From Natur(e) to Architectural Matter

Responsive Shading System

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Abstract. The short abstract text should be a couple of paragraphs long, and not longer than 10-11 lines {Abstract}.

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Introduction

From the mid XX century, we have seen an increasing interest in exploring a building capacity of changing, of dynamically and automatically responding to the internal and external environments and to different patterns of use. These ideas found its basis on reciprocal relationships between users, spaces and environment. This means that these three factors have direct consequences on each other, affecting reactions, sensations, configuration and even behaviour. The main idea behind this theory is not new; what has changed are the means through which those relationships interact – technology and materials science (Kolarevic, 2014).

In 1962 James Ballard, a British novelist, described a 'psychotropic house' as a mood sensitive house that responds and learns from its occupants. The house was made of a new material called plastex – a combination of plaster and latex – that enabled it to change its configuration and form. Equipped with sensor cells, the 'psychotropic house' could interpret its occupant's mood and position, in a way that could change its configuration and environment, fulfilling the needs of the users (Ballard, 2001). In the same decade, Gordon Pask starts setting the foundations for the interactive environments with his 'Conversation Theory' concept based on his Cybernetics knowledge - control processes in electronic, mechanical, and biological systems. This 'Conversation Theory' grew up from his work in the cybernetics fields, where he conceived human-machine interaction as a form of conversation, a dynamic process in which the participants learn about each other. Influenced by Pask theories, Cedric Price and Nicholas Negroponte developed their own research field. Price adopted the cybernetic principles and worked on the 'anticipatory architecture' developing the Fun Palace, an unbuilt 1962 design project for a flexible, open-plan structure that has influenced Rogers and Piano's Pompidou centre in Paris; he further developed his ideas with the 'generator projects' that were a reflex of his research field – time and movement in architecture [1]. Price was probably the first architect questioning and expressing publicly his concerns and thoughts about the component of time as an essential and forgotten factor in architecture. Later in 1975 Negroponte start working in 'architecture machines', incorporating the computational potential into buildings, developing several concepts such evolutionary mechanisms and augmented and assisted reality. At the same time, Charles Eastman was working in the reciprocity and feedback-loop between spaces and user. Eastman came up with a thought that automated systems could control buildings responses. In 1987, Jean Nouvel has completed the Institut du Monde Arabe in Paris, building the first large scale building with an adaptive envelope (Kolarevic & Parlac, 2015).

In 'Flexible: Architecture that responds to change', Robert Kronenburg (2007) argues that for a building to be flexible, it must be capable of: (I) Adaptation – responding to several functions, uses and requirements; (II) Transformation – being capable of alterations of shape, volume, form and appearance; (III) Movability and (IV) Interaction – internal and external to the building. This flexible capacity is induced by environmental factors.

But to get to the ground breaking ecological architecture, we still need to answer some fundamental questions, related to morphological change and time and its correspondent dimension in the architectural field. As Kolarevic has stated in Alive: Advancements in Adaptive Architecture, we need to look after the mechatronics, and understand what change means in architecture, how does it evolve and how could it be expressed. Climate responsive buildings, adaptive skins, spatial program readjustments, reprogrammable systems are all features that may be at stake. The concept is about architecture as one integrated entity, software and hardware working as one single organism, a unique system. These conceptual thoughts lead us to questioning what kind of changes can/should a building undergo? Is it necessary? At what scale? At which velocity should it occur? Is it useful?

Nowadays, designers are increasingly incorporating innovating sensing, control and actuation in their constructions, creating kinetic and adaptive responsive spaces; does this mean that more basic forms of interactions are being underestimated? Is it possible that simple mechanisms using some wheels, bearings and hinges assure the flexibility of the built environment? This kind of low-tech mechanisms could improve and create potent space transformations without the need and costs of sophisticated engines and mechanics. For instance, buildings used to have adaptive facades with hinged and louvered shutters fixed outside the windows for protection, privacy and for shading control. This kind of simple solution still has its applicability in today's architecture providing user-control and adaptability to the building.

