Parametric Mashrabiya as a Shading System for Optimized Daylighting in Egypt

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Abstract
The major drawback in hot climate zones is the high intensity of solar radiation, which produces undesired solar heat gain and influences indoor daylighting dispet the advantage of having enough natural lighting. Several attempts have been made to use Mashrabiya as an environmentally friendly architectural design element. This study presents a new methodology for optimizing parameters of parametric Mashrabiya oriented to the west in a hot arid climate in Cairo, Egypt. The study concentrates on the pattern parameters (Lattice) in the body part of the Mashrabiya, so it uses parametric design and simulation techniques to reach an optimal geometrical parameter for the patterns, which enhances the indoor daylighting and builds an Associative model for the Mashrabiya. The study also aims to investigate the influence of each parameter to find effective parameters on daylighting. Grasshopper for Rhino is used to generate the parametric variations. Ladybug and honeybee -Grasshopper plugins- for daylighting simulation. The methodology includes field experiments and simulation. The result of the study shows a significant impact of some parameters rather than others. Some cases achieve the required daylighting, which proves the advantage of using parametric Mashrabiya in façade treatment for sufficient daylighting in hot arid climates.

Keywords
parametric Mashrabiya, Daylighting, Optimization, Associative model.

1 Introduction

The world shares the same prevailing mission: to reduce energy consumption and pursue a sustainable development path for all (Feng et al. 2019). Presently, to solve the problem of indoor lighting, attention is focused on using artificial light sources. According to the IEA’s data, artificial light consumes about 2650 TWh of electricity per year (≈19% of world electricity production), exceeding the total amount of electricity produced by all nuclear power plants. (Burmaka et al. 2020). Reducing energy consumption and using natural daylight instead of artificial lighting should be taken into consideration. Mashrabiya is one of the environmental elements that can be built in different places. It can be defined as; an opening shielded with a wooden lattice for daylight, ventilation, aesthetics, and privacy appeal for places as shown in figure 1 (A. A. Bagasi and Calautit 2020). It is used to regulate the temperature and to block out direct sunlight. Mashrabiya also prevents undesirable direct solar gain in summer and permits solar gain to warm the building in winter. (Alqalami 2020).

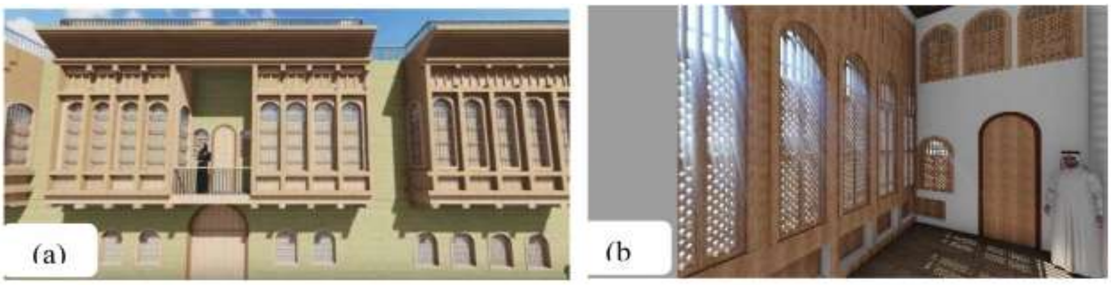


Figure 1 using Mashrabiya in modern design a: façade, b: indoor source: (Park 2021)

Some researchers have focused on using this concept of parametric design in some parts of Mashrabiya. Mohamadin (2016) has used a six-point star geometric pattern shading screen design in terms of daylight and energy performance. Emam and Giles (2016) assessed geometric patterns as shading screens and showed how the geometric patterns function as a design agency, environmental control system, and cultural element. They evaluated the performance of a screen inspired by a Persian pattern. Tabadkani and Banihashemi (2018) studied the parametric analysis of daylighting and visual comfort through a sun-responsive shading system to estimate the annual daylight metrics and indoor glare discomfort. Their approach can significantly improve the shading flexibility based on the LEED v4 certificate to operate glare and daylight metrics through a full-potential responsive pattern to reach the best visual comfort (Tabadkani, Banihashemi, and Hosseini 2018). However, there is no associativity method for the Mashrabiya in the research. They need to generate Mashrabiya with different techniques to allow the designer to control its parameters to improve daylighting. Besides the lack of improved design methods, the western façade has a major problem with its low-angle sun in the late afternoon and its significant heat gain into interior spaces (Napier 2015). The research only suggested supplying west façades with a reduced amount of glazing or using dynamic systems, which are expensive to apply and need special technical work to be perfectly done (Lu et al. 2019, Rizi and Eltaweel 2021).

Other investigates a model using machine learning-based. His adaptive façade units are dynamically adjusted based on the extracted discomfort states, allowing him to create a customized visual and thermal environment that improves visual and thermal comfort (Wang et al., 2022). Several attempts have been made to create an adaptive façade that considers thermal discomfort. The dynamic behaviors of the complicated shading system they proposed can improve energy performance by 19.9% and daylighting performance by 91.5% (Mangkuto et al. 2019, Wu and Zhang 2022). Other researchers used parametric design to investigate daylighting performance and glare for an office in Tehran. Their results demonstrated that adopting their proposed framework fulfilled the daylight requirements needed for LEED v4.1 by improving UDI by approximately 50% and reducing ASE by 100% over the baseline model (Khidmat et al., 2022). Considerable research has studied the impact of different control strategies for perforated curved or split louvers on visual comfort and energy consumption. They demonstrated that these strategies minimize the total energy consumption of the office space. The researchers argue that ensuring visual comfort and the best strategy match "blocking control" for the south façades, while fixed louver blinds (tilt angles of 60°) are better performed than active control strategies for the west façade orientation (Uribe et al. 2019, Alsukkar 2022). Other researchers used fixed shading devices as elements of the building's façade. Their adaptive option of simulation results suggested that all metrics in all zones can fulfill the performance requirement, with sDA300/50% $\geq$ 74% and ASE1000,250 $\leq$ 12%. (Martokusumo et al., 2017; Mangkuto et al., 2022). This study presents a new methodology for optimizing the pattern parameters for parametric Mashrabiya oriented to the west in an office building in a hot, arid climate in Cairo, Egypt. Figure 2 shows the use of mashrabiya, or the body part of it, in several designs. The study concentrates on the pattern parameters (lattice) in the body part of the mashrabiya. It uses parametric design and simulation techniques to reach optimal geometric pattern parameters, which enhance indoor daylighting by extracting their parameters. The study presents how Islamic geometric patterns are realized in the shading screens and the degree of daylighting performance in a hot climate that they provide for architectural spaces in new capital city office buildings. The study aims to investigate the influence of each parameter to find effective parameters on daylighting and present a framework for optimizing the Mashrabiya with its parameters. Grasshopper for Rhino was utilized to build the model and generate the parametric variations. Ladybug and Honeybee, Grasshopper plugins, for daylighting simulation (Goharian, Daneshjoo, and Yeganeh 2022). Some adjustments achieve the required daylighting levels with point-time illumination and useful daylight illumination. It shows the affordance of the parametric Mashrabiya in façade treatment for achieving sufficient daylighting in office buildings in hot, arid climates.

