Integrating Vernacular Designs of Mashrabiyas to Promote Sustainable Architecture: Insights from an Experiment in Egypt

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Abstract

Mashrabiya, a traditional architectural feature, is a significant building element in the context of preserving vernacular architecture amidst modern architectural developments. As urban environments evolve, there is a pressing need to find a balance between contemporary design and cultural heritage. In this context, this research investigates how Mashrabiya can be effectively integrated into modern architecture to enhance both aesthetic appeal and environmental performance.

It employs a comprehensive analysis using the Design Builder program, which evaluates environmental performance with a focus on thermal performance, and daylighting illuminance. The research includes a detailed examination of the historical context, functions, and construction techniques of Mashrabiya, as well as an exploration of contemporary design practices and the application of new materials. This approach allows for a nuanced understanding of how traditional elements can be adapted for modern use.

The findings reveal that incorporating Mashrabiya into modern architecture not only improves environmental efficiency but also helps to maintain cultural identity. The study highlights the advantages of utilizing innovative materials to create versatile, cost-effective, and safe Mashrabiya designs, ultimately demonstrating the potential for harmonizing traditions with contemporary architectural practices. These insights could guide the architects in integrating vernacular elements into their designs while addressing contemporary challenges.

Keywords: Mashrabiya; Vernacular Architecture; Arab Identity; Functions; Rethinking Traditional Architecture; Materials.

Introduction

The Mashrabiya, a distinctive feature of traditional Arab architecture, exemplifies the intersection of cultural heritage and functional design. Derived from the Arabic word "sharab," meaning "to drink," it originally referred to spaces for cooling jars of drinking water (Bagasi, Calautit and Karban, 2021). Over time, the Mashrabiya evolved into a sophisticated wooden lattice screen that serves both aesthetic and essential environmental functions, particularly in hot climates (Almerbati et al., 2016). Gaining prominence during the Islamic Golden Age, especially under the Tulunids and Abbasids (868-1258) (Taki and Kumari, 2023), the

Mashrabiya became a defining characteristic of Islamic architecture, showcasing intricate craftsmanship and geometric patterns that varied by region (Muci, Purde and Recep, 2023). Interestingly, local artisans utilized native wood to create detailed carvings that reflected both artistic skill and functional requirements (Langdon, 2014) giving rise to unique mashrabiyas.

The design of a Mashrabiya's lattice balusters features closer spacing at the eye level for enhanced privacy and wider spacing above for airflow and light entry (Taki and Kumari, 2023). This arrangement reflects the cultural emphasis on privacy and modesty, which are fundamental values in Islamic architecture (Elwan, 2020). However, despite its rich history and functional benefits, the Mashrabiya faces challenges in modern applications. In fact, contemporary interpretations often overlook its original significance and environmental functions (Alelwani, Ahmad and Rezgui, 2020). Hence, unfortunately, many projects adopt its aesthetics without comprehending its historical context, risking the integrity and relevance of the design (Bagasi and Calautit, 2020). Undeniably, addressing these issues is essential for preserving the architectural role of the Mashrabiya while adapting it for modern use (Özsavaş Akçay and Alotman, 2017)

The significance of the Mashrabiya extends beyond its visual appeal; it plays a crucial role in optimizing thermal performance and managing natural light (Rajeev, 2024).By allowing controlled daylight entry, the design reduces glare and maintains a comfortable interior environment (Aljawder and El-Wakeel, 2019).This is vital in regions with extreme heat, where managing solar gain is essential (Ideas, 2022). As the Fig. 1 shows, the lattice structure enables airflow, promoting natural ventilation and cooling through evaporative effects (Alqalami, 2020), enhancing indoor comfort while reducing reliance on mechanical systems (Li and Lam, 2001).

Ashour (2018) points out that misconceptions about the Mashrabiya often stem from a lack of awareness regarding its historical significance and design parameters. To integrate it effectively into modern architecture, architects and designers must be educated about the principles underpinning the design of Mashrabiya's (Abdelkader and Park, 2018).This understanding will guide the development of contemporary versions that respect the past while meeting the current societal needs (El Semary, Attalla and Gawad, 2017).

Needless to say, architects are pivotal in the evolution of the Mashrabiyas. Jose Romero et al. (20160 show that, by understanding its historical context and the environmental functions, they can integrate modern technologies while honoring the traditional design principles. The challenge lies in balancing innovation with authenticity, ensuring new designs that fulfill the ecological and social roles of their predecessors (El Semary, Attalla and Gawad, 2017). Furthermore, Mashrabiya holds cultural significance, especially regarding privacy in the Islamic society (Aljawder and El-Wakeel, 2019). Rajeev (2024) point out that its intricate lattice design offers protection from the outside views while allowing the residents to discreetly observe their surroundings.

Modern software for environmental analysis and thermal performance is crucial for making informed decisions regarding building materials in architectural elements (Petkar, 2016). Research indicates that programs like Design Builder significantly aid in assessing visual thermal comfort within the spaces (Fasi, 2013).

Despite its potential however, the Mashrabiya has not been fully utilized in modern architecture, leading to neglect in contemporary design. In this context, this paper addresses the issue of under-utilization, emphasizing the Mashrabiya's role as a sustainable element that enhances natural lighting. Unfortunately, many modern applications prioritize aesthetics over functionality. The challenge is to bridge traditional elements with innovative materials and ideas, ensuring that the Mashrabiya retains its cultural significance while adapting to the contemporary needs.

Ultimately, the Mashrabiya serves as a bridge between tradition and modernity. Indeed, this illustrates how vernacular architecture can inform contemporary design solutions (Binzagr, 2020). As the Saudi Commission for Tourism and National Heritage (2015) points out, by examining its historical significance, materiality, and functional roles in thermal performance and natural lighting, architects can enrich their designs and contribute to cultural heritage preservation. The revival of the Mashrabiya in modern architecture not only enhances aesthetic appeal but also supports sustainable design practices, making it a vital element in the ongoing evolution of architectural identity in the Middle East and beyond (Shbaita, Denerel and Asilsoy, 2024).

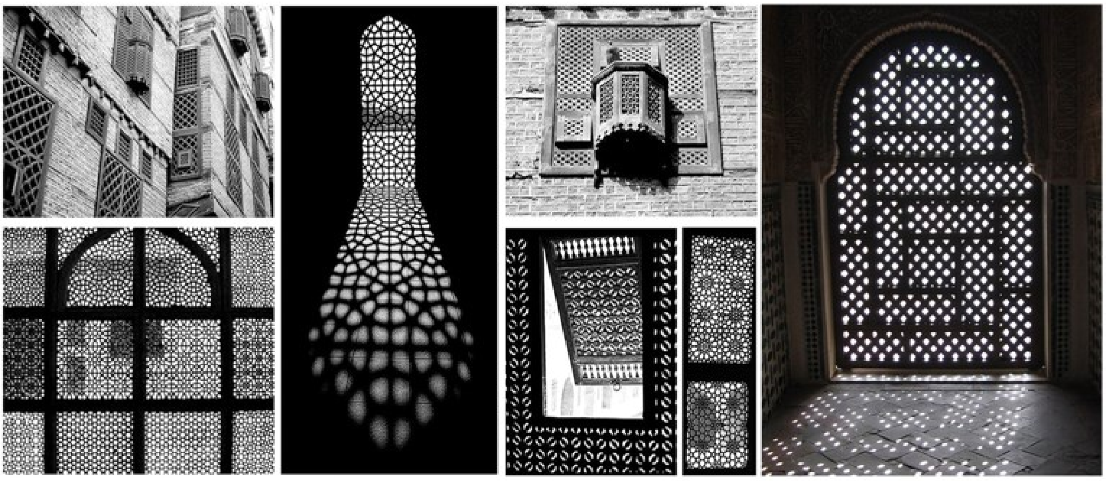


Fig 1: Patterns of Light: The Art of Mashrabiya and Geometric Lattices in Islamic Architecture
Source: Author

Theoretical Framework

The theoretical framework of this study arises from the integration of sustainability, thermal performance, and daylighting illuminance through the lens of vernacular architectural principles, particularly the Mashrabiya. According to Abdelkader and Park (2018), sustainability in architecture extends beyond mere environmental performance; it encompasses cultural and aesthetic dimensions as well. They argue that the Mashrabiya exemplifies how traditional architectural features can merge functionality with cultural identity, embodying a holistic approach to sustainability.

Taki and Kumari (2023) and Waheeb (2024) further emphasize that Mashrabiya enhances sustainability by regulating daylight and reducing glare, which in turn lowers reliance on mechanical cooling systems. Bagasi and Calautit (2020) highlight its effectiveness as a passive cooling system by blocking direct sunlight and facilitating natural ventilation, aligning with Fathy's (1986) principles of vernacular architecture that prioritize locally adapted designs for climatic comfort. Taki and Kumari (2023) also underscore the Mashrabiya's dual significance in preserving cultural heritage and enhancing energy efficiency, presenting quantitative evidence of its benefits. They show that there is a 14% reduction in indoor temperatures and a 5.7% decrease in cooling loads when Mashrabiyas are integrated into building designs. However, Alothman, Ashour and Krishnaraj (2021) caution against applying aesthetics of the Mashrabiya without fully understanding its functional and environmental roles, emphasizing the importance of informed design approaches that respect its cultural significance.