General Scope

Bio Architecture – Biomimicry and Biomimetic-based Design

Biomimicry is a keygen for this new rising architectural design processes. In nature, all types of performance-based processes may be found. Neri Oxman (2010) explores in her PhD thesis several natural performance-based processes applying them to different materials and functions. Supported by morphogenesis, she proved to be possible, with new digital design parametric tools, to reproduce nature structural performance. Introducing VPD (Variable Properties of Design) Oxman proved a valuable issue: Form, material and structure emerge simultaneously. Totally inspired in nature's production systems, the generative design processes based on biological elements enable designers to rethink the architectural design process as a complete and intricate system. Instead of seeking for a certain pictorial output, the result of architectural design may also be a direct consequence of the physical properties of matter in response to performance requirements. This makes the case for a real integration between idea and realization.

Although this generative processes have been emerging more consistently during the last decade, architecture had already tried to use nature as a reference model. But compositions appeared fragile and as pure homothetic results. Material morphogenesis can originate architectural structure, materiality, density, volume and appearance.

Understanding why and how materials provide the necessary knowledge to build efficiently strongly contributes to more adequate design answers to each type of environments and inhabitants, without any kind of superfluous material usage. Morphogenesis understanding is the key for supporting form generation by matching material properties and performance requirements.

Related work

Biological organisms have evolved multiple variations of form that should not be thought of as separate from their structure and material properties. Structural and morphological properties collaborate to create what is ultimately a material, and then what may be called form. The self-organization of biological material systems is a dynamic process that occurs over time and produces the capacity for inducing change in the order and structure of a system, modifying its behaviour and performance (Kauffman, 1993).

Passive systems - such as those observed in nature to perform feedback between structural forces and form - create new questions and potentials to rethink architectural systems and bodies (de Oliveira et al. 2016).

One iconic experience is the ‘Hygroskin - The Hygroscopic Envelope Prototype’ mobile pavilion designed by Achim Mengues, Oliver Krieg and Steffen Reichert (Figure 1a). This building envelope makes use of the hygroscopic-related expansion properties of wood, coupled with the restriction imposed to this expansion by a polymeric material. This combination creates a self-adjusted structure producing an opened or closed status, based on the environmental relative humidity. The change in the system occurs silently and without the need for any other energy stimulus, regulating air (and light) in its interior (Zuluaga, et al, 2013).

'Bloom' installation by Doris Sung at the University of the California (Figure 1b) is a sun--tracking instrument indexing time and temperature. "Bloom" stitches together material experimentation, structural innovation and computational form/pattern making into an environmentally responsive installation. The form's responsive surface is made out of 14,000 different smart thermal bimetal tiles. Each individual piece automatically curls over a specific angle when the outdoor ambient temperature rises above 21 ºC or when the sun focuses the surface [2].

Soma's 'One Ocean' pavillion, embodied the South Korea Expo's theme *The living Ocean and Coast* (Figure 1c). The facade consists of 108 kinetic glass fiber reinforced polymer (GFRP) lamellas. The lamellas are moved by actuators on both the upper and lower edge of the GFRP blade, which induce compression forces to create the complex elastic deformation. Each lamella can be addressed individually within a specific logic of movement to show different choreographies and operation modes. Upper and lower motors often work with opposite power requirements (driving – braking). Therefore, generated energy can be fed back into the local system to save energy.

The material performance of the biomimetic lamellas produces an interrelated effect of geometry, movement and light: The longer the single lamella – the wider the angle of opening – the bigger the area affected by light [3].

Figure 1
From Left to Right: (a) Hygroskin - The Hygroscopic Envelope Prototype [4]; (b) 'Bloom' installation [5]; (c) Soma's 'One Ocean' pavillion [6]

The project

Context

Probably, one of the most efficient and comfortable shading systems on the planet are the ones that are provided by trees. Their complex structure, composed by several layers of leaf's, sustained by a hierarchy of branches, produce one of the most beautiful and efficient shading systems generated by nature. Under a tree, inhabitants may experience the sensation of filtered light, moderated breezes and still have the sensation of protection.

