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Performative Design Optimization for Shading Screens

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Performative Design Optimization for Shading Screens

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Abstract. Building façade plays a significant role in architecture; it is not only a mean to express the design concepts but it is the main moderator between exterior environment and internal spaces. Ecological facades are defined as the ability to response and adapt to the changes of the environmental conditions. The geometry of the proposed screen is not a focal point of this paper, **as the aim is to find a method for designing and evaluating non-conventional solar screens that improve indoor daylight quality**, while the specified shading screen is installed in front of a transparent full floor to ceiling glass facade. It is assumed that by using the shading screen, the required lighting levels are being maintained, while the heat gain is being reduced. In addition, the designed patterns play a role as an architectural feature of the building. Ultimately, **the presented shading screens are based on geometric ornamental patterns and arranged according to the lighting requirements.** Results are indicating a multi-disciplinary approach in the design of the shading screens, which can be employed in creating similar prototypes with different climatic and loading requirements.

1. Introduction

The design process is a set of actions that are taken in a hierarchal order aiming to reach an intended final output based on specific design requirements and objectives [1]. This set of actions is constantly changing through time trying to adapt with uprising design needs and respond to the demands of new design approaches. The design process can be described as an iterative process where a number of dependent or interdependent design tasks are performed in sequence till reaching a desired goal [2]. The effectiveness of this process can be revealed through this loop of action and assessment (activity and reflection) that is highly reliable on the design media. Design tools and techniques used influence the problem representation and how is perceived. Thus, they affect the designers conceptual thinking to develop ideas and reflect upon the results [3].

2.   Generative systems in architectural design

In usual traditional design, the role of the designer is to explore a solution space. The key relationship between designer and product is a direct one 'Figure 1' (even if mediated via a third-party or medium). There is a direct relationship between the designer's intentions and that of the designed product [4].
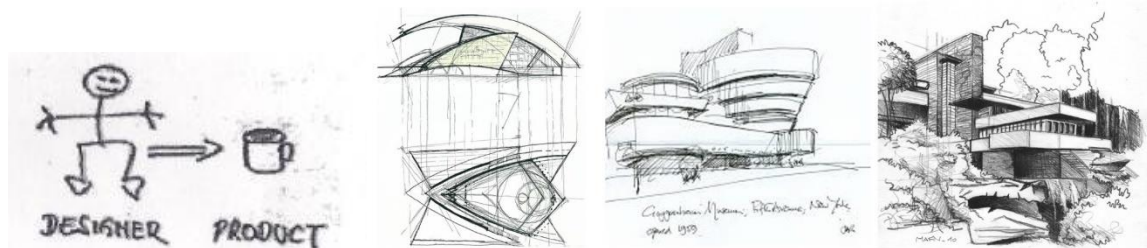

Figure 1. Traditional design approach [4].

In contrast, design using generative methods involves the creation and modification of rules or systems that interact to generate the finished design autonomously 'Figure 2' [5].
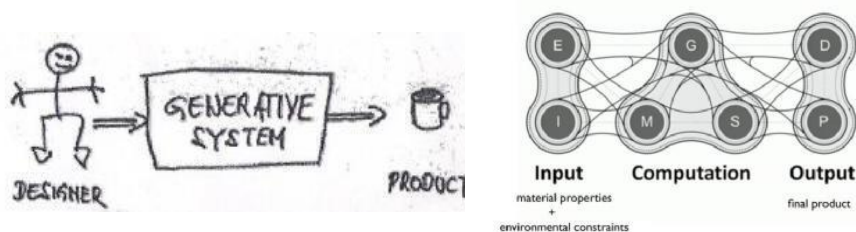

Figure 2. Form generation operation [4] [6].

"Generative design is not about designing a building, it's about designing the system that designs a building." Thus, Generative systems made a major shift in the concept of design modeling from the modelling of a pre-designed "object" to the modelling of the design "logic" [7].