In this regard, Elwan (2020) explains that the lattice structure of the Mashrabiya enhances single-sided ventilation, underscoring its effectiveness in hot climates. Aljawder and El-Wakeel (2019)also illustrate the Mashrabiya's role in daylighting illuminance, showcasing its ability to balance light diffusion and privacy, thereby reducing dependence on artificial lighting and enhancing energy efficiency.

Overall, this theoretical framework illustrates how traditional architectural elements like the Mashrabiya effectively address challenges related to thermal performance and daylighting while maintaining cultural relevance. By integrating advanced technologies and optimizing design parameters, future research can expand its application, creating designs that are both sustainable and culturally resonant.

Literature Review

Not many have examined the issue of engaging Mashrabiyas to promote sustainable architecture. However, all architects understand that direct sunlight significantly contributes to high temperatures. Fahmy and Elsoudany (2023) point out that the Mashrabiya effectively mitigates solar gain by shading interior spaces during hot summer months while allowing sunlight to enter during winter, providing warmth. Similarly, Alelwani, Ahmad and Rezgui (2020) outline five essential functions of the Mashrabiya, emphasizing its environmental significance. El Semary, Attalla and Gawad (2017) highlight that the Mashrabiya, a fundamental element of vernacular architecture, offers valuable solutions that can be integrated into various contexts. Ashour (2018) highlights Mashrabiya's role in privacy and urban integration within Islamic architectural heritage.

Bagasi and Calautit (2020) define the Mashrabiya as a wooden lattice that facilitates daylight entry, ventilation, and aesthetic appeal while enhancing privacy. Adding to this, Alqalami (2020) underscores its role in regulating indoor temperatures by blocking direct sunlight in the summer and permitting solar gain in the winter. Moreover, Binzagr (2020) illustrates how this traditional feature exemplifies the contribution of vernacular design to sustainable practices in modern architecture.

In comparison, Abdelkader and Park (2018) examine the contemporary interpretation of Mashrabiya, identifying both challenges and opportunities in design. Adding to this, Alothman, Ashour and Krishnaraj, (2021) highlight the misapplication of the Mashrabiya's aesthetics and functions, stressing the necessity for informed design approaches. Özsavaş Akçay and Alotman (2017) along with Headley et al., (2015) explore innovations such as 3D printing and parametric design to merge traditional craftsmanship with digital techniques, and demonstrate the feasibility of additively manufactured Mashrabiya for Bahraini houses through a mixed-methods study.

Many have examined environmental performance as another critical aspect. According to them, Mashrabiya enhances sustainability in modern buildings. To illustrate this, Elmousalami and Mohamed (2022) provide evidence of significant energy reductions achieved through the integration of traditional designs. Simultaneously, Bagasi, Calautit and Karban (2021) empirically verify the effectiveness of the Mashrabiyas in ventilation strategies for hot climates, showing notable reductions in indoor temperatures. Kamal Fahmy and Elsoudany (2023) however, optimize parametric designs for daylighting, enhancing energy efficiency through specific design parameters.

Aljawder and El-Wakeel (2019) explores the relationship between Mashrabiya and light, examining its ability to balance visual privacy and natural light regulation, and discuss the cultural significance of the Mashrabiya in providing privacy while allowing natural light into homes: a hallmark of Islamic architecture. Adding to these, Xiang et al., (2021) emphasize how the Mashrabiya screens effectively block direct light and any reduce solar gain.

However, Jung and Al Qassimi, (2022) caution against the health risks associated with emissions from the composite materials used in the Mashrabiyas, emphasizing the importance of material selection. These studies underscore the necessity for a balanced approach that honors traditional architecture while addressing modern environmental and health challenges. They argue that by integrating the Mashrabiya into contemporary designs, architects can contribute to sustainability while preserving cultural heritage.

As can be seen, current knowledge underscores the vital roles of the Mashrabiyas in achieving thermal comfort and sustainability. While numerous studies highlight its advantages, there are notable gaps in understanding its application across diverse climatic and cultural contexts. This research specifically addresses these gaps, focusing on the integration of vernacular designs to enhance thermal comfort in modern architecture.

The diagram as shown in the Fig 2 illustrates a complex network of relationships among research studies, with each node representing a specific paper, accompanied by the author's name and publication year for easy identification. The green and blue nodes signify different types of studies or topics, potentially indicating that green represents recent research while blue denotes older studies. Connections between nodes indicate citations or research links, with more connections suggesting a paper's influence across multiple studies. Notably, studies like Taki and Kumari(2023), Giovannini et al., (2015), and Ashour (2018) are central, indicating their pivotal role in the field, while some papers appear isolated, possibly focusing on niche topics.

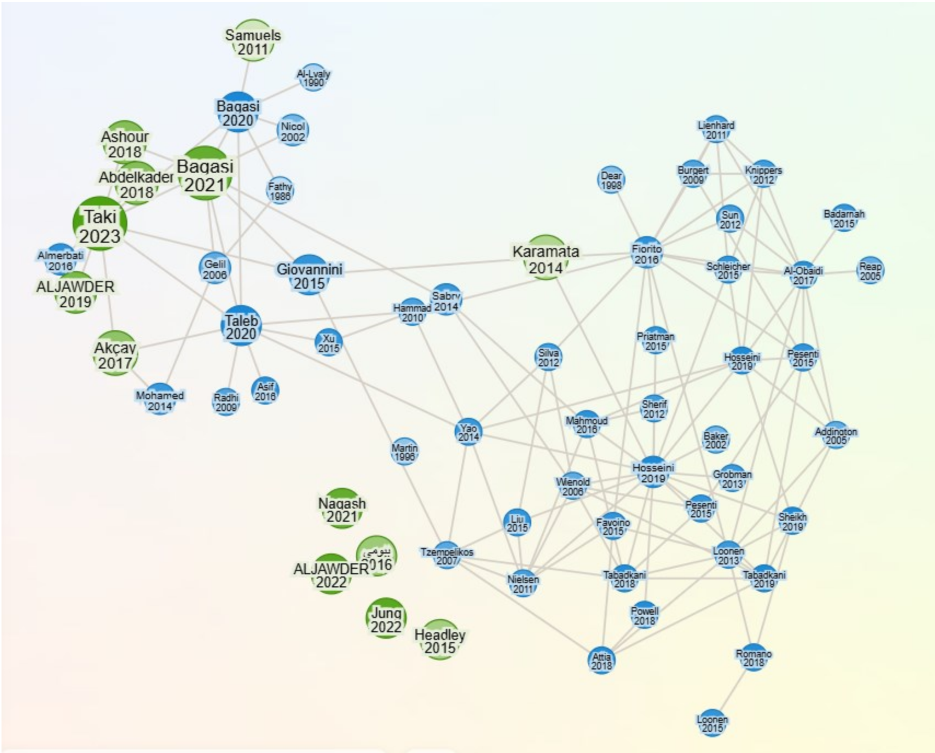


Fig 2: Citation Network of Researchers: Analyzing Connections in Sustainable Architecture and Mashrabiya Design Studies
Source: Author

The literature examined emphasizes the need for a balanced approach that respects traditional architecture while dealing with contemporary environmental and health challenges. There is an almost universal acceptance that by incorporating the Mashrabiyas into modern designs, architects can promote sustainability and preserve cultural heritage. Further investigations are however essential to optimize its design and material compositions, ensuring that the Mashrabiyas effectively meet the current needs while retaining their cultural significance.

Research Methodology

This paper employs an experimental case study approach to assess sustainability, thermal performance, and daylighting illuminance, with a particular focus on traditional architectural element: the Mashrabiya. It conducts a qualitative case study, which is then followed by an in-depth exploration.

The study investigates the impact of replacing traditional wooden Mashrabiyas with aluminum, recognized for its lightweight construction and corrosion resistance. It also examines how varying the size of Mashrabiya units and their inclination angles can optimize daylight intake while minimizing solar gain.

Data gathering involves physical experiments and simulations using Design Builder software. The performance of both materials is analyzed, and the results are compared against the Egyptian Building Code. This comparative analysis highlights the effectiveness of traditional and modern materials in improving daylighting, reducing heat gain, and promoting sustainable architectural practices that harmonize heritage with innovation.

A detailed diagram outlines the step-by-step methodology for optimizing Mashrabiya design is as shown in the Fig 3.

- Material Selection: Comparison of traditional wooden and modern aluminum materials.
- Size Adjustment: Testing various unit sizes to assess their impact on performance.
- Inclination Angle Modification: Analyzing how different angles affect daylighting and thermal efficiency.
- Performance Evaluation: Conducting physical experiments and simulations to gather data.
- Comparative Analysis: Evaluating results to determine the most effective design strategies.

Fig. 3: Design and Evaluation Methodology of Mashrabiya
Source: Author

Case Studies

Description of the case study model

Architecture has undergone considerable evolution since the early 20th century, with globalization posing threats to cultural identities and heritage (Taptiani et al., 2024). This decline has driven architects to seek inspiration from vernacular architecture**,** reviving traditional elements like Mashrabiya, which not only enhances aesthetic appeal but also provides environmental benefits (BINZAGR, 2020). As Moscatelli (2023) points out, contemporary architects are reinterpreting Mashrabiya to integrate cultural heritage with modern sustainability goals, thus merging tradition with innovation.

