sustainability

MDPI

Article

Examining Mashrabiya's Impact on Energy Efficiency and Cultural Aspects in Saudi Arabia

Ahmad Taki and Haripriya Kumari *

Leicester School of Architecture, De Montfort University, Leicester LE1 9BH, UK; ahtaki@dmu.ac.uk
* Correspondence: haripriyatks@gmail.com

Abstract: The traditional and indigenous architecture in Saudi Arabia is being replaced by modern, Western-style buildings, resulting from the growing influence of Western culture. This change is evident in architectural elements such as Mashrabiya, which was once a symbol of the country's Islamic architecture. The research paper aims to analyse the impact of modernization and the resurgence of Mashrabiya on a building's energy efficiency, as well as the cultural and religious integrity of its historical counterpart in the context of Saudi Arabia. The study employed mixed research methods, including an online survey with Saudi Arabian households to study the public perception of Mashrabiya, case studies of residences with traditional and modern Mashrabiya, and a range of dynamic thermal simulations on a residence with traditional Mashrabiya to study its impact on energy consumption. The survey revealed that the public is aware of the changing face of Mashrabiya and its impact on the cultural and religious identity of the region, mainly privacy, but it is largely uninformed about ways to preserve its true essence. The simulations demonstrated a significant improvement in thermal comfort, i.e., an approximate 14% reduction in operative temperature and a 77.8% reduction in peak solar gain; an improvement in energy efficiency, i.e., a 5.7% reduction in monthly cooling load and a 35.5% improvement in daylight factor. Based on the findings, the research provides several recommendations to preserve the identity of traditional Mashrabiya while enhancing their energy efficiency, such as the incorporation of traditional design elements into the plans of the Saudi Arabian government.

Keywords: Mashrabiya; Saudi Arabia; energy consumption; simulation; architectural identity; Islamic architecture

Citation: Taki, A.; Kumari, H. Examining Mashrabiya's Impact on Energy Efficiency and Cultural Aspects in Saudi Arabia. *Sustainability* **2023**, *15*, 10131. https://doi.org/10.3390/su151310131

Academic Editor: Dušan Katunský

Received: 11 April 2023
Revised: 13 May 2023
Accepted: 19 May 2023
Published: 26 June 2023

1. Introduction

The Middle Eastern regions, such as Saudi Arabia, are renowned for their harsh climatic conditions characterized by scorching heat, an arid sun, and minimal humidity levels [1]. To counteract the adverse impacts of such weather conditions, architects and building experts have put forward a plethora of passive design solutions that leverage indigenous materials and techniques [2]. Among them, one such innovative and historic sun-shading solution is the Mashrabiya, which was prevalent during the Middle Ages and persisted until the mid-20th century [3].

"Mashrabiya was a cantilevered space with a lattice opening where small water jars were placed to be cooled by the evaporation effect as air moved through the opening. Now the name is used for an opening with a wooden lattice screen composed of small wooden balusters that are circular in section and arranged at specific, regular intervals, often in a decorative and intricate geometric pattern" [4] (Figure 1). Figure 2 demonstrates the principal functions of Mashrabiya, which are: (a) controlling the passage of light, (b) controlling the air flow, (c) reducing the temperature of the air current, (d) increasing the humidity of the air current, and (e) ensuring privacy [4].

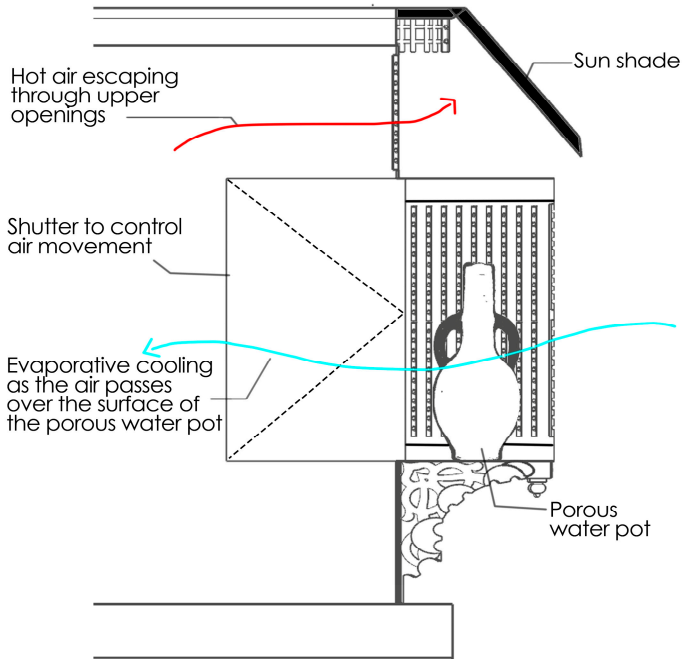


Figure 1. Indoor air-cooling system created by placing porous water jars in the Mashrabiya.

