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PARAMETRIC ARCHITECTURE TOOLS AS AN APPROACH TO OPTIMIZE DAYLIGHTING IN OFFICE BUILDINGS

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Abstract

Parametric architecture tools have been used to explore design variations and potential possibilities of architecture forms and patterns. It helps the architect to overcome the limitations of traditional tools of modelling. The computer is no longer used as a tool but rather a partner in the design process. The utilization of computers as design partners should aid architects efficiently simulating their design problems and reaching optimum goals at minimum time. As the world gives increased focus on energy efficiency and occupant comfort, there is now an emerging need to include sustainability–related performance aspects within design, most notably energy and daylighting. More recently, new methodologies have been developed to use daylight simulation as a driven tool for design, which showed the benefits of parametric driven façade to reach maximum daylight quality.

This paper will discuss how to integrate parametric architecture into daylight simulation in order to reach the optimum daylight performance in the building. The research will explain the parametric architecture techniques and tools used in the optimization process. In addition, the research will track parametric driven façade examples and the parametric process used in the optimization process. Parametric modelling tools along with validated environmental analysis tools (Grasshopper and Diva for Rhino) will be used together to achieve the optimum sustainable design. The goal of the research is to link between parametric architecture as a tool in building aesthetics and daylight simulation.

ملخص البحث:

تعتبر العمارة البارامترية من اهم الوسائل لاستكشاف الاشكال و الانماط المعمارية. فهي تساعد المعماري للتغلب علي القدرات المحدودة للتقنيات التقليدية. فاستخدام الحاسب الآلي كشريك فى العملية التصميمية يساعد المعماريين فى محاكاة المشاكل التصميمية بكفائة والحصول على الحل الامثل فى اقل وقت. يركز العالم على كفاءة

الطاقة وراحة المستخدم ، وتوجد الآن حالة ماسة الى ضم الاداء البيئي للمبني فى التصميم خاصة الطاقة والاضاءة الطبيعية. حديثاً تم تطوير منهجيات لاستخدام تحسين الاضاءة الطبيعية كمدخل للعملية التصميمة ، التى اظهرت فوائد تصميم الواجهة البارامترية للحصول على اعلي جودة للاضاءة الطبيعية . هذا البحث سيناقش كيفية دمج العمارة البارامترية فى عملية محاكاة اداء الاضاءة الطبيعية و الوصول لاعلي معدلات اداء عن طريق عمل تجارب على الواجهات باستخدام الحاسب الآلي وتحليل الطاقة مع التقييم البارامتري. وايضاً سيتم دراسة انماط الواجهات التى لديها العديد من المتغيرات التى تؤثر بشدة علي توزيع الاضاءة الطبيعية داخل الفراغ . سيتم عمل المحاكاة باستخدام برامج التحليل البيئي المعتمدة (Grasshopper & Diva for Rhino) معاً لتحقيق الحل الامثل. هدف البحث هو الربط بين العماراة البارامترية كآداة مستخدمة لجماليات المبني و عمل محاكاة الاضاءة الطبيعية.

Key Words;
Parametric Architecture, Simulation, Daylight

Introduction

Digital technologies are changing all aspects of life. In the field of architecture, they change architectural practice, research and education in ways that only few were able to anticipate just a decade ago. Today, digital architectural design processes and tools allow for unpredictable realizations of three dimensional structures and are giving rise to new possibilities for architectural spaces. Form is no longer something static that is imposed on a structure, nor a behavior that can be integrated in the characteristics of 3d modeling, but is now influenced by the properties of the digital tools used.

Parametric architecture is not simply the use of computer to design architecture and objects. It allows designers to overcome the limitations of traditional CAD softwares and 3D modeling, reaching a level of complexity and control which is beyond the human manual ability. Its behavior is often unpredictable and it frequently produces creative patterns that amaze even their own scripter. When an architect successfully reaches this point, the computer wouldn't be considered as a reflection of the mind, but rather as a partner in the design process with fundamentally different abilities and ways of thinking. Parametric Architecture allow to try all potential possibilities for design that can lead to various forms of architecture and patterns and also can help us to manufacture them.