The study focuses on the thermal and daylighting performance of Mashrabiya designs in residential spaces in Alexandria, Egypt. The model features a room measuring 5.0 m x 5.0 m (25 m²) with a height of 4.0 m and a window size of 2.5 m x 2.5 m as shown in fig.4. Two case studies are analyzed based on window orientation—South-facing and West-facing—being considered. Alexandria has significant temperature variations throughout the year (max: 30.5°C, min: 9.1°C).

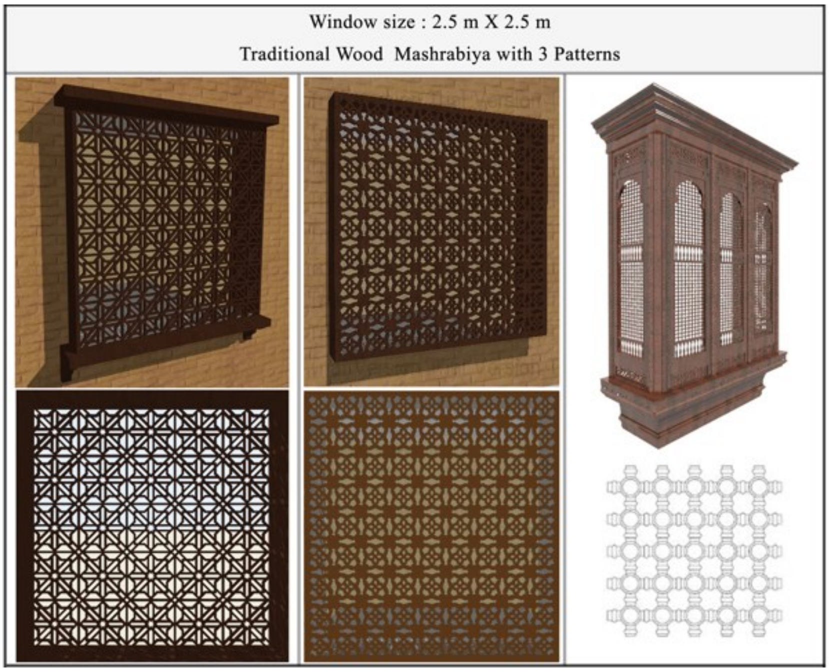


Fig.4: Parameters of Mashrabyas
Source: Author

Metrics for daylight performance assessed include Daylight Factor, Daylight Autonomy (DA), Continuous Daylight Autonomy (cDA), Maximum Daylight Autonomy (DAmax), and Useful Daylight Illuminance (UDI). Key variables in the study involve window orientation, Mashrabiya material, design ratios of void to solid (50%, 60%, 80%), window configurations (one vs. two windows), and placement (inside or outside the wall).

The building features artificial stone walls and a ceramic floor as presented in the data in Table 1, with an occupancy density of 0.0188 people/m², relying solely on the natural light for 10 hours per day.

Table 1: Data information of the case study model
Source: Author

Study Model Parameters		
Area of Model	5.0 m X 5.0 m; total area = 25 m² with height 4.0 m	
Location	Alexandria, Egypt	
Construction		
Wall:	Artificial Stone (0.2m) with 2 cm plaster on two sides.	
Floor:	Ceramic/porcelain	
Activity:	Residential	Occupancy density (people/m2) 0.0188

Overview about the program

The Design Builder program assesses heating and cooling systems by integrating both mechanical and natural elements. It also determines the lighting requirements of a building to ensure visual comfort, gradually incorporating artificial lighting as needed during daylight hours. The program includes comprehensive climate data for various Egyptian regions, providing hourly results that offer users an in-depth view of building performance. As illustrated in Fig 5, the simulation process begins with 3D model creation, where users design the building and its components. Ultimately, the results are presented in chart or table format.

Weather File

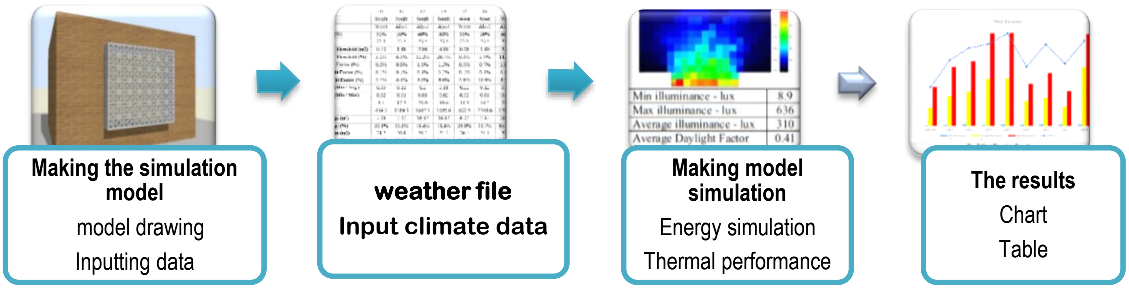


Fig 5: The steps of simulation in "Design Builder program", source researcher
Source: Author

The weather file used for this study was sourced from Alexandria, Egypt (latitude 30.13°N, longitude 31.4°E), utilizing the ASHRAE International Weather for Energy Calculations (IWEC) data. Figure 6 illustrates the monthly temperature variations, with the horizontal axis representing months and the vertical axis indicating temperature in degrees Celsius. Green bars denote temperatures above the comfort zone (warm or hot periods), while the yellow bars signify temperatures within the comfort zone, and the shaded gray area indicates the optimal comfort range per ASHRAE standards. This chart aids in climate and energy analysis, informing design decisions on heating, cooling, and ventilation to enhance energy efficiency and comfort.

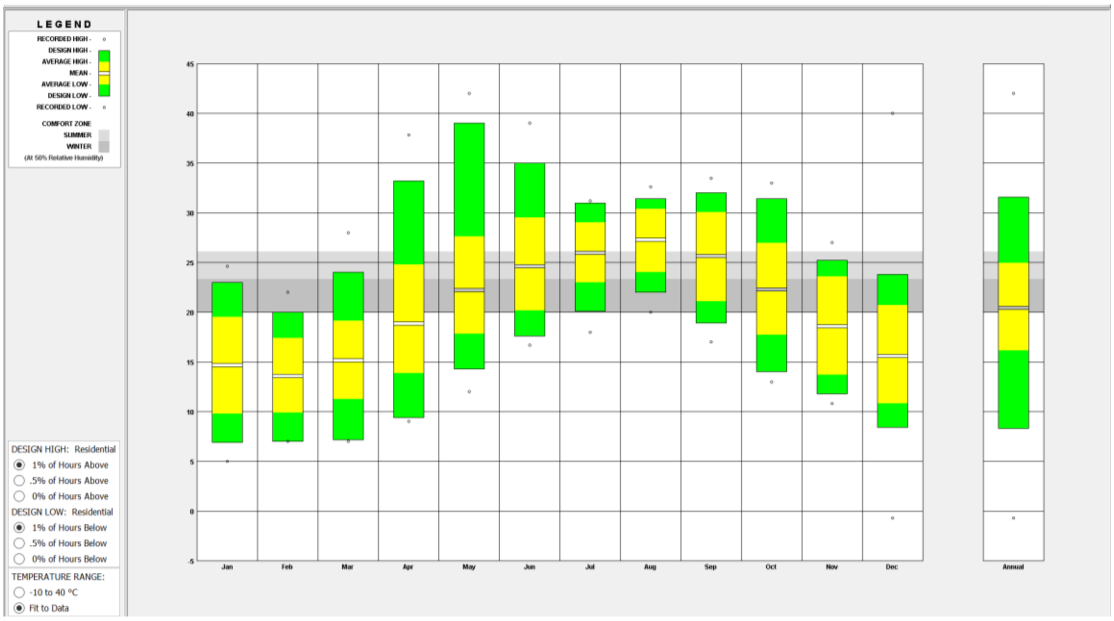
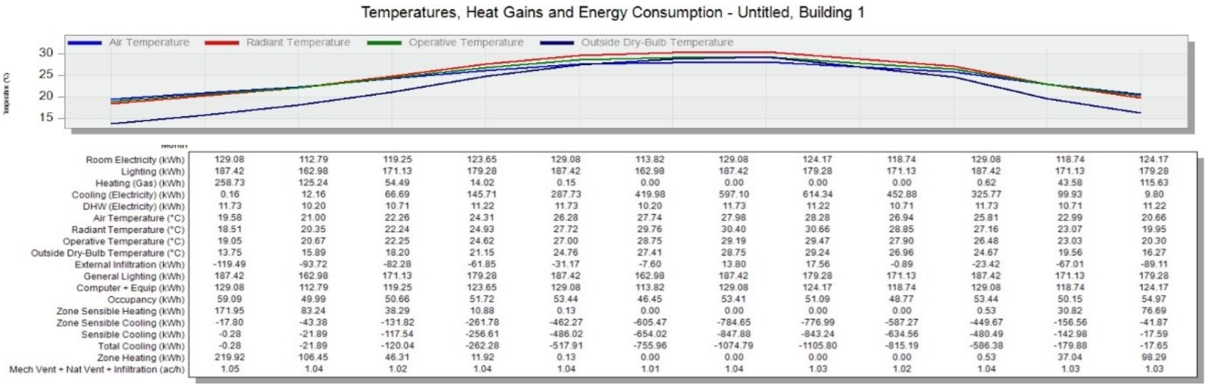