Generally, the generative systems' process is based on four main components: the input parameters, the controlled rule, the output generations and the selection of the optimal solution as shown in 'Figure3'. The design artifact could only be obtained by the fourth phase.
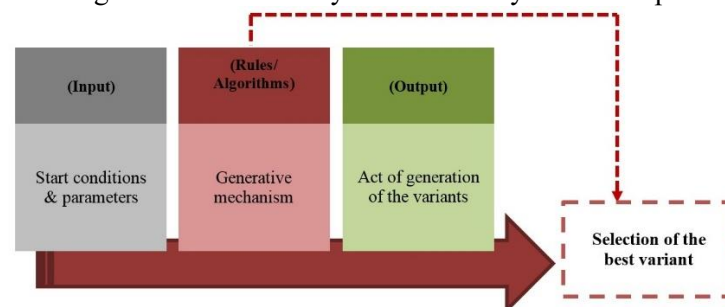

Figure 3. Generative system process
Source; by the researcher

2.1. Generative Performative Design

Performative design is an approach derived from performance models. It amalgamates form generation and performance, considering both through optimization algorithm and simulation technique as shown in 'Figure 4'. No longer are simulation tools utilized for analysis only, but they are used for both performing analysis and synthesis simultaneously; form is driven by generative processes guided by analytical simulation techniques that automatically modify the model [6].
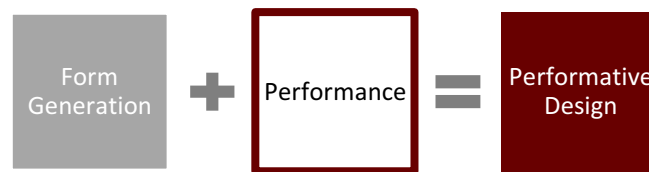
Figure 4. performative design
Source; by the researcher

The concept of form making shifted to be form finding. Geometric models are needed to be formulated in a way that reacting to the stimulus of the evaluation process and complying with the modifications of generative process can be in a consistent manner. Hence, parametric modeling is essential to support the generative process informed by the performance evaluation. It needs three consecutive processes 'Figure 5':
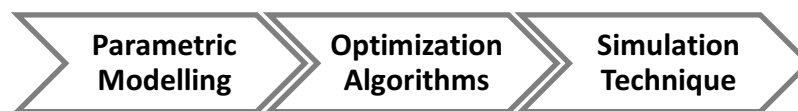
Figure 5. performative design process
Source; by the researcher

On the other hand, generative design captures the aesthetics qualities of the design through a rule-based process that inform the generation of large range of solutions. Combining both models in one approach gives the advantage of reaching the aesthetic quality aspired while respecting the performance criteria needed. This would be through 'Figure 6':

Figure 6. Generative Performative Design process
Source; by the researcher

2.2. Performative design exploration based on parametric aspects

Current CAD and simulation tools only used as a representational tools for the final design case. Conversely, parametric modelling approach allows the modelling of unlimited set of design variations depending on the parametric definition which in turn opens a wide range of possibilities to explore, evaluate and even regenerate the design model to comply with targeted aim 'Figure 7'.
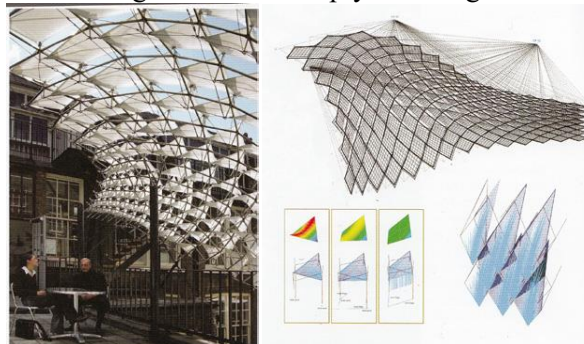
Figure 7. For the "AA Component Membrane", a terrace canopy designed at the Architectural Association, the form was simultaneously optimized for sun, wind, drainage and views using a parametric model combined with various computational analysis techniques including fluid dynamic wind flow analysis, precipitation analysis, stress analysis, and solar analysis [8].

Considering architectural field, performance simulation tools have been widely used to establish early design processes, which are effective as alternative solutions to isolate design problems. However, current simulation tools failed to address novel shading systems and façade designs due to its limitation in modeling and exploring wide range of solutions. Thus, integrating new digital generative systems such as parametric design systems as well as Genetic Algorithms with these simulation tools contributes in raising building performance through offering unlimited alternatives in specific ways that ensuring the simulation process is evaluating the resulted in a comprehensive cycle till reaching the optimal solutions. This paper will focus on the latter case.