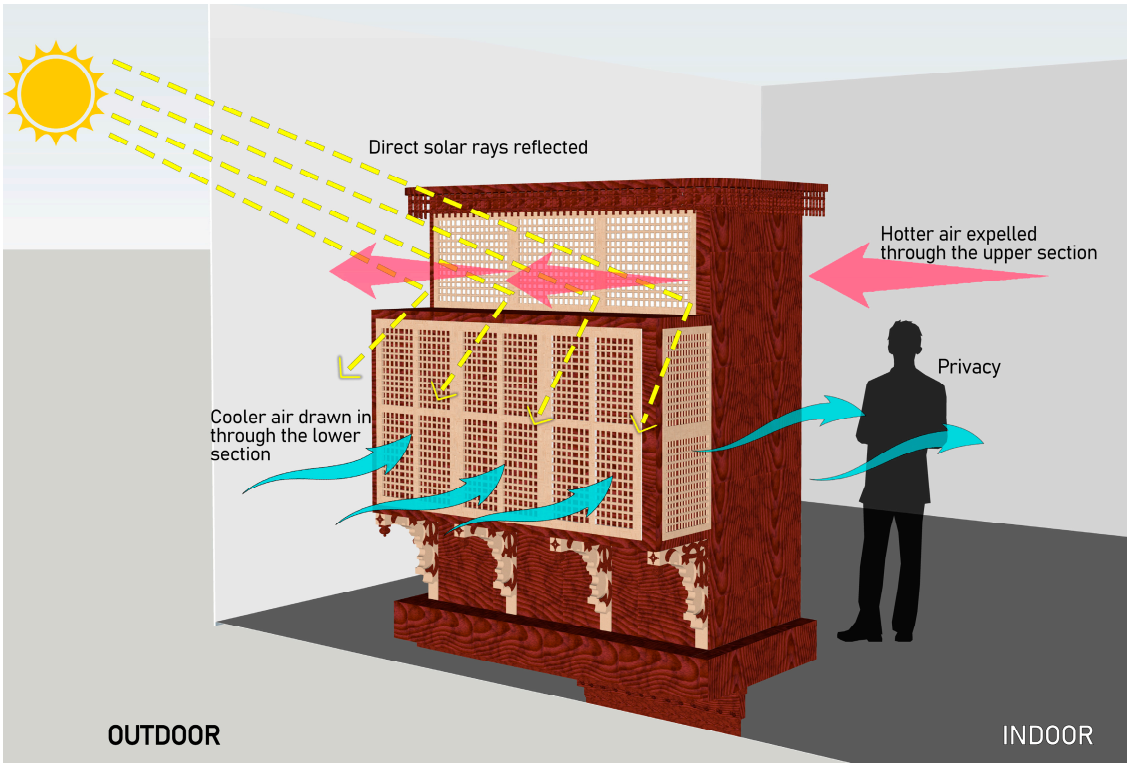


Figure 2. A schematic of a Mashrabiya showing its features and main functions.

Saudi Arabia (Figure 3), a nation with a wealth of cultural and historical legacies, has undergone significant transformation in recent years. The impact of Western culture on the architecture of Saudi Arabia has resulted in a transition towards modern styles influenced by personal preferences and media exposure [5,6]. This shift has replaced the once-prevalent traditional and indigenous architecture with Western-style buildings, which is observable in various architectural elements such as Mashrabiya [7], a proud symbol of the country's Islamic architecture, which has now been replaced by contemporary elements.

Figure 3. Map of the Kingdom of Saudi Arabia [8].

The significant economic growth of Saudi Arabia in recent years has led to an increase in domestic energy consumption [9,10]. The population of Saudi Arabia has been steadily increasing [11], and with it, so is the demand for housing and energy to power homes and buildings [12,13]. As of 2021, the volume of residentially consumed electricity in Saudi Arabia was approximately 142.48 terawatts per hour, which is a significant increase from 120.65 terawatts per hour in 2012 [14].

The government has launched new housing projects and initiatives to address the housing crisis, such as the "Vision 2030" programme, which aims to build 1.5 million housing units by 2030 [15]. In an effort to address the increase in domestic energy consumption, the government of Saudi Arabia has implemented several strategies and measures, one of which is to increase energy prices for consumers. In 2015, the government announced that it would be raising the price of electricity and water for households and businesses in order to reduce domestic energy consumption, which was met with some resistance from the public, as many people expressed that the increase in prices would be too high for them to afford [16].

The implementation of Mashrabiya, within the framework of governmental initiatives to decrease domestic energy consumption, can serve as a catalyst for propelling the nation towards decreased domestic energy consumption and, ultimately, making the country, as a whole, more energy efficient. The vision for a promising future for Saudi Arabia would be to have buildings that are not only aesthetically pleasing but also possess a high level of energy efficiency and low energy consumption. Similarly, a vision for a promising future for Mashrabiya would involve the resurgence of traditional forms of the architectural element within Saudi Arabia without compromising its cultural and religious significance or losing its unique identity.

This research explores the possibility of achieving both of these visions by incorporating traditional Mashrabiya into the plans of the Saudi Arabian government, making the two aims mutually dependent and, thus, mutually achievable. The research provides recommendations for how this can be achieved in a sustainable and culturally sensitive manner. The ultimate aim is to examine the impact of modernization and the renewed use of Mashrabiya on the preservation of traditional architecture and culture, as well as energy

efficiency, in Saudi Arabian households. Based on the aim, the following main objectives were distinguished:

1. to analyse the impact of modernization and the resurgence of the traditional architectural element of Mashrabiya on the cultural and religious integrity of its historical counterpart;
2. to investigate the potential effects of traditional forms of Mashrabiya in residential buildings on overall domestic energy consumption;
3. to recommend methods for preserving traditional Mashrabiya in a manner that aligns with cultural, traditional, and religious values, while also enhancing the energy efficiency of the buildings.

The study employs both qualitative and quantitative methods of research, including literature study, case studies, surveys, and simulations, to achieve these objectives. The study is limited to focusing on the cultural context of Saudi Arabia, thereby potentially restricting the generalizability of its findings to other regions and countries. While the insights provided offer valuable understanding of the role of Mashrabiya within Saudi Arabian culture, it is crucial to acknowledge the inherent variations in architectural practices and cultural values across the Middle East and beyond.

2. Literature Review

A literature review was conducted, exploring various elements associated with Mashrabiya, including their functional, social, and aesthetic characteristics. Additionally, the examination encompasses a detailed analysis of the materials and costs involved in the construction of Mashrabiya, providing a comprehensive understanding of the subject matter and enabling the identification of research gaps and the development of an appropriate research methodology.

2.1. Concept of Mashrabiya

The origin of the Mashrabiya in the Middle East can be traced back to its Arabic root word "Sharab", meaning "To drink" [4,17–20]. Initially, Mashrabiya referred to a location where one could access water from a clay pot. Over time, it evolved into a functional element that combined wooden lattice panels with a clay pot, serving as a means to keep the water cool and provide a cooling effect [4,19,20].

Mashrabiya, distinctive features of Middle Eastern architecture, found widespread application in traditional houses due to their exceptional suitability for coping with the region's dominant climatic condition: extreme heat. Unlike Western countries, where such conditions are less prevalent, the Mashrabiya's popularity in the Middle East can be attributed not only to environmental factors but also to the cultural values embedded in the Middle Eastern society, which are heavily influenced by Islamic principles. Among them, one such value is privacy, which holds significant importance in Middle Eastern culture [19–21]. As a result, Mashrabiya effectively addressed both environmental and social concerns, making them an integral component of Middle Eastern architecture.

Over time, the expression of the "Mashrabiya" has undergone significant transformations, adopting diverse forms. Among these, the most renowned is the projecting bay window featuring timber panels constructed from lathe-shaped wooden balusters. These balusters are arranged in a lattice pattern, forming distinct geometric designs, and they are positioned at regular intervals [22].