Using the natural trees shading and ventilation capacities of providing exterior shelter and coverage to its inhabitants as a fundamental example, this research aims to develop a methodology of design, using parametric tools, virtual simulations for environmental comfort and control and digital fabrication resources to produce a 1:1 scale shading system prototype.

Objectives

The defined goal for this research was to develop the design process of a passive control shading system, integrating tree shadows sensorial properties, material properties (in terms of opportunities and constraints) and site specific climatic characteristics.

Methodology

The methodology used to develop the passive shading system encompass four stages: the first stage was to collect not only a survey of types of tree shadows but also to gathering sensorial testimonies of shading experiences; the second stage was to develop a parametric design strategy that could allow for the geometrical configuration and re-configuration within the scope of different architectural, climatic and functional conditions; the third stage was to design a 3D structure that could accommodate different types of solar orientation; the fourth stage of this methodology was to confront the designed solution with virtual sun path analysis, confronting structure, solar orientation, pattern density and (re)configuration with real environmental data from a specific location.

1. Stage 01: Sun path and shading survey

More than an enjoyment of nature's esthetic variety, the population of public spaces with trees satisfies the instinctive need for protection. Trees also contribute much to the immediate physical environment, reducing secundary air-borne noise, securing visual privacy and reducing the glare effects. Moreover, trees also lead to a phenomenal thermal performance in the protected/shaded environment. In the winter, evergreen windbreaks, they can reduce the heat loss and in the summer leaves can absorb radiation, generating shadows and humidity. (Olgyay, 2015).

Several types of shading examples were considered, and registered (Figure2).

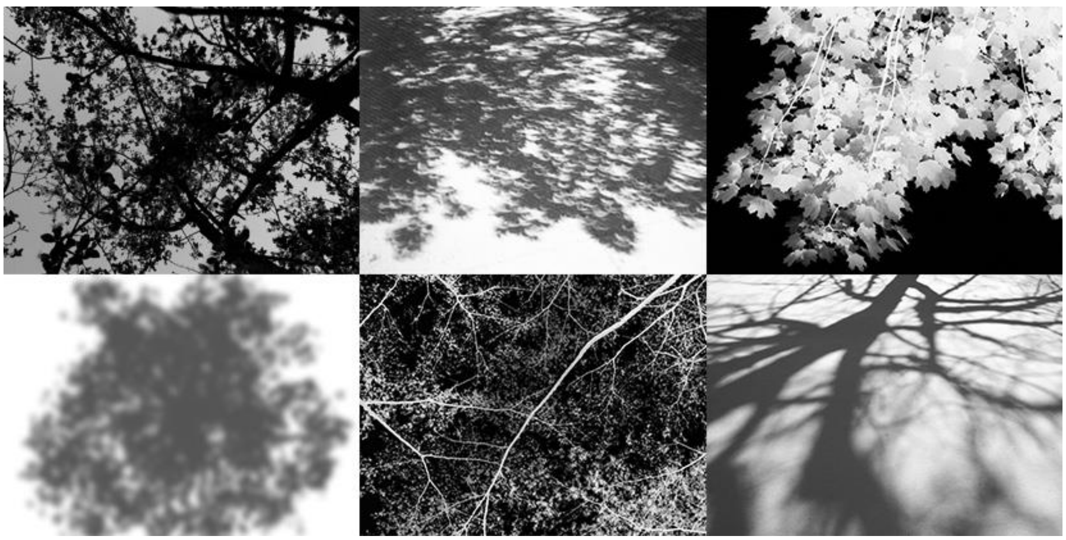

Figure 2

Tree shade survey (from left to right, top down: 1, 2, 3, 5 and 6 - images produced by the authors; 4 - extracted from: http://www.dundjinni.com/forums/uploads/Bludragn/387_TreeShadow01_Blu.png.