Research Problem

- Architects aim to design better spaces and achieve a better user experience in their designs, which includes visual and thermal comfort. Only a few consider the daylighting performance through the design process which is reflected on the quality of the designed spaces. The building skin plays the main role in delivering the natural daylighting inside the building; therefore building skins shouldn't be just designed for its aesthetic aspects but also as a functioning element in the building.
- It's difficult to run simulations on complex façades and double skin façades which have many variables and potential possibilities.
- The traditional way of simulation takes a very long time for trying changing every variable alone and get results then try again and yet doesn't get to the optimum solution.

Research Goal

Utilizing Parametric Architecture tools to enhance daylighting performance in interior spaces of buildings.

Research Methodology

The methodology implemented in this paper is divided into two successive stages. First stage focuses on the development of parametric architecture. Second stage is how to integrate daylighting into parametric design workflow. Then a simulation was done to confirm the relation between parametric architecture and daylight performance.

Parametric Architecture

Parametric design confirms using the system methodology in design. A system is a set of relationships between objects that form a greater entity. Systems clearly appear in nature, in the living organisms and in the human organization. [1]

Parametric design can provide a powerful conception of architectural form by describing a range of possibilities. Using parametric design, designers could create:

"An infinite number of similar objects, geometric manifestations of a previously articulated schema of variable dimensional, relational, or operative dependencies. When those variables are assigned specific values, particular instances are created from a potentially infinite range of possibilities." [2]

The term "parametric design" is probably the most suitable term for this kind of design, by changing any parameter in the equation new forms, and new shapes, could be created. The parameters are not just numbers relating to geometry, they could be performance-based criteria such as light levels or structural load resistance, or even a set of aesthetic principles.

Parametric Diagram:

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. There is a direct relationship between the designer's intentions and that of the designed product. [3] (Figure 1)

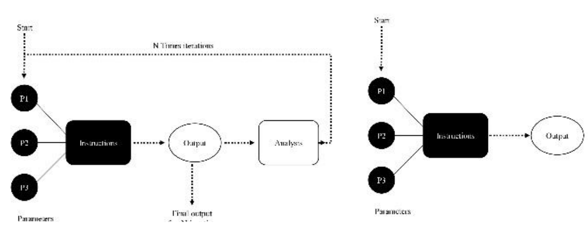


Figure 1 Left; The parametric design approach. Right the traditional design approach.

Computational systems have emerged as a fundamental keystone in architectural design during the past decades, marking the rise of a new area of study that engages with design cognition, computation and Obstetric principles in contemporary design practice [4]. Computational systems can systematically explore sets of possible architectures and are not fixed, but increases the likelihood that they will find architectures giving good performance [5]. Due to this; the design process is converted from a one-direct liner of manual try and error method to a non-direct computational operation (Figure 2) that generates unlimited alternatives to be evaluated numerically.

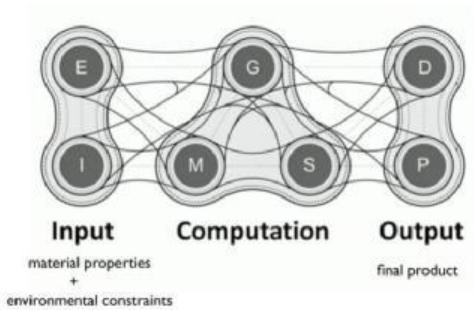


Figure 2 Form generation operation. Source: [6]

Many computer software have enabled users to interact with digital objects either by a direct manipulation or via node-based diagrams. Node based software systems such as Generative Components® by Bentley Systems and Grasshopper® by Robert McNeel & Associates [7], are two softwares that enable users to build up complex geometries by associating parametric primitives. Visual scripting makes possible a process were a line can be built by connecting two point objects, a square by connecting four line objects etc.

"In principle any conceivable network of relations between a given set of element attributes can be constructed."Patrik Schumacher [8]

The parametric diagram has the potential to create associative models that explore multiple configurations through control of the input parameters.

"While the attributes of the graphic/digital primitives...are fully determined and fixed at any time, within the parametric diagram they remain variable. This variability might be constrained within a defined range on the basis of associative functions that imbue the diagrammatic process with an in-built intelligence" [8].

