PARAMETRIC ISLAMIC GEOMETRIC PATTERN FOR EFFICIENT DAYLIGHT AND ENERGY PERFORMANCE

Façade retrofit of educational space in hot arid climate

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Abstract. The purpose of this paper is to reach an optimal Islamic geometric pattern (IGP) shading screen design in terms of daylight and energy performance in an existing educational design studio (EDS) using generative design and simulation techniques. The study was carried out in a hot arid climate, in a typical EDS in 6th October University, located in Cairo, Egypt, and the study focused on the north-east oriented façade. Grasshopper for Rhino was utilized to generate the IGP parametric variations. Diva-For-Rhino which performs daylight analysis using Radiance / DAYSIM, and Design Builder which performs thermal load simulations using EnergyPlus were utilized in simulation. The results of the study achieved the required daylight levels with significant reduction of energy consumption levels of cooling load. This shows the affordance of the parametric IGP shading screens in façade treatment for achieving both efficient daylight and energy performance in educational design studio in hot arid climates.

1. Introduction

Natural light is beneficial to human working performance in terms of both visual quality and psychological well-being (Altamonte, 2009). In educational spaces, it improves students' mood, concentration, behaviour & their learning process in general (Che-Ani *et al*, 2012). Increasing the transparent parts of the building envelope can help harvest daylight, however, in hot arid climates this solution would cause some issues such as the lack of the ability to control daylight uniformity, and the increase of heat gain when exposed to direct sunlight, which leads to higher energy consumption levels of cooling load. This led the research team to search for a solution to these issues proposing the IGP shading screen.

Shading screens are efficient architectural elements for reducing the thermal loads inside buildings (David *et al*, 2011). IGP shading screens have been widely used in ancient Islamic architecture in many hot arid climate regions, and the use of IGPs in shading screens has shown great effectiveness for decades as an environmental solution in terms of both daylight performance and reduction of thermal loads.

2. Literature Review

Barrios and Alani (2015) were able to make a complete parametric analysis of the IGP. They used traditional Islamic geometry as a starting point and performed an analysis of pattern's fundamental units and cells. Consequently, they were able to do a metamorphosis operation based on parametric variations of geometry and colour. This resulted in generating new geometries through a guided exploration of Islamic geometry (Barrios, & Alani, 2015).

Samaan (2016) investigated the impact of envelope design variables (shading – WWR – construction layers) on achieving the balance between efficient daylight with minimal cooling loads in the EDS with various orientations and dimensions in a public university in Egypt using digital simulation tools. The study showed that East & west orientations increased the energy consumption of cooling load by 47% more than optimum orientation (North). They achieved significant reduction in energy consumption using (overhangs, louvers & Low-E glass) but with poor daylighting performance. Their optimum solution has been achieved by using skylight in roof with 8% opening ratio.

In a similar context, Wagdy *et al* studied the influence of the parametric Kaleidocycle in a double skin envelope that is south oriented to optimize day lighting with efficient energy consumption for cooling loads, heating loads, and artificial lighting in a typical office building located in hot arid climate. It showed that using many Kaleidocycle units with less perforation ratios and open angles reduced energy consumption by 23% reduction and achieved appealing day lighting levels more than LEED V.4 requirements (Wagdy *et al*, 2016).

3. Methodology

This paper investigates the application of IGP shading screen as an environmental solution to solve daylight usability issues in relation to energy consumption levels of cooling load in an EDS in [..] University, located in [..], which was modeled using Rhinoceros to be investigated as shown in figure 1.

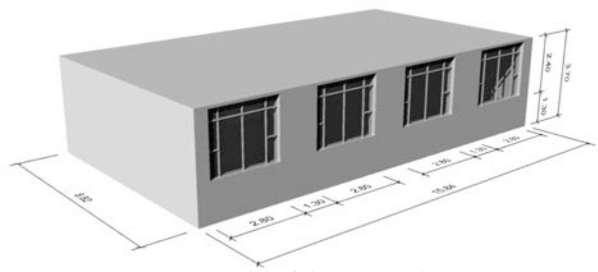


Figure 1. Model of the case study

3.1. ISLAMIC GEOMETRIC PATTERN

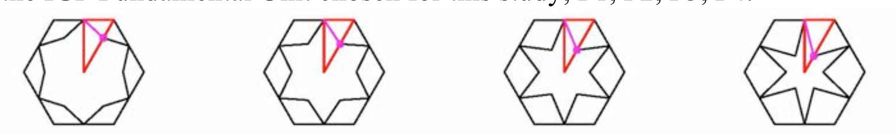
A six-point star IGP shading screen was selected to be tested parametrically, and the fixed topology approach (Barrios & Alani, 2015) was adopted in this study where the new geometry should always be topologically identical to the starting point of the variations.

