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ORIGINAL ARTICLE

The role of fenestration in promoting daylight performance. The mosques of Alexandria since the 19th century

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Abstract Mosques have always been sacred places with distinctive sustainable environments. Fenestration in the prayers' zone whether clerestories, screened windows, dome lighting and other light features have managed to produce significant spiritual human comfort areas. This paper focuses on fenestration of divine mosques and relates them to promoting daylight performance. The research process emphasizes the importance of daylight performance by promoting simulation tools on historical mosques of Alexandria since the 19th century that has witnessed change over time. The paper is a step toward sustainable lighting schemes in prayers' zones that help to achieve human comfort as well as minimize use of energy. This study aimed at investigating the daylight performance by the use of climate based daylighting metrics which is "Daylight Autonomy" (DA). Daylight Autonomy is evaluated in the year round for the day lighted prayer periods to evaluate the behavior of fenestration of the different selected sample of mosques since the 19th century in Alexandria on a simulation tool in order to check whether it complies with the required illuminate and glare levels. The research findings are an attempt to lead to performative design guidelines introducing a contemporary interpretation for use in enhancing new designs of these holistic buildings.

1. Introduction

Islamic architecture has been known for spatial relations, environmental and climatic solutions. Since the late 19th century during the Mohamed Aly era, mosques were constructed combined with mausoleum. Then rulers invested in renovation of these complexes whether in Ottoman, Neo-Moorish, Gothic Revival, and Neo-Mamluk, to Eclectic until Italianate and yet environmental conditions are to be questioned. Building construction methods have changed and conservation has taken its way. It is not known whether the passive solutions from this era which is considered a transit period with less lavish buildings were better or not. Recently, there have been a lot of conservation actions unknown if it complies with these conditions.

Mosque designs have always managed sustainable building envelopes. The prayers envelope whether walls, floors, roofs,

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fenestration and doors with the historic features such as courtyards, "mashrabiya", "shokhshekha", clerestories, and roof openings have managed to produce a significant and inspirational human comfort zone. The floor materials; roofs with openings; walls with windows; and clerestories were designed with care. Conservation of these buildings whether reconstructed, restored, rehabilitation, or preservation has changed some of these Islamic features such as courtyards, clerestories and lantern skylights "shokhshekha" hence reducing daylight performance which has always been a major privilege in sustainable design.

Some studies have shown that the best daylighting is top daylighting, and clerestory windows that can be used to increase the effective height of transom lights without increasing window-to-wall ratio (WWR) [15]. Generally, clerestories which are defined as vertical windows, located on high walls, extending up from the roofline, can manage to allow light and breeze into a space, without compromising privacy. Even relatively low WWR provides more than ample natural daylighting, if properly oriented and directed. "Natural daylighting in architecture was a lost art for many years," says Fronek. "Before we had dependable artificial lighting, offices and classrooms had tall ceilings for tall windows and clerestory glazing. Buildings had light wells and courtyards to get bi-directional lighting. Those buildings maximized daylighting by necessity. We need to get back to those design principles" [15]. Recently, daylighting system includes Daylight-optimized building footprint, Climate-responsive window-to-wall area ratio, High-performance glazing, Daylighting-optimized fenestration design, skylights (passive or active), Tubular daylight devices, Daylight redirection devices, Solar shading devices, Daylight-responsive electric lighting controls and Daylight-optimized interior design such as furniture design, space planning, and room surface finishes [2].

Daylighting is an energy-efficient strategy that includes many technologies and design philosophies, and many elements of a daylighting operation will likely already be part of a building design or retrofit [2]. These technologies could include exterior shading and control devices to diffuse natural light and such devices include light shelves, overhangs, horizontal louvers, vertical louvers, and dynamic tracking of reflecting systems. Gazing materials such as using glass with a moderate-to-low shading coefficient and relatively high visible transmittance are the simplest method to maximize daylight. Also, aperture location plays an important role in the depth of daylight penetration which is about two and one-half times the distance between the top of a window and the sill [2]. The reflectance values from room surfaces will also significantly impact daylight performance and should be kept as high as possible. It is desirable to keep ceiling reflectance over 80%, walls over 50%, and floors around 20% [2].