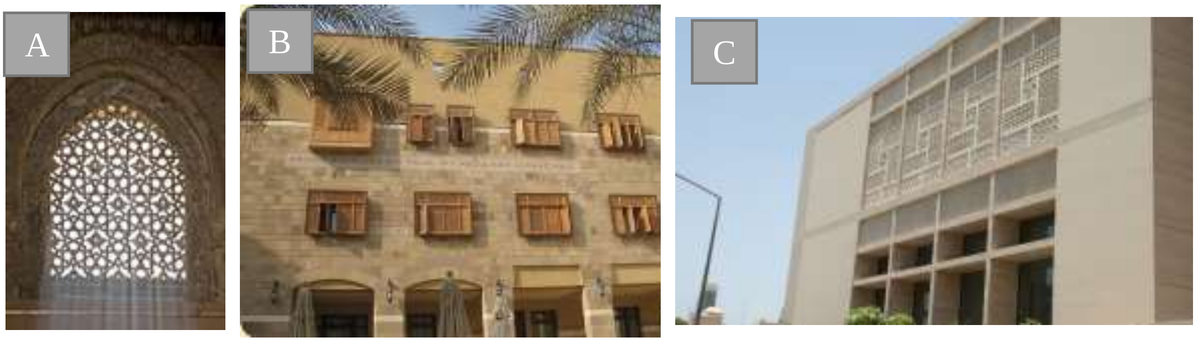


Figure 2 Using either Mashrabiya or just the body part of it with its patterns in Egypt; A: Ibn Tulum mosque Source: Mahmoud, H. T. H. (2017), B: AUC University, C: New Captial, (Source: researcher).

2 Parametric Mashrabiya

2.1 Parametric Design

Parametric design is a generic solution to a problem that includes both the problem and the solution (Woodbury 2010). Christopher Alexander used parametric design for the first time in 1977. He describes the detailed patterns for generating towns and neighborhoods, which can be called "language." It includes the first pattern-based knowledge (Alexander, Ishikawa, and Silverstein, 1977). The parametric design depends deeply on algorithms, as it contains pattern tools (Jabi 2013). Some authors have accordingly attempted to use algorithms to generate designs. It uses algorithms to repeat the patterns or generate the logic in configurable forms. The patterns have regular logic and a responsive structure. They started to understand and recognize patterns, which can be put to consistent use in algorithm development (Jabi 2013). In 1994, Christopher's book was used by computer scientists Ralph Johnson, Richard Helm, Erich Gamma, and John Vlissides in their book, which covers software design patterns. Hence, the power of parametric design is in formulating different designs or forms (Chien, SU, and Huang 2015). Afterward, Benjamin Aranda and Chris Lasch formed an algorithmic method in their book "Tooling," which practices scripts as a "Tooling" device. This work is self-organized as itinerant pattern structures. They produced a brief and intriguing set of patterns that provides high-level and succinct recipes for constructs (Lasch 2006). Robert Woodbury and his team develop and collect a comprehensive set of parametric patterns systematically (Jabi 2013). They selected the pattern's motif to distinguish its components' behaviors and to deliver new functions helpful for parametric design (Woodbury 2010). Algorithmic and parametric thinking extends beyond computer software and syntax. It is about logic, geometry, topology, and interaction. Therefore, some theorists describe parametric design by using classification systems based on the structures' mathematical properties (Sárközi, Iványi, and Széll 2017a). Jane and Mark Burry, for example, collect some projects in their book's chapters to demonstrate their mathematical concept and technique**.** The selected projects are varied in their parametric design techniques, such as optimization and topology, packing, and tiling (Burry and Burry 2010). Wassim Jabi embedded improvements in algorithmic approaches and higher-level parametric design strategies for the topologies' definition and the form's derivation (Jabi 2013). Depending on Gamma's work, in 2013, Khwaja and Alshayeb proposed a way to document design knowledge.

They added four types of pattern information: owner, author, pattern version, and language, which are necessary considered tools in pattern management (CHIEN, SU, and HUANG 2015). That improves the construction of a clear and simply usable topological classification for patterns of parametric design techniques (Sárközi, Iványi, and Széll 2017b; Fahmy 2021).

2.2 Generating Parametric Mashrabiya

Mashrabiya contains many parts. The projected part is created with a stone or hardwood cantilever, and the three sides of the projected part are shielded with finely turned wood pieces in a lattice pattern. This wood is built artistically to create different forms of diverse geometrical patterns. Wood is formed into circular surfaces to allow for easy air movement, resulting in better ventilation than rectangular surfaces. Mashrabiya can include solid wooden parts or embody glass to avoid cold in winter (Abdelkader and Park 2018). Parametric Mashrabiya is generated through a parametric technique where the relationships between objects are described semantically. Its components are not associated with a fixed distance. It does, however, include dynamic and uncertain element adjustments. Its geometries are formed to be strongly related to all other elements, where a specific variation leads to an adaptative and response model. That produces a highly dynamic and interactive model with interconnected and associative variables for the surrounding environment. Parametric Mashrabiya can simulate qualities through parametrically and algorithmically controlled generation processes. That captures the building as a dynamic set of forces. It can provide more dynamic descriptions of body patterns, indicating the morphogenetic processes. It is composed of three parts. The "taj" is located in the upper part and works as a shading device. The middle part, which has three sides, is called the body. A projected part can be found around 30 cm from the wall. Mashrabiya. Finally, the lower part of Mashrabiya is "the base." Mashrabiya's geometrical patterns appear to have an infinite number of variations. The pattern develops neither with stars nor with an end. Furthermore, The patterns are created by combining repeated geometric motifs to create intricate patterns on a symmetry group with a two-dimensional plane known as the wallpaper group (Park 2021). Geometric patterns were applied to perforated screens. Early examples of perforated screens (Mashrabiya) can be especially found in eastern architecture. These screens are fixed exterior panels that provide shading to the facade and privacy to the interior while allowing air movement around the structure. Daylight penetrates the spaces through perforated screens that allow light to filter into them. Such screens are not merely ornamental; their environmental performance is also significant (Emami and Giles 2016). Figure 3 demonstrates the part of Mashrabiya that can be used to extract the parameters of Mashrabiya. By analyzing the pattern part of the Mashrabiya, as it is the concern of this study, we find that the pattern has many parameters: the thickness of the screen, the width of the pattern, which indicates the opening ratio, and the motif design. The study uses the double pattern as a parameter in addition to the one-layer pattern.

