) Summer School, twenty-five Danish and international students have worked on creating the project displayed in the Utzon Center court yard which has been unfolded as a working process and method in the exhibition space.

Enjoy on behalf of the Utzon(x) Summer School Team 2013!
Lasse Andersson

The Utzon(x) Summer School Team:
Adj. Professor and Director, Daniel Bosia (AKT II and Aalborg University)
Associate Professor Lasse Andersson. Aalborg University
Professor Poul Henning Kirkegaard, Aalborg University
PhD. Student Isak Worre Foged, Aalborg University
Assistant Professor Dario Parigi, Aalborg University
Lab. Engineer Mads Brath Jensen, Aalborg University

Summer School Guest Lectures:
Associate Director and Senior Architect, Christian Veddeler, UN Studio
Director and partner, Kasper Guldager Jørgensen GXN/3XN

The Utzon(x) Summer School 2013 is supported by The Obel Family Foundation.

## *UTZON(x) Summer School - Experimental Design*

Isak Worre Foged MSc.Eng.Arch., M.Arch., MAA, Lasse Andersson, Associate Prof., Ph.D. Department of Architecture and Media Technology

Today, we ask architecture to enrich, protect and serve human life. Architecture must be emotionally captivating, functionally and financially optimized and environmentally performative. The complexity of the built fabric rises and the field of knowledge needed to construct a singular building expands. We know that tailoring above requirements together from the beginning of a design process improves all aspects of the final design from its construction process throughout its lifetime. This more than indicates that disciplines need to meet and interweave.
Just as Jørn Utzon was a master of merging architectural ideas with engineering principles to elevate numerous projects, contemporary architectural practice could become more than the sum of the disciplines.
Utzon(x), as a lecture series and summer school, ask architectural and design actors for approaches, methods, models and projects that attempt to construct architecture from the merged platform of architecture and engineering. Utzon(x) is an open discussion of how both academia and practice can move towards a built environment that is beautiful, social and environmental responsible at the same time.

A way of working with architecture more than a style of architecture might offer some grounds for this effort. Architecture is, according to architect and psychologist Bryan Lawson (Lawson, 2006), a prescriptive activity. That is, prescribing something that does not exist. It reaches out to something yet to be discovered and understood. Architectural endeavors are, therefore, often associated with a search, however, seldom with the extension and extended meaning of re-search. At least in terms of scientific truths in the way they are understood in the natural and engineering sciences through establishing guiding laws and principles. Situated between humanistic and natural sciences, architecture lends methods of search and knowledge inquiry from various disciplines often facing the need to argue in both quantitative and qualitative ways. While means for 'measuring' if something is 'new' or 'improved' are important to evaluate progress in the work performed, modes of inquiry for new knowledge in architecture might lie closer to the actual workings of the classical researcher than immediately understood. Alan Penn (2010), architect, researcher and educator, points to the philosopher of science Ian Hacking, who argues that the nature of research is not only the testing of hypotheses, but also that of phenomena creation. In the process of creating phenomena, we will be able to understand abnormalities and potential fields of further research undertakings.
Advancing knowledge through phenomena creation lies close to the core activity of prescriptive activities in architecture particular through physical models and digital models that includes simulated physical conditions. It does so, as material and spatial phenomena are perceivable and influenced by the actual world.
In parallel, we know from investigations of design processes that the greatest leap

forward towards an improved design (and potential understanding) is created by a rapid successive process of *analysis-making-synthesis* (Akin & Lin, 1995). This is a solution based process, typical for designers, whereas scientists and engineers typically have a problem oriented approach in which they try to figure out the problem before engaging with the process of search (Lawson, 2006). An advantage of the solution-based approach is that it constructs intended and more importantly unintended phenomena.

According to architectural theoretician Michael Speaks (Speaks, 2007), the iterative process, based on prototype making, is the gateway to what he refers to as *Design Intelligence*. This is an accumulated understanding of design aspects that can be classified as knowledge. However, for this to happen, the process needs to include registration of the conducted iterative process in order to trail both confirmation and abnormalities produced during the searching iterative design process. Here, we can raise a potential critique or question of in what way this can be applied, as how are we to understand in what direction to make design iterations to become more knowledgeable about a design problem?

Studies into classification of experts in various fields, such as music and sport might help us to understand how we can do this. By documenting the transition from being good to becoming excellent, researchers (Ericsson, Krampe, & Tesch-Römer, 1993) have discovered that a quantity of training hours has to be parsed. More specifically, 10.000 hours of training. This in itself is a substantial effort, but perhaps more important, the training needs to be what the researchers refer to as *'deliberate practice'*. The expert musician is not playing an entire piece, but often deliberately practicing fragments or scales enhancing a certain skill. The hundred-meter sprinter is not just running, but working particular muscle groups far away from the straight running course. This process of *'deliberate practice'* enhances the skills and knowledge of the performer. Interestingly, studies of elite designers show that they too take an approach where they focus on specific aspects, noted '*primary generators*' (Darke, 1979). These 'generators' are the core elements in producing both design solutions and design knowledge.

Just as good designers apply generators to their design processes, academic educational design teaching could potentially advance through such methods. Such design education process was initiated with a group of architectural design students, by one of the authors, where a series of successive generators where applied in progressive phases of design development. First working with a geometric element, then to understand the elements properties as a system of multiple elements, to, lastly, create formations based upon the learning from the first two phases (Foged, 2012). The final designs followed by this method became often geometrically advanced, but through continuous registration and documentation of the process, an understanding of a complex architectural system could be maintained and stored for further work. The process generated accumulated design intelligence and knowledge by the student.

While the usage of prototypes in modern architecture is relatively new, we find direct similarities to the work methodology as previously described of Jørn Utzon. On several projects he worked this way as we can see in the prototypes developed, among others, for the tiling of the Sydney Opera roof. The conventional separation of thinking and making, architecture and engineering, is discarded in favor of a design process that involves both at the same time.

Similarly, in the design development of the layout of the Kuwait National Assembly (1982), it appears that Utzon creates a design sketch that he can operate within, make variations and understand its capacities. In this, he sketches simple units. These units are then organized in clusters and, finally, in a greater building complex. The ability to have control of each unit, cluster and total organization seems to enable design maneuverability of several design scales simultaneously. Perhaps, this is one of the reasons why Utzon is known for creating architectures in direct relation to the human and the iconographic expression at an entirely different scale.

In this sense any model, any prototype, is not a final result but a medium for the next iteration. It is in this way a keeper of what we know in this moment. Hence, a 'final design' is not the total result, but is much more the entire learning and knowledge created through 'making-analysis' iteration by 'making-analysis' iteration usable when approaching other design problems.

Following this approach, the summer school attempts to create a working methodology that is search oriented, based upon shifting modes of physical and digital making to spatial, structural, environmental analysis to synthesis to both create a design result and a growing design intelligence by weaving architecture and engineering.

Akin, O., & Lin, C. (1995). Design protocol data and novel design decisions. Design Studies, 16, 211–236. doi:10.1016/0142-694X(94)00010-B

Darke, J. (1979). The primary generator and the design process. Design Studies, 1(1), 36–44. doi:10.1016/0142-694X(79)90027-9

Ericsson, K. A., Krampe, R. T., & Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. Psychological Review, 100(3), 363–406. doi:10.1037//0033-295X.100.3.363

Foged, I. W. (2012). On Tectonic Terms. In On Tectonic Terms (pp. 25–37).

Lawson, B. (2006). How designers think: the design process demystified. LONDON ARCHITECTURAL PRESS (Vol. 3rd revise, p. 321). doi:10.1007/s11060-008-9735-x

Speaks, M. (2007). Intelligence After Theory. In A. Burke & T. Tierney (Eds.), Network Practices (pp. 212–218). Princeton Architectural Press.

