Double-Skin Façades in Egypt between Parametric and Climatic Approaches

Omar Etman[1], Osama Tolba[2], Sherif Ezzeldin[3]
Arab Academy for Science, Technology and Maritime Transport, Egypt
www.aast.edu
[1]omar@etmanweb.com, [2]otolba@gmail.com, [3]shezzeldin@yahoo.com

Abstract. *Daylight is a crucial element for indoor environment quality. Office buildings commonly use fully glazed façades to reflect a luxurious appearance and to maximize natural light at the expenses of high energy consumption due to cooling/heating. Double-skin façades are one of the solutions that improve the building efficiency while maintaining good natural lighting. This paper studies the impact of various perforated outer skins for non-sealed double-skin facades on light quality in prototypical office space in Egypt using parametric design. A traditional solution for light such as the Mashrabiya is taken as an inspiration for this study to generate different forms of perforated screens. The cases were analysed using light simulation tool and sorted by a genetic algorithm to show best 30 solutions offered by the design criteria. A methodology to achieve these objectives was suggested in this paper to reach better light quality in indoor spaces.*
Keywords. *Double-skin façades; parametric design; mashrabiya; genetic algorithms; illumination.*

INTRODUCTION

A building's envelope plays a primary role in shielding and screening the building from external environmental factors, such as heat, light and air. The building envelope integrates about 80% of an environmental solution, creating an efficient building that interacts with its surrounding environment. Office buildings are considered high energy consumers, as they consume about 25% of the building energy consumption (Westphalen and Koszalinski, 1999). Office buildings commonly use large surfaces of glass on their façades in order to reflect a luxurious appearance while maximizing the natural light penetration to the interior space. Though glass façades provide plentiful natural lighting, the amount of energy needed to maintain indoor thermal comfort in hot climates poses a great challenge to office building designers.

Based on Köppen's climate classification system (Peel et al., 2007), Egypt's climate is classified as hot desert arid climate, which is characterized by high direct solar radiation and clear skies. These climate characteristics demand special façade treatments to minimize heat gain. On the other hand, envelope solutions in most of contemporary office buildings in Egypt follow the international style with large glass curtain walls, disregarding the climate and shading treatments (see Figure 1), which results in high levels of energy consumption.

Double-skin façades can be used to improve building efficiency while maintaining good natural lighting. There are two main types of double-skin-Facades: sealed and aerated. Sealed double-skin facades are not recommended for hot climates, as they trap heat gain by radiation. Aerated double-

Figure 1
Office buildings in Cairo, Egypt with curtain wall façades facing west and south. (Photos by author).

skin façades eliminate the heat between the inside to outside by the stack-effect (Poirazis, 2004).

Creating efficient buildings is a challenge that faces architects nowadays. However, recent developments in computer-aided design programs and digital fabrication have enabled architects to explore new building forms and new treatments of envelopes, in an attempt to solve architectural design problems (El-Sheikh and Gerber, 2011).

Parametric architecture has been gaining momentum over the past few years. This new design approach involves sketching behaviors in nature quantifying them and introducing them to advanced computational design programs that help architects in exploring new geometries (Schumacher, 2009). The impact of such a trend is yet to be seen on building forms and envelopes and their behavior with respect to climate.

This paper explores how to apply smart geometries to double-skin envelopes of office buildings in order to create a smart, efficient envelope that provides better indoor quality and gives a unique form to the building. The paper focuses, in particular, on designing west-facing aerated double-skin façades using parametric design, while optimizing illumination levels of indoor office spaces. The paper presents the initial findings of an ongoing research.

Traditional Daylight Screens

Natural lighting is an important design element of office spaces that improves indoor environmental quality and user productivity, while reducing the energy consumed by artificial lighting (Ander, 2003). Successful daylight design requires going beyond conventional techniques of integrating large openings, skylights or light shelves into architecture (El-Sheikh and Gerber, 2011). It encompasses thoughtful integration of design approaches addressing glare, heat gain and variation in light availability, and direct light penetration.

The mashrabiya, a traditional architectural feature in Egypt and the Middle East, is commonly used to encourage airflow, decrease solar heat gain and to diffuse natural lighting that is penetrating through openings [1] (see Figure 2). These perforated wooden screens follow a repetitive pattern called *arabesque* (see Figure 3). Using parametric design, we develop perforated screens that are proposed as an outer skin for the aerated double-skin façade. The resulting light intensity penetrating the room and is tested for adequacy to the work environment.