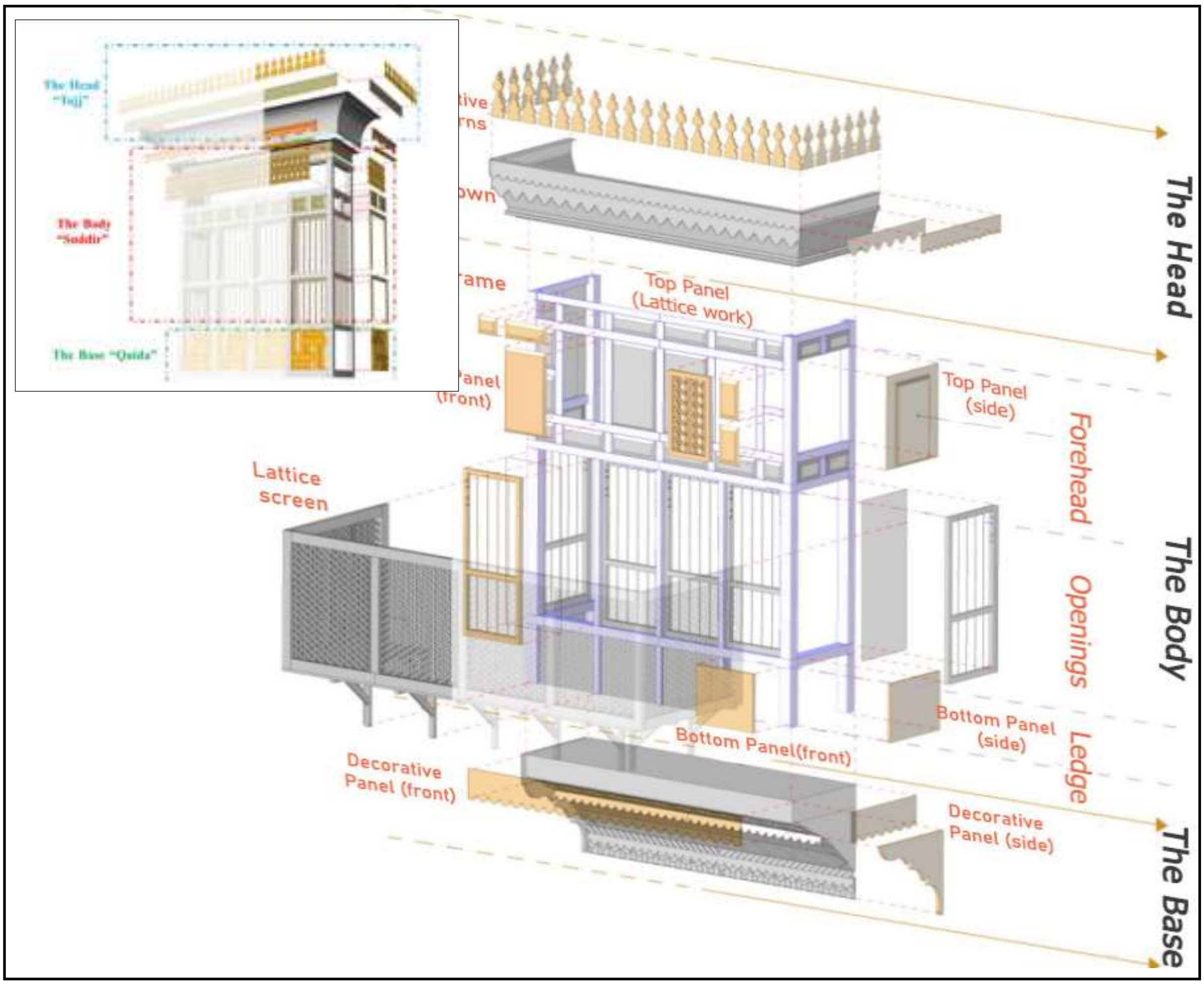


Figure 3 Mashrabiya Parts (Source: (A. Bagasi, Calautit, and Karban 2021)).

3 Methodology

The method is divided into four main stages with several processes. It begins by describing both models. Then, it clarifies the critical time and the weather analysis by using simulation for the location of the case study. Before the main optimization process is obtained, two stages are done. The first stage compares the results of field experiment and Simulation the second stage is simulating a one-layer pattern. The research compares the results of both the physical and simulated models on the 4th and 19th of April. The physical model is made to show the measurement in real site conditions, give a clear vision to help the researchers to complete the computational optimization, and demonstrate the similarities and differences between the results of both models, the tolerance between both mdel is calcoulated with stander division function. This stage is made with “one-layer pattern” as a sample for applying the parameters. becouse it is hard to apply changeable parameters in the physical model, as each change needs a new model. Then, the study simulates the same “one layer” with different thicknesses to choose the optimum one, which is used in the main optimization process for Mashrabiya parameters with the two-layer pattern. This stage contains six processes. Each process includes the examination of some fixed parameters and changeable parameters. The study extracts the parameters for the stages as follows: distance between layers, the thickness of layers2, pattern design1, pattern design 2, the thickness of layer1, and the angle of the pattern cut. Selecting and extracting the parameters depend on the objective of the study and the usage of the parameters. As the research aims at optimizing daylighting through the optimum pattern design, the study chooses the most effective parameters for the pattern configuration and daylighting optimization. The optimization stages are computationally done using Grasshopper as computational optimization is easier to apply, and the study can choose a different time for optimization, unlike the physical model.

3.1 Model description.

3.2 Physical model and Field Measurements

The model is a box with dimintions of (0.7 m, 0.5 m, and 0.3 m in height). The box has a west-facing opening. This model was attached to a tripod and balanced with the aid of a level. Then, the box's accurate direction was confirmed by utilizing a compass. The interior surfaces, the ceiling, and the floor are white-colored to achieve the utmost reflection of sunlight inside the space. The experiment is made at 15:00 PM on the 4th and 19th of April 2021, with a clear sky and sun. The point-in-time illumination was measured to compare the performance of different points. The reading points have been set in the middle (start – middle – end) using Light Level Sensor PS-2177 see Figure 4.

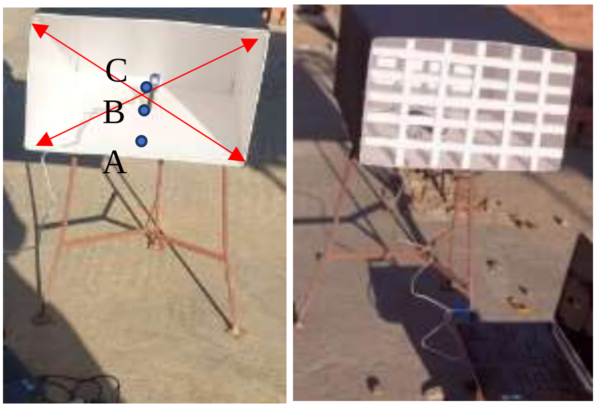


Figure 4 photos of the physical model; A: Model without shading A, B, C are the tested points, B: Model with shading system includes one layer (Source: researcher).

3.3 Base Simulation Model and Input Data

The model was built using Grasshopper and Rhinoceros 3D software with dimensions (5m length x 7m width x 3m height). Figure 5 shows the details of the model with its extracted parameters. For parametric design and daylighting analysis, honeybee and ladybug Grasshopper plugins are used. For worst-case conditions, no surroundings have been built, so consider any possible direct sunlight entering the zone. The first step as shown in Figure 6is sun path simulation analysis for the main Critical time for the West elevation is between 12:00-17:00 PM and the hottest hour is 15:00 PM.

<u>Sittings of Simulation Process:</u>

A. Model dimensions 5.00 m * 7.00 m and 3.00 m Hight with window wall ratio 90 %.
B. Point time illuminance: for comparing the results of the physical model and simulation, the simulation for the one-layer pattern model is made on April 4th, and 9th at 15:00 PM (the same time as the experiments) to make the comparison. Otherwise and for the other simulation stages, the two months of the year were chosen, the 21st of August and the 21st of January, At 15:00 PM to optimize the parameters in the summer and winter months. the measurement is for three points (A, B, C) see Figure 5.