Fig.6: Key Performance Metrics for the Study Model
Source: energy plus app edit by author



Room Electricity (kWh)	129.08	112.79	119.25	123.65	129.08	113.82	129.08	124.17	118.74	129.08	118.74	124.17
Lighting (kWh)	187.42	162.98	171.13	179.28	187.42	162.98	187.42	179.28	171.13	187.42	171.13	179.28
Heating (Gas) (kWh)	258.73	125.24	54.49	14.02	0.15	0.00	0.00	0.00	0.00	0.62	43.58	115.63
Cooling (Electricity) (kWh)	0.16	12.16	66.69	145.71	287.73	419.98	597.10	614.34	452.88	325.77	99.93	9.80
DHW (Electricity) (kWh)	11.73	10.20	10.71	11.22	11.73	10.20	11.73	11.22	10.71	11.73	10.71	11.22
Air Temperature (°C)	19.58	21.00	22.26	24.31	26.28	27.74	27.98	28.28	26.94	25.81	22.99	20.66
Radiant Temperature (°C)	18.51	20.35	22.24	24.93	27.72	29.76	30.40	30.66	28.85	27.16	23.07	19.95
Operative Temperature (°C)	19.05	20.67	22.25	24.62	27.00	28.75	29.19	29.47	27.90	26.48	23.03	20.30
Outside Dry-Bulb Temperature (°C)	13.75	15.89	18.20	21.15	24.76	27.41	28.75	29.24	26.96	24.67	19.56	16.27
External Infiltration (kWh)	-119.49	-93.72	-82.28	-61.85	-31.17	-7.60	13.80	17.56	-0.89	-23.42	-67.01	-89.11
General Lighting (kWh)	187.42	162.98	171.13	179.28	187.42	162.98	187.42	179.28	171.13	187.42	171.13	179.28
Computer + Equip (kWh)	129.08	112.79	119.25	123.65	129.08	113.82	129.08	124.17	118.74	129.08	118.74	124.17
Occupancy (kWh)	59.09	49.99	50.66	51.72	53.44	46.45	53.41	51.09	48.77	53.44	50.15	54.97
Zone Sensible Heating (kWh)	171.95	83.24	38.29	10.88	0.13	0.00	0.00	0.00	0.00	0.53	30.82	76.69
Zone Sensible Cooling (kWh)	-17.80	-43.38	-131.82	-261.78	-462.27	-605.47	-784.65	-776.99	-587.27	-449.67	-156.56	-41.87
Sensible Cooling (kWh)	-0.28	-21.89	-117.54	-256.61	-486.02	-654.02	-847.88	-843.24	-634.56	-480.49	-142.98	-17.59
Total Cooling (kWh)	-0.28	-21.89	-120.04	-262.28	-517.91	-755.96	-1074.79	-1105.80	-815.19	-586.38	-179.88	-17.65
Zone Heating (kWh)	219.92	106.45	46.31	11.92	0.13	0.00	0.00	0.00	0.00	0.53	37.04	98.29
Mech Vent + Nat Vent + Infiltration (ac/h)	1.05	1.04	1.02	1.04	1.04	1.01	1.04	1.03	1.02	1.04	1.03	1.03

Fig. 7: Building Energy Performance Metrics: Temperatures, Heat Gains, and Consumption
Source: energy plus app edited by the author

The Figure 7 presents the Temperatures, Heat Gains, and Energy Consumption data for an unnamed Building 1. The graph shows the variations in Air Temperature, Radiant Temperature, Operative Temperature and Outside Dry-Bulb Temperature over time, and The table graph provides detailed information on various energy-related metrics for the building, including room electricity, lighting, heating, cooling, DHW, air temperature, radiant temperature, operative temperature, outside dry-bulb temperature, external illumination, general lighting, computer and equipment, occupancy, zone sensible heating, sensible cooling, total cooling, zone heating, and HVAC ventilation and infiltration.

Findings

Data Analysis of Material Variations for Mashrabiya

Mashrabiya has been adapted in three primary ways in contemporary sustainable design. First, it retains its traditional form, utilizing original shapes and materials(Bagasi, Calautit and Karban, 2021). Secondly, it incorporates high-tech solutions that enhance its core functions with advanced technology (Abdelkader and Park, 2018). Thirdly, a modern interpretation emerges, employing new materials and styles while preserving the essence of the original design (Giovannini et al., 2015).

While many contemporary projects successfully integrate Mashrabiyas, some focus solely on its visual aspects without grasping its functional benefits. Others employ Mashrabiya principles without recognizing their cultural significance. This paper categorizes modern Mashrabiya into three forms: traditional, sustainable, and technologically advanced. It evaluates specific examples illustrating these categories and examines projects using similar features, often labeled as "geometric panels," without acknowledging their roots in Mashrabiya.

In this study, two primary materials were analyzed for their suitability in constructing Mashrabiya: wood and aluminum. The comparison as shown in the table 2 focused on various properties, including strength, density, corrosion resistance, formability, thermal and humidity control, tooling economics, and energy savings. Each material was evaluated for its performance in the traditional and modern contexts.

Table 2: Comparison Between Wood and Aluminum as Structural Elements in Mashrabiya
Source: Author

Property	Wood	Aluminum
Definition	Wood is a natural and local material. It has inherent properties, but it naturally distorts depending on moisture and temperature.	Aluminum is an incredibly recyclable material, which makes it one of the best construction materials for environmental sustainability. Composed of anywhere from 50 to 85 percent recyclable materials.
Strength (Tensile)	Good compressive properties, variable with the species of wood and moisture content.	Very good mechanical properties.
Density	Very lightweight.	Lightweight about 1/3 that of copper or steel.
Corrosion Resistance	Not directly applicable; decomposes in the presence of some acids	Excellent; it can be further increased, along with enhanced appearance, through anodizing or other coatings.
Formability	Poor; cannot be routinely formed.	Easily formable and extruded in a wide variety of complex shapes.
Thermal Conductivity	Poor.	Excellent; ideal for heat exchanger applications.
Temperature Control	The best material for temperature control, the varied sizes of blisters control the different pressure, airflow and the humidity.	The use of aluminum leads to the high temperatures of indoor environment.
Humidity Control	Wood is the best material to control humidity for indoor environment.	Aluminum helps to reduce humidity for the indoor environment.
Tooling Economics	$181 per square foot in addition to maintenance will be every 12 months sanding, re-painting, staining or sealing.	Extrusion tooling is relatively inexpensive. Generally, a simple shape will cost only a few hundred dollars.
Energy Savings	In certain applications.	Lightweight aluminum extrusions can offer energy savings for transportation vehicles.

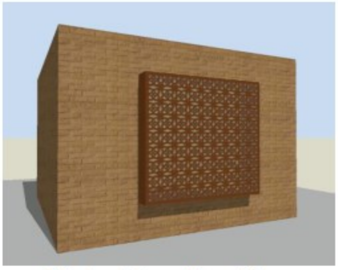
The analysis highlights the distinct advantages of wood and aluminum in Mashrabiya construction. Wood is favored for its aesthetic appeal, humidity control, and comfort enhancement, though it requires significant maintenance. Conversely, aluminum excels in durability, formability, and corrosion resistance, making it ideal for modern applications, particularly in harsh climates. While the thermal performance of aluminum may necessitate additional cooling solutions, its low maintenance and cost-effectiveness are appealing for large projects. Ultimately, the choice between these materials should consider project-specific needs, and a hybrid approach that integrates both that could optimize performance and sustainability of architectural design.

Mashrabiya Size and Material Variations Analysis

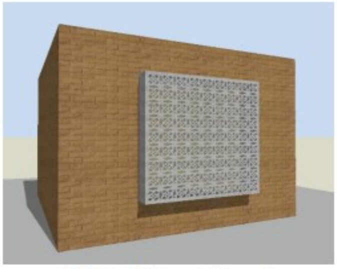
Various mashrabiya design configurations were tested to evaluate their performance. These designs incorporate material, size, and inclination angle variations to optimize their functionality. They are illustrated as shown in the Table 3.

The Base Case features a traditional wooden mashrabiya as a reference. Subsequent cases explore aluminum designs, including a denser 9x9 grid (Case 1) and a more open 7x7 grid (Case 2). Other configurations include different orientations (Cases 3 and 4), slopes of 87° (Case 5), 83° (Case 6), and 77° (Case 7) for enhanced shading and light control. Case 8 tests an inverted 87° slope for reverse shading efficiency. These variations facilitate the assessments of thermal performance, light penetration, and aesthetics, aiding in the refinement of mashrabiya designs.

