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Enhancement of Visual Comfort Using Parametric Double Skin Façades

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***Abstract*—**Parametric design deemed to be one of icons of the modern architectural trends that facilitates taking complex design decisions counting on altering various design parameters. Double skin façades are one of the parametric applications that are used in parametric designs. This paper opts to enhance different daylight parameters of a selected case study office building in Cairo using a parametric double skin façade. First, the design and optimization process was executed utilizing Grasshopper parametric design software package, in which the daylighting performance of the base case building model was compared with the one used in the double façade showing an enhancement in task plane illuminance by 180%. Second, execution drawings are made for the optimized design using Revit software. Finally, computerized digital fabrication stages of the designed model with various scales are demonstrated to reach the final design decisions using Simplify 3D for mock-up digital fabrication.

***Keywords*—**Parametric design, Double skin façades, Digital Fabrication, Grasshopper, Simplify 3D.

I. Introduction

NOWADAYS, parametric design deemed to be one of the important trends in architecture design. Complex architecture design forms can be executed using parametric software by changing several scripted parameters to reach the needed forms. The word “Parametric" is derived from "parameter", which is taken from the Greek para, which means "beside" [1]. Design in architecture means solving problems. According to [2], design is founding solutions for problems. "Exploration means exploring what variables might be proper" is how [3] defines the design process. In the book "Parametric Design for Architecture" [4], parametric design is defined as the process of algorithmic thinking and mathematical equations to give a set of optimized solutions for the design problem through selected parameters, in which they together support and explain the connection between architecture design goals. The process would last until the proposed outcomes were determined based on proper "performative" and esthetic criteria [5]. Users can use parametric software to create links and associations between geometric objects and items that define variables or functions. Therefore, parametric design is also known as an associative design. Parametric modeling sets the expression of elements as a set of relations that have variable dimensions [6], so parametric design defines the conceptual design forms throughout a set of algorithmic relations and parametric scripting to give definition for the design path.

Furthermore, Building Information Modeling (BIM) is a process that involves the generation and organization of digital representations of physical and functional features for the project. The created models can be extracted, exchanged, or networked to support the decision-making process [7].

Double skin façades (DSF) are exterior structures that afford adequate daylight to the interior space even under overcast conditions [8]. DSFs are classified according to many parameters: geometry of the façade, principles for ventilation, and types of airflow. However, the geometry of the façade and DSF classification appears to be the most appropriate classification that can affect daylighting performance. DSF can be classified according to the façade geometry into four main types: box-window façade, shaft box façade, corridor façade, and multi-story façade [9]. Moreover, DSFs. can be classified based on secondary characteristics such as the thickness of the façade cladding, their heights, or air openings mechanisms.

Daylight for the interior spaces can be defined as the natural illumination practiced by the residents of any man-made construction with openings to the outside [10]. The buildings' façade designs are performed to achieve definite purposes such as function, environment, occupant comfort, energy and daylight comfort, and sustainability [11]. According to [12], to evaluate the daylight system, there are various performance parameters' indicators for the indoor spaces that should be taken into consideration, which are task illuminance, luminous distribution, illuminance contrast ratio, glare, and light penetration depth. Task illuminance is light flux falling on surfaces per unit. IESNA, for example, recommends illuminance levels in a typical office space of 200-500 lux [13]. The daylight illuminance distribution in the range of 500 to 3000 lux inside office space, is stated as desirable and tolerable [14].

The history of fabrication technology began with a mass generation that was presented and created by Henry Ford, founder of the Passage Engine Company early in the 19th century [15].

Digital fabrication has filled the gap between conception design and fabrication. Computer Numerically Controlled (CNC) manufacture makes the coordination from the design file to the factory product [16]. Advanced creation comes from CAD (Computer-Aided Design) at that point exchanged to CAM (Computer-Aided Manufacture) computer program. The yield from CAM is prepared to fabricate to a particular machine, like a 3D printer or CNC processing machine.

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II. Methodology

The reference model is an office building of two stories located in Cairo, Egypt as shown in Fig. 1 where the south façade for each office includes windows that affect the task plane illuminance for six working tables, in which the measurements of the task plane are taken, either in summer or winter at 12 pm. Each office is 6 m width by 8 m depth and the ceiling height is 4 m. Each office accommodates six users located as shown in Fig. 2.