## *UNFOLDING UTZON: ADDITION AND REPETITION*

Poul Henning Kirkegaard Professor, Aalborg University, Department of Civil Engineering, Denmark

For many, the architecture by Jørn Utzon is synonymous with the design of the Sydney Opera House (1973) that was made a UNESCO World Heritage Site in 2007, being one of the 20th century's most distinctive buildings and one of the most famous concert halls in the world.

*"It stands by itself as one of the indisputable masterpieces of human creativity, not only in the 20th century but in the history of humankind."*
[The UNESCO World Heritage Committee, 2007]

However, Utzon's architecture is more profound than the Sydney Opera House. Among other examples, his architecture includes the Melli Bank in Tehran (1962), Irans's National Bank (1963) and the National Assembly of Kuwait (1985) as the finest examples of Utzon's architecture where features of the traditional bazaar in the Middle East influenced his way of thinking and creating his modern form of architecture.

*"We had the idea of constructing the building around a central hall, a bazaar street, in such a way that all departments met in side roads off the bazaar road, just as we know from the bazaars in the Middle East and North Africa..."*
[Jørn Utzon]

Prior to these projects, Utzon designed his own house (1952) in Hellebæk, where he introduced 'the open plan' in Denmark inspired by his studies of Frank Lloyd Wright's houses. Careful consideration was given to the surroundings, especially the environmental factors such as sun, view and shelter from the wind.

*"What is important for me is that the architectonic approach or system behind a house should not limit the house's function and thereby hamper life inside"*
[Jørn Utzon]

This one-storey private home project was followed by Utzon's courtyard housing project, the Kingo Houses (1958) in Helsingør, a project with 63 L-shaped houses which can be seen as a prototype for the Fredensborg Houses (1963) consisting of 30 terraced houses with gardens and 47 L-shaped atrium houses form a three-winged estate. The materials chosen for the houses were tiles and wood, traditional Danish materials. Utzon originally called this concept for 'private life' due to the balance between the private space and the public areas organized for community life. Both of these two housing projects are based on Utzon's additive approach, starting modestly with one house followed by more houses, taking the landscape and its character into account. Utzon has talked about the layout of the houses as "flowers on the branch of a cherry tree, each turning towards the sun." This inspir-

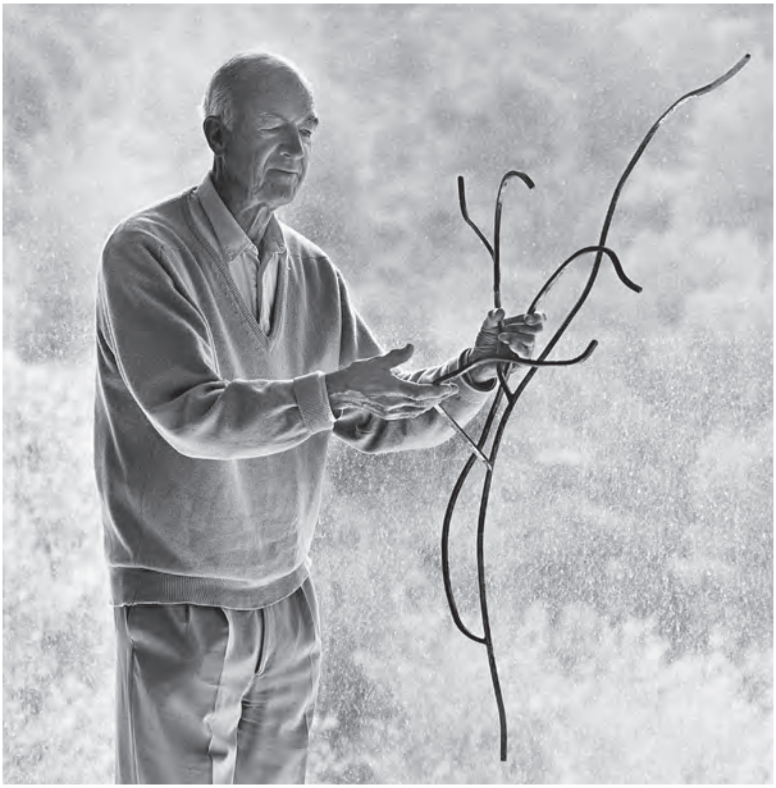


*Photo by Ole Haupt: The essence of Danish architect Jørn Utzon's architecture is a fusion of form and structure inspired by nature and the visual universe of other cultures.*

ation from nature for his additive approach is also outlined in the manifesto 'Additive Architecture' (1970) where he refers to examples from nature like 'a group of deer at the edge of a forest' and 'the pebbles on a beach'. The concept of additive architecture relies upon open-ended building systems of almost organic growth based on a limited number of prefabricated units. The application of the additive approach can be seen in many of Utzon's projects besides the housing projects. Examples are found in the proposals for the un-built projects like the Silkeborg Art Museum (1963), the Farum Town Centre (1966) and the proposal for a major sports center in Jeddah (1969). However, the flexible building system 'Espansiva approach' for low-cost housing, only build as a prototype, is, perhaps, the best and most well-known example. In addition to these projects, using the additive approach, the Bagsværd church (1977) and Paustian's furniture store (1987) should also be mentioned and of course Utzon's own houses Can Lis (1973) and Can Feliz (1994) at Mallorca and the furniture project Utsep (1968). Many of these projects include original approaches to variation and repetition. Due to Utzon's awareness on  construction, the repetition of a component becomes the expedient by which complex geometrical and constructional problems can be rationally solved, as in the case of the shells of the Sydney Opera House, the beams in the National Assembly of Kuwait etc. The construc¬tion of a complex geometry is simplified and rationalized with a brilliant solution that allows to employ only a limited set of standard prefabricated components. The combination of prefabri¬cated components in a structural assembly in such a way as to achieve a unified form that while incre¬mental, is at once flexible, economic and organic. Conversely, the variation of a component is related to his refusal of reductionist approaches: in his design, he aimed to embrace the complexity and the multifarious. Therefore, a structural component can vary its shape and adapt to the states of stresses. Utzon also unfolded this understanding of additive components in his use of folded plates. For many of Utzon's projects, the roof is a variant on the folded-plate structures which fascinated him. Folded-plate structures were not in themselves unusual for the late sixties, however, Utzon had an ability to add layers of meaning without adding physically to the minimal structure. Utzon lifted well articulated folded-plate structures from a role as an ornament into a modern construction, returning it to the constructive purity of its tectonic origin. In the competition for the Madrid Opera House (1964), Utzon designed the roof as a variant on folded-plate structures and presented as almost to be in the process of unfolding. His facination of folded structural elements was first introduced in the Melli Bank project where the lighting inside, through the roof, was inspired by the skylights in Isfahan's bazaar which Utzon previously had seen on one of his journeys. The roof is articulated with folded-plate beams of various depths, allowing the light to penetrate narrow openings before being diffused by deep V-shaped troughs. An approach Utzon later further developed for the Bagsværd church project.

*Photo Seier+Seier Jørn Utzons, Madrid Opera House proposal*

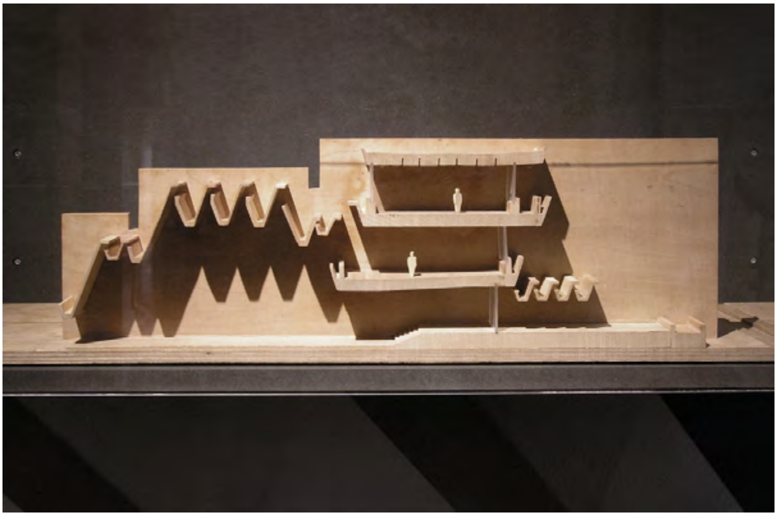


*Photo Seier+Seier: Model for the Interior of the Melli Bank*

## *A ONE-TO-ONE LABORATORY IN SPACIAL-PERFORMATIVE ARCHITECTURE*

Daniel Bosia Adj. Professor, Aalborg University, Director AKT II

In the Utzon Centre together with Aalborg University, an interesting spacial-performative experiment took place this summer over a period of two weeks; a one-to-one prototype for a material system that can create space, form, pattern, structure and environment all at the same time. Organized as a two stage competition between teams of students, the intense workshop produced an installation for the internal courtyard of the Utzon Center.

