Additive Manufacturing in facades
Sun shadings on demand

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Additive Manufacturing in façade design

Sun shadings on demand!

ENERGY PROBLEM
Daylight control through Building Envelope

Availability of glazing, heating-cooling systems and artificial light (32% of energy consumption worldwide) result in the oversizing of the application of passive systems for sun control in design envelope solutions. However these systems are responsible for energy consumption in building sector. In commercial buildings, the energy consumption of the mechanical and lighting systems is among the top energy end-uses according to the Buildings Energy Data Book, Information (DOE 2011) in 2010, cooling, heating and lighting represented 51% of the site electricity consumption in commercial buildings. Cooling and heating represented 16% and 15% and lighting 20% (DOE 2011) respectively. Energy demands depend on the building envelope, and can be reduces with performance oriented façade design.

The load on building services (heating, ventilation and air conditioning - ‘HVAC’) is associated with the efficiency of the envelope, so when the envelope performs sufficiently, the demand of energy for cooling or heating is reducing. Environment and climate change and sustainability issues force professionals mostly in the built environment to design innovative solutions focusing on an adequate level of human thermal comfort in buildings while decreasing energy consumption. So, it is really important that architectural solutions in building design are responsive to the use of passive strategies for thermal comfort in buildings. Thus, design of building envelope, which as we mention before is directly related with energy reduction has to react to solar radiation control having suitable daylight strategies in order to decrease the use of artificial lighting systems, and as a result energy consumption.

The facade represents a thermal and visual border between indoors and outdoors. Therefore, it is responsible for controlling the indoor climate and also, affects the lighting, heating, cooling and ventilation demands and as a result the overall operational energy expense of a building. When it comes to an energy efficient design, the relation between the facade and the above parameters is crucial to understand. Taking into consideration the visual comfort of a façade, shading plays a critical role, because it is related with the amount of heat and light entering the room. A building façade is a technical challenge because it combines many functions, however this research focuses in the scope of daylight and shading.

“Daylighting is the use of light from the sun and sky to complement or replace electric light.” (O’Connor, 1997)

As far as this definition is concerned, the importance of daylighting in the context of operational energy can be asserted through a reduction of the energy demand for artificial lighting. Lighting and its associated cooling energy use constitute 30 to 40% of a commercial building’s total energy use in average. (O’Connor, 1997) Hence, by using efficiently the natural light, both annual operating and mechanical system costs can be decreased considerably. As the penetration depth of natural light is limited to a certain distance from the façade, the possibility of daylighting depends on the shape of the construction-geometry of the window and the sunshade.
SHADING

Regarding the above, the façade needs to deal with conflicting demands as solar heat gains on one hand and daylight access on the other. Thus, the façades transmittance of solar energy has to be flexible. This adaptability can be achieved with the application of sun protection, exterior or interior shading. **Incorporate shading elements with windows.**

“Shading devices perform triple duty: they keep out the sun's heat, block uncomfortable direct sun, and soften harsh daylight contrasts.” (O’Connor, 1997)

So façade has to be adaptive to external changing conditions. This adaptivity raises from basic shading systems – eg. simple venetian blinds– or technically sophisticated – eg. by using integrated mechanisms or smart materials.

There are several projects of kinetic facades that tries to regulate sun light, shading and as a result heating-cooling load. Kinetic facades consist of dynamic systems. Dynamic are characterized all the systems that can adjust in height or rotate, slide, open, fold/unfold, stretch, change in position or dimensions, in order to control the daylight entry into the building. Such systems are: venetian blinds, curtains, sliding shutters, opening shutters, rolling textiles, stretchable textiles, tensioned fabric systems, awnings, rotating panels, folding and unfolding devices etc. All these shading devices can be manipulated manually or mechanically to adjust the sun angles of the different hours of the day or the different seasons of the year. However dynamic systems consist of a lot of motors and gears that need maintenance and a high amount of energy to achieve the motion.

On the other hand, static shading devices are easy to maintain, not needing energy to work, however they are not adjustable in climate conditions. Esplanade theatre in Singapore consists of 7,139 aluminium sun shields with an optimized shape in order to be efficient regarding the different sun angles. However this kind of approach in fixed sun shields has an important disadvantage during the fabrication process as it is very time and cost consuming to fabricate costumised objects with traditional techniques.