Unfortunately, architectural conservation in Egypt describes the process through which the material, historical, and design integrity of humanity's built heritage are prolonged through carefully planned interventions, according to the Egyptian Law 144 for Heritage Conservation [11]. Only little legislation restricts environmental considerations. Based on the Housing and Building National Research Center [7,8], different choices of glazing transmittance and interior reflections were proposed for the different window ratios and Projection Factor (PF). Modifications within 25% of fenestration in residential and commercial buildings are permitted [7,8].

This research adopts an inductive methodology, by which the issue of admitting natural daylight into religious buildings is examined and elaborated upon. The detailed inquiry is aimed at revealing the range of variables and parameters which together affect this matter and hence the performance, quality and human comfort of interior spaces and zones. An experimental approach is presented in this study whereby the architectural features that interact together to promote daylight autonomy are examined to determine their role in achieving higher efficiency and better performance of natural lighting. The study and technical measuring is achieved through the use of modeling and simulation software, Diva plugged into Rhino. This digital tool has primarily allowed a quantitative analysis and facilitated the systematic appraisal of lighting levels and value. It is also useful for the cross-comparison of different architectural solutions in order to assess their efficiency. Based on the outcome of this review, a set of recommendations and guidelines are formulated and presented at the end of this paper.

This paper consists of five consecutive parts. First, the mosque design and daylighting techniques are defined. Next, the relationship between daylighting in mosques and simulation tools is examined in order to understand their association and their mutual impacts. The third part is a review of a sample of local mosques renovated or reconstructed in the 19th century in the city of Alexandria. A simulation tool was used to record readings of daylight autonomy in each of them. The fourth part is an application of the main notions of daylight autonomy on the selected local mosques. The fifth and final part has a recap on the main issues raised through this study and a set on concluding remarks, general recommendations and guidelines for designers.

This research aimed to constitute a daylight-based architectural design knowledge which could promote the preservation of the built heritage as well as help support the contemporary environmentally friendly design of mosques. Building design using daylight system is considered as having excellent passive lighting design [3]. According to Whole Building Design Guide (WBDG) [2] daylighting is the controlled admission of natural light dash; direct sunlight and diffuse skylight. The amount of daylight penetration into a building through sunlit area from windows and door openings provides dual functions not only of admitting natural light into the indoor area but also allowing the occupants to have visual contact with the outdoor environment [5]. For daylighting, window size and spacing, glass selection, the reflectance of interior finishes, and the location of any interior partitions must all be evaluated.

1.1. Daylighting in Mosques

There have been very few theories regulating mosque design. Recently, most of the studies have concentrated on size and architecture style rather than function. Diffusion of light by decorative features has also taken a share of studies [16]. From the very few studies on daylighting through fenestration in mosques there are a few guidelines to consider. If from walls, daylight is not preferred to enter from the wall where the "kebla" is located where prayers face, due to intensive glare [10]. In Egypt the "kebla" indicated by the "mehrab" is mostly south/east. According to Khlousy [10] north fenestration and south fenestration are considered suitable, as for east fenestration they are the most preferred.

Clerestories closer to the ceilings are better for daylighting to penetrate inside interior space. The daylight window should start at almost 2.30 m above the finished floor and have a high visible light transmission (VLT) (50–75%); the view window should be placed lower and have a VLT of less than 40% in most climates [2]. The higher the "shokhshekha" (sometimes named as lantern skylight) represented by a ring of openings at the base of the dome (or any other form) the better it is for prayers because daylight has more chance of being diffused until it reaches the prayers. According to WBDG [2] it is recommended to increase perimeter daylight zones—extend the perimeter footprint to maximize the usable daylighting area. It is also recommended to allow daylight penetration high in a space. Windows located high in a wall or in roof monitors and clerestories will result in deeper light penetration and reduce the likelihood of excessive brightness.

1.2. Simulation tools for daylighting performance

Developments in computational design and simulation applications are providing methods to improve current design practices, since the uncertainties about various design elements can be simulated and studied from the design inception. Building performance simulations aid in investigating design options and the overall building performance and are an integral part of the design process for high-performance buildings [1].