It is under the pressure of time and economy of material, but with the tools of parametric design and structural/environmental form-finding, that the student realized a piece that offers both new technological opportunities and the qualities of an unexpected emerging aesthetic. The project is laboratory for new ideas, but also a flexible installation, designed to tour different venues by being dismantled and reassembled in a multitude of different configurations.

The piece is the antithesis of a static building or a finished object; it is more like a fluid that can occupy void, separating and organizing space, program and circulation. It can filter or diffuse light, shade the sun and mould itself to different contexts. To some extent, it can be seen as a four-dimensional system, able to grow or reduce, morph in time, adapting to different programmatic, structural or climatic conditions.

Tetraleaf is a modular system composed of interlocking circular ply disks. It is based on a tiling of regular tetrahedra and octagons, where the ply disks are arranged parallel and at the centre of each face of the polyhedral tiles and perpendicularly and at the midpoint of each edge. Variations of the pure circular interlocking disk use other shaped units of quadrilateral or triangular ply shapes, according to the valency of each module.

With simple one-to-one prototype projects like Tetraleaf, developed between practice and academia, we are hoping to generate new performative models for the investigation of full scale technologies, construction systems or spacial configurations. If successful, these concepts will develop into the products and technologies that will revolutionize our industry addressing the urgent challenges that it faces.

Opposite are two examples of such prototypes and pavilions where Daniel Bosia have been reseponsible for the engeneering part. The first being the The Coca Pavillion during the 2012 London Olympics and the second being the Mathew Richie installation 'The Evening Line' for the XI Venice Architecture Biennale 2008.

*Coca-Cola Beatbox, London 2012 Olympics, Pernilla & Asif and AKTII p.art*
*photo courtesy of AKT II (photo by Hufton+Crow)*

*Experimental and Parametric Design,*
Utzon(x) Summer School Team

## Parametrics

Using parametric modeling means to connect all parts of the architectural model and make them interdependent. These interdependencies we then control to develop and modify the design according to our intentions as a designer or in relation to simulations such as structural and environmental performance. We use software that links all the geometry and mathematical expressions together.

## Experimental Design

When experimenting in architecture, we analyze, we make and we synthesize. We use different media and techniques to understand the problems and solutions towards a design proposal. To investigate and explore rapid changes between design activities create the best conditions for creating something new and innovative. The different models and methods here show some of that effort.

## Structural Design

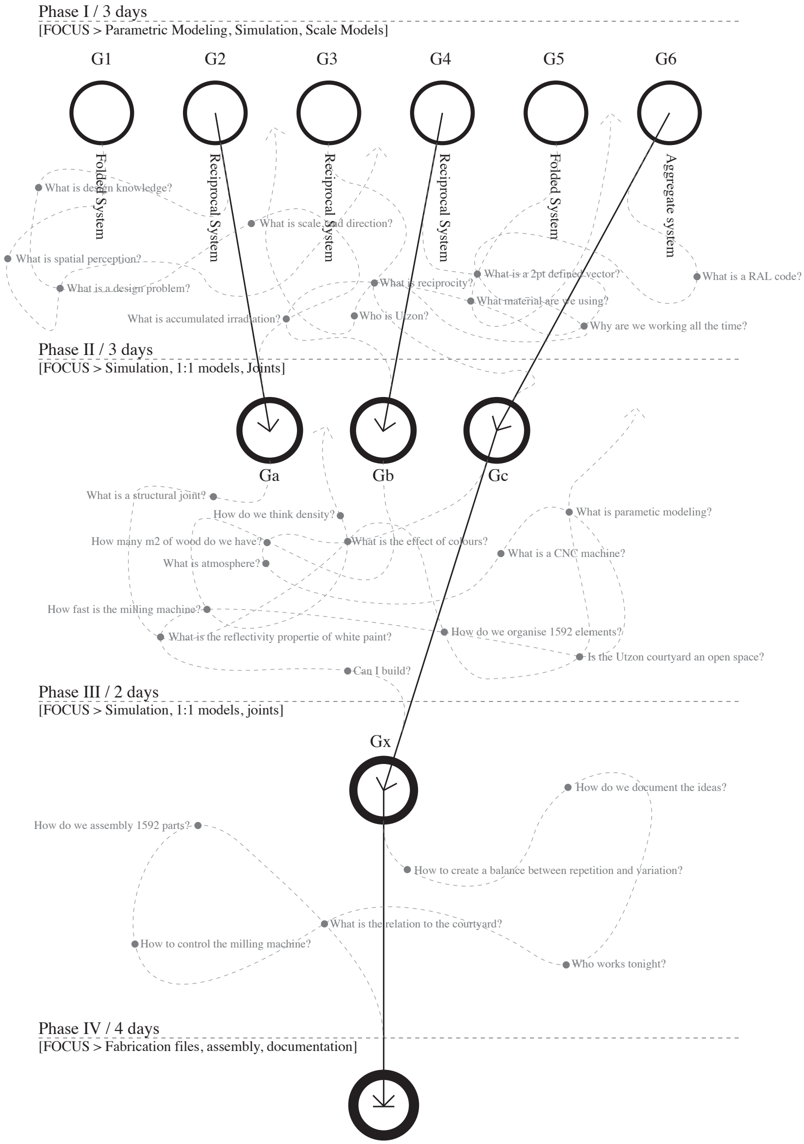
It stands or it falls. In architecture, we use a large series of known structural concepts. When we do something entirely different structural simulation offers us the insight of how a structure behaves, how we can modify it and understand it. In a complex spatial aggregated system, it is only by simulation we can understand the structural forces.

## Environment

Environment shapes architecture and we therefore digitally simulate the physical environment to advance our architectures. When simulating daylight, we can see by colours or numbers how natural light moves around the structure during the design process. We can observe the environment as sections through the model space or on the surfaces of the structure.

## Fabrication

When engaging with complex built structures, fabrication is a central aspect as an active design parameter. By using computation, we create systems that dynamically make digital manufacturing files, calculate the placement of each element on a wooden plate, material waist and the time needed for production. Every one of these aspects as a design variable enables time and money saved.


Phase I / 3 days
[FOCUS > Parametric Modeling, Simulation, Scale Models]
G1
G2
G3
G4
G5
G6
Folded System
Reciprocal System
Reciprocal system
Reciprocal System
Folded System
Aggregate system
What is design knowledge?
What is scale and direction?
What is spatial perception?
What is a design problem?
What is reciprocity?
What is a 2pt defined vector?
What is a RAL code?
What material are we using?
What is accumulated irradiation?
Who is Utzon?
Why are we working all the time?
Phase II / 3 days
[FOCUS > Simulation, 1:1 models, Joints]
Ga
Gb
Gc
What is a structural joint?
How do we think density?
What is parametric modeling?
How many m2 of wood do we have?
What is the effect of colours?
What is a CNC machine?
What is atmosphere?
How fast is the milling machine?
How do we organise 1592 elements?
What is the reflectivity propertie of white paint?
Is the Utzon courtyard an open space?
Can I build?
Phase III / 2 days
[FOCUS > Simulation, 1:1 models, joints]
Gx
How do we document the ideas?
How do we assembly 1592 parts?
How to create a balance between repetition and variation?
What is the relation to the courtyard?
How to control the milling machine?
Who works tonight?
Phase IV / 4 days
[FOCUS > Fabrication files, assembly, documentation]

## *DESIGN 1:1- The Tetraleaf project*

Utzon(x) Summerschool Students + Utzon(x) Summer School Team + Daniel Bosia

Tetraleafs is a modular interlocking system of circular units forming tetrahedral aggregations in space. These are obtained by fully tiling space with regular tetrahedra and octahedra Then the circular units are mapped parallel to the polyhedral faces and perpendicular to the edges, forming a spatial grid system.