Fig. 1 The existing building located in Cairo, Egypt

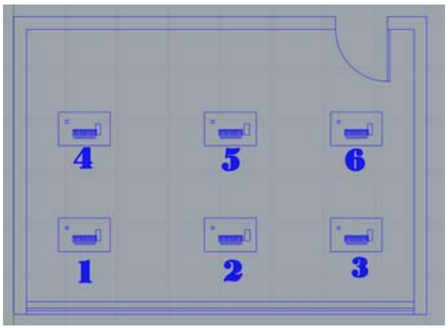


Fig. 2 Office plan including six desks

While calculating the task plane illuminance for the reference model, the results show the presence of overheating nodes on the desks used by the users, in which all points are above 3000 lux in winter at 12 pm. Therefore, these results lead to visual discomfort for the users throughout their working hours.

The calculation for task plane illuminance ranges from 14000 to 15000 lux as shown in Fig. 3 that also leads to glare for the users. In Fig. 4, the green line represents the task plane illuminance without the double screen façade or the reference model, whereas the blue line represents the allowed illuminance from 500 lux to 3000 lux. The section for each office is shown in Fig. 5 to show the direct sunlight that enters the office through the southern window. Table I shows the measurements for task plane illuminance for each sensor grid.

TABLE I
Measured Lux for Each of the Six Points in the Space

Points of task plane	The measurement in lux
1	15187
2	15392
3	15269
4	14642
5	14871
6	14688

The criteria of the design for the DSFs are derived from the Islamic shape “Mashrabiya” which is a wooden perforated screen that is characterized by its beautiful ornamental elements and functional purpose. It depends on the idea of the perforation ratio between the solid and void cladding in the shape of rectangular forms. The “Mashrabiya” screens are found a lot in old Islamic buildings in Cairo like “Beit Al-Sehimy” as shown in Fig. 6.