One of the primary advantages of simulation tools is that they are able to provide researchers with practical feedback when designing real world systems. Another advantage is by approaching a system at a higher level of abstraction, and the designer is better able to understand the behaviors and interactions of all the high level components within the system. In other words, as the designer better understands the operation of the higher level components through the use of the simulator, the lower level components may then be preserved and subsequently simulated for verification and performance evaluation.

2. Case study description

A selected sample of six significant mosques rebuilt or restored since the 19th century was studied on a simulation tool to compare DA in the prayers area to find out which complied most with best human comfort during "zuhr" and "asr" prayers (which are the second and third of the five daily performed prayers practiced by Muslims). Daylight during these two time periods is at their highest levels. The optimal mosque was then studied in terms of fenestration parameters which were peripheral WWR, clerestory to wall ration, "shokhshekha" openings, in order to reach a suitable bench mark for mosque fenestration that achieved human comfort and energy saving.

2.1. Brief history of the selected mosques

2.1.1. El Bosseri mosque

The first and second mosques chosen for the study were of El Bosseri Mosque (Fig. 1) located in Alexandria's beachfront in the "Anfoushy" neighborhood facing Mursi Abul Abbas Mosque. The mosque was first a mausoleum of El Imam El Bosseri who was a poet, writer and a "soufey" imam that died

Figure 1 El Bosseri Mosque.

in 1295 AC then a small mosque "saweya" was later built at the corner of the mausoleum until the current mosque was constructed in 1858 AC (BA Alexandria and Mediterranean Research Center (Alex Med) and the Egyptian Ministry of Awqaf [4]). In 2002 the mosque was restored without changing any of its Neo-Ottoman architecture style. Both old and new mosques were selected for the study (Figs. 2 and 3).

The prayers' area located on the southeastern side of the mosque is a square shaped 18.5 m * 18.5 m * 10 m. The square shaped zone is covered by a dome lined by 14 windows at the bottom of the dome. There are two windows on the southeastern side, one on the southwestern side and another on the northeastern wall. In the new design there was an extension on the northeast wall; therefore, the northeastern window was eliminated. An extra window and door were added to the southwestern wall. There are no clerestory windows.

2.1.2. Abu El Abbas mosque

The third mosque (Fig. 4) selected for the purpose of this study is Abu El Abbas mosque which was a mausoleum of a famous "Sufi sheikh" during the 13 century, and then a small mosque was constructed in 1775 A.C. [10]. Later, it was reconstructed by a Moroccan elite. Again in 1945 A.C., it was rebuilt in a Neo-Mamluk style with a large piazza by the famous architect Mario Rossi who was working for the Egyptian Ministry of Endowments during Ahmed Fouad's period [12].

The mosque's octagonal plan covers almost 3000 m^2 of which each side is 22 m long with walls 23 m high (Fig. 5). The prayer's zone located in the center is covered by the ceiling

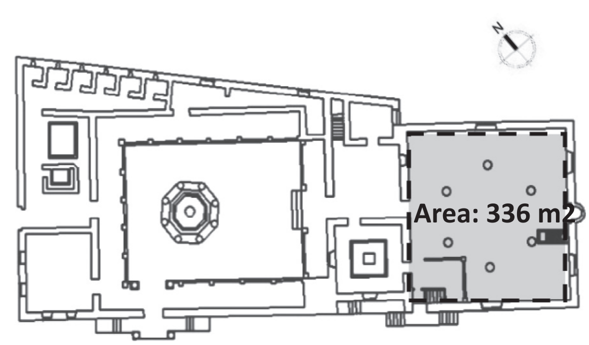


Figure 2 Plan of old Bosseri Mosque.

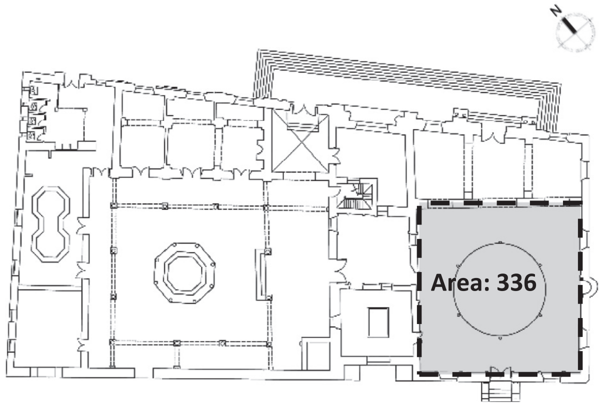


Figure 3 Plan of new Bosseri Mosque.