Circular units are all of identical diameter with slots at 3 and 4 positions to interlock with their neighbours. These form rigid aggregations, which can then be carved and eroded into efficient structures, screens and light diffusers.
The system can be exploited at different scales to create installations and pavilions, which are reconfigurable, expandable and optimizable in time.

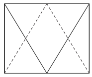
The build project in the Utzon Center courtyard consist of two interlinked parts which basically is a well-defined polyhedral shape formed by tetrahedra which again form octahedral shapes. To adapt it to the Utzon Center a central inner piece is carved out creating two elements in the courtyard.

A new basic sculptural element and a spatial structure, where the first is left uniformed showing the basic structural system. The second spatial structure is informed and further adapted to both Utzons architecture and the environmental conditions in the courtyard. This is done by eroding the basic circular elements of the system into new optimized shapes according to load forces and light, which then again are coloured to enhance the environmental capabilities of the architectonic space.

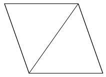
The installation in the courtyard is both a pedagogically explanation of the ideas and analysis behind the project showing both the uninformed and informed versions of the system. But most importantly it is the intentional work with an architectonic space that relates to Utzons architecture, the environmental conditions and the perceived qualities of being in an architectonic space. The process of forming this architectonic space is an iterative process made up by the use of computational design software and analogue models.

META GEOMETRY A

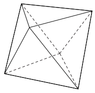
Side A



Side B



Perspective



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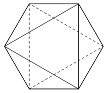
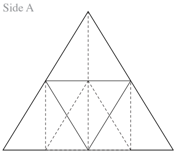
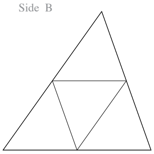


META GEOMETRY B

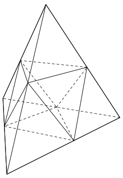
Side A



Side B



Perspective



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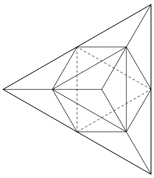
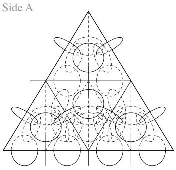
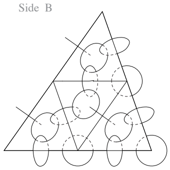


ELEMENTS

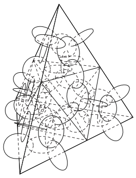
Side A



Side B



Perspective



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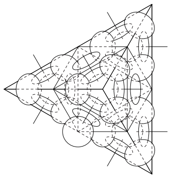
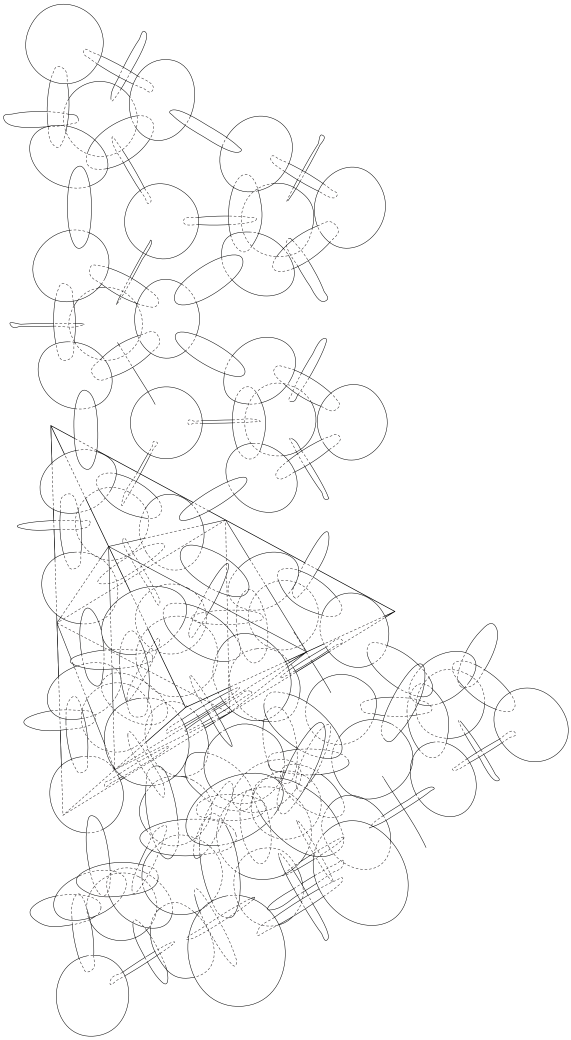


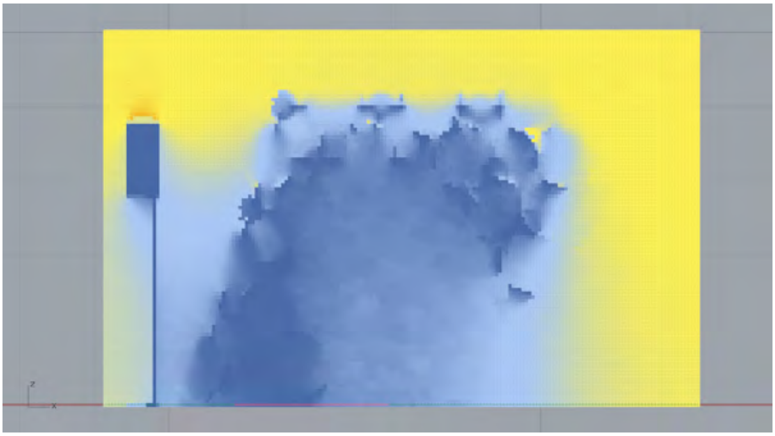


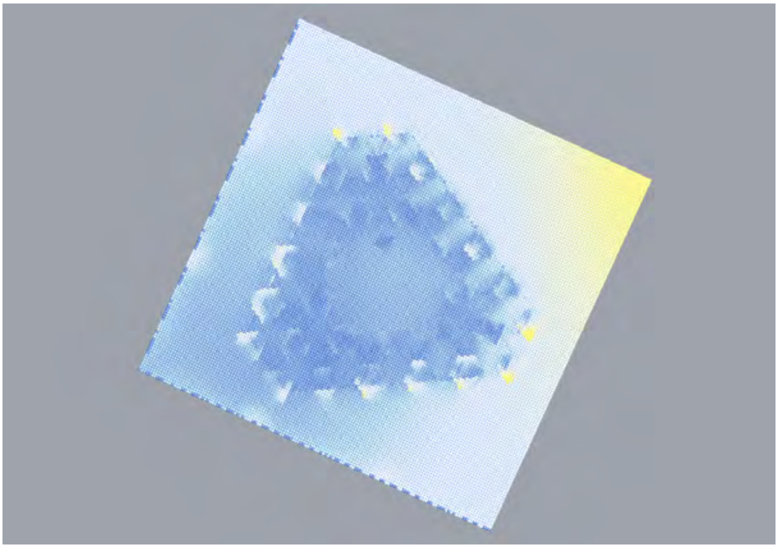
*Elements of Tetraleaf  - The complexity of the pavilion is derived from a few defined geometrical structures. When combined, these can be packed densely. They then serve as an invisible system that organizes the elements we can see. In this way, the structure is continuous and can be forever expanded according to design intentions. Illustration credits: Utzon(x)*