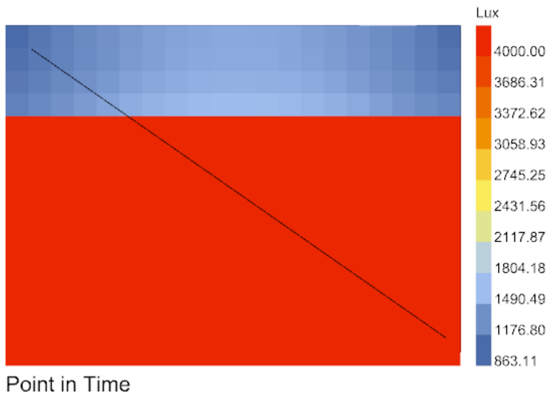


Fig. 3 The task illuminance plane in the indoor space for one office

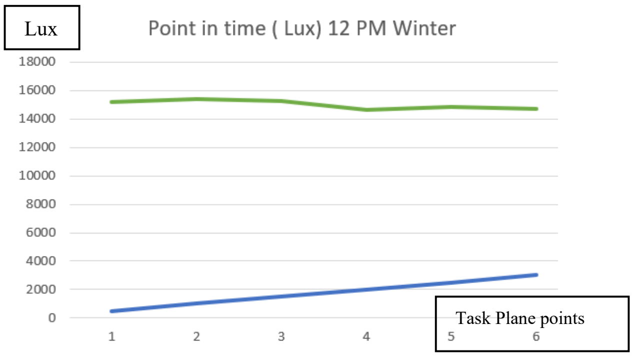


Fig. 4 Graph to compare the existing and needed calculations

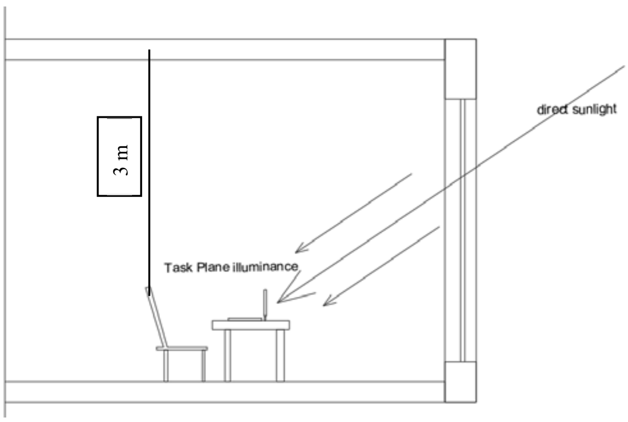
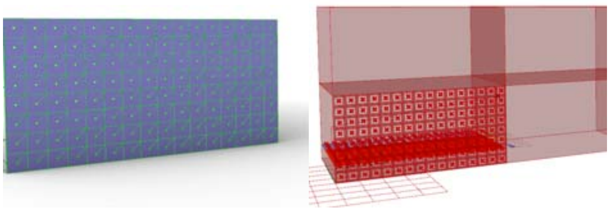


Fig. 5 Section for one office

The shape of DSFs differs in its perforation ratio ranging from 10% to 90% perforation area with respect to the whole façade area to enhance the task plane illuminance as the lighting intensity for the indoor work spaces must not exceed 500 lux on the task plan [17]. Fig. 7 shows the perforation in the parametric DSF designed.

Fig. 6 Shape of the Islamic Mashrabiya in Beit Al-Sehimy in Cairo, Egypt



(a) (b)

Fig. 7 Two figures for the perforation ratios for the cladding, (a) 10% perforation area, whereas (b) 90% perforation ratio

At 12 pm in winter, the scripting was developed in grasshopper (plugin in Rhino) using the Galapagos optimizer to give the desired results. The optimizer gives the best readings when the DSF perforation ratios are from 65% to 75% of the whole area which can only achieve the six-point indicators to give the needed calculations of less than 3000 lux and more than 500 lux. The location, date, and weather data file path were written in the algorithmic scripting as shown in Fig. 8.

The optimizer Galapagos was used for solving the parametric equations written in grasshopper as shown in Fig. 9. Table II shows the measurement calculation for task plane illuminance for the best perforation ratio that the optimizer solves.

TABLE II
PERFORMANCE OF 65%, 70%, AND 75% PERFORATION RATIO

Points of Task Plane	65%	70%	75%
1	820 lux	961 lux	1089 lux
2	891 lux	1036 lux	1167 lux
3	835 lux	959 lux	1136 lux
4	593 lux	681 lux	795 lux
5	670 lux	768 lux	903 lux
6	604 lux	719 lux	832 lux

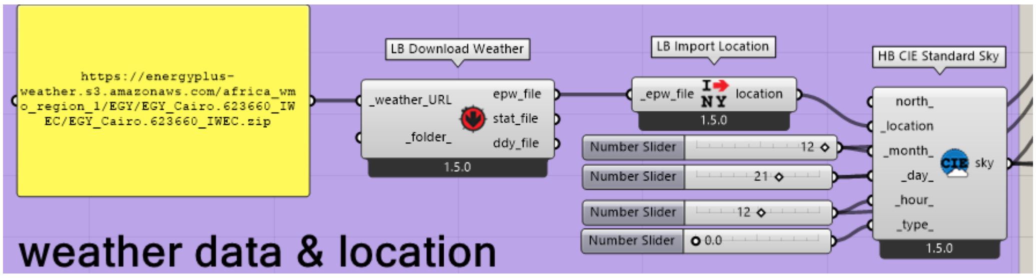


Fig. 8 The location, time, and weather data file

Fig. 9 The Galapagos optimizer running

At 12 pm in summer, the optimizer gives the best calculations when the DSFs perforation ratio is more than 80% of the whole area of the cladding to achieve less than 3000 lux and more than 500 lux for the six points indicators for the task plane.

The location, date, and weather data file path were written in the algorithmic scripting as shown in Fig. 10. Table III shows the measurement calculation for task plane illuminance for the best perforation ratio that the optimizer solves.