A Mashrabiya offers occupants the benefit of privacy from external views while enabling them to observe the surroundings through the lattice. When the Mashrabiya faces the street, the spacing between the balusters is typically narrower at eye level, while the upper part, situated above eye level, would have a wider arrangement in order to facilitate sufficient airflow [23] (Figure 4). It can permit the passage of ambient light into spaces while preventing direct sunlight. In order to avoid optical discomfort due to glare, architects are advised to opt for Mashrabiya designs featuring balusters with a circular section, as specified by Fathy. This choice ensures the creation of gradual shadows, minimizing

contrast and distinguishing it from shading devices utilizing square sectional balusters or similar alternatives [4].

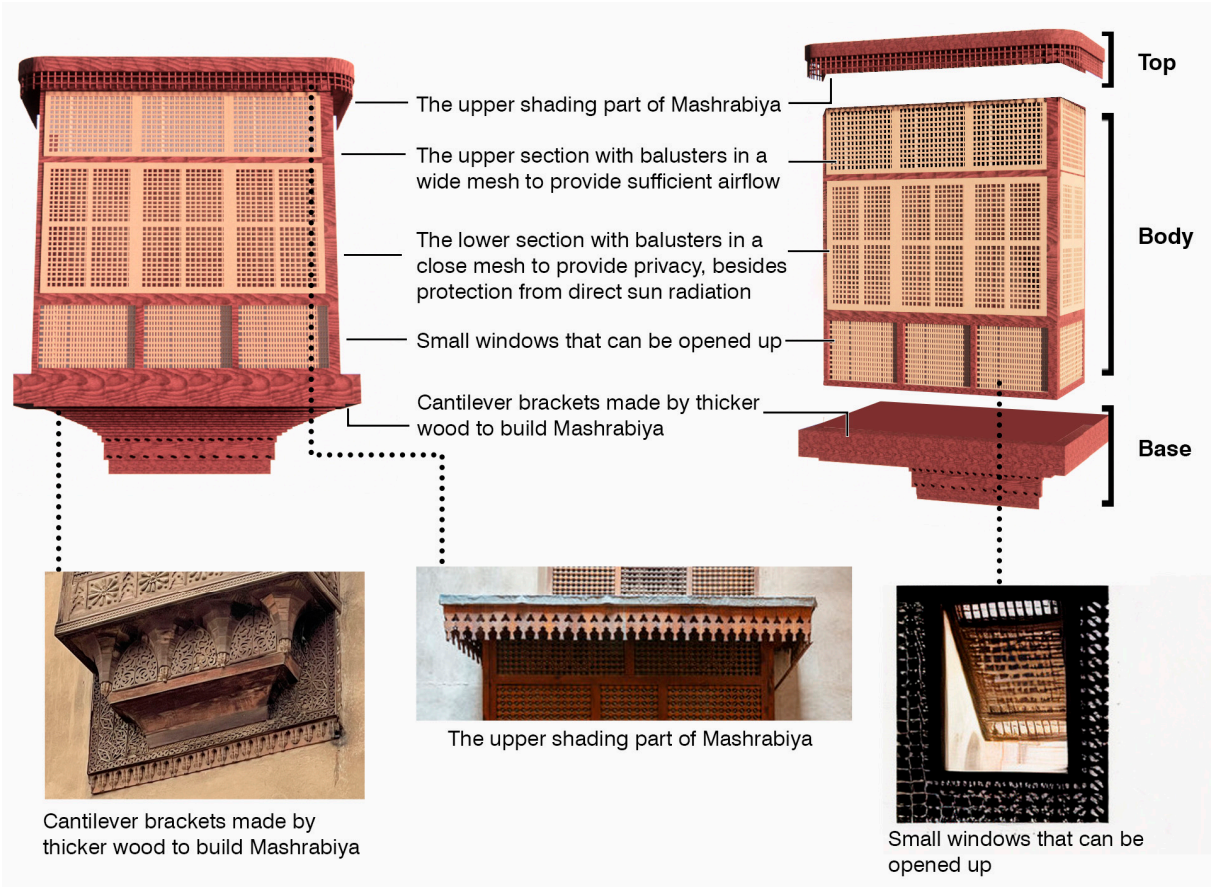


Figure 4. Components of Mashrabiya (Illustrated by author, referencing Abdelkader et.al. [20]).

2.2. Privacy

The significance of social values in Islamic culture cannot be overstated, and among these values, privacy holds a paramount position in Muslim households [23–25]. The traditional Mashrabiya, with its intricate lattice design, offered residents the necessary protection from outside prying eyes, while still affording them the opportunity to view their surroundings from the comfort and privacy of their own abode. It is notable that the spacing between the balusters of the Mashrabiya, when facing the street, is carefully considered, with a more closely spaced design at eye level and a more open design above eye level, as stated by Alothman and Akçay [23]. This intricate consideration of privacy in the design of the Mashrabiya highlights the importance placed on this cultural value in traditional Islamic architecture.

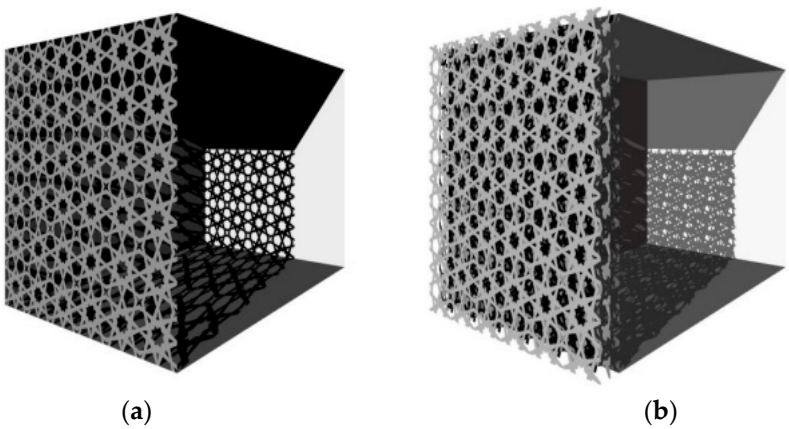
According to the Islamic religion, to preserve the modesty and seclusion of women, strict segregation between males and females is deemed necessary to preserve decorum [20]. This principle is reflected in the design, form, and function of both residential and public spaces, providing female occupants with the opportunity to experience outdoor life without attracting undue attention or compromising their privacy.