More than a photoghrafic survey, we have catalogued an environmental and sensorial survey. Season, sun orientation, surrounding architecture, type of leaves and their size and type of crown - shape and shadow effects. For our research it was important to understand wich type of shade could be more expressive when applied in different directions - mostly horizontal or verticallly.

2. Stage 02: Parametric design strategy

The first step for the system creation is to establish a frame that will determine the size of the panel and the origin of the pattern that will influence directly not only the geometry, but also the thermal permeability and filtering properties.

Using VPL (Visual Programming Language) two domains were constructed. A general domain starting 0,0 and ending 1,0 divided in ten equal segments and an image domain based on the gray gradient levels of the base image. These two domains converge into a dispatch process that will perform two target lists. This process provides us the center of a circular form.

Enabling a variable circular population density, we could essay several combinations of permeability. The start point was to consider three panels with same dimensions and same material properties. The panels run in three different rails, enabling three different and distinct moments of permeability (Figure 3).

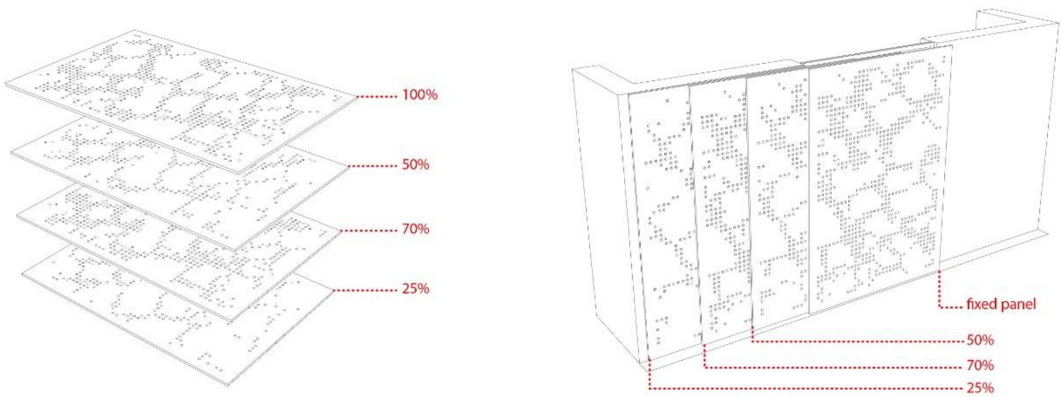

Figure 3
3D Simulation of the three rail system.

The first critical issue that was identified was the moment of change of the different panels because the transition was always unnatural and forced, imposing a mechanic order and not the natural order of transition of the gradual natural shading. The second relevant issue was the space needed when the panels are not in front of the window; this solution requires a storage area equivalent to the window area. Another problem associated to this solution was the intensive heating air layers between the panels, achieving extreme values.

Assuming the need for improvement, we needed to engage in a new task which was to define a system that could provide the effect of the three shading panels in one unique panel and with no need for additional space storage. This demand led us into a two-panel solution (Figure 4).

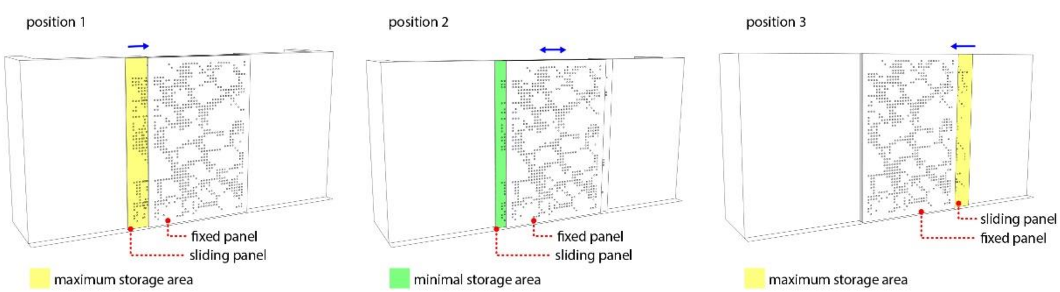

Figure 4
3D virtual essays - movement pattern and vertical aplication.