Genetic Algorithms as Design Aids

Genetic algorithms are effective if integrated in the design process (Jaime et al., 2010). Genetic algo-

Figure 2
Perforated screen in Amr Ibn Al Aasse mosque (photo by author).

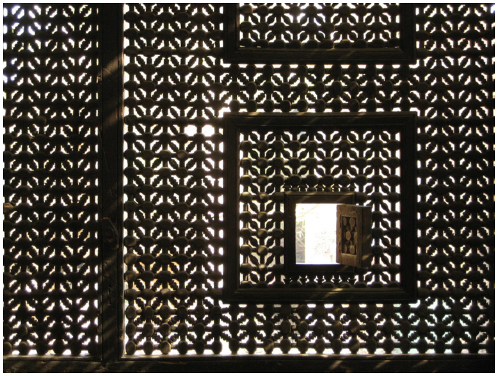


Figure 3
Close up of a mashrabiya (source: BlogSpot).

rithms can be used in finding good and efficient architectural solutions in the design phase; they are used nowadays to find unconventional solutions for different design criteria, such as building forms, façade shading and daylight harvesting. Genetic algorithms were shown to be effective in presenting new solutions to optimize light penetration and shading (Zemella et al., 2011).

The main benefit of the evolutionary solving process in a genetic algorithm is that it enables the designer to adopt a holistic approach, taking into account many different aspects influencing the performance of a façade. However, the processing time of such a process is known to be somewhat prohibiting. Another limitation of genetic algorithms is that the generated solutions are picked randomly, which may result in skipping some cases that may have been beneficial. This can be avoided, to some extent, by forcing the algorithm to use more generations.

SIMULATION PROCESS

In order to evaluate the impact of a perforated screen on the internal light quality, we used a west-facing prototypical office space measuring 4x6 meters with a height of 3 meters (see Figure 4). These dimensions represent an average span structural grid that can hold 3 workstations. The depth of the space is set at twice the height of the window (Ander, 2003). The distance between the perforated screen and the inner skin is 0.6 meters, which is considered a minimum distance for a maintenance catwalk. The inner skin consists of a double-glazed window with low-emissivity coating, and the inner room surfaces are chosen as typical smooth light paints.

The outer skin (perforated screen) is envisioned as a grid of rectangular modules. The different parameters of these modules include the width (w), height (h) and incremental rotation angle (Θ). As seen from the outside of the building, the bottom-left module starts with zero-rotation. Then, the module directly above it is rotated, and so on, until the top of the first column of the grid is reached. At this point the rotation is applied to the next column of grid, starting from its bottom. This results in a repetitive pattern, similar in principle to a traditional wooden screen. The different values of the perforated screen's parameters are as follows (Table 1):

A total of 540 different cases were simulated to determine the illumination level inside the office space. An analysis grid, where the illumination levels are measured, is placed 1.0 meter above ground with a resolution of 0.4x0.4 meters. Each generated screen undergoes lighting simulation 18 times: three different days, at 6 hours per day. The three days are: 21st of June, 21st of December, and 21st of March, representing summer, winter and spring, respectively. The 6 hours per day start from noon till 5 pm, as the most critical period for the west façade. The typical weather data file of Egypt is used in all simulations [2].

The genetic algorithm evaluates the fitness of each screen using the following fitness function:

Table 1
The tested parameters of the repetitive modules of the perforated screen.

Parameter	Possible Values
w	10, 20, 25, 40, 50 cm
h	10, 15, 20, 25, 30, 50 cm
Θ	10, 20, 30, ...180 *around an inclined rotation axis (1, 1, 1) at center of module*