*Elements of Tetraleaf  - Photo credit: Isak Worre Foged*

*As a design system inserted into the Utzon Center courtyard, the design is related to the specific space and the human scale. The space it creates frames light conditions and meeing for observers of the spatial construction. Photo credit: Isak Worre Foged*

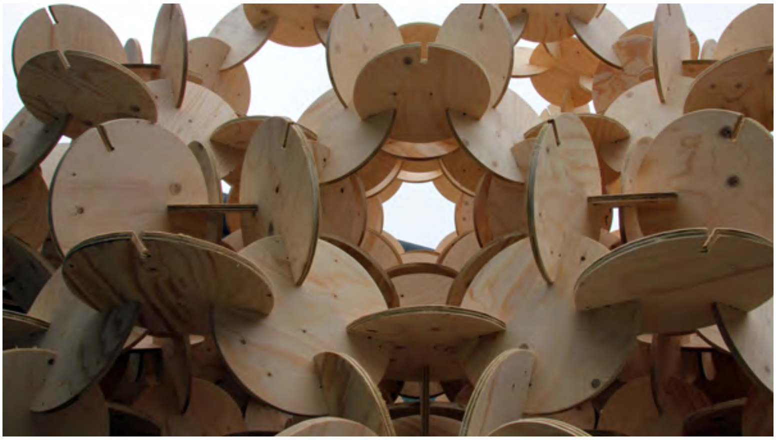
*An early version - A 1:20 model showing the design from above before it has been modified to its spatial and environmental context. Photo credit: Lars Henriksen*



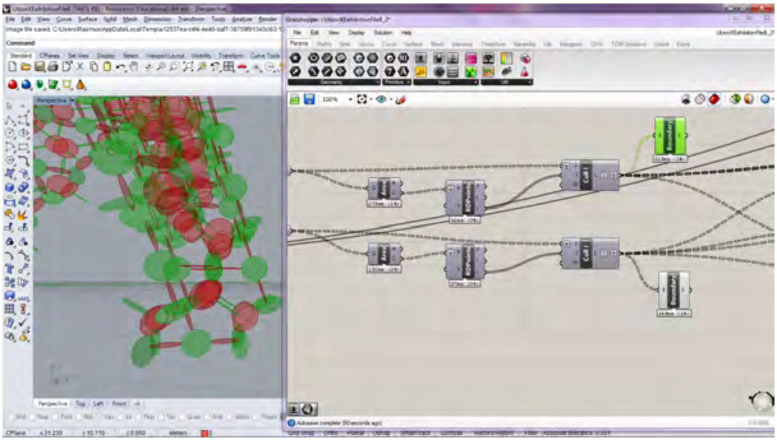


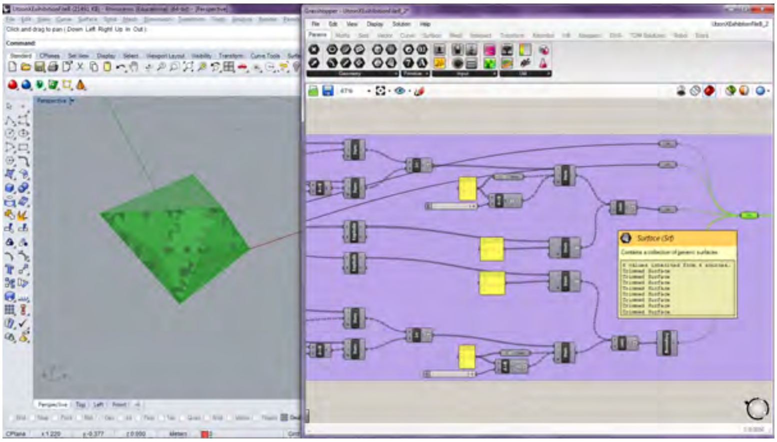
*Understanding structure from environment - The cross section and plan section simulations of the final design illustrate the light condition of the space but also how the organization of the elements create a 'deep' structure where the envelope becomes a thick transferring layer rather than a thin façade. Illustration credit: Utzon(x)*

*Organising elements in relation to the human scale*
*As the organization of the design can be scaled in all directions, several studies are created to understand the proportions and sizes of elements in relation to the human scale and movement through the structure, Photo credit: Lars Henriksen*



*Symmetry and variation - The complexity of the pavilion is from specific perspectives incomprehensible. From others, it is perfectly symmetrical and ordered. The design allows for both a chaotic and calm reading of the design. Photo credit: Isak Worre Foged*





*The parametric organization - By organizing the design as an ordered parametric system, variations of design proposals can be created in an instance. What takes time is the careful orgsanisation of geometric elements combined with mathematical expression and logical operations. Illustration credit: Utzon(x)*

# *ENVIRONMENT AS A GENERATOR FOR ARCHITECTURAL DESIGN*

Isak Worre Foged, MSc.Eng.Arch., M.Arch., MAA

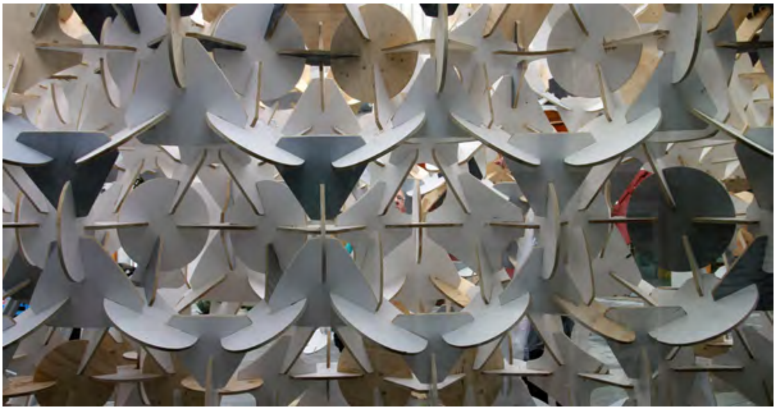
Environment is what surrounds us. But it is also what interacts with us and forms us, and our architectural constructs.

We breathe the air around us, we absorb the solar energy through our skin and we hear the sounds in our perceptible proximity. According to biologist Jacob von Uexküll (Uexküll, 2010), every organism has its own environment and this environment is in direct relation to the complexity of the organism. Hence, one-cell organisms has little understanding and perception of its environment, whereas multi-celled complex organisms, such as humans, have a radically expanded understanding and interaction with its environment. Uexküll refers to this as the *Umweltstheorie*, in which feedback between the organism and environment constantly creates the perception of the organism in the environment. The interrelation is, therefore, inseparable and suggests that an organism and an environment is so intimately linked that they cannot be understood apart.

This biological understanding is becoming evident in different scientific fields in which environment must be said to have an important role. In fact, it is difficult to think of a field of study that, in some way or another, does not have to relate its enquiries to its environment. An example is, in the natural sciences, related to artificial intelligence and robotics. Current research (Sumioka, Hauser, & Pfeifer, 2011) suggest that control systems, artificial intelligence, is not only located in one processor, the previous image of the equivalent to a human brain, but rather as embodied intelligence and perception. Actions and control are performed outside the 'brain' and, from this understanding, the development of robots have started to become more focused on material properties and the potential inherent processing capacities in local material organisations. A simple example is to use materials with particular elastic properties in robotic legs. When the robot move, the material will perform actuations (movements) as a direct response to the force applied to it, without getting a signal from the control unit to act in this way. Without having to send information to the central control unit, response is faster and less costly for the entire system.