The diagram consists of nodes and connections. Square nodes are the main functions: draw a circle, divide a circle, and create a line. The circular nodes are the parameters: the radius of each circle, and the number of subdivisions. Figure 3

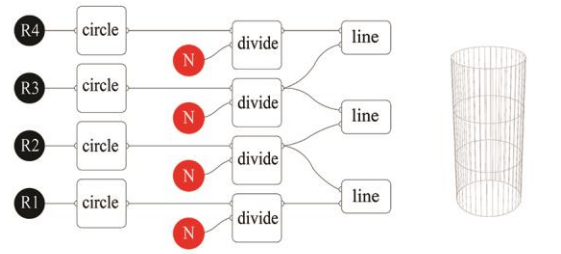


Figure 3 Conceptual Parametric Diagram "By the author"

The geometry can be further modified by manipulating one of the (R) parameters, the radius of (R3) is increased. (Figure 4)

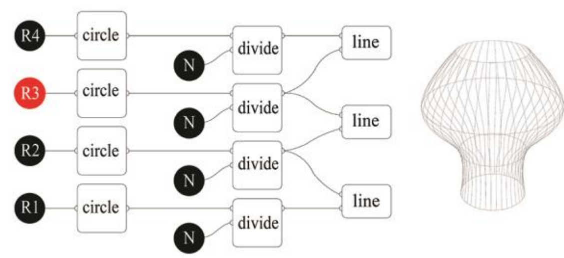


Figure 4 Increase R3 "By the author"

The geometry can be once again be modified by manipulating (R1, R2, R3, R4) as shown in

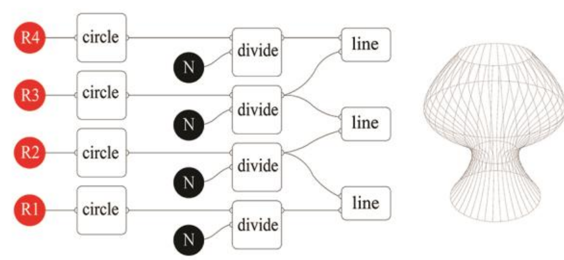


Figure 5 Manipulating (R1, R2, R3, R4) "By the author"

The advantage of a node diagram resides in the intuitive logic which allows you to quickly interact with parameters. For example, if the N parameter is modified, more lines are generated.

The parametric diagram can be considered a smart medium for architecture and design, since it provides an internal self-consistency transposed in a graphic language which can be easily manipulated, enabling designers to explore form-finding and form-making strategies.

"Form – making, loosely defined, is a process of inspiration and refinement (form precedes analysis of programmatic influences and design constraints) versus form – finding as (loosely) a process of discovery and editing (form emerges from analysis). Extreme form – making is not architecture but sculpture.... Extreme form – finding also is not architecture but applied engineering, where form exclusively determined by function" [9].

Parametric Implementation:
Parametric architecture can be used as a form finding technique. For aesthetics approach, parametric architecture was utilized to design, build and manufacture the Museo Soumaya museum (In Figure 6).

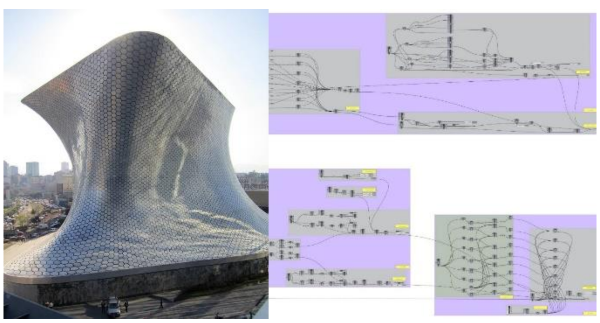


Figure 6 Left: Museo Soumaya, on the right the GH script used to model and manufacture the museum [10]

Parametric architecture can be also driven by a sustainable approach especially in façade openings. Façade openings play an important role in providing daylight, which is considered the best source of light that matches human visual response and required color. Thus, they have a substantial positive impact on the occupants, the most distinguished example is AlBahar towers.