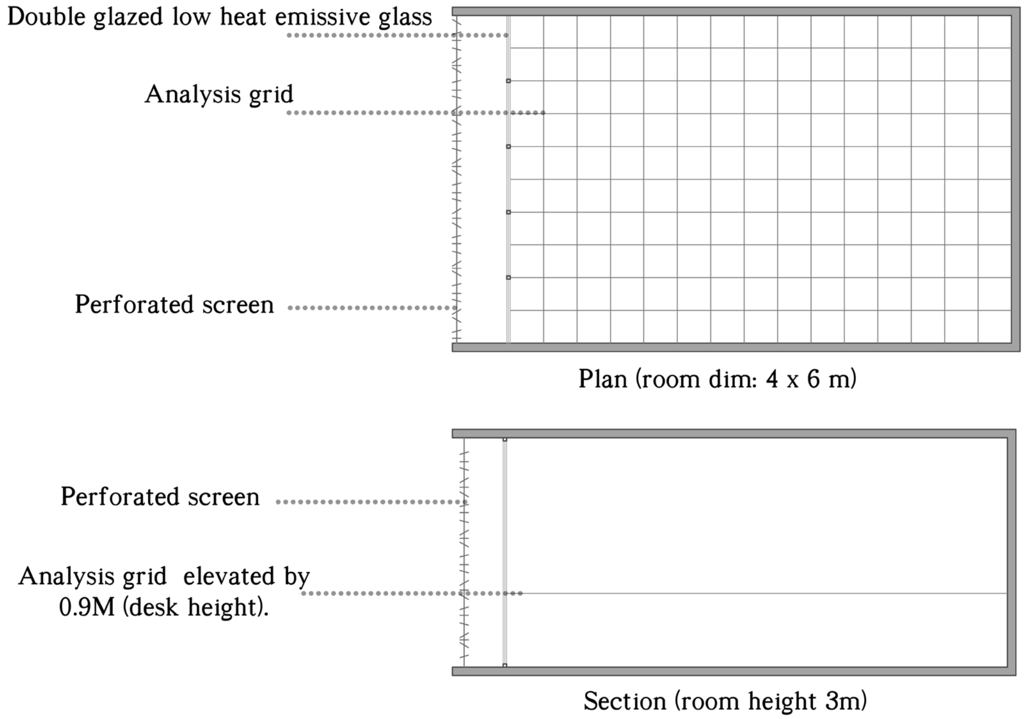


Figure 4
Dimensions of the office space used in the simulation process.

F =
Σ (Measured illumination - Desired illumination) ^{2} (1)

The measured illumination is that for the 18 simulation grids mentioned above, while the desired illumination for office space is considered to be 500 lux (Burberry, 1997). This fitness equation places penalties on illumination levels that depart from the desired level, keeping the transitions between the readings as smooth as possible in order to avoid glare.

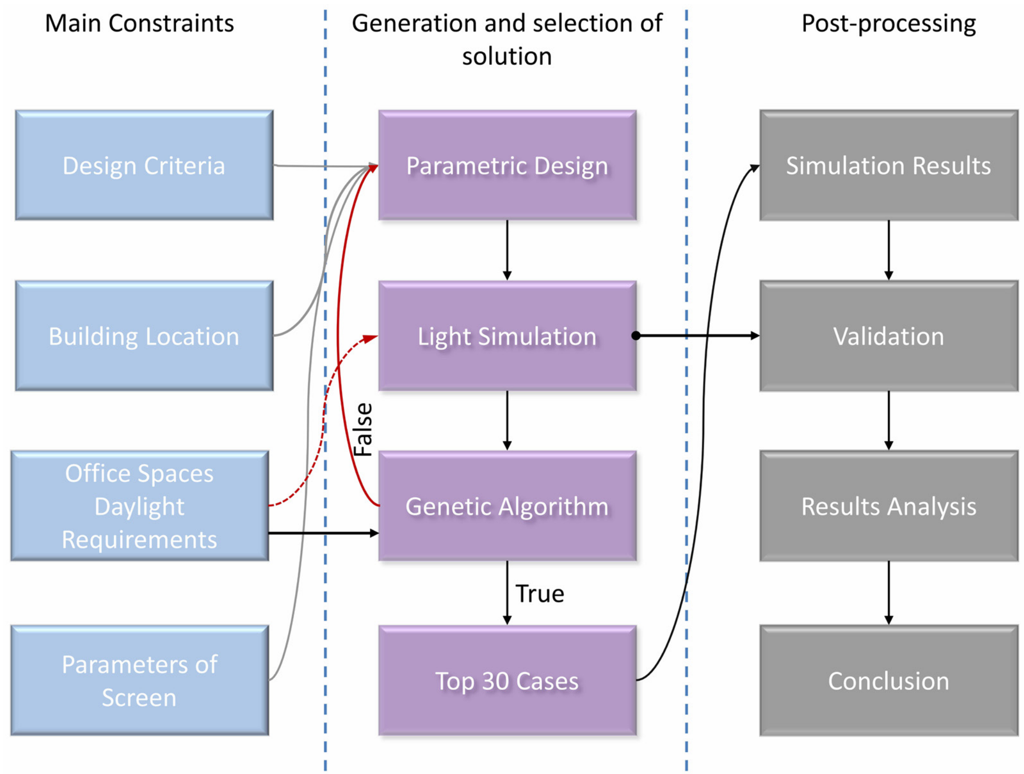
After the simulation process finishes, the best case is validated against another case with a similar rotation angle while changing the size of the modules. Figure 5 shows the simulation process in the form of a flowchart.