So, what if we take advantage of a new fabrication method to customize shading devices? Additive manufacturing is this new fabrication method that allows the uniqueness of each object without affecting the time, cost and complexness during the fabrication process. As much as complicated is the geometry of the object, is the same for the fabrication technique, since every model of the computer can be directly fabricated, no matter if it has a different shape. The cost of transportation and the assembling process of the pieces is eliminated as it is a process from the file to the factory, one can download the file and fabricate the object directly in 3d dimensions!

ADDITIVE MANUFACTURING

“A new digital revolution is coming, this time in fabrication. It comes through communication and computation, but now what is being programmed is the physical world rather than the virtual one. Digital fabrication will allow individuals to design and produce touchable objects on demand, when and where they want them. Widespread access to these technologies will challenge traditional models of business, and education. This revolution is the ability to turn data into things and things into data.” (Gershenfeld 2012)

“Additive Manufacturing is the official name of 3d printing which is any of several processes to produce a three-dimensional object”. (Excell, J 2010) The technique used in 3d printing is additive pro
cess in which the real object is printed slice by slice on top of each other under computer control. During the process, the printed objects are produced from a 3d printer which is a type of robot. The objects are firstly developed from a 3D model having simple or complicated shapes or geometries. Currently the term has extended to a variety of techniques like extrusion and sintering based processes. So the term has become broader to “Additive manufacturing (AM)” . The Industrial 3D printers use proprietary powdered metals, casting media (e.g. sand), plastics, paper or cartridges, and are used for rapid prototyping.

The common process of Additive manufacturing—from the file to the factory- is simple. First of all, the parts have to be defined digitally in computer aided design software (CAD) and then save the file as a recognizable format (SLT). The next step is transferring the file to the machine, where might some further manipulations have to be done, whereas setting up the printer includes certain settings to be done, like, energy source, layer thickness, timing etc. The building process is almost automated and when it is completed the printed parts have to be removed. Finally, the built objects may be ready to use or may they require additional treatment like cleaning or painting in order to achieve the texture and finishing required.

The applications of AM technologies starting in the 1980s in product development, data visualization, rapid prototyping, and specialized manufacturing whereas during the decades their extension into production (job production, mass production, and distributed manufacturing) has been under development. In the early 2010s Industrial production roles within the metalworking industries (Zelinski P. 2014) achieved significant scale for the first time. Since the start of the 21st century the growth in sales of AM machines increased dramatically and as a result their price has dropped sharply. (Sherman, L. M. 2004) More specifically the cost of 3D printers has dropped significantly since 2010, regarding the fact that machines that used to cost $20,000 now costing less than $1,000. (Bilton N. 2013)

“There are many applications for AM technologies, including architecture, construction (AEC), industrial design, automotive, aerospace, military, engineering, dental and medical industries, biotech (human tissue replacement), fashion, footwear, jewelry, eyewear, education, geographic information systems, food, and many other fields. An additional use being developed is building printing, or using 3D printing to build buildings. This could allow faster construction for lower costs”. (Zolfagharifard E 2014)

As far as a study in distributed manufacturing is concerned (Heather K 2013) additive manufacturing has the potential to become a mass market product giving the opportunity to consumers to save money when it comes to buy common household objects. (Wittbrodt, B. T, 2013) For example, a client might instead of going to a store to buy a brand constructed in a factory he could print it at home from a downloaded 3D model.

“The development of AM is still in the beginning stage, however, AM technologies offer the potential to lastingly change design and construction methods. The change in our way of thinking has long begun: file-to-factory, Building Integrated Modelling (BIM), digital materials are the key words in this ongoing discussion in the day and age of Grasshopper”. (Strauß H 2013)

Everything designed from the paper to the computer can be realized in the future. It is just a matter of time. The new technologies and processes of Additive Manufacturing are progressing very fast, in terms of new materials, sizes of printed objects, production time, accuracy etc. that one can guess that they will be naturally and broadly used in the future in many new sectors, even in the conservative building sector like facades technology.
CUSTOMIZATION

The progress of 3-D printing is related with “customization,” where individuals are invited to contribute to the design process of a brand like jewelry, mobile case, headphones or toys. Since it prints one piece at a time, it can fit the buyer’s identity, geometry, form or preference, and his opinion becomes part of the design and fabrication process. Dissimilar to typical factories, which make massive production of things and so have minimum special orders and set-up costs, 3-D printers create unique objects by carefully placing material layers on top of itself. As Shapeways marketing director Carine Carmy put it to Re/code, “The printer doesn’t care whether it’s 1,000 of one thing or one of 1,000 things.” (Carmy C. 2013) So we are going from the DIY culture (Do it yourself) to the DYO phase (Design your own). The attractiveness of mass-customization, the mass-production of individually customized products, is the potential of manufacturers to decrease costs and gain an advantage in the competitive market.