One fixed panel, that represented the full potential exposure and a secondary panel that combined the three moments of exposure - the cycle initiates at 100% of the exposure (using the full openings of the main panel) and passing to the 50% and to the 25% of exposure.

3. Stage 03: Virtual prototype

The intention is to develop a self-supporting shading structure. Made of recycled material panels, triangular-based geometry, the structure is intended to test the shading effects at a 1:1 scale.

The structure will consider three testing panels, all with different solar orientation: two vertical façade simulation panels, one oriented northeast and other oriented south; the third panel is working horizontally (Figure 5).

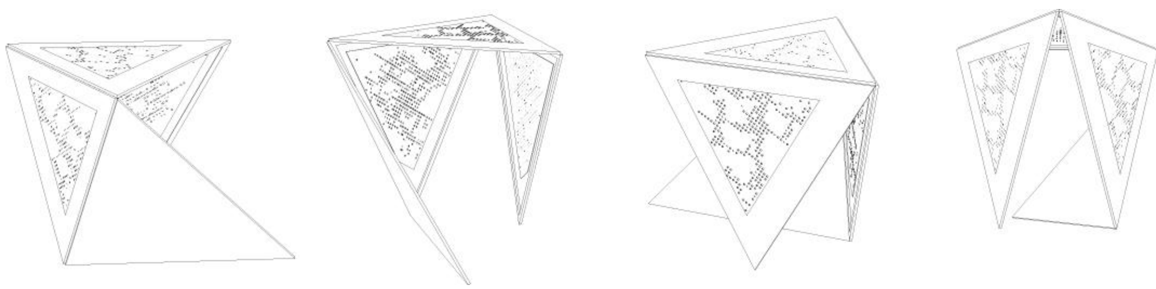

Figure 5
3D Prototype Visualization.

The created system consists of a two panels-sliding system. The main panel has a fixed number of light openings, while the secondary panel works below the main one, allowing for a combination of three moments of light openings. The secondary panel will slide during the daylight exposure adapting to the exterior environment daylight.

To define and optimize the size and material of the structure, the type of movement of the sliding panel had to be defined. This movement is performed diagonally, to optimize and diminish the hidden areas of the secondary panel. As we are considering a triangular shape combined with a diagonal movement, the frame effect happens to be unequal for the three sides.

4. Stage 04: Virtual simulations and shading analysis

Having the virtual prototype defined, the challenge was to simulate the sun path on and through the panels. Using Ladybug, a Grasshopper plug-in, we could inform our prototype model and optimize the patterns on each panel.

The experiences were informed by the Lisbon .EPW weather file, focusing on the equinoxes and solstices dates of the current year. The considered hours were between the 11h00 and 15h00, being this the period of the day with the greater variation of solar angle, azimuth and intensity (Figure 6).