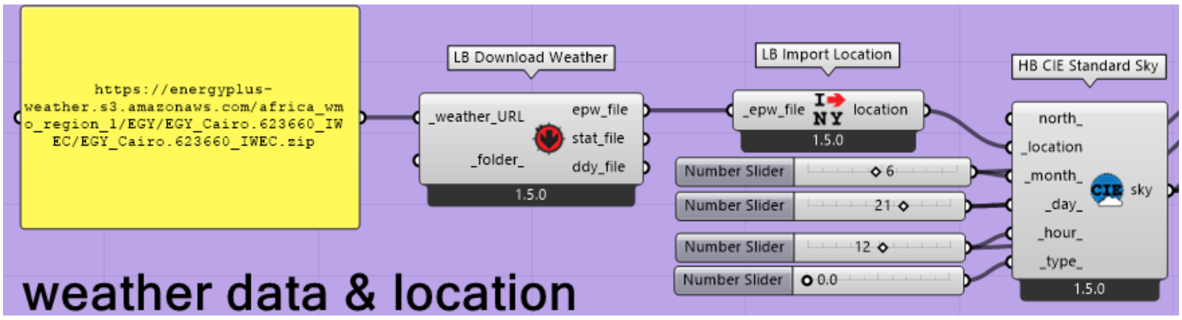


Fig. 10 The location, time, and weather data file

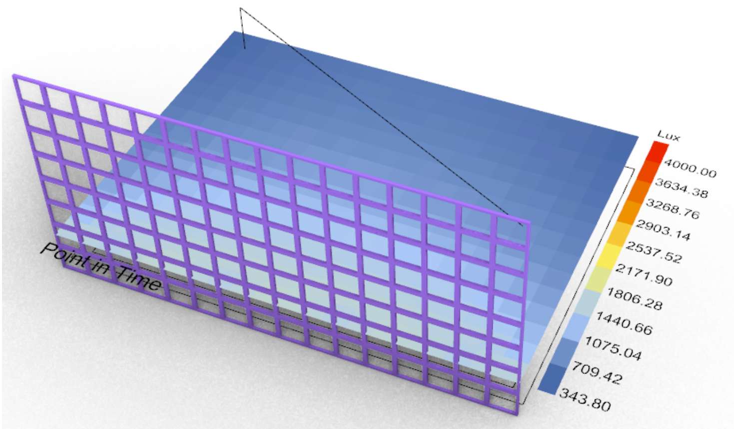


Fig. 11 Illuminance distribution in the office space during 12 pm in summer with the cladding used

TABLE III
PERFORMANCE OF 80%, 85%, AND 90% PERFORATION RATIO

Points of Task Plane	80%	85%	90%
1	940 lux	961 lux	1200 lux
2	1060 lux	1036 lux	1350 lux
3	944 lux	959 lux	1200 lux
4	542 lux	681 lux	697 lux
5	648 lux	768 lux	821 lux
6	540 lux	719 lux	680 lux

The DSF leads to uniform daylight distribution indoors in each office as shown in Fig. 11. The scripting started with the design stage for the conceptual form, then was assigning materials to the reference model, the simulation was performed by Honeybee radiance, which is a Ladybug tool. The optimizer Galapagos was used for giving the perforation ratio for the double screen façade to achieve 6 points of visual comfort as shown in Fig. 12.

The optimized design for DSFs will be exported from Rhino to Simplify 3D for the preparation for the fabrication process where they are designed with different small scales to measure the time used for fabrication, stability, and cost. Simplify 3D was used for the preparation for the fabrication process as shown in Fig. 13. After the preparation for the fabrication process, the file will be fabricated through CNC where the file will be read as G-code. Finally, the Revit program was used to produce the detailed execution drawings for the semi-adaptive façade screen that will be installed using steel plates and sheets. The double screen façade will be fixed to the existing wall for the reference model.

III. CONCLUSION

This paper is considered as an application for using Ladybug-Honeybee tools in Grasshopper to obtain different solutions for the fittest perforation ratios for the design of the conceptual forms through optimization process. The optimized design forms achieved an enhancement for the indoor visual comfort in the reference office in which the six indicator task plane sensors have adequate illuminance.

The optimized design is exported to Simplify 3D for the process of the preparation for the fabrication process to be able to be fabricated after that with a scale of 1:1.