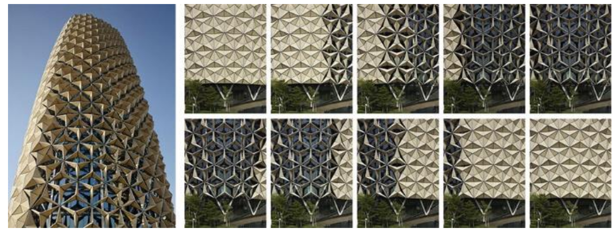


Figure 7 Left: Al-Bahar Towers after Construction, Right: Folded and unfolded shading device © Christian Richters [11]

AlBahar towers is a mixed use, office twin towers The geometry of the shading screen folds and unfolds in response to the movement of the sun, reducing solar gain by up to 50%, whilst simultaneously improving admission of natural diffused light into the towers and improving visibility (Figure 7).

Parametric Optimization:
The power of algorithms lay in the ability to solve a wide range of computational problems including but not limited to sorting and searching, data structure operations, combinatorial problems, numerical problems (including random number generation), and computational geometry. [12] Optimization tools used to extensively search the design alternatives looking for high performance solutions in terms of specified goals. In order to combine parametric modeling with an optimization technique to support design explorations and form finding, Genetic algorithms (GAs) have been considered. GAs can perform a series of simulations in a multidimensional search space, increasing the relevance of the cases simulated. They are used to find the configuration that best matches desired performance goals. [13]

Adjusting the parameters in any parametric model enables exploration of different design options, each of this options can be evaluated by quantitative and qualitative criteria. When used in combination with a multi-objective optimization algorithm [14], multiple designs can be generated and evaluated automatically within the set parameter constraints, with high scoring designs stored and identified.

Case Study:

Room Parameters

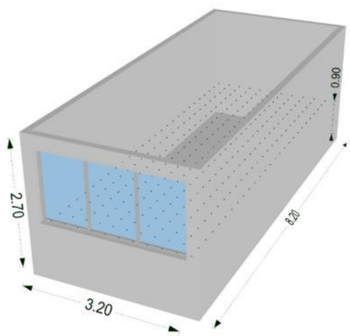


Figure 8 : The reference shoebox office showing the configuration of the space

In this paper, we selected a generic south-east oriented work space to conduct this simulation experiment. The space is located in Cairo, Egypt (30°6'N, 31°24'E, alt.75m), with no external obstructions. The space parameters and screen configurations are shown in Figure 8, Table 1, Figure 9 and Figure 10.

Table 1: Room and Screen Parameters

SPACE PARAMETERS		
Floor Level	1st floor	
Room Area	$26.24m^2$	
Floor Height	2.70m	
INTERNAL SURFACES REFLECTANCE		
Ceiling	80%	
Walls	50%	
Floor	20%	
Furniture	50%	
WINDOW PARAMETERS		
Window-to-Wall Ratio	3m * 1.5m	
Glazing	Double Clear Pane VT=80%)	
Window Frame	Metal Diffuse	
SCREEN PARAMETERS		
Geometry	5	Origami-based designs
Horizontal Rotation Angle	7	(-10, -6.67, -3.33, 0, 3.33, 6.67, 10) °
Vertical Rotation Angle:	7	(-10, -6.67, -3.33, 0, 3.33, 6.67, 10) °