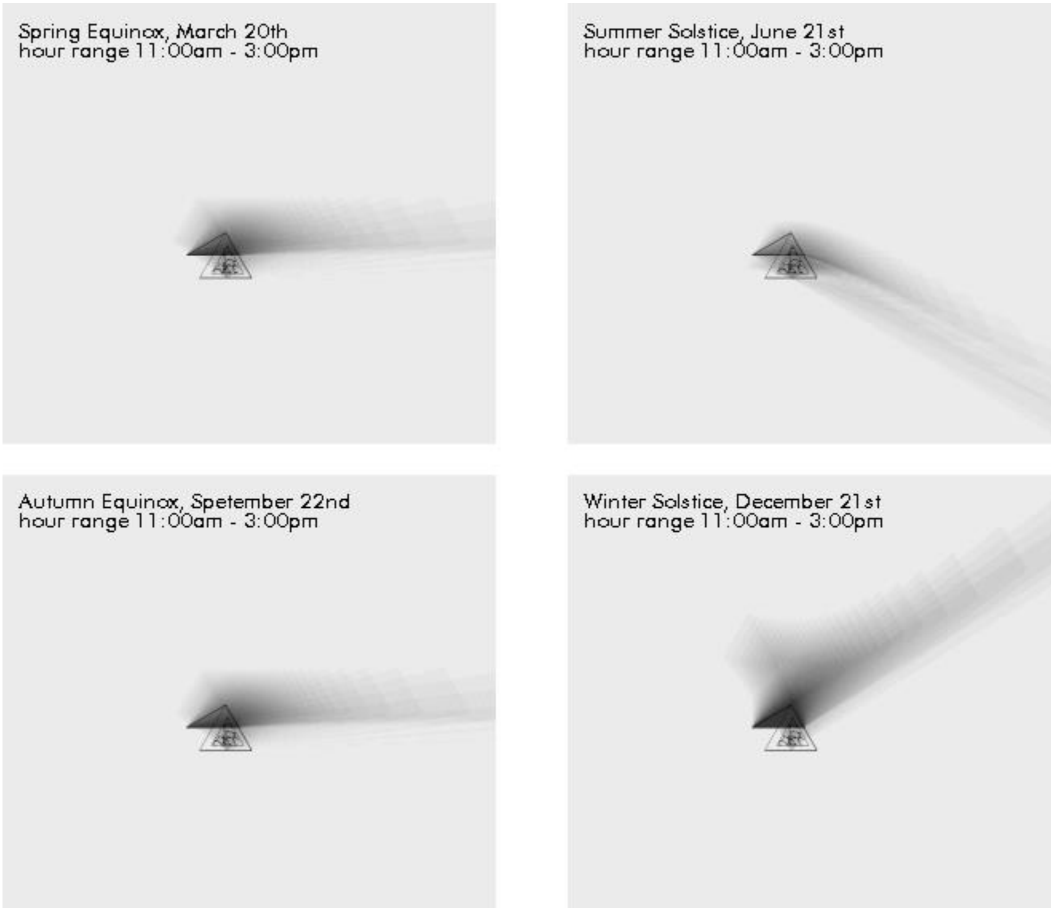

Figure 6
Sunlight hour analysis. Ladybug virtual simulations.

Analyzing the shadow diagrams, it was not only possible to recognize the different areas of shading during the defined period (11h00am-3:00pm) on the different selected days (Solstice and Equinox days of de year 2017), but also to visualize the intensity, the shapes and the influence areas of the resulting shadow on the surrounding environment. Not being a surprise, the northeast side of the structure are the one that registers the most intense and permanent shading moments. Although during the Summer Solstice the effect is reduced, in consequence of the higher focuses of the sun vectors and by the density of openings of the panel pattern.

The horizontal panel seems to have a minor influence on the interior shading system, however its repercussion expresses on the near areas of the system perimeter. To optimize its influence the structure should be implant in a specific surrounding architectural context, its orientation, exposure and shadow influence could redefine the exterior environmental perception and change its habitability.

The south panel are probably the most determinant element of the structure, considering the analyzed sun exposure. The panel drastically influence the sense and perception of the interior system, by generating the most relevant and consequent shading moments in the interior of the installation.

Conclusions and Insights

The design of the virtual prototype is still not closed. The application of nature-based design still needs further improvement. However, comparing with pure geometric patterns, the adaptation and movement of the panels prove to be more versatile, achieving more efficient results. Regarding these simulations, the integration of natural patterns, the two-layer concept and the material properties were essential to achieve a more precise output and even to (re)configure the entire process - from the planning to the design of the pattern, from the concept of apparent random layers of leaves to a nonlinear sliding panel system, from an apparent unbalanced structure to a progressively better integration.

Shading simulation is a very sensitive task to accomplish. The number of properties and characteristics to explore could be many, starting with geometry pattern variations, material physical properties, environmental constraints and human behavior.

To prepare the physical construction of the prototype, there's still more virtual simulations to run. The following steps will be to integrate wind data, and comfort temperature, and to test the structure strength and the shading system efficiency.

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