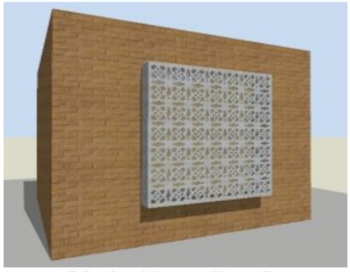
Table 3: Design Variations of Mashrabiya Patterns and Configurations
Source: Author



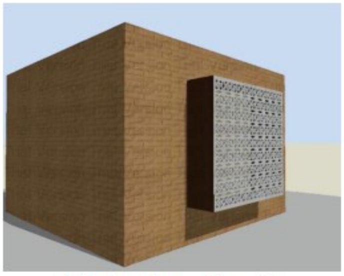
Mashrabiya – Base Case
Wood Mashrabiya



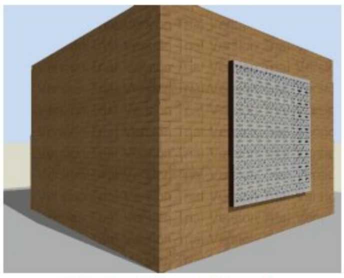
Mashrabiya – Case 1
Aluminum 9 x9 units



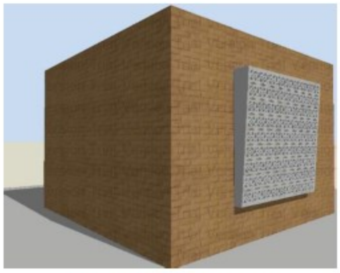
Mashrabiya – Case 2
Aluminum 7X7 units



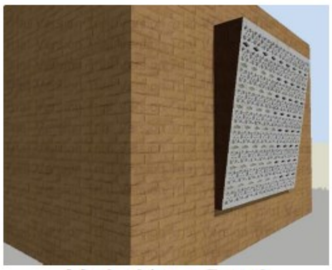
Mashrabiya – Case 3
Aluminum to outside



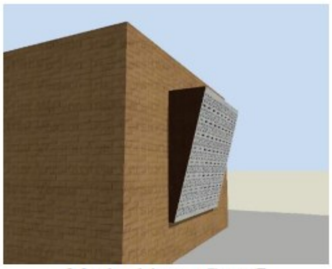
Mashrabiya – Case 4
Aluminum to inside



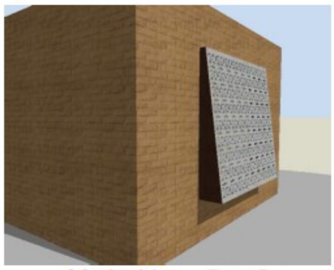
Mashrabiya – Case 5
Aluminum slope 87^{0}



Mashrabiya – Case 6
Aluminum slope 83^{0}



Mashrabiya – Case 7
Aluminum slope 77^{0}



Mashrabiya – Case 8
Aluminum inverse slope 87^{0}

The Mashrabiyas serve five essential functions: light control, humidity control, temperature regulation, airflow management, and visual privacy (Alelwani, Ahmad and Rezgui, 2020). The choice of building materials also impacts the light control capabilities of Mashrabiya (Bagasi and Calautit, 2020). Internal daylighting is influenced by the orientation of the openings; for instance, blocking direct sunlight from southern exposures is crucial, as it can lead to overheating and visual discomfort (Ashour and Gogo, 2024). During the hot summer months, Mashrabiya minimizes solar gain by shading interiors, while in the winter, it allows beneficial daylight to warm the spaces, demonstrating its dual function in temperature regulation (Almerbati et al., 2016). The lattice design, including its size and porosity, plays a significant role in these processes (Alothman, Ashour and Krishnaraj, 2021).

The Table 4 presents the illumination ratios for various building materials and mashrabiya angles, showcasing the illumination strengths in each case study analyzed with the Design Builder software. The results indicate that daylight performance varies significantly based on the materials used, orientation, and void ratios. Higher void ratios (e.g., 80%) correlate with increased maximum illuminance and broader daylight coverage. Notably, west-facing facades (Cases 05-08) achieve higher maximum illuminance levels than south-facing ones, highlighting the critical influence of material choice. Aluminum facades, in particular, demonstrate a distinct daylight performance compared to wooden ones, emphasizing the importance of selecting appropriate materials for optimal lighting outcomes.

Table 4: Daylight results comparison
Source: Author

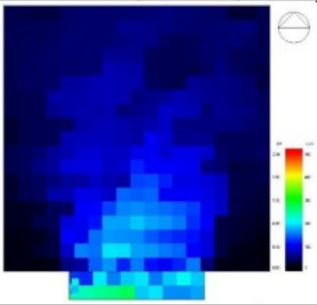
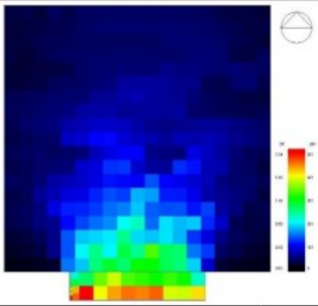
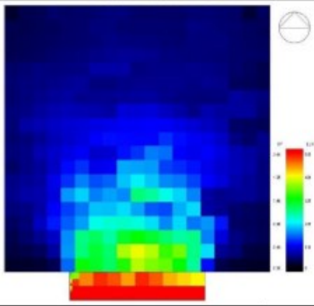
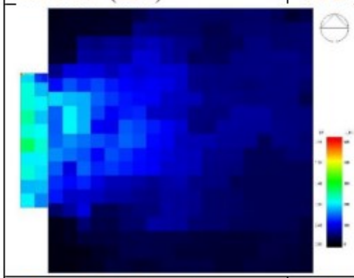
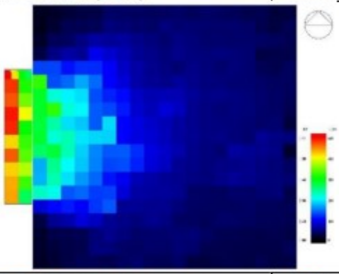
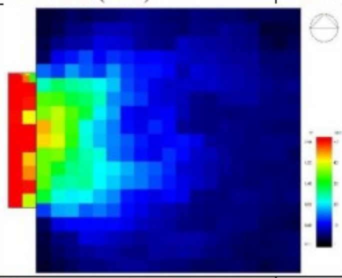
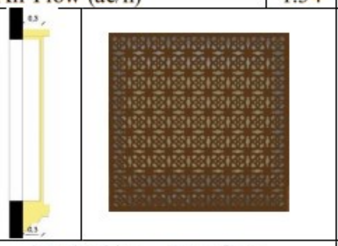
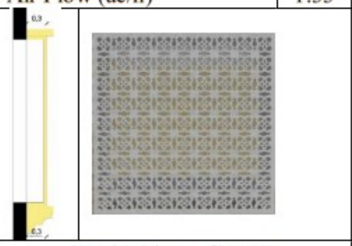
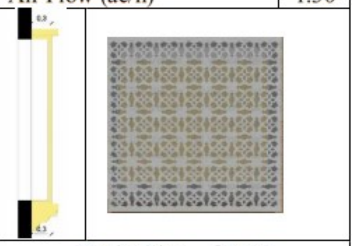
Case	01	02	03	04	05	06	07	08
Direction	South	South	South	South	West	West	West	West
Material	Wood	Alu-1	Alu-2	Alu-3	Wood	Alu-1	Alu-2	Alu-3
Void /Solid ratio (%)	50%	50%	60%	80%	50%	50%	60%	80%
Floor Area (m2)	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5
Floor Area above Threshold (m2)	0.73	1.48	2.86	4.88	0.08	1.40	2.80	4.75
Floor Area above Threshold (%)	3.1%	6.3%	12.2%	20.7%	0.3%	5.9%	11.9%	20.2%
Average Daylight Factor (%)	0.5%	0.8%	1.0%	1.5%	0.5%	0.7%	1.0%	1.5%
Minimum Daylight Factor (%)	0.1%	0.1%	0.1%	0.2%	0.1%	0.1%	0.1%	0.2%
Maximum Daylight Factor (%)	2.1%	6.4%	8.0%	8.0%	2.9%	10.9%	8.5%	13.1%
Uniformity ratio (Min / Avg.)	0.09	0.11	0.1	0.11	0.11	0.12	0.12	0.12
Uniformity ratio (Min / Max)	0.02	0.01	0.01	0.02	0.02	0.01	0.01	0.01
Min Illuminance	9.4	17.3	20.0	33.6	11.3	16.5	24.7	36.4
Max Illuminance	439.2	1319.3	1642.3	1645.6	600.5	2248.6	1747.6	2678.9
sDA Area in Range (m^2)	7.08	7.32	16.82	16.82	6.32	7.47	20.09	13.99
sDA Area in Range (%)	30.1%	31.1%	71.4%	71.4%	26.8%	31.7%	85.3%	59.4%
UDI Area in Range (m2)	21.2	20.8	20.2	21.3	20.1	21.1	20.4	21.4
UDI Area in Range (%)	90.1%	88.2%	86.0%	90.5%	85.5%	89.6%	86.8%	91.0%

This table presents the performance metrics of different mashrabiya designs (wood and aluminum) with varying orientations (South and West) and void/solid ratios. Key indicators include daylight factors, illuminance levels, and spatial daylight autonomy (sDA) and useful daylight illuminance (UDI). Aluminum cases with higher void ratios (e.g., 80%) showed improved daylight penetration but reduced uniformity, with maximum illuminance reaching 2678.9 lux. Wood (Case 01) exhibited the lowest daylight performance, with minimal illuminance (9.4 lux). Overall, UDI values remained high (85–91%), highlighting the effectiveness of the designs in providing optimal daylighting across cases.