The significance of privacy has been further corroborated by a comprehensive study conducted by Alelwani et al. [3], which indicated that a significant majority of participants, amounting to 61.15%, held the strong belief that privacy holds utmost importance, whereas only a negligible proportion of 1.23% expressed the view that privacy is not a crucial factor.

2.3. Natural Lighting

A Mashrabiya plays a crucial role in regulating the amount of direct daylight that enters a building, with the design parameters determined by the architect [26]. During the summer, it helps block out the harmful sun rays, minimizes internal heat build-up, and still allows for an adequate amount of light to penetrate into the building. The presence of a Mashrabiya enables ambient light to permeate the interior space without admitting direct sunlight, hence reducing excessive glare, which can cause visual discomfort even though it does not raise the room temperature [27]. As a result, a Mashrabiya proves to be one of the most effective solutions to this issue. According to Fathy [4], the architect must select a Mashrabiya with a circular cross-section for the balusters, as this creates a gradual shadow that minimizes contrast. This is in contrast to square sectional balusters or similar shading devices that may cause sharp shadows. It is important to note that this condition is often overlooked in contemporary projects that utilize Mashrabiya, particularly when using steel in their construction, resulting in a recurrent mistake [28].

Mashrabiya are being reinvented by designers as high-tech daylight systems, often on a grand scale, utilizing computer technology. Their purposes extend beyond being oriental ornaments for covering tall buildings to being major responsive daylight systems [19]. Giovanni et al. [29] explore the possibility of designing a "Shape Variable Mashrabiya (SVM)" (Figure 5) for lighting and shading. The study compares its performance with standard Venetian blinds, and diffused daylight, and proves that, at low elevation angles, it provides sufficient daylighting under direct sunlight, in contrast to typical Venetian blinds.



(**a**) (**b**)

Figure 5. Images of the SVM [29]: (**a**) opened; (**b**) closed.

A follow-up research paper by the same authors in 2015 [30] demonstrated the SVM's ability to provide significant quantitative advantages in terms of daylighting, energy savings, and visual comfort for users by controlling glare. It reduced the primary energy required for lighting by up to 65.7% compared to reflective glazing with 16% light transmittance (RG16) and 30.7% compared to Venetian blinds (VB). The results were identified through simulations, however, a better methodology to gain insights into the practical implementation of an innovative kinetic Mashrabiya system would be the use of real scale prototypes, which can provide performance monitoring, as well as insights regarding its potential aesthetic value.

2.4. Energy Efficiency

Mashrabiya can reduce a building's energy consumption by limiting solar gain, cooling the interior spaces, and ensuring adequate air flow [31]. Most of the authors who have studied the lighting, cooling, and thermal comfort effects have also concluded their findings on the energy performance of the building as well.

Madan and Saxena [32], as well as El Semary et al. [19], conducted case studies on the Al Bahr Tower, Abu Dhabi, and found that the kinetic Mashrabiya contributed to a 25% reduction in cooling load and a 20% to 50% reduction in solar gain.

Karamata et al. [30] developed Shape Variable Mashrabiya (SVM), which proved to be a promising innovative technology for arid climates. Through experimentation in a sample peripheral space, SVM was found to significantly reduce overheating issues, leading to a decreased primary energy demand for cooling compared to selective glazing and Venetian blinds (17.2% and 9.9%, respectively). It also minimized the primary energy requirement for lighting (by 65.7% and 30.7% compared to RG16 and VB, respectively) while simultaneously improving lighting efficiency (the concept is shown in Figure 6), resulting in a reduction in global primary energy usage by 27% and 16.3% compared to RG16 and VB, respectively, as cited by Bagasi and Calautit [33].

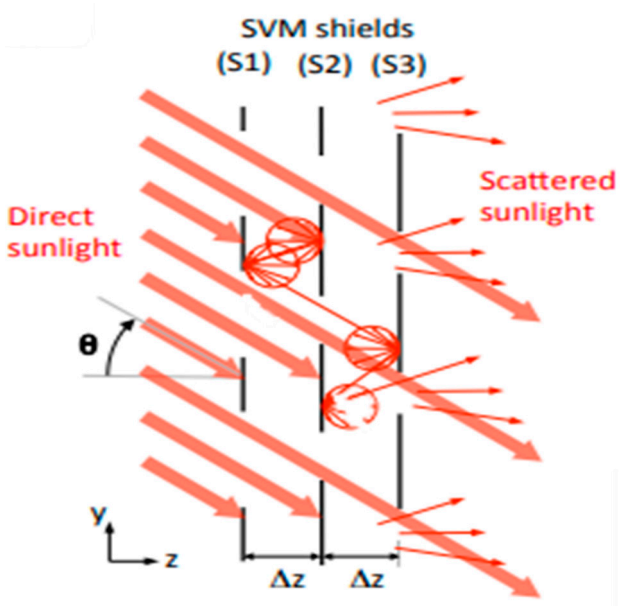


Figure 6. Concept of the direct to diffuse light transformation (DDT) function [30].

Taleb and Antony [34] further endorse this in their experiments, which were conducted by adding Mashrabiya as a 75% tinted, frosted adhesive film to the glazing. A 40% coverage of the glazing unit used the Mashrabiya pattern, and results showed that this could lower the cooling load by 23%. A survey by Alelwani et al. [3] shows that 78% of the participants ranked aesthetics as the most critical factor, and for 58.48%, energy efficiency comes second to aesthetics.

The Mashrabiya has evolved from a simple window screen to a highly complex facade system that may work as a possible shading screen for the entire building, making it more energy efficient [35]. When it comes to commercial high-rise buildings, the most prominent criterion aimed at by contemporary Mashrabiya is their energy efficiency, rather than other functional factors, such as ventilation, or social factors, such as privacy. However, the findings by Alelwani et al. [3] imply that contemporary façades, modelled after Mashrabiya in smaller structures, such as residences, are built solely for pretentious and aesthetic reasons, ignoring the functional features that made them environmentally viable in the first place.

2.5. Material and Construction

The primary traditional material used for the construction of Mashrabiya is wood, owing to its capability to regulate internal shadows, minimize glare, withstand high temperatures, and influence humidity buffering and airflow cooling [36]. The Mashrabiya was originally constructed using one of three local wood varieties: pine, walnut, or beech.