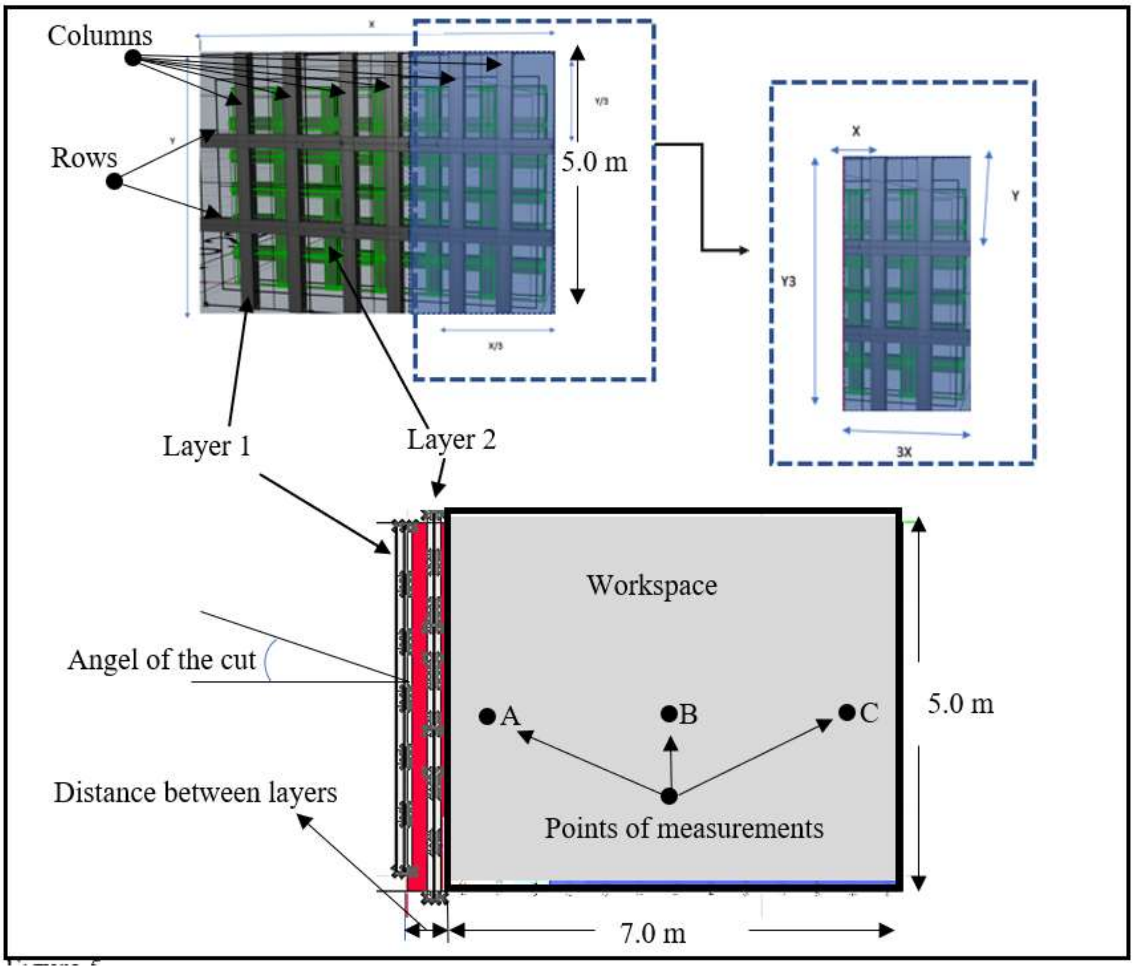


Figure 5 is the description of the simulation model components (Source: researcher).

3.4 Weather analysis

Before the simulation and optimization process are done, weather analysis should be made, such as the analysis of the critical time in the western façade. There is a clear temperature difference between summer and winter and large diurnal temperature differences. The model was built using Grasshopper with the main Critical time for the West façade the simulation as shown in Figure 6 it shows the sun angles and sun temperatures in the

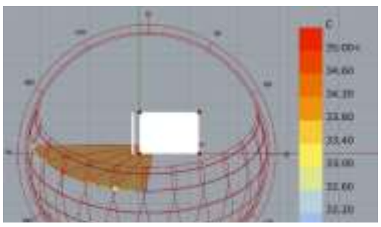


Figure 6 critical time for simulation (Source: researcher).

western façade in Cairo, in addition the critical time of the hottest sun temperature.

3.5 Comparison Between Field Experiment and Simulation Results

The comparison is necessary to show the difference between both models' results and permit the use of computational simulation. The field experiment also gives a real vision for the measurements in real-world environmental conditions. It is made for a model with one layer pattern only at two different times in April becouse the physical models are not as flexible as the simulated models, in the term parameters adjustments changeability, which is necessary for the optimization process. In both models, three testing points are chosen; A, B and C -see figure 4 and Figure 5-. Finally, a chart for both results is made then the tolerance is determined by calculating the standard deviation function for the differences.

3.6 Simulation for one layer

The first simulation is for a one-layer pattern to determine the optimum width needed in the next stage. The simulation is run for the western façade at 15:00 PM. On August 21st. the simulation is run for three different widths; 0.4, 0.3, and 0.2.

3.7 Simulation Processes for double layers with Variable Parameters

The study concentrates on the lattice (pattern) part in the body of Mashrabiya. Figure 5 shows the parameters of the pattern part containing the distance between layers, layer thickness, distinctive design for the columns and rows, and the angle of the pattern cut. Two different pattern designs are examined with different thicknesses as the study describes in the “parametric Mashrabiya part”. The parameters are studied in 5 case studies each one including two or three different types. Table 1 shows the sequence of examined cases and the adjustment parameters for each case. For example, case one includes three types; A, B, and C. This case examines the impact of changing the distance between the layers. So, all other parameters are fixed except the “distance between layer” change between the three cases. Hence, the optimum thickness is determined. The same is applied to the other cases. In each case, the study fixes all the parameters except the examined paramere, which is changed through the different types of cases. These examined parameters are ordered as the following:

A. The Distance Between Layers
B. Thickness Of Layer 2
C. Different Thicknesses Pattern Design 1
D. Different Thicknesses with Pattern Design 2
E. The thickness of Layer 1
F. Angles Of the Pattern Cut

Table 1 demonstrates the sittings and chosen parameters for each case the √ and cells shaded demonstrate a selection of the item CN refers to Columns number and RN refers to Rows number. (Source: researcher).