The cell is the basic unit for the pattern, and the fundamental unit in the cell is the group of geometrical elements with non-repeating components (Alani, 2015).

Selected pattern	Cell	Fundamental Unit

Figure 2. Pattern, cell, and fundamental unit

Fixed Topology: (Barrios & Alani, 2015) proposed this method in which the total number of points and edges of the IGP remain identical at every stage in the parametric variation. While the geometry changes, any parametric variation shouldn't result in a topological transformation. The geometry of the new designs can be generated by adhering to the following rules, for all the points within the fundamental region: 1) Point overlap is not allowed; 2) line overlap is not allowed; 3) Intersections are allowed; and 4) Points should not leave the fundamental region. Fig. 3. shows the 4 cases of the parametric variations of the IGP Fundamental Unit chosen for this study; F1, F2, F3, F4.



F1 F2 F3 F4

Figure 3. Fixed topology parametric variations on a six point star IGP

A total number of 12 cases were tested under the fixed topology method as follows:
IGP cell grid: diameter = 35 cm (fixed)
IGP fundamental unit (F): 4 cases (variable)
Thickness (T): T1 = 2.5 cm , and T2 = 5.0 cm (variable)
Depth (D):D1 = 2.5 cm, and D2 = 5.0 cm (variable)

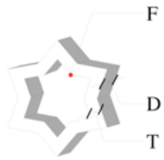


Figure 4. IGP parametric variables F, T, D

3.2. THE PROCESS

In a first stage, Grasshopper-For-Rhino was utilized to generate the parametric variations of the IGP. Diva-For-Rhino was used to test the cases for an optimum solution in terms of daylight performance. In the second stage Design Builder (DB) was used to test the outcome of the first stage in terms of thermal performance so as to achieve the best solution with the lowest energy consumption of cooling load.

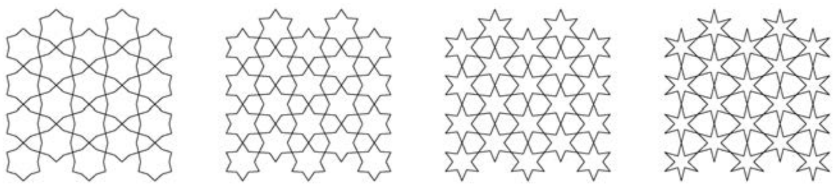


Figure 5. Grasshopper generated variations for the IGP fundamental unit

3.2.1. The first stage

Daylight simulation was conducted using Diva-for-Rhino 3.0 to measure Daylight Autonomy (Da), Daylight Factor (DF), and Useful Daylight Illuminance (UDI). Daylight Autonomy (DA) is represented as a percentage of annual daytime hours that a given point in a space is above a specified illuminance level (Reinhart 2001). We selected a Daylight Autonomy threshold of 500 lux (DA500). The daylit area is the area of space at which the Spatial Daylight Autonomy corresponds to at least 50% of the occupied time of one year in which the daylight levels are above the target illuminance. Daylight Factor DF is the mean ratio between the interior illuminance level and the exterior illuminance level under overcast sky conditions.

Zach Rogers (2006) proposed Continuous Daylight Autonomy (cDA) as a basic modification of Daylight Autonomy. Continuous Daylight Autonomy awards partial credit to values below the target threshold. If a sensor point exceeded 500 lux 50% of the time on an annual basis, then the cDA500 might result in a value of approximately 55-60% or more.

Useful Daylight Illuminance (UDI) is a modification of Daylight Autonomy proposed by Mardaljevic and Nabil in (2005). It provides full credit only to values between 100 lux and 2,000 lux suggesting that horizontal illuminance levels outside of this range are not useful.

3.2.2. The second stage

Thermal model was built using Design Builder 4.7 which works on accurate details related to building design, construction layers & internal loads, climatic weather file data was selected and the building air condition. The current study assumed that no natural ventilation was set, and neglected artificial lighting and system loads. The study focused on energy consumption of cooling load.

3.2.3. Base case simulation results

Daylit Area : 64% of floor area .
(DA): 68% of time occupied .
Mean Daylight Factor (DF): 2.5% .
(cDA): 87% for active occupant behaviour
(UDI): 89% for active occupant behaviour.
Annual energy consumption level of cooling load: 6485 kWh .