With additive manufacture people can customize and order products directly. So far, the available goods from 3d printing to the market are not that much, but this fabrication method is promising. It’s establishing a new world of creativity for every consumer, new opportunities for manufacturing, and a new era for entrepreneurs. Right now what happens in the process of the design is that experts are designing, fabricators are producing and the mass is consuming what the others are creating. The revolution of digital fabrication offers the people the opportunity to produce their own things, what they want to use-consume.

Imagine if we give people the tool to customize their own sunshade regarding the shape, the size, the color and even the material they prefer. Then, they can print it to their home or to the fabrication lab of their neighbor. What is next is just adjusting it to their own window frame and probably it works! What relates the fabrication process, on the one hand and the performance oriented design of sun-shading-in this case- on the other hand, is parametric design.

PARAMETRIC ASSOCIATIVE DESIGN

“From the software side, parametric design is the setting up of computable models, composed by objects that are defined by a series of geometric items based on variable parameters.” (Clinici et al, 2008)

These objects can be linked together through a set of relations, which allow adapting the variables anytime during the design process. Thus, it is offering the ability to quickly compose, adjust and estimate different design alternatives and the impact of design choices appears quickly. The opportunity for such parametric modelling is provided by programming interfaces like Grasshopper. “Grasshopper is a graphical algorithm editor tightly integrated with Rhino’s 3-D modelling tools.” (Grasshopper3D) Developed by David Rutten at Robert McNeel & Associates Grasshopper (2011) it is now a prominent modelling tool. One of the potentials of the program is the fact that it allows designers to get used with the concept of parametric or associative design without being professionals in scripting/programming. Instead of using programming languages, it uses an interface where definitions are created by dragging components onto a canvas and connecting them. The components consist of outputs and inputs that can be used to connect other components. The script based software is fast growing to become a potential platform for architects and engineers, to experiment with new ways of representing design concepts, build generative algorithms and explore new shapes and forms. Additional benefit in using. Grasshopper, also, provides analysis and optimization tools for building performance such as daylighting and energy helping designers create an environmentally-responsive architectural design, using mathematical equation for building physics.
PROBLEM STATEMENT

Nowadays, software programs for simulation, analysis, performance oriented design for solar envelope-shading devices aiming to control daylight through the facade. These tools have great potential, not only could they respond to energy use performance but also enhance the building’s skin aesthetic perception. On the other hand manufacturing techniques are directly related with these tools-software and with customized products as it is mentioned before, as they make easier the manufacturing process of totally different parts of the construction. Although these two potentials exist, neither building sector has taken advantage of additive manufacturing potential (“file to factory” approach) so far, nor individuals have the opportunity to customize-personalize their own things related to building sector.

What is missing so far is the exploration of computational-performance design and fabrication in building sector and the tool (“file”) which will permit the average costumer to customize his own object, in this case a sunshade which is responsive for the unique context of his window.

In this research there is an attempt for an old problem which is shading to be solved taking advantage of new design methods and fabrication techniques, Additive manufacturing. This problem is the lack of customized shadings for different contexts, and uses-occasions (temporal use, permanent use) regarding that shading is a dynamic phenomenon.

AIM

This study focuses on exploring the field of additive manufacturing and façade design introducing a tool-interface available for each user giving him the opportunity to design his own sunshade. The performance of the shading is regulating by its geometrical characteristics. So, a direct relation between geometry, fabrication and light control performance is suggested.

Research and development in the fields of architecture and computation design, suggest a pyramidal relation between computation, fabrication and performance. This project tries to connect design with shading performance by taking advantage of new parametric and computational design techniques, and by utilizing additive manufacturing for the final product.
When AM is used as a production technique, the design will become different than when contemporary production techniques are used. There are a wide range of options available for additive manufacturing. Geometric freedom, material properties and the fact that the design is independent on production eliminates a lot of boundary conditions for the design process, however introduces other limitations like materials, limited dimensions, production cost etc. with the current techniques.