In a similar way, we can imagine architecture respond to its environment by organising materials in an intelligent manner. We know that various materials respond differently to environmental changes. For decades this has been seen as a problem in architecture, but instead we can turn this around and start to suggest a strategic application of such material processes. Wood, as an example, has been controlled by shifting fiber directions, so that when one layer bends, another layer will bend the opposite direction and counteract its final form changes. In architectural studies performed within the last recent years  (Hensel, 2010) we, how-

*Detail of structure - Each element is coloured according to its specific properties of reflecting or absorbing the solar energy accumulated on its surface. The strategy is to maximize absorption where there are high values of light energy, and maximize reflection where little light energy is present. The environment colours the pavilion. Photo credit: Isak Worre Foged*



*Assembly of colours  - The aggregation of colours are added as a repetitive and varying layer to that of the geometric variations. From this, the understanding of the assembly as a complex and yet homogenous organization is strengthened. Photo credit: Isak Worre Foged* ever, see a growing understanding of how the material properties of wood can be used in correlation with environmental changes. The hygroscopic properties, woods ability to absorb and release moisture, enables a single layer wooden surface to bend and be used as an architectural dynamic responsive element.

Organising the materials in a way in which the building surface becomes open according to humidity constructs, not only the potential of a dynamic façade, which potentially can improve the spatial qualities, but also suggest a profound and interdependent relationship between architecture and, what we consider, external to an architectural construct, the environment. Thus, as moist, a property of the environment, is absorbed by the wood, it becomes the determining material that alter the form of the wood and therefrom the perceived architecture. Moist is temporarily and explicitly part of the materialization of architecture before it is released again when the moisture concentration of its local surroundings decreases.

While the above example with wood is a known material artifact, understood through new optics, more dramatic and unconventional approaches can be applied. If we consider architecture 'as the construct of artificial environment', as prescribed by the german philosopher Peter Sloterdijk (1999), there should be no reason to think of architecture as only constructed in solid forms. In fact, there is a much more direct way to construct environments, that is, constructing the environment itself. Diller Scofidio+ Renfro does exactly this by their Blur Pavillon, in which thousands of nozzles spray moist forming a spatial condition for humans. By controlling the density of the moist, they control the humidity, visual transparency and temperature. Furthermore, as they argue, humans can drink the building and thus reach another level of interaction with the architecture/environment they inhabit.

From a subtler and less intruding approach to the above environment and architectural construct can be articulated to enforce a particular atmosphere and perception of an environment. Such an approach is visible in the Nordic Pavilion in Venice from 1962 by Norwegian architect Sverre Fehn, who, by placing a double layer of high perpendicular oriented beams, transform the direct and sharp Mediterranean light to the diffuse and soft light of the north. The architectural atmosphere intended becomes, thus, the driver for the distinctive architectural expression of the pavilion, emphasizing once again, that environment can be the primary objective in articulating architectural constructs.

Since the 1960s great advances have been made in computational science. The above example of robotic science takes great use of this development. To make something in a digital setting, but with the intentions of creating for the physical world, ask for a technique that links these two, digital andphysical, together. Simulation of physical phenomena coupled with digital processing enables this and further more rapid design iterations between making and analysis, enabling synthesis.

The summer school project does exactly this, coupling making and analyzing in rapid succession. By simulating light conditions, the designer understands the spatial spreading of light in even complex geometrical organisations in its context of the Utzon Center courtyard before it is constructed. Even small visual design modifications might have a radical effect on how daylight is reflected through the enclosing surface. Another strategy for an environmental architecture is to let the computer suggest material application based on the local climatic conditions. In this manner, the summer school project analyses the amount of solar energy on each surface of the construct and suggest, from this, a colour that will enhance the reflectivity or absorbance of the surface, which, again, result in a change of the perceived light environment of the pavilion.

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## *Performance-Aided Design (PAD)*

Dario Parigi - Assitant Professor, MSc Arch. and Construction,

When looking at the constitutive elements of Jørn Utzon's designs, it is possible to discover and identify at least two original approaches to variation and repetition. The first relate to his awareness on the issues of construction. The repetition of a component becomes the expedient by which complex geometrical and constructional problems can be rationally solved, as in the case of the shells of the Sydney Opera House: the construction of their complex geometry was simplified and rationalized with a brilliant solution that allowed employing only a limited set of standard mass-produced ribs components. The prefabricated components are combined in such a way to achieve a unified form while incremental is at once flexible, economic and organic.

The second relate to his refusal of reductionist approaches: in his design the variation of a component allows to embrace the complexity and the multifarious. Therefore, a structural component can vary its shape and adapt to the states of stresses it is subjected to, as for example the concourse beams of the Sydney Opera House. Its folded plate roof is made of an array of identical beams whose corrugation varies along their span to sustain adequately the prestressing and to be structurally most effective. Among the possible ways to reconsider Utzon's legacy, one can look at those strategies for variation and repetition in the light of the recent development of parametric modeling, computational techniques, digital fabrication and their application in architectural design. Parametric software enable the possibility to explore almost effortlessly infinite geometric variations that can be coupled with performance simulations, optimization and iterative design processes, enriching and potentially infinitely expanding a design space whose roots can be found in much of Utzon's work. These approaches can be translated in a computational environment to Performance-Aided Design (PAD).

### Performance-Aided Design (PAD)

PAD is a term that indicates the shift in the use of CAD tools from a mere translation in a digital environment of the operations once carried on on paper to an evolving paradigm where the increasing integration of parametric tools and performative analysis is changing the way we learn and design. PAD is coined in 2012 during the teaching experiences at the Master of Architecture and Design at Aalborg University.

The aim of PAD is the development of the tools and the understanding required to develop integrated design with respect to form, material, structure and fabrication. Parametric design environment supports the definition of advanced geometry, and the interaction between geometry and structural analysis. Finite Element Method is used as a design tool since the initial stages of design, in order to include structural considerations early in the architectural design process. PAD can be regarded as a new paradigm to, in a short time, achieve an intuitive understanding of the structural behavior of different solutions thanks to the provided tools that enable real-time feedback loops from geometric exploration of forms and performative analysis. The proposed methodology includes the extensive use of feedback loops from exploration of form and structural analysis, and it can be applied to include other performance criteria as acoustic and environmental analysis. The ultimate goal is to enable the possibility to create a synthesis of architectural, structural and acoustic requirement in complex buildings by using parametric design tools that support the definition and control of advanced geometry, digital fabrication and performance analysis.

Following the two above mentioned approaches, a proposal for the summer school theme is formulated. The aim of the summer school is to explore new approaches to design in the line of Utzon´s work, by extending his design principles with the use of computational techniques in a parametric design environment. The summer school should be a hands-on learning environment where theoretical knowledge is coupled with physical and practical assignments related to the design theme.

Construction of complex three dimensional structures can be greatly simplified with the use of elements that can easily be operated by few people without the use of mechanical lifts. Innovative researches in rationalization of construction use optimization strategies to employ short and standardized components for the fabrication of free-form geometries, as in the case of reciprocal structures, where short standardized components can be used to generate potentially infinite variety of complex three dimensional structures (Parigi & Kirkegaard, 2014). The combination of folded plates and reciprocal system is the point of departure to extend the line of Utzon's work with the introduction of computational techniques in a parametric design environment.

## The Reciprocalizer: embedded tectonics

According to the original and approved theme of the summer school, the author developed another iteration of a tool, the "Reciprocalizer" that allows to deal with the complex geometry of reciprocal structures (Parigi & Kirkegaard, 2013).