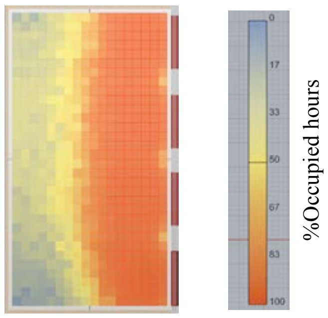


Figure 6. Daylight simulation results for the base case, occupancy 1680 hours per year

4. The Investigation

The tested EDS in the faculty of engineering building of [..] university, in [..] is climatically located in a hot arid climate based on Koppen classification. The façade of the EDS is oriented towards north-east with a Window-to-wall ratio (WWR) equal to 43%. The dimensions of the EDS are 16m X 8.6m, and its clear height is 3.6m, with a total area of 138 m2. The selected EDS is settled in the second floor of a four story building in the University.

Daylight model parameters (DIVA for Rhino) were set as follows:
Target illuminance for the EDS is 500 lux, Inner walls: Reflectance 50%, floor: Reflectance 20%, Ceiling: Reflectance 70%, Glazing: VLT = 80%
A Daylight Autonomy (DA) simulation was run on the 12 cases shown in table 1 where (F) refers to the different variations of the fundamental unit, (T) refers to the thickness; T1 = 2.5 cm, and T2 = 5.0 cm, and (D) to the Depth; D1 = 2.5 cm, and D2 = 5.0 cm.

The windows consist of a single layer of blue glass 6mm thickness with total solar transmission (SHGC) 0.62 and U-value 5.778 W/m2.K. The opaque wall consists from 0.02 m plaster, 0.25 m & 0.02 m plaster with U-value is 1.826 W/m2.K and all Ceiling, flooring & internal walls are set adiabatic. Natural ventilation & Lighting template are set off. Air condition default setting software were used where set point 23 °C m The occupancy is (3.40 m2/person), 12 cases were tested for an energy consumption kWh on an annual basis.

TABLE 1. The 12 cases tested

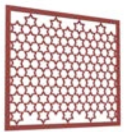
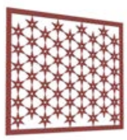
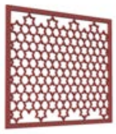
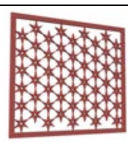
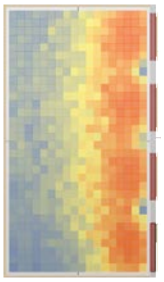
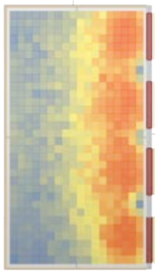
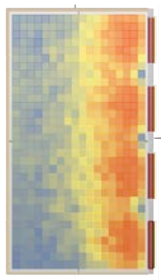
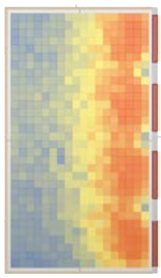
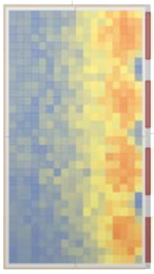
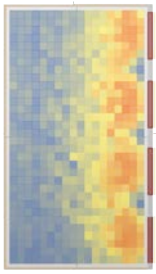
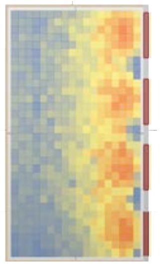
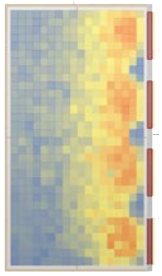
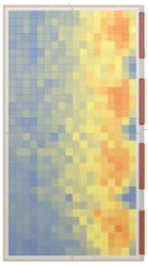
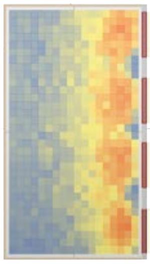
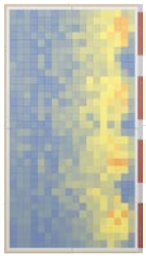
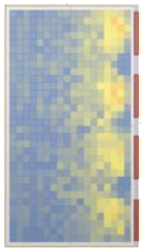
					
Case1 F1 - T1 - D1	Case2 F2 - T1 - D1	Case3 F3 - T1- D1	Case4 F4 - T1 - D1	Case5 F1 - T2 - D1	Case6 F2 - T2 - D1
					
Case7 F1 - T1 - D2	Case8 F2 - T1 - D2	Case9 F3 - T1 - D2	Case10 F4 - T1 - D2	Case11 F1 - T2 - D2	Case12 F2 - T2 - D2