The aim of this study is to explore the relation between digital modelling, digital manufacturing and performance through the paradigm of a sunshade.

The specific goal of the study is to use scripting software in facade design, to integrate environmental data and parametric thinking in facade design, and to explore different geometries for efficient and aesthetically pleasant sunshadings for facades. Based on the objectives, the project focuses on developing the design proposal for changeable solar shading in respect to every user’s needs and occasions, in order to create a different aesthetic effect, while being environmentally smart.

The parametric modeling tool can easily generate various different designs with different variables while provides information regarding building performance as result of design parameter updates. This can help to make proper design decision in considering performance optimization.

So this thesis proposes a sunshade “from file to factory”, any client-user can create his own individual sunshade for a specific window. The user-customer will choose one of the specific designs- geometries existing in a tool-interface for every person and then he will adjust its dimensions changing the parameters of the tool regarding his own individual situation. (room dimensions, sun latitude, orientation etc.) Finally he will print the sunshade to his printer or to the laboratory’s printer of his neighbor and he will adjust it to his window. After the development of the interphase this “file” will be used to a specific case study and it will be printed “factory” to the final product.

Digital Fabrication intent to play a significant role in building design, the use of associative design, supported by environmental parametric, material properties and mass customization is opening new ways of work in architecture.

“How could solar control and shade systems be designed to take advantage of the opportunities that digital fabrication brings?” This is a potential path for exploration. (Strauß H 2013)

“This newfound ability to generate construction information directly from design information….is what defines the most profound aspect of much of the contemporary architecture.” (Kolarevic, 2003).

RESEARCH QUESTIONS

-How costumers could become part of the design and fabrication process of a sunshade through parametric design and additive manufacturing?

-What is missing in order to permit people in the future customize-print their own shading for different contexts?

-How could solar control and shade systems be designed to take advantage of the opportunities that digital fabrication brings?

-What is missing in the industry of shadings?
Subquestions

- What are the parameters that affect daylighting control shading in a facade?
- What Additive manufacturing techniques can we use for a sunshading?
- What is the assembling method of a 3d printed sunshade with typical window frames?

This research explores the potential of computational design trying to develop an easy tool-file for every user offering him the opportunity to design his sunshade regarding his needs and then fabricate it with a simple 3d printing method.

METHODOLOGY

1. The first part of the thesis includes literature study and research on digital fabrication, additive manufacturing processes in order to define the limitations of the techniques in respect to materials and dimensions of the final product. Also, literature related to light, light properties, visual comfort and control/shading systems and relevant mechanisms will be studied, in order to define the variables that affect shading.

2. The second part of the research includes the development of the tool-interface and consists of three parts:
   - The first phase of this phase includes the shape generation through parametric design and generic algorithms of several sunshades and screens to form the preliminary boundary conditions.
   - In the second phase the logical framework of the script with other boundary conditions and variables will be developed.
   - The third phase will use parametric tools and genetic algorithm software to produce the script with these variables and boundary conditions which the customer will be able to change regarding his needs and create his own- efficient sunshade.

3. The third part includes the selection of a case study with specific conditions and the application of these conditions to the variables in order to achieve a final design of a sunshade.

4. The fourth part consists of the fabrication process of the final product with different materials and the comparison of them.

5. In the fifth part assembling methods of different materials (metal, plastic) with 3 types of window frames (timber, aluminum, pvc) will be proposed.
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   - Goals
   - Research questions
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   - Visual comfort - Light control: glaring

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   - External shading
   - Horizontal shading
   - Vertical shading
   - Manipulators
   - Special types of shading systems: Screens

Part 2
5. From computational tools to digital fabrication - Procedure

6. Create the tool
   - Define the boundary conditions (design parametrically a number of sunshades and sunscreens with different geometries, limitations of final product regarding the AM process)
   - Define the variables (Room dimensions, window dimensions, window position in the wall, location, orientation)

Part 3
7. Select a specific design and apply it to a case study

8. Examine the performance

Part 4
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Part 5
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LEMONIA KARAGIANNI | GRADUATION REPORT P2
## LEOMIA KARAGIANNI

### GRADUATION REPORT P2

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Literature


Cinici, Akipek, Yazar, (2008) “Computational design, parametric modelling and architectural education” - Yildiz Technical University, Department of Architecture


Heather K (2013). “Study: At-home 3D printing could save consumers “thousands””. CNN.