Mashrabiya Assessment: Comprehensive Performance Evaluation and Comparison

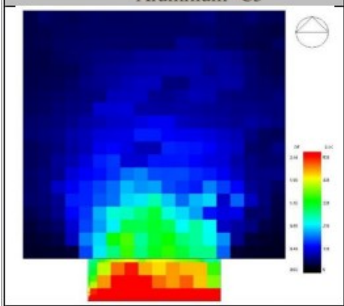
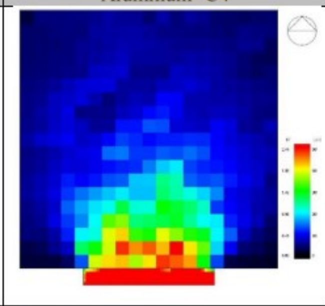
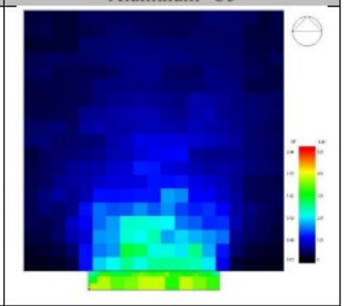
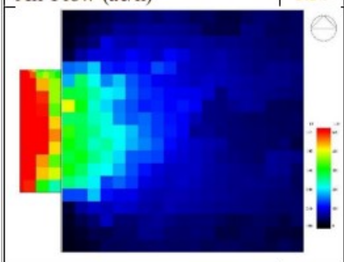
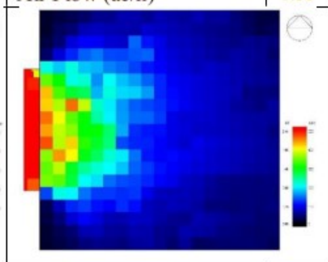
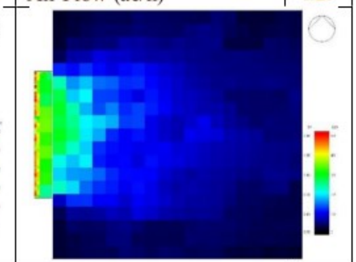
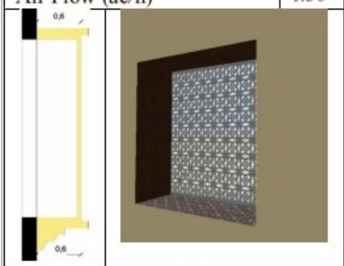
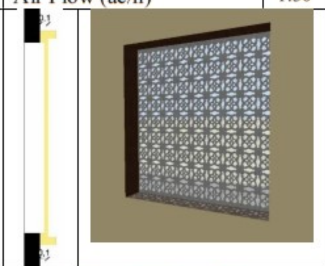
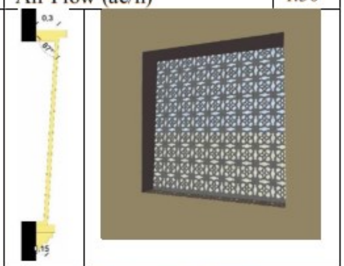
The design incorporates a 0.3-meter projection from the window frame, which improves daylight distribution and thermal comfort. The evaluation indicates that Aluminum C2 and Mashrabiya Case 2 attain the highest UDI percentages and average illuminance levels, with values of 405 lux and 420 lux, respectively. In comparison, the base case (wood) records a maximum illuminance of 343 lux and a UDI of 48.5%. as shown in table 5.

Table 5: summary of Results (case 1 and case 2)
Source: Design builder edited by the author

Wood (Base Case)		Aluminum -C1		Aluminum -C2	
					
Min illuminance - lux	6.5	Min illuminance - lux	8.9	Min illuminance - lux	15.2
Max illuminance - lux	343	Max illuminance - lux	636	Max illuminance - lux	795
Average illuminance - lux	186	Average illuminance - lux	310	Average illuminance - lux	405
Average Daylight Factor %	0.32	Average Daylight Factor %	0.41	Average Daylight Factor %	0.55
Useful Daylight Illuminance - UDI %	48.5	Useful Daylight Illuminance - UDI %	75.8	Useful Daylight Illuminance - UDI %	93.4
Indoor Tempertature °C	21.2	Indoor Tempertature °C	21.2	Indoor Tempertature °C	22.5
Relative Humidity %	59.5	Relative Humidity %	59.5	Relative Humidity %	61.5
Air Flow (ac/h)	1.32	Air Flow (ac/h)	1.30	Air Flow (ac/h)	1.30
					
Min illuminance - lux	6.4	Min illuminance - lux	12.2	Min illuminance - lux	18.6
Max illuminance - lux	479	Max illuminance - lux	718	Max illuminance - lux	792
Average illuminance - lux	222	Average illuminance - lux	365	Average illuminance - lux	420
Average Daylight Factor %	0.31	Average Daylight Factor %	0.43	Average Daylight Factor %	0.57
Useful Daylight Illuminance - UDI %	39.5	Useful Daylight Illuminance - UDI %	66.9	Useful Daylight Illuminance - UDI %	79.2
Indoor Tempertature °C	23.7	Indoor Tempertature °C	23.7	Indoor Tempertature °C	24.0
Relative Humidity %	56.5	Relative Humidity %	56.5	Relative Humidity %	61.2
Air Flow (ac/h)	1.34	Air Flow (ac/h)	1.33	Air Flow (ac/h)	1.30
					
Mashrabiya – Base Case.		Mashrabiya – Case 1.		Mashrabiya – Case 2	

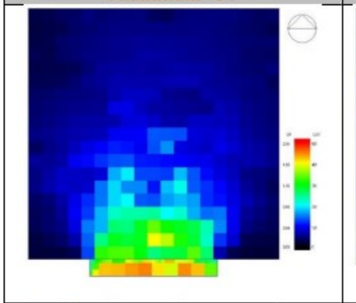
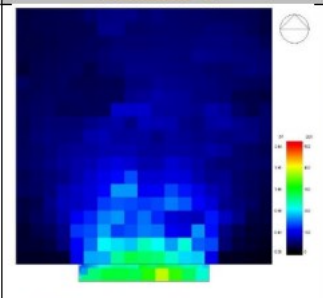
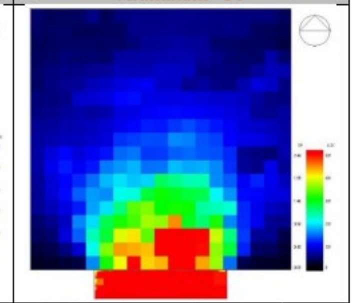
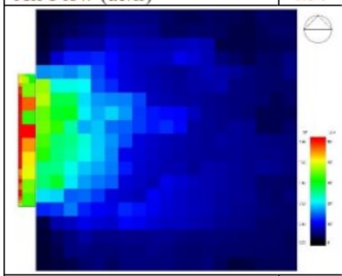
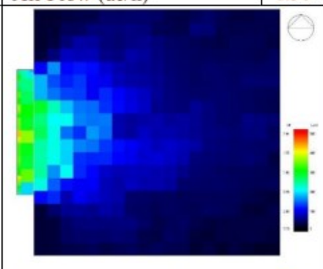
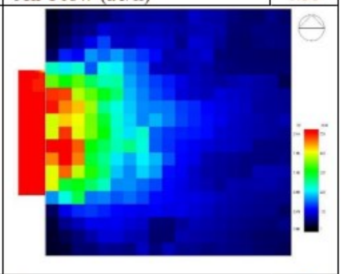
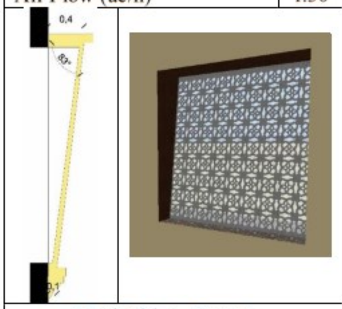
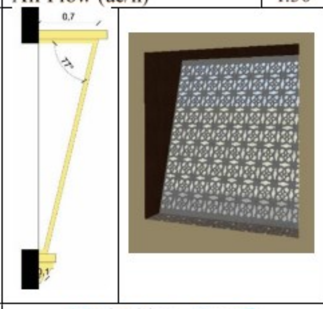
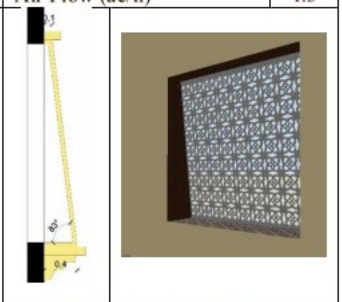
The cases in the table 6 analyzes daylight, thermal comfort, and airflow for various aluminum configurations (C3, C4, C5) and Mashrabiya patterns (Cases 3, 4, 5). Key metrics include illuminance levels, Useful Daylight Illuminance (UDI), indoor temperature, relative humidity, and airflow performance. Aluminum C4 and Mashrabiya Case 4 show the highest daylight performance, with Aluminum C4 achieving a UDI of 96.3% and a maximum illuminance of 831 lux, while Mashrabiya Case 4 records a maximum illuminance of 1135 lux and a UDI of 94.1%. Larger Mashrabiya dimensions (e.g., Case 4 at 0.6m x 0.6m) enhance daylight distribution compared to smaller patterns (e.g., Case 5 at 0.3m x 0.3m). Thermal and airflow conditions remain stable across all configurations, indicating minimal impact from design variations.