A digital model of the office space is constructed using Rhino. Then, a genetic algorithm definition was developed to generate the different alternatives for the perforated screen based on combinations of parameters. For this purpose, we used Galapagos [3], a genetic algorithm imbedded in Grasshopper [4]. The design criteria take the repetitive order of the *arabesque* pattern into consideration. The illumination levels of the generated cases will be determined using RADIANCE [5] through DIVA [6]. The final cases are compared against both the base case (without a screen) and a validation case in order to understand the behavior of the perforated screen and the impact of its geometric parameters on natural light distribution in the office space.

SIMULATION RESULTS

The simulation process took 10 days and 18 hours to complete 50 generation with a population of 30 genomes. The combinations of parameters for the best 30 cases, as selected by the genetic algorithm,

Figure 5
Flow chart of the simulation process.



are shown in Figure 6 in an ascending order based on the fitness coefficient. These values show the amount of deviation from the desired illumination level (500 lux). The best generated case is presented first with least fitness coefficient (0.52); its perforated screen consists of repetitive square modules of 10x10 cm, with an incremental rotation angle of 180 degrees around the rotation vector (1, 1, 1).

It can be seen from the results that the selected 30 cases, with least discrepancy in illumination level around 500 lux, provide small modules; just three cases with modules exceeding 25 cm exist. In addi-

Figure 6
Table of results showing selected cases.

NO	W	H	Θ	F
1	10	10	180	0.5179
2	10	15	180	0.6168
3	10	20	160	0.9948
4	20	30	130	0.9901
5	10	20	170	1.0103
6	20	25	60	1.0128
7	10	30	90	1.0179
8	20	10	110	1.0245
9	40	20	80	1.0289
10	10	20	120	1.0321

NO	W	H	Θ	F
11	10	15	140	1.0331
12	10	10	170	1.0532
13	20	25	160	1.0572
14	25	25	160	1.0625
15	10	20	150	1.0641
16	20	15	140	1.0698
17	10	10	90	1.0701
18	10	10	130	1.0756
19	10	10	140	1.0798
20	10	10	80	1.0824

NO	W	H	Θ	F
21	10	15	90	1.0952
22	10	15	120	1.1013
23	10	15	80	1.113
24	10	10	110	1.1252
25	10	15	100	1.1321
26	10	10	140	1.1335
27	10	15	160	1.1382
28	20	25	50	1.1396
29	20	20	170	1.1425
30	10	10	160	1.4231

tion, nearly all the incremental angles are between 80-180 degrees; only 2 cases are below 80 degrees. Thus, smaller modules with large incremental rotational angles seem to be more preferable than larger ones with small angles.

By comparing the simulation results of the best generated case against those of the base case (without a screen), light level distribution of the best generated case showed that 74% of the room area is supplied with acceptable illumination level (300-500 lux) within the 6 simulated hours and the 3 selected days. On the other hand, just 54% of the room area of the base case is supplied with acceptable illumination level (see Figures 7, 8).

By analyzing the illumination levels at different hours of the day, natural light penetrates more deeply inside the space, as expected, with a risk of potential glare at late working hours, especially in winter days. The results of the base case showed that solar radiation penetrates inside the space starting from 2 pm. On the other hand, the generated case delayed this problem two more hours with fine scattered solar spots as shown in figure 8.

In order to understand the impact of module size on the distribution of light levels, a validation case is generated with reference to the best generated case, where the size of the modules is increased keeping the same incremental rotation angle. The validation case with large modules provided a fitness coefficient value of 1.14101. The large repetitive modules cause more potential glare, which affects the fitness coefficient value (see Figures 9, 10).