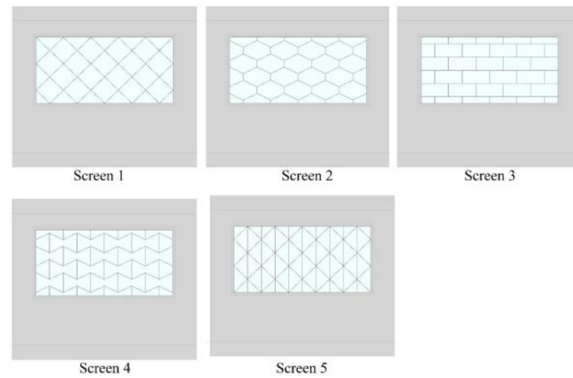


Figure 9: Parameter 1: The five origami-based designs

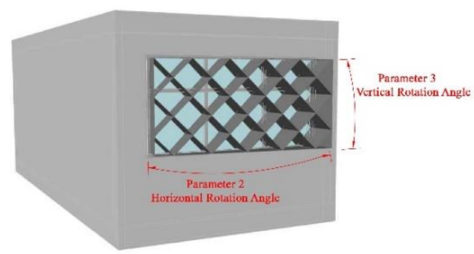


Figure 10: Shading Horizontal and Vertical Angles

Daylighting evaluation criteria

In this study, the daylighting criteria used for evaluation are based on the approved method by Illuminating Engineering Society described in report number LM-83-12 [15]. These criteria are annual climate based metrics and consist of: Spatial Daylight Autonomy (sDA300/50%) and Annual Sunlight Exposure (ASE1000/250 h). Spatial Daylight Autonomy (sDA300/50%) reports the percentage of the floor area in which the illuminance levels reach 300 lx for at least 50% during the 10 occupied hours (8 am–6 pm) throughout the year. ASE1000/250 h measures the percentage of the floor area in which the illuminance levels reaches 1000 lx for at least 250 h during the occupied hours (8 am–6 pm) throughout the year [15].Annual Sunlight Exposure gives an indication of the possibility of visual discomfort as a result of direct sunlight. The preferable daylighting conditions set by IES Committee are as follows: (1) Spatial Daylight Autonomy (sDA300/50%) should be equal or more than 75% of the room area. (2) Annual Sunlight Exposure (ASE1000/250 h) should be less than 3%. However, more preferred acceptance criteria were employed in this study to determine if this is achievable. In this condition, Spatial Daylight

Autonomy (sDA300/50%) has to cover 100% of the room area, while the Annual Sunlight Exposure (ASE1000/250 h) should be equal to 0% of the room area.

Simulation Results

Simulation is done by using Dive-for Rhino, plug-in for Rhinoceros modelling software that interfaces Radiance, Daysim, and Energy Plus software. [16]

The Simulation process is finished after 245 (5*7*7) simulation iteration trials. Simulation results are shown in (Figure 11) and (Figure 12) below that shows the relation between sDA and ASE values and the three parameters.

Screen one and two have the highest values for ASE which is no accepted. The best cases approved by IES (ASE 3%, sDA 50%) are the marked in the table which refers to cases number 112, 126 and 128 (Table 2).

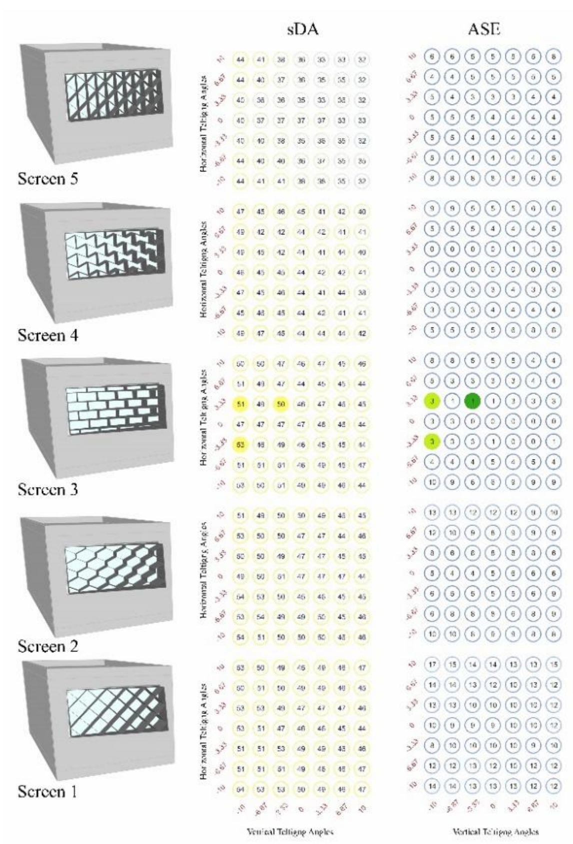


Figure 11: The 245 Simulation result.