TABLE 2. Daylight Autonomy (DA) & Annual Cooling Load simulation results

			
Case 1 Daylit Area :42% DA: 45%,DF: 1.3% cDA:73%, UDI:100% Cooling load:5533kWh	**Case 2** Daylit Area :41% DA: 44%,DF: 1.3% cDA: 73%,UDI:100% Cooling load:5326kWh	**Case 3** Daylit Area :40% DA:42%, DF: 1.2% cDA: 71%,UDI: 99% Cooling load:5389kWh	**Case 4** Daylit Area :41% DA: 45%,DF: 1.3% cDA: 73%,UDI:100% Cooling load:5392kWh
			
Case 5 Daylit Area : 26% DA: 31%,DF: 0.9% cDA: 62%, UDI: 95% Cooling load:5177kWh	**Case 6** Daylit Area :26% DA: 31%, DF: 0.9% cDA: 62%, UDI: 95% Cooling load:5201kWh	**Case 7** Daylit Area : 28% DA: 34%, DF: 1 cDA: 66%, UDI: 99% Cooling load:4959kWh	**Case 8** Daylit Area :24% DA: 32%, DF: 0.9% cDA: 65% ,UDI: 99% Cooling load:5443kWh
			
Case 9 Daylit Area : 24% DA: 32%, DF: 0.9% cDA: 64%,UDI: 98% Cooling load:5301kWh	**Case 10** Daylit Area :28% DA: 34%,DF: 1% cDA: 66%,UDI: 99% Cooling load:5332kWh	**Case 11** Daylit Area : 7% DA: 20%, DF: 0.6% cDA: 52%,UDI: 88% Cooling load:4750kWh	**Case 12** Daylit Area : 3% DA: 16% ,DF: 0.5% cDA: 46%,UDI: 77% Cooling load4603 kWh

5. Discussion of Results

The results showed that Case 1 provided the best daylight performance, as it includes the widest perforation ratio the pattern provides (F1) with the least depth and thickness values (D1 and T1), however, it had the highest energy consumption levels with 14% reduction than Base case. On the other hand, Case 12 had the lowest energy consumption levels 29% reduction, as the amount of shading in the space increased with the increase of the values of T and D (T2 and D2), and with using the lowest perforation ratio the pattern provides (F4), but had very low daylight levels. The case that provided a sufficient daylight level of DA 45% of occupied time, with 41% daylit area, and at the same time achieved a notable reduction in energy consumption levels of 17% less than the base case was Case 4. Though this case includes the lowest value of F for the star pattern (F4), meaning having the narrowest perforation inside the star geometry, it appears that it widens the perforation outside the star geometry to an extent that balances the whole perforation ratio of the pattern, providing sufficient daylight and at the same time significant reduction in energy consumption. This is also shown in Case 10, where using F4 provided the best daylighting values among the four cases that used the variables T1 and D2 (Cases 7, 8, 9 &10).

The study also showed that the slightest change in pattern geometry affects the daylighting and energy consumption levels. The differences between the four pattern variations is a few centimetres, however, each F value corresponded to a slight change in the daylighting and energy consumption results. On the other hand, the change in thickness and depth had a major effect on the results. As shown in Table (2), switching from D1 and T1 to D2 and T2 took the results to another level of both daylighting and energy performance.

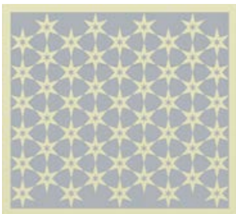


Figure 7. Case 4, IGP pattern the best case for retrofit

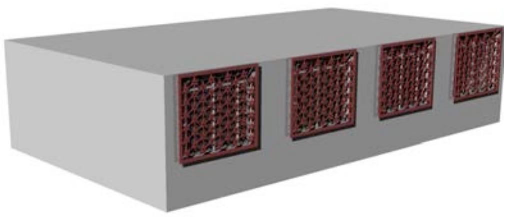


Figure 8. 3D model of the retrofitted façade

6. Conclusion

This study presented a retrofitting method to achieve sufficient daylighting levels and increase energy efficiency in an educational space. It showed the significance of using IGP shading screens for better daylighting and energy performances. Through a parametric setup for modelling and simulation, the study revealed the affordance of the geometry variations of the islamic geometric 6-point star pattern to affect daylighting and energy performances. It also showed the effect of the thickness and depth parameters over daylight and energy consumption values and the significance of balancing between those variables and the geometry itself. This has opened the way for further exploration of more complex IGPs with more geometry variations. We suggest that by the analysis of more complex geometries and consequently generating new ones, along with balancing the dimensional variables of the material used as thickness and depth, we can generate effective IGP formulas for facade retrofitting meant to enhance daylighting and energy performances of the space.

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