Changeable parameters (Stage name)			Design					Distance between layers			Tackiness Of Layer1		Tackiness Of Layer1	
			First layer			Second layer								
			CN=5, RN=3	CN= 3, RN=2	CN=2, RN=2	CN=4 RN=3	CN=2, RN=2	0.0 m	0.1 m	0.2 m	0.2 m	0.15 m	0.2 m	0.1 m
Case1	Impact of the distance between layers	A	√			√		√				√		√
		B	√			√			√			√		√
		C	√			√				√		√		√
Case 2	Changing the thickness of layer 2 with 5 columns and 2 rows	A	√			√				√		√		√
		B	√			√				√		√		√
		C	√			√				√	√			√
Case 3	Different thicknesses with 3 columns and 2 rows	A		√		√				√	√			√
		B		√		√				√		√		√
Case 4	Different Thicknesses with 2 Columns and 2 Rows	A			√	√				√	√			√
		B			√	√				√		√		√
Case 5	Changing the Thickness of layer 1	A			√	√				√	√			√
		B			√		√			√	√		√	
Case 6	Angles Of the Pattern Cut	A			√		√			√	√		√	
		B			√		√			√	√		√	
		C			√		√			√	√		√	

3.8 Evaluation parameters

Useful Daylight Illuminance (UDI): UDI UDI is a modification of Daylight Autonomy. It provides full credit only to values between 100 lux- 2,000 lux suggesting that horizontal illuminance levels outside of this range are not useful. Useful daylight illuminance (UDI) is the ratio of the number of hours in the year, when illuminance provided by daylighting is within a useful range, to the total number of occupied hours in a year. UDI aims to determine the daylighting level that is neither too dark nor too bright UDI is usually presented by three metrics: UDI 2000 lux. The illuminance range which is considered useful is between 100 lux to 2000 lux. Illuminance below 100 lux is considered too dark, and illuminance above 2000 lux is considered too bright. (Mardaljevic et al. 2012; Samadi et al. 2020) as shown in figure 7.

Figure 7 legend bar for the simulation (Source: researcher

3.9 Spatial Daylight Autonomy sDA

It is the best metric to describe annual daylight sufficiency in a space (Heschong, Wright, and Okura 2013). It was proposed by IES Committee as the percentage of the tested area that gets the accepted illuminance specified for a space for a specified percentage of occupied hours per year (IES, 2012). it is calculated by how much area gets 300 lux for 50% or more of the occupied hours per year, which is the evaluation equation to calculate sDA. For LEED V4 and IES, sDA is categorized as described in Table 2 (Salem and S.E. Ismaeel 2016; Elghandour et al. 2019). All the simulations follow the legend bar in Figure 8.

sDA 300 lux/50%	LEED V4 Points	IES
sDA ≥ 55%	2	accepted
sDA ≥ 75% or more	3	preferred

Table 2 LEED V4 and IES requirements for sDA (Source: researcher).

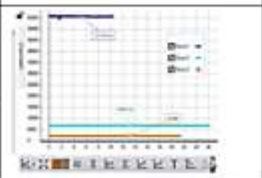
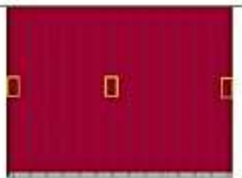
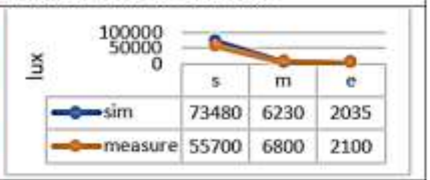
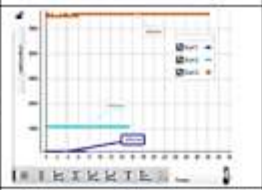
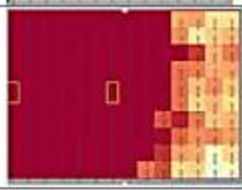
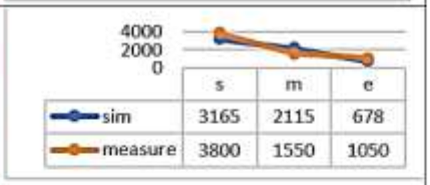
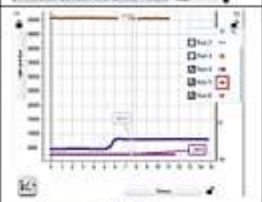
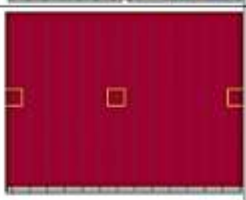
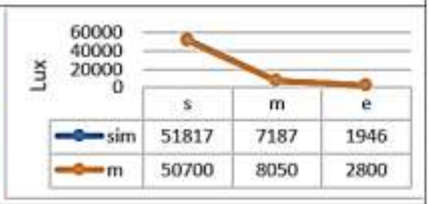
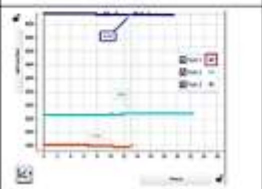
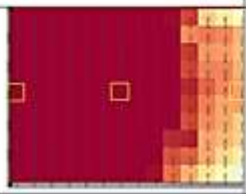
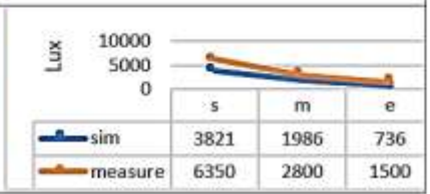
4 Results and Discussion

4.1 Comparing experimental and simulation results

The first stage of the methodology is to compare the experiential results with the simulation. This stage allows us to calculate the tolerance of the simulation and to apply the model in a real environment see

Table 3.

Table 3 Comparison between the experimental results and simulation (Source: researcher).

	Expremant	Simulation	Comparing the experminal results with simulation
Average of Week 1 Without Shading			 lux; s / m / e; sim: 73480 / 6230 / 2035; measure: 55700 / 6800 / 2100
Average of Week 1 With Shading			 s / m / e; sim: 3165 / 2115 / 678; measure: 3800 / 1550 / 1050
Average of Week 2 Without Shading			 Lux; s / m / e; sim: 51817 / 7187 / 1946; m: 50700 / 8050 / 2800
Average of Week 2 With Shading			 Lux; s / m / e; sim: 3821 / 1986 / 736; measure: 6350 / 2800 / 1500

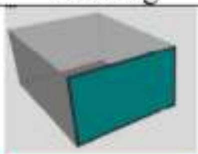
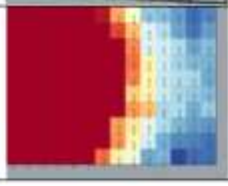
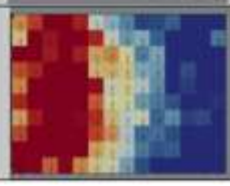
The illuminance value is determined in three different points for both models. The results obtained from the comparison are presented in Table 2. It shows significant similarities between the two techniques. The changing rate is about 19% by calculating the stander division for the differences. It shows that the shading devices need some improvements while enhancing the daylighting. However, it needs to be optimized.

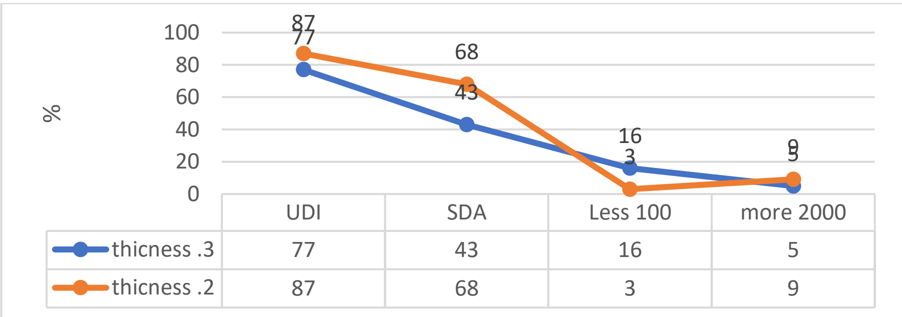
4.2 Pattern With one Layer

This stage examines applying a shading system with one layer of pattern with the simulation of three different widths; 0.2 m, 0.3 m, and 0.4 m. the results show that 0.2 m and 0.3 m deliver the best distribution of daylighting rather than 0.4m which have darkness spot at the end of the space see The figure shows that the pattern with 0.2 has better values for the UDI and SDA. So, this thickness is used in the next stage of simulation to determine the optimum parameters which deliver the best metrics values.