3. Movement as performance

It is often the movement of people around and through a building that gives architecture its performative capacity. It is the experience of the building's materiality and spatial presence. In some recent projects, performativity is in the kinetic effects of the architecture. Rather than the subject that moves, the object itself creates an architecture of spectacle and architecture of performance [9] as shown in 'Figure 8'.
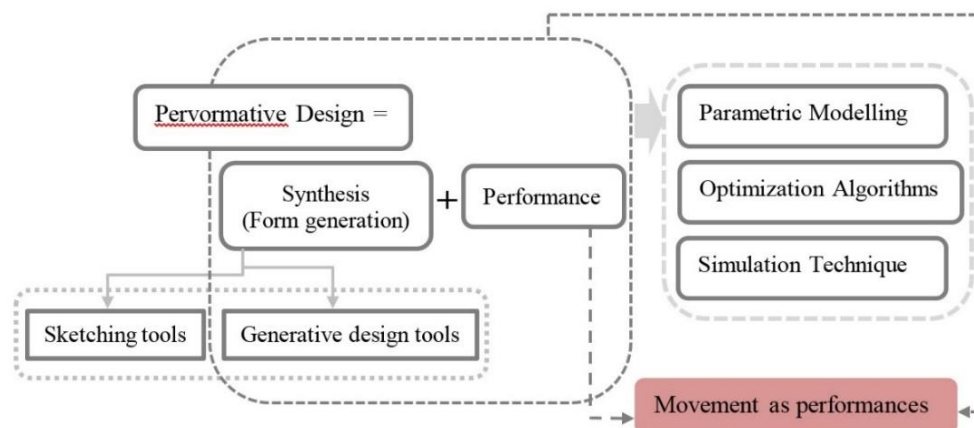

Figure 8. Schematic diagram suggested for approaching the performative design
Source; by the researcher

4. The Concept of Time in Design

Many scientists, also the architects addressed the concept of time as a term that has an impact on all aspects of life. Science until this moment still reveals to us that the time has great importance. This was at the level of physiological influence on human or on his environmental and urban surroundings or on his tools and uses. However, the virtual worlds through the means of communication can jump on the time, crossed the borders and exceeded the distances, and this forces us to understand the impact of time in the world in architecture now [10].

4.1. The importance of the role of Eye in the Design

The eye distinguishes between the types of movement, either dynamic or static in the design [11]. The architectural projects that give the sense of movement, give the design the pleasure and excitement. The movement represents the continuous change in the position of the image, as long as it does not interfere with the function required by the power of formation. The good movement design requires hundreds of the ways to read it, and this factor has a big role in distinguishing between the fertile form and the simple form.

It is the continuous change in a location of the body in relation to a location of another object are assumed it is constant. The movement in architecture 'Figure 9' depends on two main factors: [12]

The first factor: Benefiting from the human perception of dynamism in giving the spirit of movement in the still image, where the movement is only a developing concept to the conscious dynamism. The second factor: It relates to the same form where the dynamism does not use the usual coordinates of design (X, Y, Z), but depends on temporal time coordinates similar to the coordinates of energy [13].
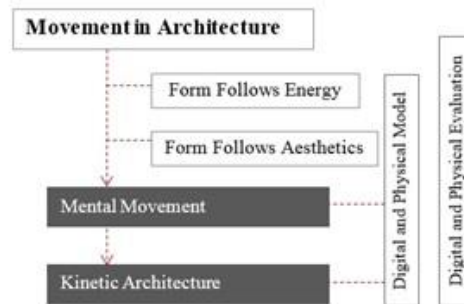

Figure 9. Diagram of action research and investigation
Source; by the researcher

4.2. Kinetic architecture

Kinetic architecture is a type of architecture that includes the concept "movement as performance", while approaching the concept of Adaptive architecture [14]. However, not all Kinetic architecture can be included in Adaptive architecture. Kinetic architecture allows parts of the building's structure to move, without decreasing the overall structure integrity. This skill for motion can be used, not only to improve the building's aesthetic qualities, respond to environmental conditions, but also to add functions that would not be possible in a static structure [15]. This type of architecture existed already in the past, but since the end of the 20th century its presence has increased due to the evolution in the fields of mechanics, robotics and electronics, which, consequentially, promoted more possibilities for the practical implementations of this architecture. Within Kinetic architecture, only the buildings that use movement to adapt to external conditions in order to optimize the energetic costs, can also be classified as Adaptive architecture.