BIM Revit software is used to produce the detailed execution drawings. This paper shows the workflow for the parametric design process from the conceptual form passing through the simulation using Honeybee Radiance to achieve adequate task plane illuminance for the users, the process for preparation for fabrication was done, and finally, execution drawings were extracted from Revit to show the fixation of the double screen façade within the existing building.

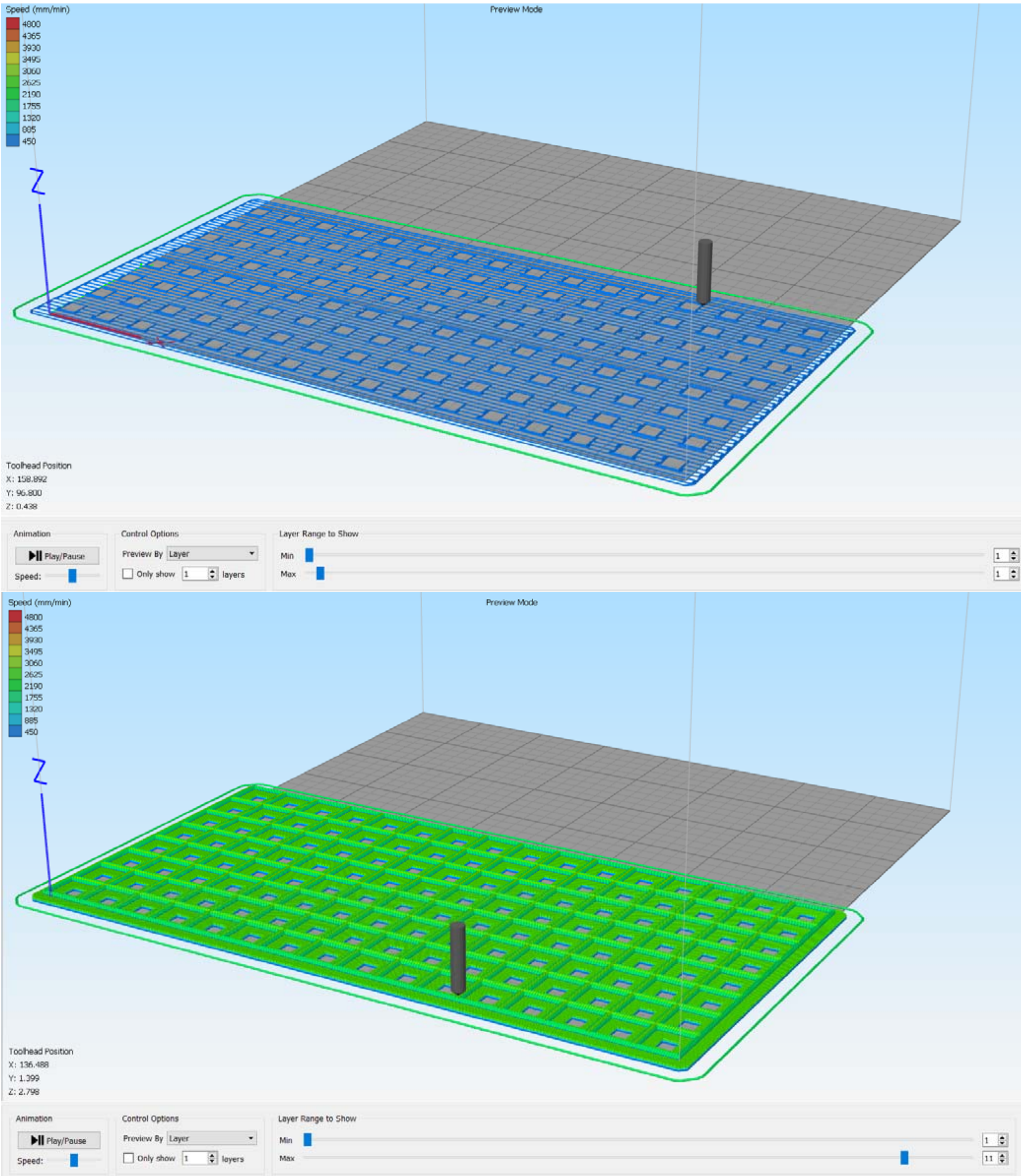


Fig. 13 The process for preparation for fabrication

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