Table 4. So, both widths can be used in the next stage. the study simulates the UDI and sDA for both cases see Figure 9. The figure shows that the pattern with 0.2 has better values for the UDI and SDA. So, this thickness is used in the next stage of simulation to determine the optimum parameters which deliver the best metrics values.

Table 4 simulation one layer pattern with different widths (Source: researcher).

	Without shading	Width = 0.2 m	Width = 0.3 m	Width = 0.4 m
Shading form				
Iluminunce Distributio in LUX				



	UDI	SDA	Less 100	more 2000
thicness .3	77	43	16	5
thicness .2	87	68	3	9

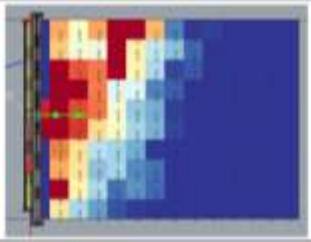
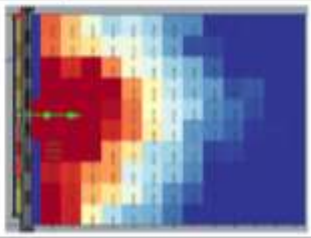
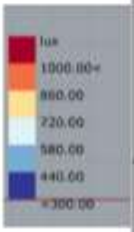
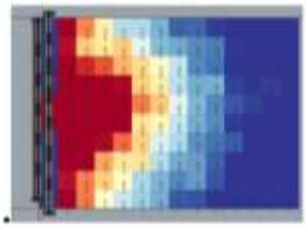
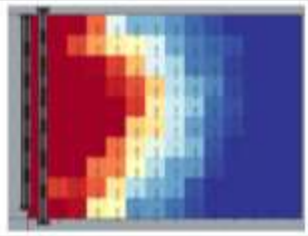
Figure 9 UDI and sDA for the pattern with one layer, it is simulated for three different thicknesses; 0.2m, 0.3m thicknesses (Source: researcher).

4.3 Impact of the distance between layers

After applying the "one layer" pattern, the case of double layers is optimized with its different parameters. The study optimizes each parameter in the sequence described in the method part. The first parameter is the distance between the layers, which optimizes the distance between the layers by simulating three cases with different thicknesses; 0.0

m, 0.1 m, and 0.2 m while fixing parameters: Thickness of layer 1 = 0.2 m, Thickness of layer 2 = 0.2 m, pattern design: number of columns =5, number of rows = 3. see Table 5. The results show that case 1C -Distance between layer = 0.20 m- has the best results from the three cases. Its UDI = 50.5 % and SDA = 19 .2%. But it still provides the space with insufficient day lighting. Therefore, the other parameters are optimized while fixing the distance with 0.2m. see table 4.

Table 5 shows the results of applying different distances between layers on UDI and sDA(Source: researcher)

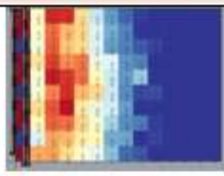
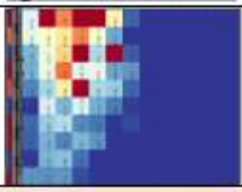
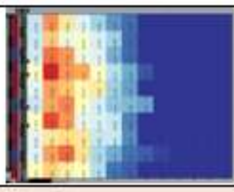
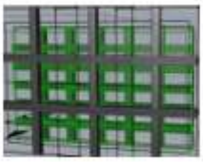
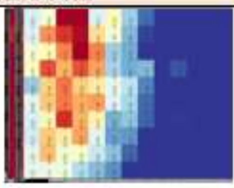
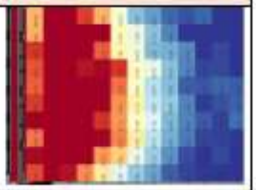
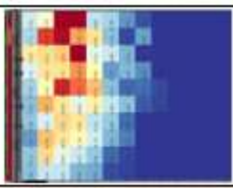
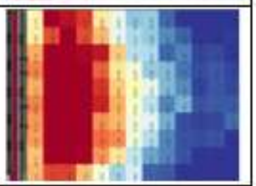
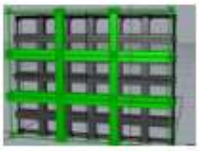
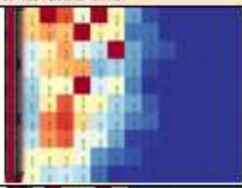
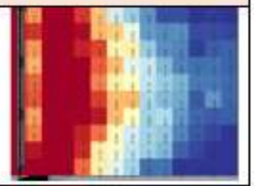
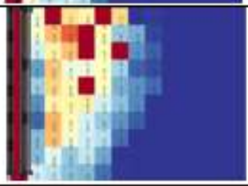
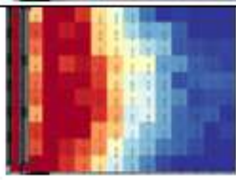
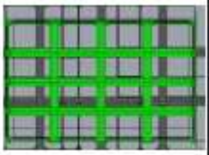
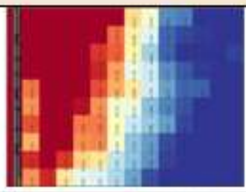
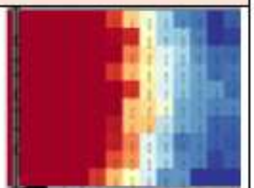
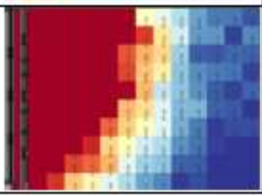
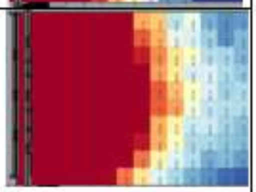
Parameters	Model	Winter illuminance	Summer illuminance
Applying different distances between layers			
Case1 A Layer thicknesses= 0.2 m Distance = 0.0 m UDI = 40 .15% SDA =14.3 %			
Case 1 B Layer thicknesses= 0.2 m Distance = 0.10 m UDI = 37.7% SDA = 5.7%			
Case 1 C Layer thicknesses= 0.2 m Distance = 0.20 m UDI = 50.5 % SDA = 19 .2%			

4.4 Double Layers' Pattern Parameters Effect on The Daylighting

In this stage, two different thicknesses of layer 2 are simulated with different pattern designs applied by changing the count of the pattern columns and rows. Table 1 shows the settings for each simulation process. It shows the sequence of the parameter's selection. the proof that the depth of the change in the Layer 2 thickness is not notably effective as it has no significant change in the values. The most effective parameter is the pattern design. the pattern width is also an effective parameter see The figure shows that the pattern with 0.2 has better values for the UDI and SDA. So, this thickness is used in the next stage of simulation to determine the optimum parameters which deliver the best metrics values.