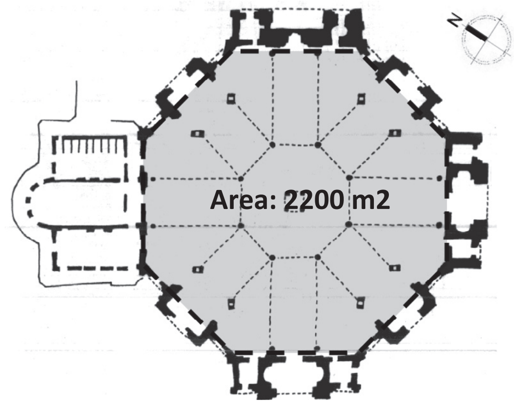


Figure 5 Plan of Abu El Abbas Mosque.

Figure 4 Abu El Abbas Mosque.

Figure 6 Yaqout El Arshi Mosque.

of the ambulatory which is 17.20 m high and the 24 m-high central "shokhshekha" surrounded by 24 windows between both ceilings. Four mausoleums are placed on four sides of the octagon. Surmounting the mausoleums are four double domes of diameter respectively 5 m, 7.50 m, 11 m and 22 m high measured from ground level [17]. The four mausoleums located on the North, South, East and West have one side window and double clerestory windows, and there are two other windows in each of the sides of the mausoleum but with single clerestory window above. There were no windows on the other four walls of the octagonal shaped mosque.

2.1.3. Yaqout El Arshi mosque

The fourth and fifth mosques (Fig. 6) selected were of "Yaqout El Arshi" which was a mausoleum of again another "Sufi sheikh", a follower of "Abu El Abbas" and his son-in-law from "Habasha". The small mosque which was rebuilt in 1863 A.C. was totally reconstructed in 2002 A.C. Again, both the old mosque and the new mosque similar to Abou Abbas style were selected for the study.

The old mosque's prayer zone which was a rectangular shaped space of 320 m^2 25 m * 13 m * 15 m is located at southeastern side of the mosque (Fig. 7). The old mosque had 24 windows lined at the bottom of the central dome. There were four windows on the southwestern wall, two on the southeastern wall where the "kebla" is located and one window at the end of northeastern wall. There were no clerestory windows.

The newly constructed mosque is larger in size. The rectangular shaped prayers area is 540 m^2 23 m * 22 m * 15 m also located at the southeastern side of the mosque (Fig. 8). The central dome has 24 windows lined at the bottom of the dome. There are four other smaller domes surrounding the central dome each lined up with 16 windows at the bottom of the domes. The southwestern façade contains four windows, four middle story windows and four clerestory windows. The southeastern side wall where the "kebla" is located has two win-

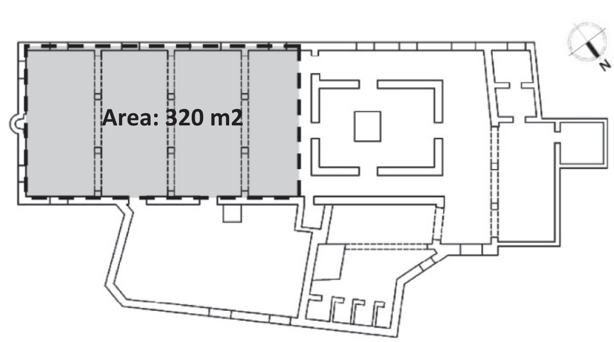


Figure 7 Plan of old Yaqout El Arshi Mosque.

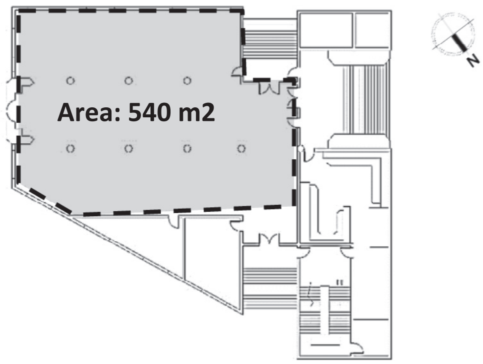


Figure 8 Plan of new Yaqout El Arshi Mosque.

dows, two middle story windows and three clerestory windows. The eastern wall has only two windows at the far eastern side.