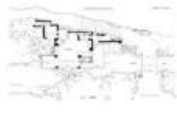**Table 1.** Typological Classification of Kinetic Architecture.
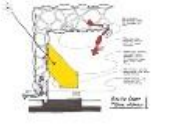
4.3. The mental movement -Dynamic configuration

It exists in all aspects of the perception, represents the idea of movement in a simple and formal manner and what including constant formative relationships resulting from the simulation of

movement and time. There are many potentials and relationships, such as the formation, juxtaposition, overlay, friction, exaggeration, absence as a few of the techniques and potentials used by the architect to express the apparent movement without the existence of time [16]. The main idea of the static movement does not depend on the direct physical movement, but is indirectly represented by the expressive form of the movement that depends on the nature of form, where each shape has values different in its mental movement or in parts of it in the same field [17]. The movement through the stability in design is the dynamic of architectural form of the building means the dazzling with the movement, which simulates the dynamic movement, but at rates lower than the changes resulting from the dynamic movement [18]. Therefore, the line and curved surface of the highest variables that give a continuous change in the building mass and architectural space that includes several components such as the position, direction and size [19]. It is the movement by inspiring through the arrangements of the elements, lines, basic forms and levels of the building to give the sense with the movement.

Table 2. The mental movement in the process of perception "The latent dynamism"

The outer lines of the building	Architectural form including shape and mass	shaping the building	The Composition of the Building Surface	Foldable surfaces
façade configuration	Elements' Distribution	Elements' Size	Elements' Deformation	Shape Grammar	Shape Grammar Structure

Generally, ecology is one branch of environmental science which is more concerned about the available natural resources scattered throughout an environment. Ecological impacts together with economic and social impacts of buildings on their surroundings are the main three principles of sustainable building design. Thus, ecological façade could be defined as the building facade that relates to climate conditions and surrounding environment resources while responding to conflicting needs for heating, cooling, daylight and ventilation.

5. Shading screens
Shading screens have traditionally evolved to control solar penetration in the buildings of the middle-east such as the Mashrabeya 'Figure 10'. Generally, shading screen systems can be considered as an essential integral part of ecological facade systems. They can be used to improve the indoor daylight quality [20].
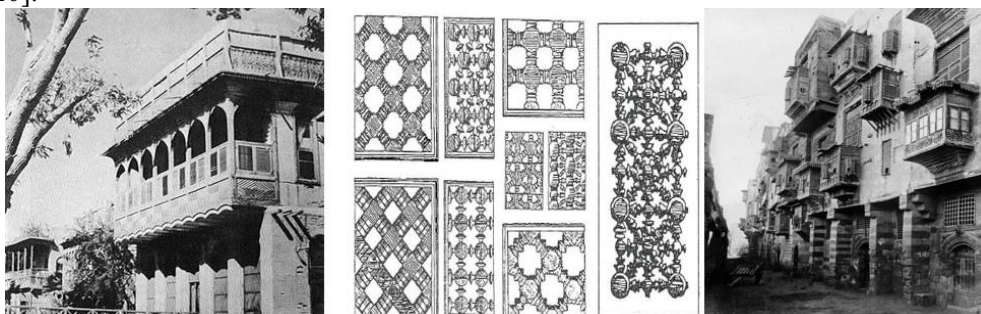

Figure 10. Conventional solar screens

Natural daylighting is desired in building envelopes, however thermal discomfort and the incidence of glare is unwanted [21]. One type of shading system that is used to permit daylight while controlling solar penetration is "shading screens". Shading screens are defined external perforated panels that are fixed in front of windows.