O’Connor (1997) ’Tips for daylighting with windows” - Berkeley, USA: Ernest Orlando, Lawrence Berkeley National Laboratory, University of California.


ZolfaghariFard E. (2014) “NASA’s plan to build homes on the Moon: Space agency backs 3D print technology which could build base”. TechFlesh

“3D Printer Technology – Animation of layering”. Create It Real.
During the process to define the topic of this thesis several papers about computational design and light performance were studied and literature related with definitions of light, light properties, sun-shading devices etc as well. In this appendix the related literature is listed.

**Regarding computational design** -The importance for integrated conceptual design is increasing due to a number of parameters, like the current global energy crisis. Some of these works suggest methodologies about designing with the daylight and use specific simulation software to prove the results of their design and research. The importance of integrated design is highlighted in all these papers and computation seems to be the tool for this approach to become true. However, other researches do not focus only in the performance approach, which is a method to guess what is the performance of a building in the real world, with the help of related environmental data and parametric thinking. What they do more is constructing prototypes and physical models in order to compare the results of the performance design with the results of the calculations based on measurements of the prototypes in the real world. Several researches about responsive envelopes and intelligent building skins have been, also, studied. Michael Wigginton and Jude Harris in their book Intelligent Skins, mentioning that the word “skin” is not just a metaphor in the building design. They argue that “the building’s envelope can be considered quite literally as a complex membrane capable of energy, material and information exchanges.” (Velikov & Thun, 2012, p. 76). All these studies try to reduce the energy demands of a building through facade design, and to explore, in the same time different geometries for efficient and aesthetically attractive façade modules.

Bader S (2011) ” High-performance façades for commercial buildings” University of Texas, school of architecture


Sharaidin K, Burry J, Salim F “Integration of Digital Simulation Tools With Parametric Designs to Evaluate Kinetic Façades for Daylight Performance” eCAADe 30 - Vol 2 - Simulation, Prediction, and Evaluation pp691-699


El Sheikh M, Gerber D (2011) “Building Skin Intelligence a parametric and algorithmic tool for daylighting performance design integration” acadia 2011 proceedings


Velasco R , Robles D,” Eco-envolventes1: A parametric design approach to generate and evaluate façade configurations for hot and humid climates” Generative and Parametric Design - eCAADe 29 pp 539-548


Regarding definitions of light, light properties, sunshading devices—Le Corbusier wrote in 1923 that “Architecture is the masterly, correct, and magnificent play of masses brought together in light”, this statement raises a constitutional question – Is it possible to design taking into consideration light as a performance parameter?

Light, except from the illumination of the space, carries energy, so it affects the thermal comfort and physiology of buildings and people respectively. Thus, it is crucial for the human metabolism, as the efficiency of people in a working environment is consequential because it benefits them to concentrate and be productive when there is enough daylight. It affects human hormones, controlling the rhythm of night and day. Daylight is a dynamic light source as it changes continuously from day to day, dawn to dusk and from season to season.

“Light is electromagnetic radiation, with those frequencies that it’s able to be seen by the human eye, in general including ultra-violet light and infrared light. Light can be described by its properties. The four basic properties are intensity, wavelength of frequency, polarization and phase.” (L. van Ginkel 2010)

Light consists of the visible spectrum, infrared and ultra-violet light. It has several properties that affect glaring and shading like reflection, refraction and absorption which affect the illuminance of an interior space.

The rules of thumb in relation to façade design define that:

- North facades provide good access to strong illumination but vary throughout the day and require shading.
- South façade provide high-quality, consistent daylight with minima heat gains, but thermal loss occurs on cooler days.
- East-West façade also require shading, but have to take account of lower sun angles”(O’connor et al, 1997)

When it comes to fixed shading devices the most important parameter is the angle under which sun rays hit a surface and it dependents on the orientation of the façade, the moment of the day and the season of the year. Thus, the solar path should be taken into consideration when shading devices are designed in order to define the optimal position and geometry that block sun rays during summer, whereas allow them to enter the building in winter. Regarding the literature, for South windows horizontal devices like awnings and overhangs are recommended, whereas for East and West windows a vertical form should be used.


van Ginkel L (2010) “Rapid Manufacturing in façade design-Case study to an innovative shading device” master thesis for TU Delft university, Netherlands