Table 6: Summary of Results (case 3, case 4 and case 5)
Source: Design Builder edited by the author

Aluminum -C3		Aluminum -C4		Aluminum -C5	
					
Min illuminance - lux	13.6	Min illuminance - lux	16.1	Min illuminance - lux	10.1
Max illuminance - lux	845	Max illuminance - lux	831	Max illuminance - lux	495
Average illuminance - lux	445	Average illuminance - lux	410	Average illuminance - lux	256
Average Daylight Factor %	0.56	Average Daylight Factor %	0.62	Average Daylight Factor %	0.37
Useful Daylight Illuminance - UDI %	90.1	Useful Daylight Illuminance - UDI %	96.3	Useful Daylight Illuminance - UDI %	78.1
Indoor Tempertature °C	22.4	Indoor Tempertature °C	22.4	Indoor Tempertature °C	22.4
Relative Humidity %	61.3	Relative Humidity %	61.2	Relative Humidity %	61.3
Air Flow (ac/h)	1.30	Air Flow (ac/h)	1.30	Air Flow (ac/h)	1.29
					
Min illuminance - lux	10.1	Min illuminance - lux	17	Min illuminance - lux	16.2
Max illuminance - lux	1130	Max illuminance - lux	1135	Max illuminance - lux	516
Average illuminance - lux	576	Average illuminance - lux	581	Average illuminance - lux	305
Average Daylight Factor %	0.59	Average Daylight Factor %	0.66	Average Daylight Factor %	0.39
Useful Daylight Illuminance - UDI %	83.3	Useful Daylight Illuminance - UDI %	94.1	Useful Daylight Illuminance - UDI %	60.2
Indoor Tempertature °C	22.4	Indoor Tempertature °C	22.4	Indoor Tempertature °C	22.4
Relative Humidity %	61.2	Relative Humidity %	61.2	Relative Humidity %	61.2
Air Flow (ac/h)	1.30	Air Flow (ac/h)	1.30	Air Flow (ac/h)	1.30
					
Mashrabiya –Case.3		Mashrabiya – Case 4		Mashrabiya – Case 5	

The three aluminum Mashrabiya configurations, C6, C7, and C8 in table 7, exhibit varying performance in terms of daylight, temperature, and airflow. C6 and C7 balance lighting and thermal comfort effectively, while C8 achieves superior daylight levels but experiences a notable temperature increase. The specific projection size and angle of inclination were not provided, but the cases tested differing slopes of 83°, 77°, and 87° for enhanced shading and light control.

Table 7: Summary of the Results (case 6, case 7 and case 8)
Source: Design Builder edited by the author

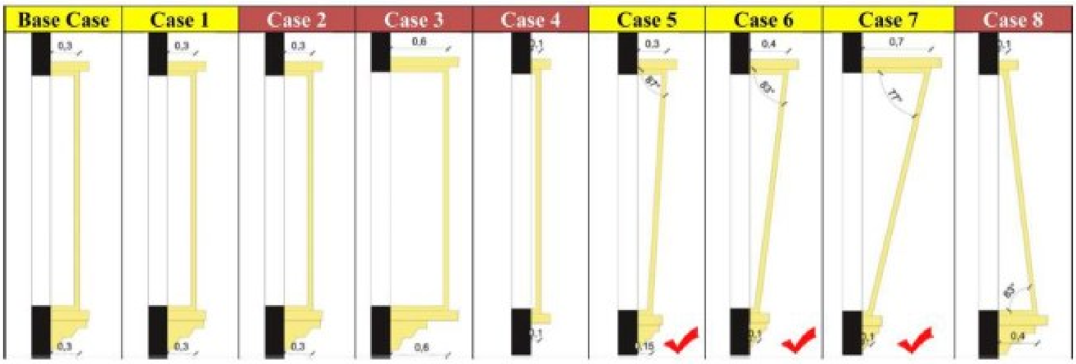
Aluminum -C6		Aluminum -C7		Aluminum -C8	
					
Min illuminance - lux	21.7	Min illuminance - lux	9.1	Min illuminance - lux	13.4
Max illuminance - lux	450	Max illuminance - lux	377	Max illuminance - lux	1130
Average illuminance - lux	250	Average illuminance - lux	196	Average illuminance - lux	672
Average Daylight Factor %	0.48	Average Daylight Factor %	0.34	Average Daylight Factor %	0.76
Useful Daylight Illuminance - UDI %	95.2	Useful Daylight Illuminance - UDI %	84.2	Useful Daylight Illuminance - UDI %	96.8
Indoor Tempertature °C	22.5	Indoor Tempertature °C	22.4	Indoor Tempertature °C	25
Relative Humidity %	61.2	Relative Humidity %	61.2	Relative Humidity %	66
Air Flow (ac/h)	1.30	Air Flow (ac/h)	1.30	Air Flow (ac/h)	1.33
					
Min illuminance - lux	18.6	Min illuminance - lux	15.8	Min illuminance - lux	15.2
Max illuminance - lux	646	Max illuminance - lux	426	Max illuminance - lux	1121
Average illuminance - lux	345	Average illuminance - lux	235	Average illuminance - lux	715
Average Daylight Factor %	0.46	Average Daylight Factor %	0.34	Average Daylight Factor %	0.88
Useful Daylight Illuminance - UDI %	83.1	Useful Daylight Illuminance - UDI %	63.3	Useful Daylight Illuminance - UDI %	86.5
Indoor Tempertature °C	22.4	Indoor Tempertature °C	22.4	Indoor Tempertature °C	28
Relative Humidity %	61.2	Relative Humidity %	61.2	Relative Humidity %	67
Air Flow (ac/h)	1.30	Air Flow (ac/h)	1.30	Air Flow (ac/h)	1.3
					
Mashrabiya –Case.6		Mashrabiya – Case 7		Mashrabiya – Case 8	

Results and Discussion

The results obtained for the South-facing Mashrabiya configurations reveal significant insights. The table 8 evaluates configurations based on the Egyptian Code, focusing on illuminance, temperature, humidity, and airflow. Case 6 (21.7 cm projection, 95.2° inclination) achieves the best balance, meeting comfort criteria. In contrast, Case 8 (13.4 cm projection, 96.8° angle) provides high illuminance but leads to thermal discomfort. Other cases exhibit varying performance levels, highlighting the importance of design choices in optimizing indoor conditions.

Table 8: Summary of the Results in the South elevation
Source: Author

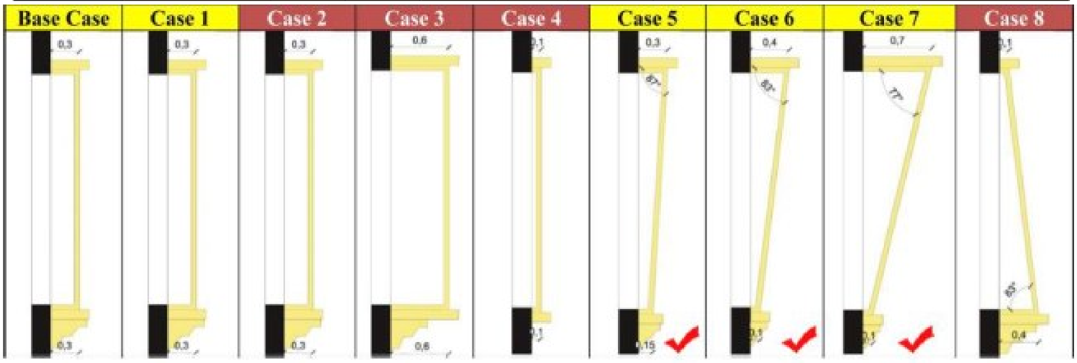
South Elev	Min illuminance lux	Average illuminance lux	Max illuminance lux	UDI %	Tempertature °C	Relative Humidity %	Evaluation according to Egyptian Code			
							T (21:26 C)	RH (20:70 %)	Lux Level 200:300 Living Space	Evaluation
Base Case	6.5	186	343	48.5	21.2	59.5	✓	✓	✓	within comfort Zone
Case 1	8.9	310	636	75.8	21.2	59.5	✓	✓	✓	within comfort Zone
Case 2	15.2	405	795	93.4	22.5	61.5	✓	✓	✗	out comfort Zone
Case 3	13.6	445	845	90.1	22.4	61.3	✓	✓	✗	out comfort Zone
Case 4	16.1	410	831	96.3	22.4	61.2	✓	✓	✗	out comfort Zone
Case 5	10.1	256	495	78.1	22.4	61.3	✓	✓	✓	within comfort Zone
Case 6	21.7	250	450	95.2	22.5	61.2	✓	✓	✓	within comfort Zone
Case 7	9.1	196	377	84.2	22.4	61.2	✓	✓	✓	within comfort Zone
Case 8	13.4	672	1130	96.8	25.0	66	✓	✓	✗	out comfort Zone



The results for the western-facing Mashrabiya configurations reveal significant insights. Case 6 (18.6 cm, 83.1°) emerges as the best-performing configuration, effectively balancing daylight, temperature, and humidity within the comfort zone set by the Egyptian Code. In contrast, Case 8 (15.2 cm, 86.5°) achieves high illuminance but exceeds thermal comfort limits. The varying performance of the other cases highlights the importance of optimizing design parameters to address the unique environmental conditions associated with a western orientation. As shown in Table 9.