2.1.4. Sidi Gaber mosque

The sixth and last mosque chosen for the study was of "Sidi Gabr El Sheikh" mosque (Fig. 9) which was also a mausoleum again of another "Sufi sheikh", a follower of "Abu El Abbas". The mosque is located elsewhere than "Anfoushy" in Sidi Gabr which is considered a residential area close to important public facilities. The mosque was reconstructed by the famous architect Mario Rossi in 1945 A.C. again in a Neo-Moorish style; it was restored in 1999 A.C.

The prayer zone is located at southwestern side of the mosque which is 625 m^2 25 m * 25 m * 15 m. The central "shokhshekha" 18 m * 18 m is lined by 28 windows (Fig. 10). The southwestern wall has seven clerestory windows. The southeastern where the "kebla" is located has one window at the eastern end of the wall, and seven clerestory windows. The northeastern wall has four windows, and seven clerestory windows. As for the northwestern wall where the main entrance is located there are two windows and seven clerestory windows.

2.2. Simulation tool

To apply simulation tools and techniques successfully, a clear understanding of the building design process and its relation-

Figure 9 Sidi Gaber Mosque.

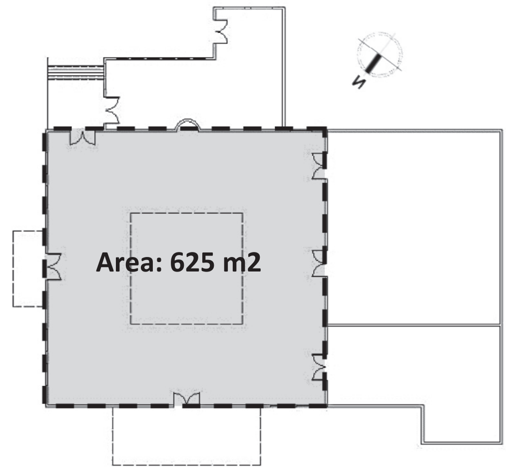


Figure 10 Plan of Sidi Gaber Mosque.

ship with the simulation environment is advisable since humans (in other words architects) and not computers dictate the creative and evaluation process [6]. There are several softwares that are available in the market for lighting simulation. Built by companies promoting daylighting and integrated lighting, each of these softwares caters to a separate application and hence has its own benefits [6].

Climate-based simulations revealed that, Rhino as a modeling platform with the DIVA lighting analysis plug-in gives the most comprehensive data set when calculating daylighting metrics [13].

DIVA performs a daylight analysis on an existing architectural model via integration with Radiance and DAYSIM [14]. Simulations in DIVA are controlled from a toolbar integrated into the Rhinoceros interface. Diva is used to interface Radiance and Daysim for annual simulation and illuminance computation. Diva can also be used to interface Evalglare for calculating the Daylight Glare Probability (DGP).

3. Simulation methodology

The scope of this survey is to simulate the indoor lighting performance of the six selected mosques and to do a comparative analysis of the results among these mosques.

A CAD program was used to generate a standard DXF file of the architectural drawings of the selected mosques and this was used as the starting point. The model was created through Rhinoceros software and simulation experimentation was conducted using Diva for-Rhino, a plug-in for Rhinoceros modeling software.

Table 1 Description input.

Parameter	Inputs
Location	Alexandria, Egypt
Climate	Hot Arid
Occupancy	Prayer Time "Zuhr" & "Asr"
Target illuminance	100 Lux