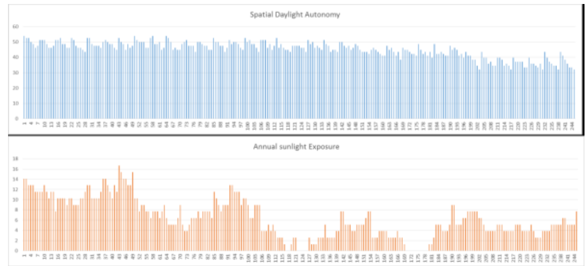
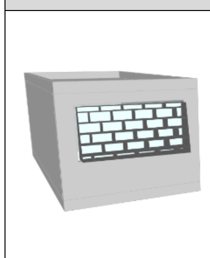
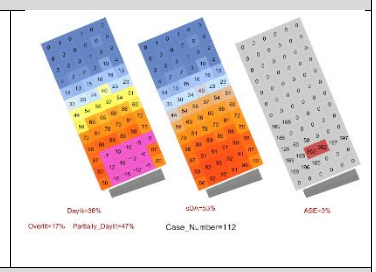
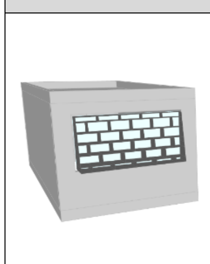
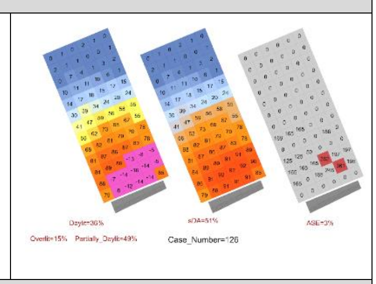
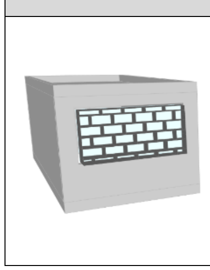
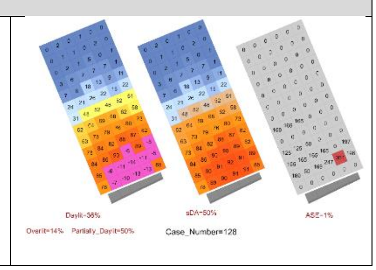


Figure 12: sDA and ASE in the all 245 trials

Daylighting results were analyzed. It was shown that daylighting performance regarding sDA and ASE was significantly affected by all three parameters: shading model configuration, horizontal tilt angle and vertical tilt angle. ASE is decreased when the shading is more vertical "Screen 3" but increased when the shading is so vertical that direct sunlight has no obstacles.

Table 2 Optimum Cases Configurations

Shading	DA, sDA and ASE Values
Case 112: Screen 3 - H angle -3.33 - V angle -10	
	
Case 126: Screen 3 - H angle 3.33 - V angle -10	
	
Case 128: Screen 3 - H angle 3.33 - V angle -3.33	
	

Conclusion

The Paper has presented computational and generative methods in architectural design through Parametric Architecture. Parametric Architecture can be used as a form finding technique in the design process and help the architect explore infinite design solutions. Parametric Architecture can not only be used for the aesthetics approach, it can also be driven by a sustainable approach especially in façade openings. Façade openings play an important role in providing daylight.

Also paper has presented a new method to explore the simulation of daylight through parametric architecture tools. Daylight simulation through parametric architecture is more applicable than the one-way traditional design operations. It enables the architect to simulate all the possible potential solutions for complex forms of architecture and reach the optimum solution in minimum time.

Then a simulation was done for a parametric shading device with three variables, each variable has multiple options. After 245 parametric simulation for all the possible trials, a result for the optimum design of the shading device was concluded to reach the optimum daylight.

These results are limited to the conditions of the case study; however, the same methodology paves the way for further exploration of the impact of shading devices on other orientations.

Recommendations

This research intentionally explored Parametric Architecture such a fascinating and innovative approach of design for future researchers and educators, to know how to address different design issues digitally. It is also recommended to integrate teaching performance optimization in design studios in undergraduate education. This would insure that the notion of understanding spatial performance is in the core of future architects, and is set as one of their primary goals.

The findings of this paper highlight the importance of using performance simulation tools in design process. Considering and testing these parameters makes a real difference in the overall performance. Finally, the results show the promising future of using computational methods along with simulation tools. It paves the way for more research in the area of building performance and its relation with the design of the building.

Also the study should encourage manufacturers to fabricate parametric façades in Egypt that can help reduce the expenses of parametric driven façades.

Future Work

The research can be extended in several ways:

- The results of this research can be investigated and compare its performance for other environmental aspects such as: Energy consumption, Thermal comfort. Natural ventilation. Digital fabrication, paneling and structure aspects. Life cycle cost.
- Moreover, investigating the use of dynamic and kinetic systems for more adaptive solutions and comparing the feasibility of dynamic systems and fixed systems may give a better guide for designing even more performative facades.
- Finally, verification of the results of this study by real life measurements can strengthen the thesis recommendations.

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