Reciprocal structures are low-cost and relatively simple in fabrication. It is extremely easy to assemble a reciprocal structure by interlocking, for example, three simple sticks in a closed circuit of forces. However, despite the simplicity and naivety of the joint, the geometry of reciprocal structures is particularly complex to predict and control or, in other words, to design. It cannot be conveniently described neither with available CAD software nor by hierarchical, associative parametric modelers. This can be explained from the fact that, in a reciprocal network of elements, each element position, at the same time, determine and is determined by the position of all the elements in the assembly. Instead, the geometry of the network is a property emerging, bottom-up, from the complex and simultaneous interaction among all the elements in the network. This behaviour

reflect the non-hierarchical nature of reciprocal assemblies both geometrical and structural.
The "Reciprocalizer" is a tool developed to deal with the complex geometry of reciprocal structures. It can be used, for example, to arrange and solve the geometry of a reciprocal network of elements on arbitrary free-form surfaces. The output is the geometric data on the basis of which the joints and the shape of the elements can be further detailed while maintaining the geometric compatibility of elements.
This tool embeds all the necessary data for further shaping the elements' geometry and for detailing the joints and the constructional aspects, with real-time feedback loops. Therefore it enables to:
i) adjust all elements' size, orientation, depth according to a goal performance criteria, for example structural, acoustic, or environmental;
ii) to develop designs that integrate consideration of the assembling and fabrication by embedding the tectonics of the construction in the design process.

Application and conclusions
Here, two examples are provided that show the potential of the tool and its neutrality with respect to the development of original designs.
In the first example, the structure is composed by planar elements whose height is adjusted with a feedback loop with the structural analysis tool in order to improve the overall efficiency and to minimize the use of material (Figure 1). The orientation of the elements can also be adjusted in order to fit to other performance criteria as environmental analysis. Figures 2, 3 and 4 show the same elements with different orientation to increase/decrease the opacity of the structure.
In the second example, the structure is composed with curved interwoven planar elements (Figure 5). Such a shape allows elements to interlock without the need of notches that would weaken the joints. In this solution, the material is efficiently used, and the structure can be assembled with minimum effort.
The "Reciprocalizer" was developed in an attempt to extend the line of Utzon's work with the introduction of computational techniques in a parametric design environment. Inspired by Utzon´s approach to variation and repetition, the aim of the tool is to focus on, and ultimately enable, performative analysis and construction–aware design.

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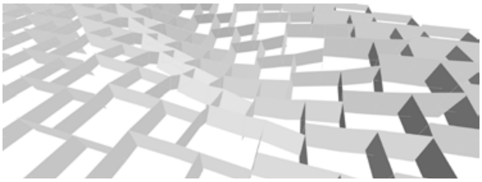

*fig.1*

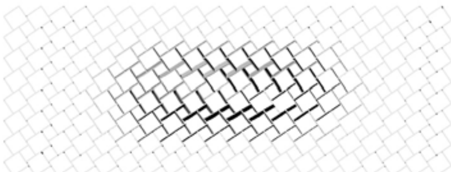

*fig.2*

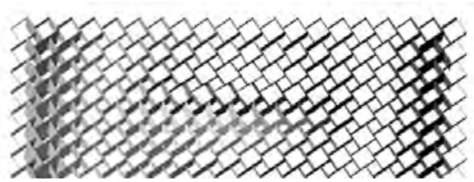

*fig.3*

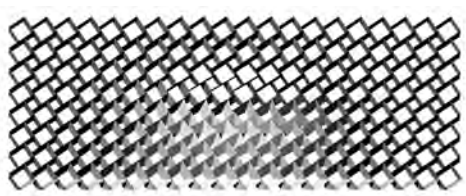

*fig.4*

*fig.5*

## *THE ARCHITECTURE PROJECT*

Christian Veddeler, Associate Director UNStudio, Visiting Professor Staedelschule-Frankfurt

Recent digital developments in today's technological and social reality, redefine conditions of communication, collaboration and production and open up the potential for extensive participation and diversity. At the same time, however, conditions of association, relativity and complexity are introduced. As a necessity, the world has shifted its focus to become sustainably conscious – in the widest sense of the term - physically changing how we live our lives and run our economies. The ever-changing environment in which we architects thrive, calls for architectural agility in order to be able to contend with local and global concerns, while balancing short-term ambitions with long-term goals. In recent times, we have begun to adapt ourselves and to strengthen our role in order to answer critical questions concerning how to approach planning and design and this, in turn, changes the way we think about and shape our future. We do this in order to create an awareness of the motivation of our endeavours and properly manage the tools upon which we heavily depend. Here, open-source thinking seems to favour bottom-up strategies, while still unconventional visionary leadership seems to carry many of today's most flamboyant innovations.

Current Observations

The focus on intellectual initiative challenges current generations of architects to position themselves within the knowledge driven economy of the 21st century; one which is facing increasing competition for productivity, creativity, originality and innovation. Today, we architects have the substantial ability to digitally manipulate form and structure and virtually generate complex geometries with relative ease. As a new generation of designers, we have emerged into a world of seemingly endless possibilities. Consistent computational design strategies and related construction processes have evolved far beyond a previously commonplace infatuation with specific formal manifestations with the result that we are now in a position to ask that the architecture becomes a central focus once again. This focus lies within research and the importance given to the various relational conditions that influence the design and fabrication process and go beyond the "plug and play" scripted environments that we so commonly encounter today. However, we must be systematic and critical in the study of such future setups and involve ourselves conscientiously throughout the process as intellectuals. To take the role of 'the architect in control', we must engage our own critiques in the further development of systems that are materially conscious, deployable, permanent, reactive, adaptive, thoughtful and that are utilising the rapidly evolving tools we have at hand. Today's technological redefinition to the conditions of computationally-assisted design and production, allows for the potential of large-scale differentiation and the introduction of conditions of association, relativity and complexity that an architect for the most part could not wholly comprehend with-

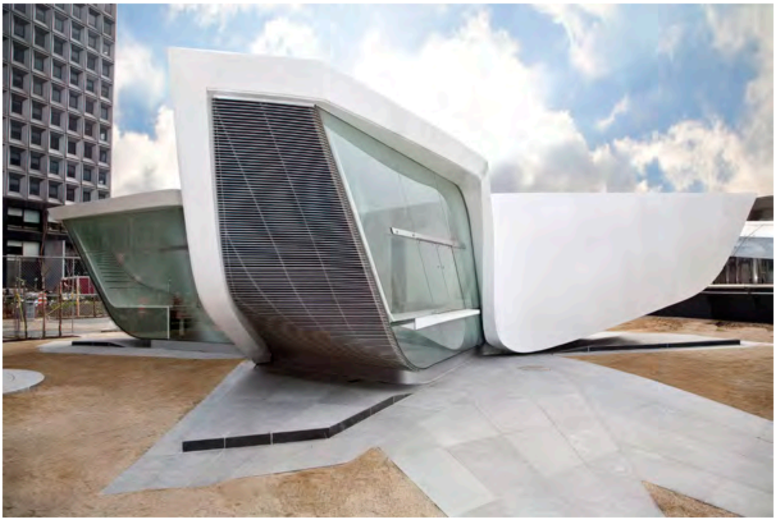

*Photo courtesy of UN Studio - New Amsterdam Pavillion* out the use of these algorithmic aides. Within the relevant discourse, target could, again, be formulated to generate speculative design scenarios for enduring architectures. In alliance with an emerging toolset, new forms of environments can be developed through the logic of rule-based approaches, with specific control and attention to relative parameters. But obviously, as tooling evolves into adaptable design controls, with proper strategy and administration, this approach to design will go well beyond form generation, collaboration, time-saving and bottom-lining into the manipulation of our understanding of the role we architects should, could or would want to have. In his 1970 "Architecture Machine", Nicholas Negroponte describes a future scenario in which architects are no longer needed to take the wheel. Machines, instead of the former protagonist, would act as an "all-purpose artificial design assistant", negating any need for an architect to intervene but to serve only as a conduit for deployment.