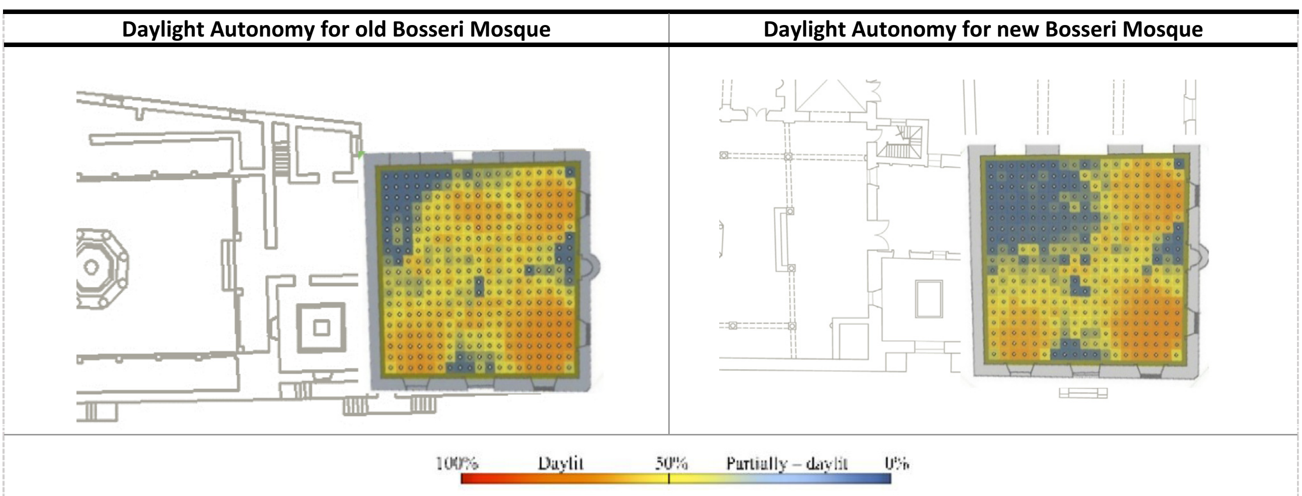
Experimentations were conducted using the Daylight Autonomy as a dynamic daylight performance metric (DDPM) and daylight glare probability (DGP) was chosen as a qualitative daylight metric. The recommended illuminance value was considered 100 lux (HBRC, Arab Unified Codes for Building Design and Construction, 2009). A schedule for the occupancy as indicated in Table 1 has also been selected.

The percentage of the space with a Daylight Autonomy larger than or equal to 50% is considered the moderate threshold for a well Daylight for a non-residential zone. The type of uses that need 100 lux level of illumination was not expected to occupy more than 50% of the space [9].

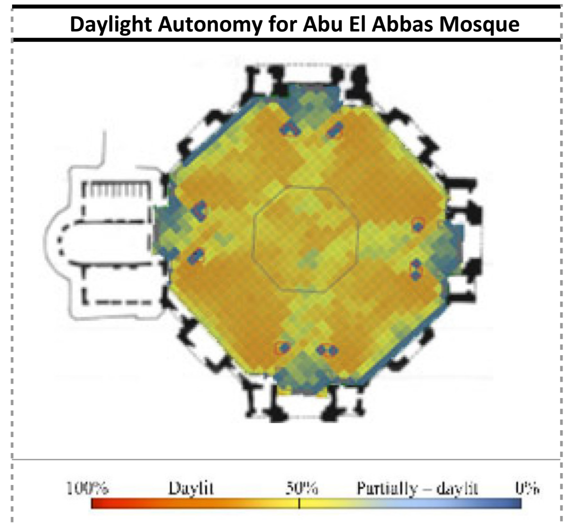
The actual choice of radiance simulation parameters as indicated in Table 2 decisively influences the accuracy time of the retracing calculations. The set of geometry, material, weather input file and simulation parameters were used for all simulations.