Table 4

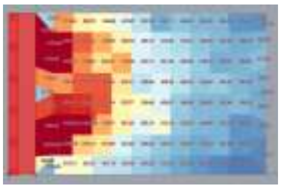
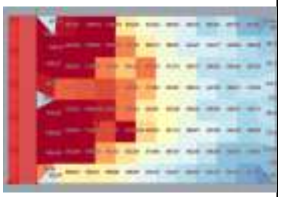
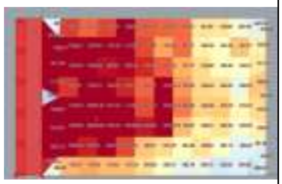
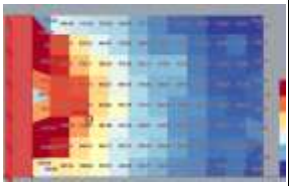
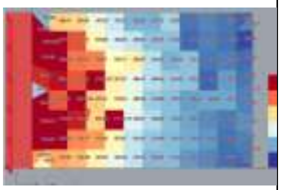
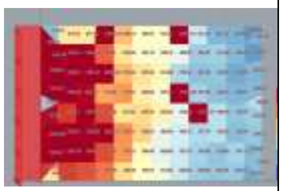
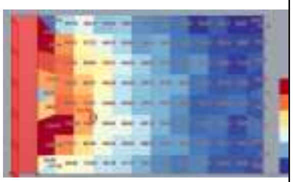
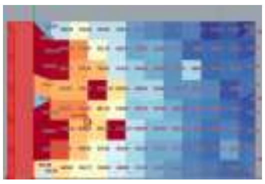
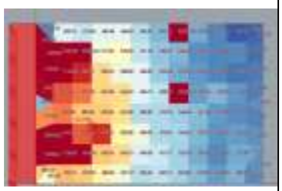
Table 6 Applying sequential different simulations to optimize the Mashrabyia parameters (Source: researcher)

Fixed distance between layers 0 .2		Winter ilumninuce	Summer iluminunce
A. Changing the thickness of layer 2 with 5 columns and 2 rows			
Case 2 A *Layer 1 thickness = 0.1 m* *Layer 2 thickness = 0.15 m* *Design= 5 columns and 2 rows* *Distance =0.2 m* ***UDI =54% , SDA =11.4%***			
Case 2 B *Layer 1 thickness = 0.1 m* *Layer 2 thickness = 0.2 m* *Design= 5 columns and 2 rows* *Distance =0.2 m* ***UDI=45.3%, SDA=17.4%***			
B. Different thicknesses with 3 columns and 2 rows			
Case 3 A *Layer 1 thickness = 0.1 m* *Layer 2 thickness = 0.2 m* *Design= 3 columns and 2 rows* *Distance =0.2 m* ***UDI = 70%, SDA = 40%***			
Case 3 B *Layer 1 thickness = 0.1 m* *Layer 2 thickness = 0.15 m* *Design= 3 columns and 2 rows* *Distance =0.2 m* ***UDI = 67%, SDA= 37.4%***			
C. Different Thicknesses with 2 Columns and 2 Rows			
Case 4 A *Layer 1 thickness = 0.1 m* *Layer 2 thickness = 0.2 m* *Design= 2 columns and 2 rows* *Distance =0.2 m* ***UDI =75%, SDA = 55%***			
Case 4 B *Layer 1 thickness = 0.1 m* *Layer 2 thickness = 0.15 m* *Design= 2 columns and 2 rows* *Distance =0.2 m* ***UDI = 70%, SDA = 52%***			
D. Changing the Thickness of layer 1			
Case 5 A *Double layers* *Layer1 thickness=0.1* *Layer2 thickness=0.2* ***UDI= 81%, SDA =57.7%***			
Case 5 B *Double layers* *Layer1 thickness=0.2* *Layer2 thickness=0.2* ***UDI = 87.1%, SDA= 65.6%***			

4.5 The angle of the cut

As described in the method, the study tests the angle of the pattern cut. For more enhancement, the study changes the angle of the cut in summer as it is more problematic. It applies three different pattern cut angles with one layer; 0°(base case of pattern cut angle), 15°, and 18°. Pattern cut angle is one of the most effective parameters, as shown in Table 7. It enhances the distribution of daylighting beside the acceptable values for the UDI and sDA

Table 7 changes the angle of the pattern cut (Source: researcher)

A. Changing the pattern cut			
	3:00 PM	4:00 PM	5:00 PM
Case 6 A Pattern shaped layers Angle of the cut =0° Layer1 thickness=0.2 Distance =0.2 m **UDI = 78.6%** **SDA = 56.3%**			
Case 6 B Pattern shaped layers Angle of the cut =15° Layer1 thickness=0.2 Distance =0.2 m **UDI = 77,1%** **SDA = 55.1%**			
Case 6 C Pattern shaped layers Angle of the cut =18° Layer1 thickness=0.2 Distance =0.2 m **UDI = 65%** **SDA = 41.5%**			

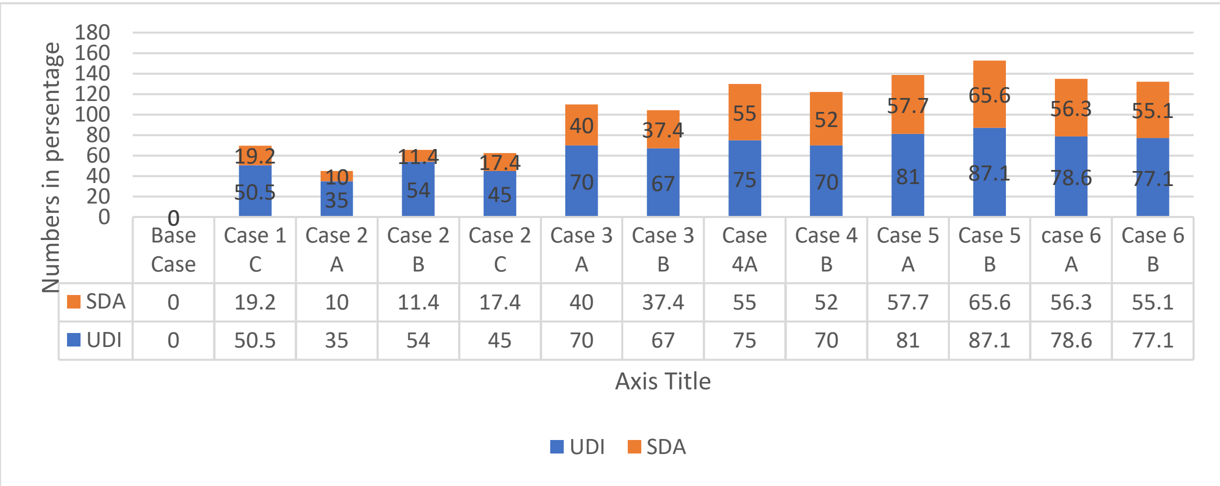
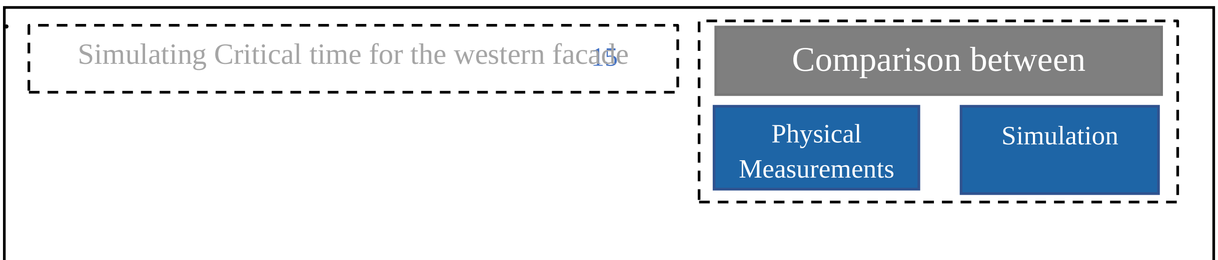