However, craftsmen also incorporated imported woods, such as oak and walnut, from Europe and West Asia, as well as ebony from Somalia, South Sudan, and Ethiopia [30].

The construction of Mashrabiya in Bahrain and the Middle East has been notably influenced by the region's local materials and skilled craftsmen, making it unique to its region. When solid wood was not available as a local source, gypsum clay was utilized instead. Gypsum's porous quality made it well-suited for use in humid regions. Nonetheless, the design constraints and decorative features of gypsum-based Mashrabiya were considerably different from those made from wood [31].

Almerbati et al. [37] investigated the feasibility of developing parametric Mashrabiya via 3D printing technology, with the objective of identifying the implications for new digital craftsmen and fabricators. Their research focused on developing input data that would enable the generation of assemblies capable of delivering functional performance, while also supporting cultural development, as cited by Almurbati [36]. The emergence of 3D printing technologies over the past two decades has opened up the possibility of using the performative analyses of existing Mashrabiya to inform the development of new parametric models, which can be customized for specific sites and produced using large-scale 3D printing [36] (Figure 7).

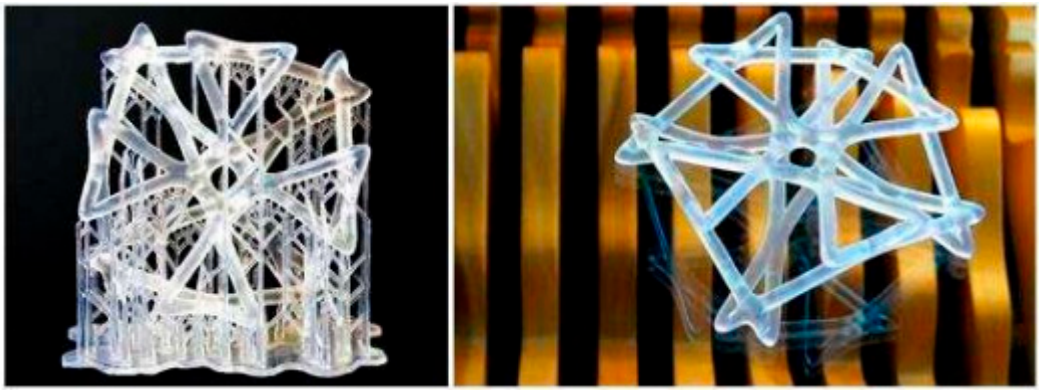


Figure 7. The use of 3D printing enables the production of parts that cannot be made in any other fashion, 10 cm by 10 cm test prints [37].

The key findings of Almerbati's [37] research suggest that the utilization of parametric Mashrabiya provides the digital artisan with the opportunity to integrate advanced construction and production techniques into the conventional art form. Although the cost of 3D printing the Mashrabiya may currently be equivalent to—or higher than—the cost of traditional fabrication methods, factoring in factors such as durability and scope, it can be predicted that, as technology progresses, the cost of 3D printing will decrease. Conversely, the scarcity of skilled craftsmen is expected to increase, thus driving up the cost of conventional fabrication.

Additive manufacturing is the procedure of solidifying powder or liquid by using a melting laser or a binding agent [38]. Almerbati et al. [15], in their research based in the Middle East, explore the possibility of innovative construction methods, such as additive manufacturing (AM), for the production of Mashrabiya. The result indicates that creating a Mashrabiya model using additive manufacturing (AM) technology is feasible, and it would represent an innovative step forward for Bahrain and the wider Middle East region, as there is a strong appreciation for personalized and craftsman-free products.

2.6. Cost

The materials used for production heavily affect the cost of Mashrabiya. Traditional Mashrabiya, which are made from wood (mainly teak), average about $2788, which is almost four times the price of contemporary GRC (Glass fibre Reinforced Concrete) or marble and granite moulded products [17].

When compared to a standard wood or aluminium window, the cost of Mashrabiya construction has increased. Nonetheless, a Mashrabiya, according to Alothman et al. [23], still offers advantages over mechanical air conditioners, which waste a lot of energy and have high operating expenses.

In the most intricate Mashrabiya, a single square yard of latticework can be composed of as many as 2000 components [39], and an average piece of Mashrabiya latticework can take 2 to 3 days to complete [40]. This level of time intensive labour and skills required to assemble them can result in very high costs of production. The research conducted by Headley et al. [41] seeks to alleviate this problem by replacing craftsmanship with new manufacturing techniques such as 3D printing. According to Crolla and Williams [42], as cited by Headley et al. [41], it can be hypothesized that additive manufacturing may become cost-competitive with traditional manufacturing, as the cost of this technology may decrease significantly.

The increase in the cost of production of traditional Mashrabiya has highly influenced users to move on to cheaper contemporary forms. The study conducted in Bahrain found that most Bahraini locals and residents would be willing to spend less than $663 on a window treatment, which is about a quarter of the cost of a solid wood Mashrabiya [41]. This finding, compiled with the survey by Alelwani et al. [3] showing that 78% of the users considered aesthetics to be the most important factor of Mashrabiya, proves that, regardless of the functionality, modern users would turn to contemporary Mashrabiya purely for aesthetics and the reduction in the initial cost.

2.7. Exploring Determinants of Public Acceptance of Energy Saving Initiatives

Over the past few years, there has been a significant surge of interest in understanding consumer perspectives, attitudes, and opinions regarding green energy, encompassing energy-saving measures as well as the adoption of renewable energy technologies [43]. Wüstenhagen et al. [44], in his research on the social acceptance of renewable energy innovations, "clarified social acceptance understanding, distinguishing three dimensions, namely, socio-political acceptance, community acceptance, and market acceptance", as cited by [45]. These factors can be considered when exploring the adoption and acceptance of Mashrabiya as sustainable architectural features.

The survey by Alewani et al. [3] revealed that 61.15% of respondents considered privacy to be highly important and influential in their choice of window or opening for their homes. Experts interviewed in the same study unanimously recognized privacy as the foremost consideration for incorporating Mashrabiya into the Saudi Building Code. Previous studies have consistently emphasized privacy as the primary factor when evaluating the importance of Mashrabiya [17,21,46]. Therefore, the Mashrabiya's acceptance in the social context heavily relies on its ability to symbolize privacy, reflecting the cultural values of Saudi society.