4. Results and discussion

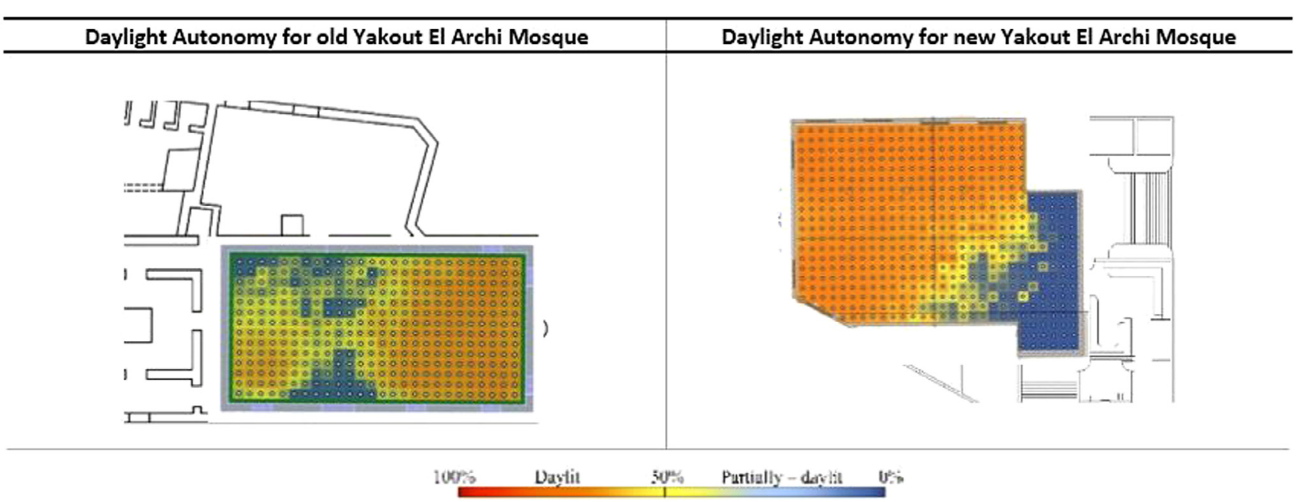
4.1. El Bosseri mosque daylight autonomy



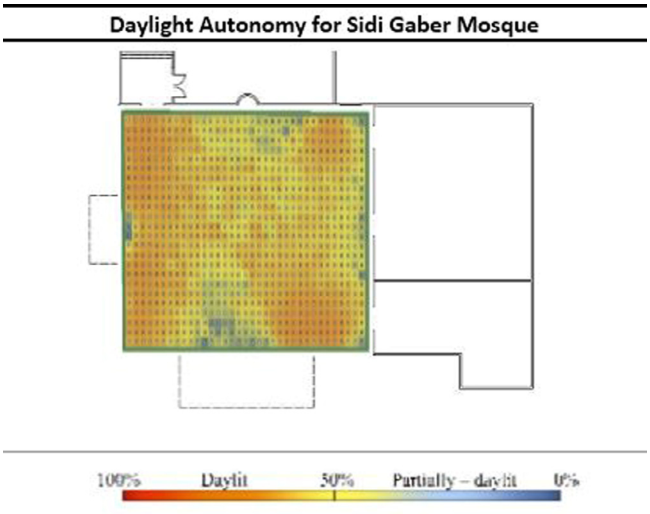
4.2. Abu El Abbas mosque daylight autonomy



4.3. Yakout El Archi mosque daylight autonomy



4.4. Sidi Gaber mosque daylight autonomy



According to simulation results of the six selected samples of mosques illustrated in Table 3 it is found that the percentage of the space with a Daylight Autonomy larger than 50% is achieved in four of the mosques and therefore is considered the moderate threshold for a well-lit space of a non-residential zone. Only El Bosseri mosque (old and new) did not satisfy the threshold requirements of 100 lux level of illumination occupancy more than 50% of the space. It can be observed that the new El Bosseri mosque achieves 39% Daylight Autonomy while the old mosque achieves 49%. Due to the extensions built on the northeastern side, side windows were eliminated, and hence less daylight admitted.

Although total opening ratios to walls were the ultimate comparatively in Abu El Abbas mosque, yet Yaqout El Arshi mosque achieved 73% compared to Abu El Abbas mosque who achieved much less percentage which was 55% Daylight Autonomy. It is obvious that "shokhshekha" openings, two rows of clerestory windows and window glazing transparency have strong effect on daylight performance. For this reason Sidi Gaber mosque with "shokhshekha" openings scored 65% Daylight Autonomy followed by Yaqout El Arshi mos-

Table 2 Radiance parameters for simulation.

Radiance simulation parameters					
Ambient bounces	Ambient divisions	Ambient sampling	Ambient resolution	Ambient accuracy	Direct threshold
7	1000	20	300	0.1	0

Table 3 Comparison between different design features of different mosques achieving optimal DA and Glare.