## Centre of Attention

Establishing the architectural project as the centre of attention, once again means giving priority to the research of relational conditions which are connected to possible layers of influences within architecture, such as organisation, programming, material, structure, space, atmospheres, etc. These individual aspects are currently perceived as soft, transformable entities with the ability to, eventually, become important through the design process. Information-based analysis, application of digital design techniques and the evaluation of design-steps will form the basis of how to conclude with the formulation of a clear architectural statement that can and will only be orchestrated by the architect. While the potential combinatorial importance of diverse parameters – between analytical research and methodological form generation, between interdependencies of behavior and geometry, between contextual field and elastic object – favours a cyclical rather than linear understanding of a design process. It simultaneously raises questions about the production of merely formal inventions. In 1964, Bernard Rudofsky wrote about the vernaculars of architecture and described this progression of design typology as "Architecture Without Architects". In fact, to develop a design ideology that is future-proof is to do just the opposite; it is to go beyond pedigreed design and to maintain, understand, and control all bottom-up and top-down strategies and to create an Architecture with Architects, particularly through the conduction of computational approaches. Not only can intricate form be generated with specific control and attention to relative parameters, but on all scales, attendant formal structures and organisation will be further resolved in a relational context and, thereby, helping to overcome many former design limitations that only the architect can emphasise. Only in our abilities to understand and evaluate, architecture can critically be revisited.

Responsibilities

With this approach, a precise understanding, not merely of how architecture appears, but also of how it operates, –becomes essential to the design process. This inherent principle of relativity will oppose the understanding of stasis and idealisation of type, for example. As form is seen to be the result of geometrical prescription, the precise control of geometrical conditions in relation to challenges of structure, function and skin is the key to the expression of any architect. Our responsibility, as architects, is to use technological advancements in the field and adapt our techniques and processes in order to develop an idea of new and adaptable systems that will prepare us for deviations in our environments. By doing so, we place ourselves in a position to orchestrate and optimise the vast amount of information that both challenge our approach and suggests solutions for a future condition.

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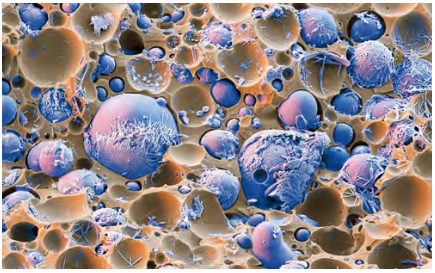
## *The Age of Designed Materials*

Kasper Guldager Jørgensen, Partner in 3XN and Director of GXN

The word design is mainly associated with the design of objects – that is, external objects that relate to the human scale. In the world of materials, design is something internal. The development of production methods on the micro scale has led to far greater control of how we design and construct new materials - a kind of design mainly invisible to the eye. Through time the ages of civilization have typically been named after the materials we have used: stone, bronze, iron. Today the silicon of the computer might be a candidate for such a nominator, but the world is no longer dominated by just one material; there are many different, and the combinations they permit are particularly interesting. New materials are very much a matter of new scientific knowledge. The volume of research in the world of biology, physics and chemistry doubles every ten months – a rate of development that remarkably parallels that of the development of computing power. The materials of the future are already a reality. They exist in many of the products we use in our everyday life, and they can help us to find answers to many of the challenges we face in the development of sustainable design.
The question is not which material you want to choose, but which properties are desirable for the specific job. Ultimately, the periodic table of elements defines our building blocks. The following two sections describe two of the most fascinating material groups: the intelligent materials and the materials of nanotechnology.

Intelligent materials
The intelligent materials are also called responsive materials, because they react to external stimuli such as changes in temperature, pressure, movement, electricity, radia¬tion and the action of chemicals. This means they can change form, structure, colour or generate energy in accordance with the conditions around them, which opens up a brand new understanding of materials where they can interact directly with the architecture and the users. Conventional materials are static. Usually their function is to withstand external influences such as pressure, tension and temperature effects. Smart (or intelligent) materials are dynamic, since they react to external influences. This is a fundamental difference that inspires new thinking about the use of materials. Instead of building passive constructions and climate screens as hitherto, we can use intelligent materials for dynamic buildings, where functions and information can in principle be installed anywhere; intelligent systems with the scope to adapt to the users. Houses that react to changes in temperature and light, or constructions that can reinforce themselves at peak loads, for example during storms and earthquakes Intelligent materials already exist to a great extent in our everyday life. Many products contain monitoring or responsive functions – for examples windows that tone down harsh sunlight, surfaces that change colour at different temperatures, or windows



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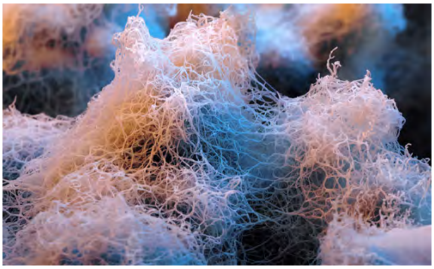

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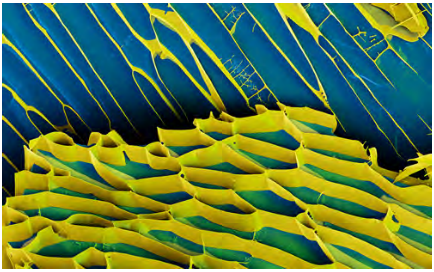

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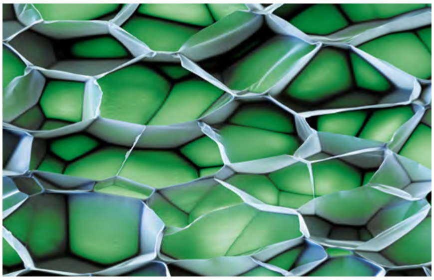

insulation material,
design chemistry by basf

that are temperature-sensitive and open and close automatically. At the overall level there are two categories of intelligent materials: property-changing materials and energy-exchanging materials. Let us look a little closer at the two groups.

### Property-changing materials

Intelligent materials that change in response to a changed context – chemical, mechanical, optical, electrical, magnetic, or changes in temperature – are called property-changing materials. They can be divided into a number of sub-groups, including: Chromatic materials, which are a group of smart materials that inevitably fascinate any designer because of their ability to change their optical properties and thus change colour. They are used to indicate changes in light, heat, pressure, aci¬dity and electricity. For example a thermochromatic coffee cup changes colour when it is filled with hot coffee, and an electrochromatic window can be dimmed by running a current through it. Phase-changing materials, which are able to store and release large quan¬tities of energy. They change between solid and liquid form with shifts in pressure or temperature. These processes are reversible, which means that phase-changing materials can undergo infinitely many phase shifts without degenerating. There are for example microcapsules with phase-changing materials that can be calibrated to store and release energy at room temperature. Electroactive materials are either polymers or metallic materials that are woven into textiles, making them electrically conductive. With the increasing use of electronic equipment in our time, current-carrying materials are particularly interes¬ting.

### Energy-exchanging materials

Intelligent materials that transform energy from one state to another to start a process or change form are called energy-exchanging materials. They function with the aid of an external control. Luminescent materials light up when they absorb energy – a phenomenon known for example from natural phosphorescence. Many properties, including the colour of light, can be adjusted for the desired purpose. The use of photoluminescent or electroluminescent materials can make things luminous. We know this from among other things diving lights and organic LED light, which is said to be the light source of the future. Piezoelectric crystals react by creating an electrical current when they are affected by mechanical forces. This effect is reversible. If an electric current is applied to such crystals they change form. Piezoelectric materials are therefore used as sensors and actuators. In the architectural perspective kinetic energy from wind and humans can be converted into light, mechanical cooling or other energy-requiring functions. Materials with 'shape memory' are either metals or polymers. It is characteristic of both groups that they return to their original form or geometry after a defor¬ma¬tion. For example a suture has been developed for surgical operations that ties a knot in itself. If the thread is tied around a blood vessel and actuated by body heat it goes back to its original form.

*In the further development of systems that are materially conscious, deployable, permanent, reactive, adaptive, thoughtful and that are utilising the rapidly evolving tools we have at hand for us, to take the role of 'the architect in control'*
*(Christian Veddeler)*

*Utzon(x) 2013 - Tetraleaf , Photo credit: Isak Worre Foged*

Utzon(x) 2013:Tetraleaf

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