Community acceptance of Mashrabiya can be influenced by various factors, with cost being a significant consideration. The importance of income level and residence ownership status in the adoption of microgeneration technologies within a community is highlighted in the research of Karytsas et al. Lower incomes and non-property ownership are identified as potential barriers to the installation of such technologies [43]. Previous studies conducted within the Bahraini community of Saudi Arabia reveal that residents are willing to pay only a fraction of the cost of a traditional wooden Mashrabiya for a window treatment [41]. These findings have implications for assessing the feasibility and acceptance of Mashrabiya, as its implementation may require certain financial resources, and it may be more suitable for certain communities than others.

The research conducted by Karytsas et al. further emphasizes the impact of subsidies and cost-related factors on the installation of microgeneration technologies. It suggests that subsidies and incentives can improve market conditions and, in turn, contribute to the adoption of such systems [43]. This finding can be applied to the integration of Mashrabiya

in residences, as it underscores the importance of financial incentives and cost-effectiveness when considering energy efficient initiatives for the public.

3. Methodology

This study employs pragmatics as its research methodology, combining elements of positivist and interpretive approaches, to investigate the functional and aesthetic features of Mashrabiya in contemporary and traditional architectural contexts using both qualitative and quantitative data collection methods, as shown in the methodology flowchart in Figure 8.

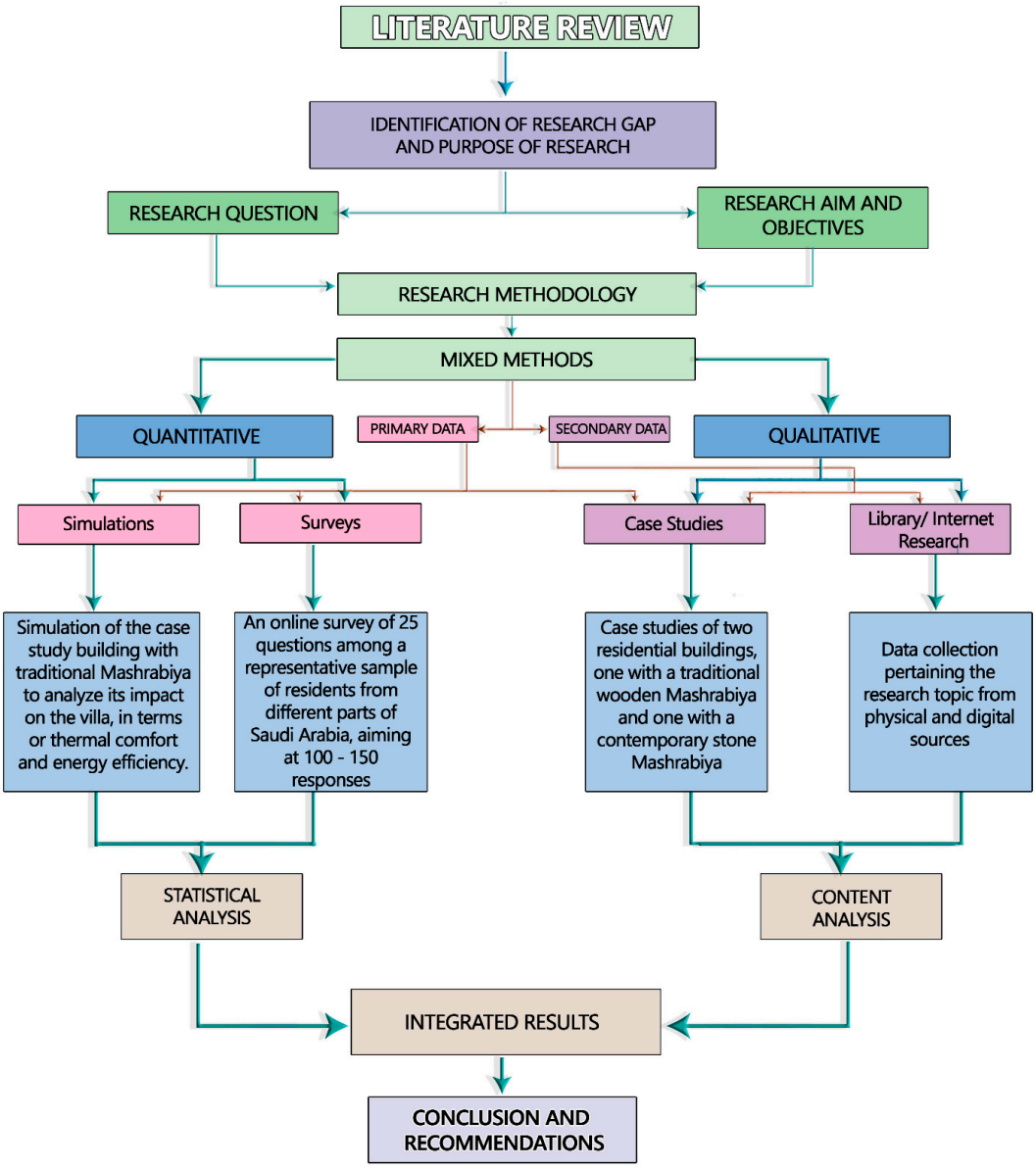


Figure 8. Methodology Flowchart.

Qualitative methods include a comparative case study analysis of two buildings: one traditional and the other modernized. A 3D model is created using SketchUp and Enscape software, and photographs are analysed to examine the impact of daylight. Quantitative methods include an online survey and a simulation using EnergyPlus DesignBuilder software version 6.1.8.021 to evaluate the energy efficiency and comfort of a building.

The survey aims to uncover reasons for the decline in popularity of traditional Mashrabiya, as well as their impact on cultural and religious aspects such as privacy, and explore strategies for promoting its use in domestic architecture. The simulation assesses the feasibility of increasing Mashrabiya usage in future building projects, potentially reducing overall domestic energy consumption in Saudi Arabia.

The survey questionnaire and research protocols adhere to the guidelines, which conform to the legal regulations of the United Kingdom and were approved by the ethics committee. The ethics process is detailed in Section 5.

4. Case Studies

The first case study is the analysis of a contemporary residential building located in the city of Riyadh, Saudi Arabia, which provides a deeper understanding of the ways in which the Mashrabiya affects the inhabitants' day-to-day experience of the building. The second case study is a contemporary residential building, located in Israel, called the 'Mashrabiya House'. Despite being situated outside of Saudi Arabia, this building was selected as a case study due to its unique incorporation of traditional Mashrabiya elements into its contemporary design. The climatic conditions of Saudi Arabia and Israel are comparable, with both countries experiencing subtropical to tropical weather patterns, making the Mashrabiya House an ideal candidate for analysis in terms of the performance of both traditional and modern Mashrabiya in a similar context.