Architectural features/mosques	EL Bousseri (OLD)	EL Bousseri (NEW)	Abu El Abbas	Yaqout EL Arshi (OLD)	Yaqout El Arshi (NEW)	Sidi Gaber (NEW)
Area of studied space (Footprint)	336 m^2	336 m^2	2200 m^2	320 m^2	540 m^2	635 m^2
Height of studied space	9.75 m	9.75 m	18 m	15 m	15 m	15 m
Peripheral WWR						
Northeastern	10%	0%	22%	6%	0%	32%
Northwestern	0%	0%	22%	0%	15%	16%
Southwestern	20%	20%	22%	20%	47%	7%
Southwestern	20%	20%	22%	18%	31%	0%
Middle clerestory to wall ratio						
Northeastern	0%	0%	0%	0%	0%	0%
Northwestern	0%	0%	0%	0%	0%	0%
Southeastern	0%	0%	0%	0%	25%	0%
Southwestern	0%	0%	0%	0%	35%	0%
Upper clerestory to wall ratio						
Northeastern	0%	0%	20%	0%	0%	17%
Northwestern	0%	0%	20%	0%	0%	17%
Southeastern	0%	0%	20%	0%	25%	17%
Southwestern	0%	0%	20%	0%	35%	17%
"Shokhshekha" (Opening number)	14 windows	14 windows	24 windows	14 windows	24 windows 4 * 16 windows	28 windows
VLT (Window glazing transparency)%	65%	65%	65%	80%	80%	65%
Window shading/screen perforation	20%	20%	20%	20%	20%	20%
DA	49	39	55	60	73	65

Table 4 Imaginary comparison between the different architecture features achieving optimal DA of Yaqout El Arshi (new) Mosques.

Architectural features	Condition 1	Condition 2	Condition 3	Condition 4	Actual
Peripheral WWR	Closed	23%	23%	23%	23%
Middle clerestory to wall ratio	15%	Closed	15%	15%	15%
Upper clerestory to wall ratio	15%	15%	Closed	15%	15%
"Shokhshekha" (opening number)	Available	Available	Available	Closed	Available
DA	36%	70%	70%	67%	73%

que then Abu El Abbas mosque. On comparing DA for every architecture feature in Yaqout El Archi mosque separately (Table 4) it was found that side windows are of extreme importance, followed were the "shokhshekha" openings, and last but not least were the clerestory windows. Despite the WWR in each orientation, and size/height of windows all architecture features played an important role in DA.

5. Conclusion

The purpose of this paper was to present a general overview of the role of fenestration on daylight performance in order to examine the close relationship between fenestration and daylight autonomy. To conclude mosques since the 19th century whether old or new did not have a specific strategy in terms of daylight performance. This has been noted despite the fact that early architecture features in mosques such as "shokhshekha", clerestory, and window perforation have strong impact on daylight performance. In addition, this research is an attempt to review the possibility of changing the priorities through simulation tests on the different design parameters that have strong impact effect on daylight performance. The contents have covered fenestration enhancement methods through simulation procedures.

This research has addressed a limited scope within the quest of viable strategies to achieve the broader environmental goals. This is a dynamic domain, one that continually engenders new ideas and involves new roles on the part of architects, designers and conservation authorities. It is believed that new theories and approaches will continue to merge as the physical environments and circumstances change. The role of designers and heritage preservation personnel will thus acquire further significance in this field.

6. Recommendation

As a broad perspective, it could be concluded that the principle of fenestration which affects daylighting and hence human comfort is a vital one. There is a need for this matter to be considered/addressed through a number of recommendations, guidelines and special measures. The following is a focused set of recommendations based on the above-presented study:

- Some of the architectural features such as "shokhshekha", clerestories and suitable window perforation for the prayers' zone must be used again due to their importance in daylighting performance and in turn in energy savings. This can be shown on comparing land prices on the long run and energy saving.
- Maintain heritage preservation of mosque features that have a functional effect and not just spiritual ones.
- Simulation tools can help in the study of historic buildings in order to develop new design guidelines.
- More studies can be made on other human comfort issues such as temperature, and sound.
- In addition to visualization, daylight autonomy, and annual glare simulation tools such as DIVA can help in the design of dynamic shading, electric lighting, lighting controls, as well as integrating thermal and lighting analysis.
- Daylighting, temperature and sound can be studied from an urban design context/perspective in mosques.
- Daylighting in historic Islamic architecture could be further studied.
- Further studies can be made on window sill, shelf, height, size, location and orientation.

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