Figure 10 compares the results of the cases (Source: researcher)



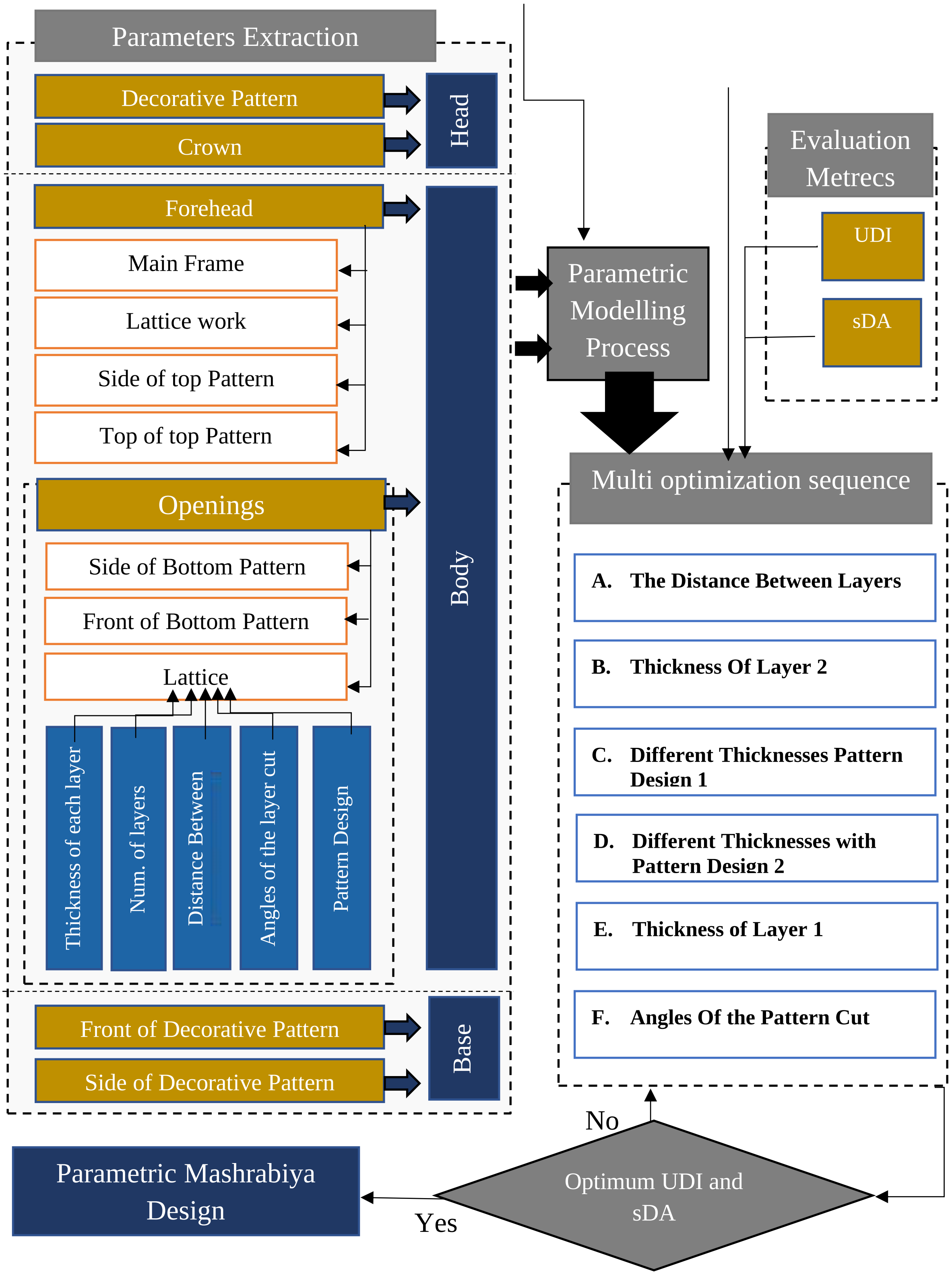


Figure 11 framework of optimizing parametric Mashrabiya (Source: researcher)

By applying the physical model, All cases with one layer pattern deliver unacceptable daylighting results. Some parameters have a great effect, such as the effect of the pattern depth, number of layers, and pattern design while other parameters have an insignificant effect, such as the thickness of each layer. Moreover, the angle of the pattern cut enhances the daylighting distribution and values for the UDI and sDA. Figure 10 includes the comparison between the case studies. It shows that cases 4 (A, B), 5 (A, B), and 6 (A, B) have acceptable results for UDI and sDA. Case number 5 B, with double layers, pattern depth = 0.0 m, Layer 1 thickness = 0.2 m, and Layer 2 thickness = 0.2 m, has the best results. Moreover, the angle of the pattern cut enhances the daylighting distribution and values for the UDI and sDA

5 Conclusion

This study presented a method to achieve sufficient daylighting levels for office spaces oriented to the west by using parametric Mashrabiya. This enables control of the parameters of Mashrabiya, which shows the significance of using parametric design for improving Mashrabiya as a shading screen for better daylighting. The study starts by comparing a physical model and a simulated model with the one-layered pattern. The tolerance is 19%. Then, the study extracts the parameters of the Mashrabiya and builds a model using Grasshopper. It revealed the affordance of the geometric variations of the pattern to affect daylighting. We study the effect of different parameters by using a simulation sequence. Using the best result of a stage in the stage after enhancing the results and leading to the optimum solution, the best result is for Case 5 with double layers, 0.2 m for each layer thickness, and a 02 m distance between layers. It generates UDI of 87.1% and SDA of 65.6%.Figure 11 shows the framework for optimizing parametric Mashrabiya. This framework can be followed in optimizing different parts of Mashrabiya. It can be used to optimize more parameters for the rest of Mashrabiya to enhance indoor daylighting.

This study presented a method used with parametric Mashrabiya to achieve sufficient daylighting levels for office spaces oriented to the west, which enables control of the parameters of Mashrabiya and shows the significance of using parametric design for improving Mashrabiya as a shading screen for better daylighting. The study starts by comparing a physical model with a simulated model with a one-layered pattern. The difference in tolerance between both models is 19%. Then, the study extracts the parameters of the Mashrabiya and builds a model using Grasshopper. It revealed the affordance of the geometric variations of the pattern to affect daylighting. We study the effect of different parameters by using a simulation sequence. Using the best result of a stage in the next stage enhances the results and leads to the optimum solution. The best result is for Case 5 with double layers, 0.2 m for each layer thickness, and a 2 m distance between layers. It generates UDI of 87.1% and SDA of 65.6%. Figure 11 shows the framework for optimizing parametric Mashrabiya. The proposed framework can be followed to optimize different parts of Mashrabiya. It can also be used to optimize more parameters for the rest of Mashrabiya par to enhance indoor daylighting.

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