Table 9: The Summary of Results in the West elevation
Source: Design Builder edited by the Author

West Elev	Min illuminance lux	Average illuminance lux	Max illuminance lux	UDI %	Tempertature °C	Relative Humidity %	Evaluation according to Egyptian Code			
							T (21:26 C)	RH (20:70 %)	Lux Level 200:300 Living Space	Evaluation
Base Case	6.4	222	479	39.5	23.7	56.5	✓	✓	✓	within comfort Zone
Case 1	12.2	365	718	66.9	23.7	56.5	✓	✓	✗	out comfort Zone
Case 2	18.6	420	792	79.2	24.0	61.2	✓	✓	✗	out comfort Zone
Case 3	10.1	576	1130	83.3	22.4	61.2	✓	✓	✗	out comfort Zone
Case 4	17.0	581	1135	94.1	22.4	61.2	✓	✓	✗	out comfort Zone
Case 5	16.2	305	516	60.2	22.4	61.2	✓	✓	✓	within comfort Zone
Case 6	18.6	345	646	83.1	22.4	61.2	✓	✓	✓	within comfort Zone
Case 7	15.8	235	426	63.3	22.4	61.2	✓	✓	✓	within comfort Zone
Case 8	15.2	715	1121	86.5	28.0	67.0	✗	✓	✗	out comfort Zone



Discussion on Mashrabiya Daylighting analysis

The potential for enhancing daylighting using the Mashrabiya was explored across several cases as follows.

- **Successful Cases**: Cases 1, 5, 6, and 7 achieved standard daylighting levels for residential spaces, as per the Egyptian Code, without significantly affecting temperature and relative humidity.
- **Unsuccessful Cases**: Cases 2, 3, 4, and 8 yielded excessively high daylighting rates, surpassing the standard for residential areas, but resulted in very low useful daylighting illuminance.
- **Case 1**: This case demonstrated the use of aluminum instead of wood, maintaining the unit size (9 horizontal and vertical units) and resulting in improved daylighting rates.
- **Case 2**: Here, the unit size was reduced to 7 units to increase daylighting rates. However, the southern and western elevations reached a maximum of 800 lux, exceeding the acceptable limit of 500 lux per the Egyptian Code.
- **Cases 3 and 4**: The depth of the Mashrabiya was adjusted from the base case of 30 cm to 60 cm in Case 3 and reduced to 10 cm in Case 4. Neither adjustment resulted in satisfactory daylighting rates.
- **Cases 5, 6, 7, and 8**: The inclination angle of the Mashrabiya was modified. Cases 5, 6, and 7 involved tilting the Mashrabiya outward with increasing inclination angles. Case 5 improved daylighting on the southern elevation to a maximum of 516 lux (UDI = 60.2%), while Case 7 enhanced daylighting on the western elevation to 426 lux (UDI = 63.3%).

- In contrast, Case 8, with the Mashrabiya tilted inward produced poor and uncomfortable daylighting conditions on both southern and western elevations.

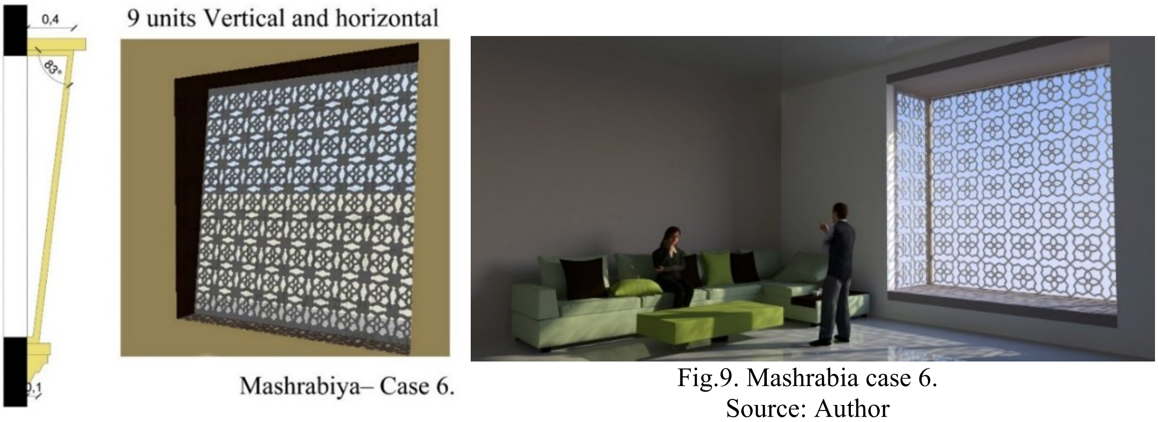


Fig.9. Mashrabia case 6.
Source: Author

For the West Elevation, the graph shows significant variations in illuminance levels between the different cases. Case 6 exhibits the most balanced performance with moderate illuminance.

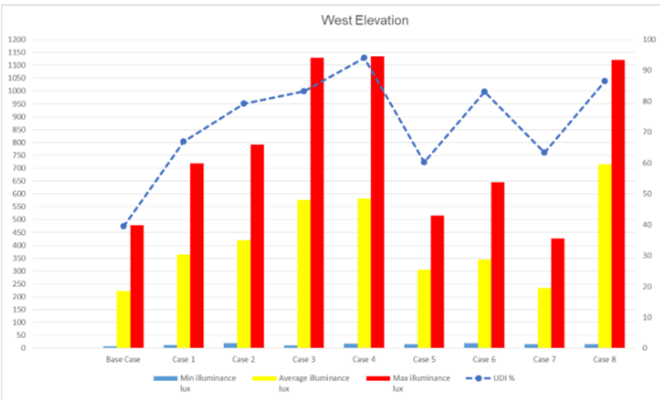


Fig.10: West elevation results
Source: Author

This suggests that the southern orientation provides more controlled and uniform daylight distribution, potentially requiring less shading compared to the west-facing facade. The performance differences between the West and South Elevations highlight the importance of considering the specific solar exposure and environmental conditions for each orientation when designing the Mashrabiya configurations as shown in the Fig 10 and11.

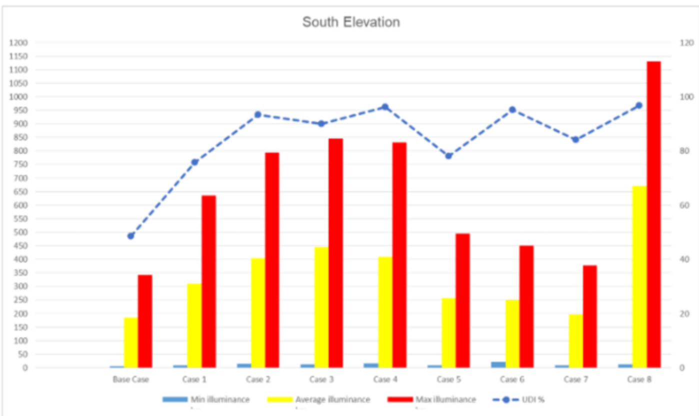


Fig.11: South elevation results
Source: Author

Conclusion

This study establishes the Mashrabiya as a vital traditional architectural element that effectively balances the preservation of vernacular architecture with modern sustainability practices. It demonstrates that specific configurations of the Mashrabiya can meet standard daylighting levels for residential spaces, adhering to the Egyptian Code. Notably, transitioning from wood to aluminum in Mashrabiya designs has shown significant improvements in daylighting performance, showcasing the benefits of modern materials in traditional contexts.

The research emphasizes that design adjustments, such as inclination angles and material choices, play a crucial role in optimizing daylighting rates and thermal comfort. Furthermore, the Mashrabiya proves to be effective in regulating daylight and minimizing glare, thereby reducing reliance on mechanical cooling systems and enhancing passive cooling strategies. Performance analysis software contributed significantly to the comparison of case studies, aiding in the selection of the most suitable building materials for optimal performance.

The study underscores the importance of respecting the cultural significance of the Mashrabiya, advocating for informed design practices that honor traditional architecture. However, it also identifies challenges, such as limited historical data and the complexities of merging traditional and modern approaches, which highlight the need for further interdisciplinary research. Overall, the findings support the integration of the Mashrabiya as a means to enhance environmental performance while promoting sustainable architectural practices that honor cultural identity.

Future Directions for Mashrabiya Research

Future research on Mashrabiya should adopt interdisciplinary approaches to effectively integrate traditional designs with contemporary architectural practices, addressing the challenges of merging historical significance with modern needs. Additionally, efforts should focus on gathering comprehensive historical data to inform contemporary applications of this architectural feature. Investigating innovative materials and technologies can enhance the functionality and aesthetic appeal of Mashrabiya, particularly in improving thermal performance and natural lighting. To combat misconceptions, educational initiatives aimed at architects and designers are essential for fostering a deeper understanding of the Mashrabiya's historical context and environmental benefits. Finally, conducting case studies that evaluate Mashrabiya's performance in various modern contexts will provide valuable insights into its adaptability and effectiveness in contemporary design.

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