4.1. Case Study 1: Villa in Riyadh

4.1.1. Location and Climate

The first case study building is a villa situated in the Al-Bathaa district of Riyadh, Saudi Arabia (Figures 9 and 10). This district is in the old part of the city, and it is known for its traditional architecture, historic buildings, and vibrant markets. It is considered one of the more exclusive neighbourhoods in the city and is home to many wealthy Saudis and expatriates [47].

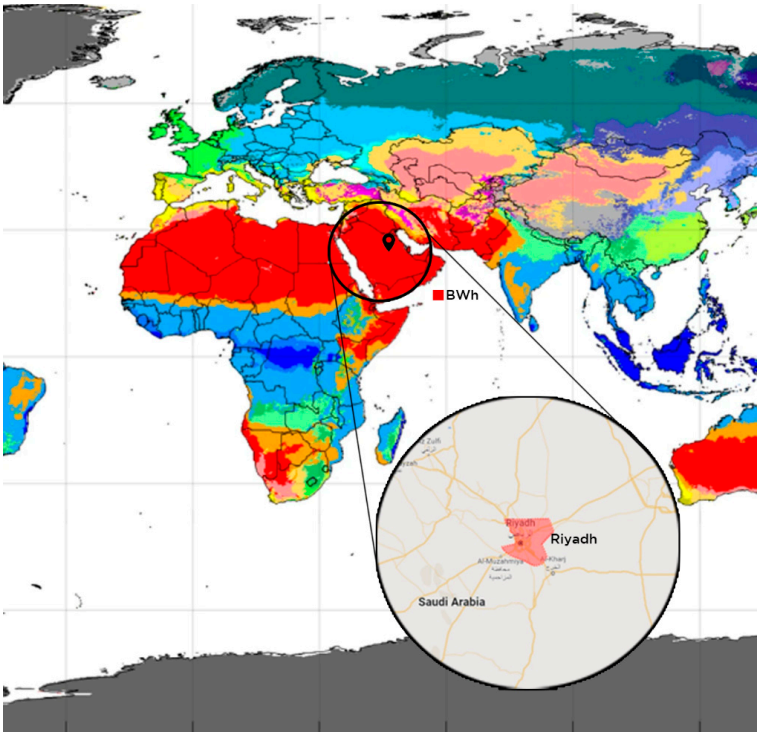
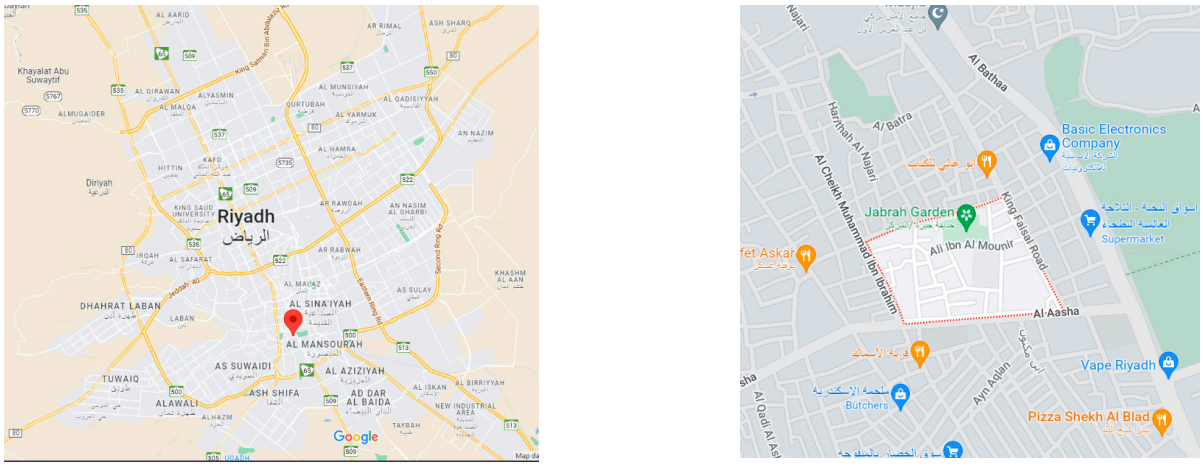


Figure 9. Location and climatic condition of the case study villa (based on the Köppen–Geiger climate classification map [48].



(**a**) (**b**)

Figure 10. Location of the villa (modified by the author): (**a**) map showing the location of the Al-Bathaa district in Riyadh [49]; (**b**) map showing the Al Bathaa district [50].

The Köppen–Geiger climate classification subtype for the climate of Riyadh, Saudi Arabia, is "BWh", which is the tropical and subtropical desert climate [48] (Figure 9).

Saudi Arabia is a desert country with a hot and dry climate, which varies in temperature from very high to moderate depending on the region. The geography and location of the country have a significant impact on its climate. The average temperature ranges from 27 to over 50 degrees Celsius. Rainfall is scarce, with an annual average of less than 100 mm, and the eastern and central regions, where Riyadh is located, are among the driest places on earth. The western highlands receive more rainfall, ranging from 150 to 300 mm per year [51].