An additional advantage of these screens lies in their provision of privacy, which is a social-cultural need in its original region. During the past decade the traditional patterns of shading screens has been transformed to new patterns, by varying some of the basic mathematical rules like symmetry of the patterns or equal dimension of a replicated geometry. Furthermore, some active solar screens with such patterns has been developed. There is a close connection between the geometric patterns and the design of shading screens which play a role as daylight control systems [22].

Screens became a common and rich architectural device that can separate spaces, while maintaining a certain visual. In contrast to glass, screens have a strong presence and offer the possibility to vary their materials, color, texture, etc. They can assume other functions such as passive shading on facades 'Figure 11'.

Figure 11. Generative Design Systems for Patterns Formation

6. Façade geometry

Pattern was designed and then replicated in the plane. A hexagonal grid 'Figure 12' was the underlying grid of the pattern. After the basic diamond pattern was designed, the diamonds were offset towards inside in order to create apertures. The offset value is dependent on the distance between hexagon's centers and a defined attraction point. This pattern provides the opportunity that the size and ratio of the apertures change, which leads to a change in the perforation ratio of the screen. This ultimately affects the daylight illumination.
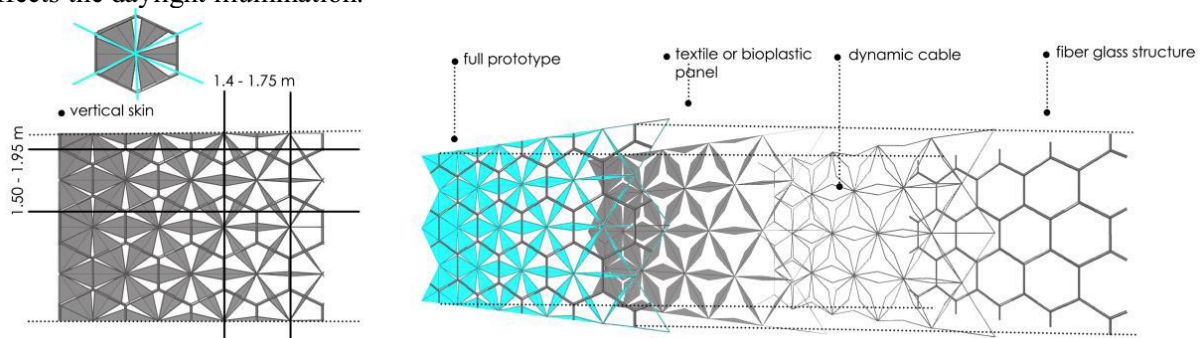

Figure 12. Skin design: a possible development of the skin system for the environmental rehabilitation of buildings.

All configurations have a dynamic surface on the front side of the wall. This provides the opportunity to change the perforation ratio of each module depending on the specific program of the space and the required daylighting levels of that space. On top of this, the screen walls can change their role from shading screen to the main building facade, by placing the glass panes in the apertures instead of adding a layer to the glass envelope.

7. Pilot study

The aim of this study is to offer a simple method that could be embedded within the typical design process of building façade, in order to evaluate and optimize façade daylighting performance during the design process. The proposed method could be applied to different oriented facade to offer a guide line for façade design.