Although the total number of cases is 540, the genetic algorithm simulated 1500 cases to reach the selected optimal solutions. This wasted more time than necessary because genetic algorithms are suited toward solving problems with very large search spaces. In our future research, we will expand our search space by employing more parameters with finer steps.

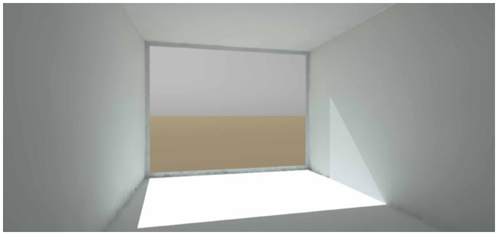


Figure 7
Base case 21st June at 4 o'clock.

Figure 8
Generated case21st June at 4 o'clock.

Figure 9
Top case - 21st of march at 4 o'clock.

Figure 10
Large modules - 21st of march at 4 o'clock.

CONCLUSION

This paper presents initial findings of an ongoing research about design optimization of the outer skin of west-facing façades in order to maintain acceptable illumination levels within a prototypical office space using parametric design. Based on the presented simulation results, it was concluded that an effective ecological design of the west façade could increase the potential use of daylight in indoor spaces. The use of the fitness function helps in providing smooth light ranges that decreases the risk of potential glare. Accordingly, perforated screens with repetitive modules, assembled as an outer skin and developed from the traditional *Mashrabiya*, improved the distribution of acceptable indoor illumination level from 54% to 78%. The proposed skin delayed the periods of solar penetration and potential glare; the space achieved acceptable indoor illumination level from 9 am to 4 pm.

Using a genetic algorithm definition, the best 30 alternatives of the perforated screen and their parameters were presented. Perforated screens with small repetitive modules and large incremental rotational angles were chosen by the algorithm as they diffuse more light and increase acceptable daylight levels in the space. The used parameters and genetic algorithm need further refinement as they failed to give conclusive results and consumed more time than expected.

The paper showed that perforated screens with repetitive modules derived from the traditional *Mashrabiya* are effective in west elevations. More refined analysis grid, more values for module parameters, different geometries of the modules, materials used and different rotation axis are suggested to be tested in the future in order to reach more efficient solutions.

REFERENCES

Ander, GD 2003, *Daylighting Performance and Design*, 2nd edition, John Wiley and Sons, U.S.A.

Burberry, P 1997, *Environment and Services (Mitchell's building series)*, Longman, London.

El-Sheikh, M and Gerber, D 2011, 'Building Skin Intelligence', *Proceedings of ACADIA, pp. 170-177*.

Jaime, M, Gagne, L and Andersen, M 2010, 'Multi-objective Façade Optimization for Daylighting Design using a Genetic Algorithm', *Proceedings of 4th National Conference of IBPSA-USA* (SimBuild 2010), New York.

Peel, MC, Finlayson, BL and Mcmahon, TA, 2007 'Updated World Map of the Köppen-Geiger Climate Classification', *Hydrology and Earth System Sciences* 4: pp. 439-473.

Poirazis, H 2004, '*Double Skin Façades for Office Buildings*', Department of Construction and Architecture, Lund Institute of Technology, ISBN: 91-85147-02-8 / ISSN: 1651-8128, Lund University, Lund.

Schumacher, P 2009, 'Parametricism – A New Global Style for Architecture and Urban Design', *AD Architectural Design*, Volume 79.

Westphalen, D and Koszalinski, S 1999, *Energy Consumption Characteristics of Commercial Building HVAC Systems, Volume 2: Thermal Distribution, Auxiliary Equipment, and Ventilation*, p. 128.

Zemella, G, De March, D, Borrotti, M and Poli, I 2011, 'Optimised Design of Energy Efficient Building Façades via Evolutionary Neural Networks', *Energy and Buildings*, 43(12), pp. 3297-3302.

[1] www.saudiaramcoworld.com

[2] apps1.eere.energy.gov/buildings/energyplus/cfm/weather_data2.cfm/region=1_africa_wmo_region_1

[3] www.grasshopper3d.com/profiles/blogs/evolutionary-principles

[4] www.grasshopper3d.com

[5] radsite.lbl.gov/radiance/framer.html

[6] diva4rhino.com