8. Methodology:

To design the geometric patterns, Rhino has been opted as the modelling platform and Grasshopper, which is a parametric modelling plugin for Rhino, has been used. Grasshopper provides the opportunity to parametrically design and then alter the variables, in order to create various iterations of the design downstream as show in 'Figure 13'. By using Rhinoceros and Grasshopper, a model was created for a hypothetical indoor office space of **60** m2 area (6 m (w) x 1**0** m (l) x 4 m (h)). The space is a sidelit space facing the south direction at the ground floor, located in Cairo, Egypt. The designed shading screen is applied to a base case open-plan office space with minimum 500 lux illumination daylighting requirement [23].
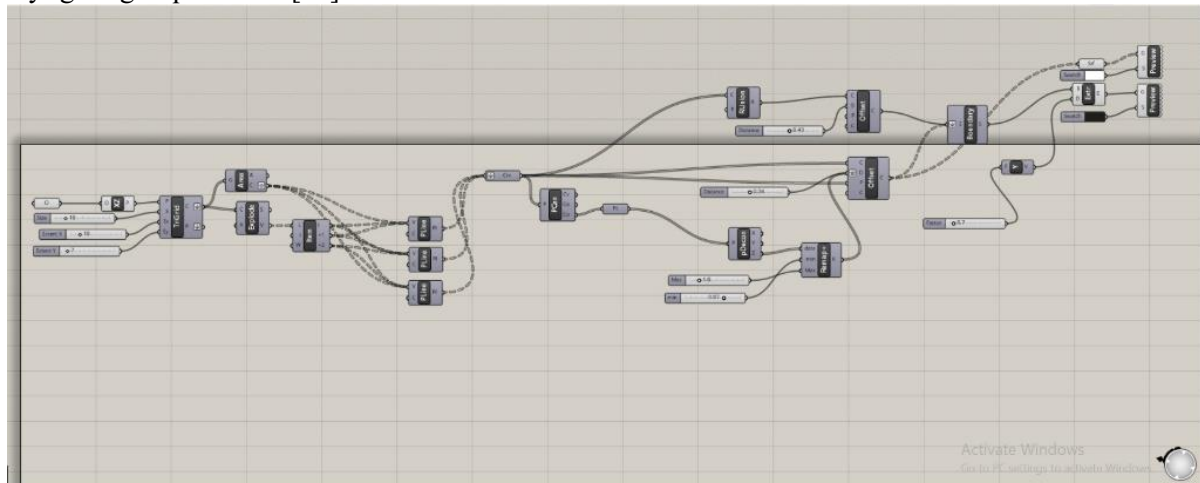

Figure 13. The Modeling Process
Source; by the researcher

Since Rhinoceros has been chosen as the modeling platform, DIVA-for-Rhino, which is a highly optimized daylighting and energy modeling plug-in for Rhino, has been chosen for daylighting simulations. The default DIVA materials have been assigned to the geometry. Year round performance is addressed by using a Dynamic Daylight Performance Metrics (DDPMs). Climate- The "Daylight Autonomy" index (DA) is defined as the percentage of the occupied hours of the year when a minimum illuminance threshold is met by daylight alone.

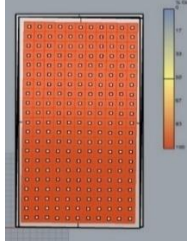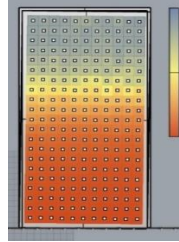**The process will follow two successive stages:**
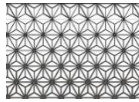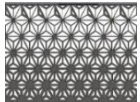
Stage one: this stage will evaluate daylighting performance for the hypothetical space with a mere glass façade.

Stage two: this stage will use optimization process to guide façade design and define the perforation of shading screen that is needed to optimize daylighting uniformity in the space. The aim of this stage is to evaluate the effect of changing the Shading Screen perforation percentage on annual performance, in order to conclude the best perforation percentage.

9. Results

Next table illustrates the four different stages and its results, all three configurations have been simulated and the results have been compared with a base case model with no shading screen as show in (Table 3).

Table 3. Visual daylighting simulation results.

| Case 1 Space with a mere glass façade- no screen. | Case 2 70% perforation | Case 3 50% perforation | Case 4 30% perforation |

Point in time visualizations are included in the table for September 21st 2019 at noon, to better understand the shading effect of each configuration. Case 1 which is the window with no shading screen is included in order to have a base case for comparison. It was expected that as the perforation ratio gets lower, the daylighting performance becomes lower too. Therefore, the decreasing trend in mean daylight autonomy from case 2 (70% perforation) and case 3 (50% perforation) compared to case 4 (30% perforation), can be clearly explained. The optimum solution is using shading screen (70% perforation) that offer 69% daylit.

10. Conclusion

Perfromative design as an important design paradigm in architecture intended mainly to meet building performance requirements. This research looks at a multi-objective performance evaluation of a screen wall, inspired by geometric patterns. The study contributes to the design of screen walls, in order to control daylighting and to provide shading for the buildings. The perforation ratio of each module can differ to accommodate the unique daylighting needs of a specific space.

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