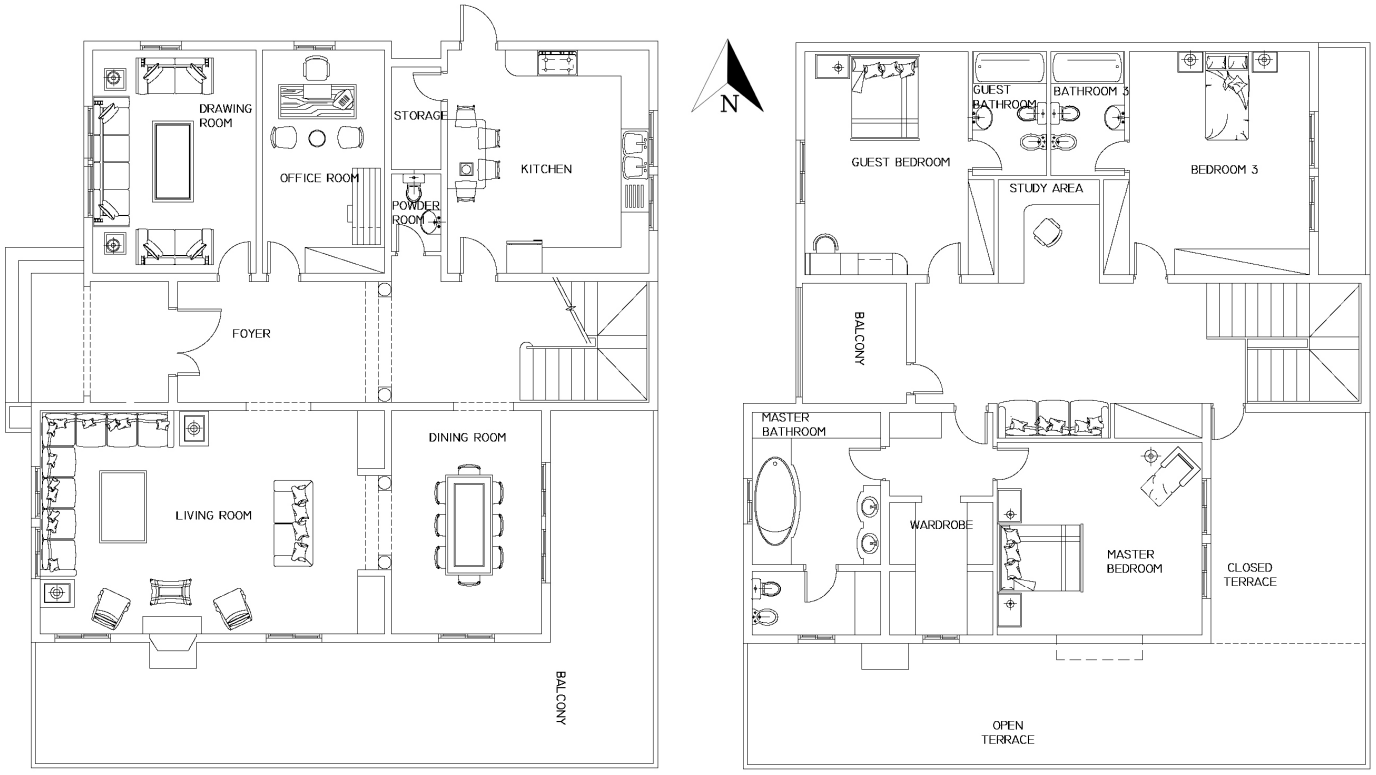
4.1.2. Building Details

The construction of the villa in question dates back to the 1950s. The architectural design of the villa featured multiple traditional Mashrabiya on its west and south facades, which were located along the areas now designated as the living room, balcony, and master bedroom. The floor plans are shown in Figure 11. Further details about the villa are given in Table 1.

Table 1. Villa details.

Villa Criteria	Description
Location	Saudi Arabia, Riyadh, Al-Bathaa district
Building Height	7 m
Temperature Regulation Design	Cooling: Setpoint 17 °C to 22 °C
Lighting	LED and Halogen
Occupancy Schedule	Weekdays: 13 h Weekends: full day
Ventilation	Mechanical and Natural
HVAC	Central

Over time, the building underwent renovations to modernize it, resulting in the removal of three Mashrabiya and the installation of steel windows and a balcony area. However, one wooden Mashrabiya remained in the master bedroom, which can be seen on the south elevation of the villa (Figure 12), which used to be an upper living area. It is now equipped with an internal steel and glass window that can be opened and closed, allowing for some functionality. Curtains are also installed to regulate the lighting in the room.



(**a**) (**b**)

Figure 11. Villa floor plans (drafted by the author): (**a**) ground floor plan; (**b**) first floor plan.

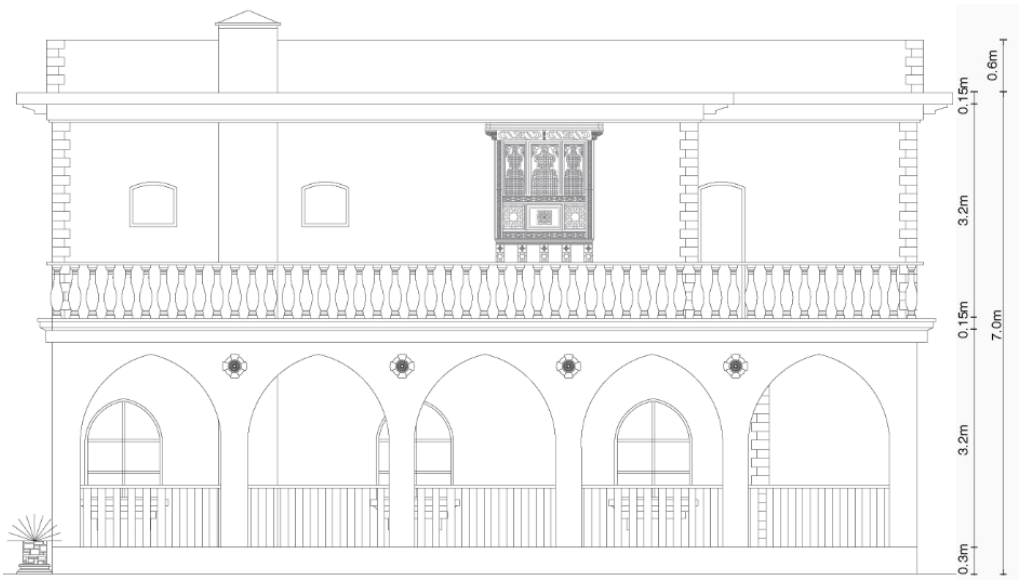


Figure 12. South elevation of the residence showing the existing traditional Mashrabiya (drafted by the author).

4.1.3. Performance Analysis of Mashrabiya in the Villa

The study conducted to evaluate the performance of the Mashrabiya in a villa involved discussions with the residents, according to whom the internal window made of steel and glass, fixed on the interior of the Mashrabiya, did not hinder its functionality. A window along the Mashrabiya in the master bedroom was included to maintain air tightness when the air conditioning (AC) was used. The window can be opened or closed for normal

functioning of the Mashrabiya, acting as a traditional component when open but becoming ineffective when closed. The 3D rendering of the Mashrabiya from the outside of the villa is shown in Figure 13.

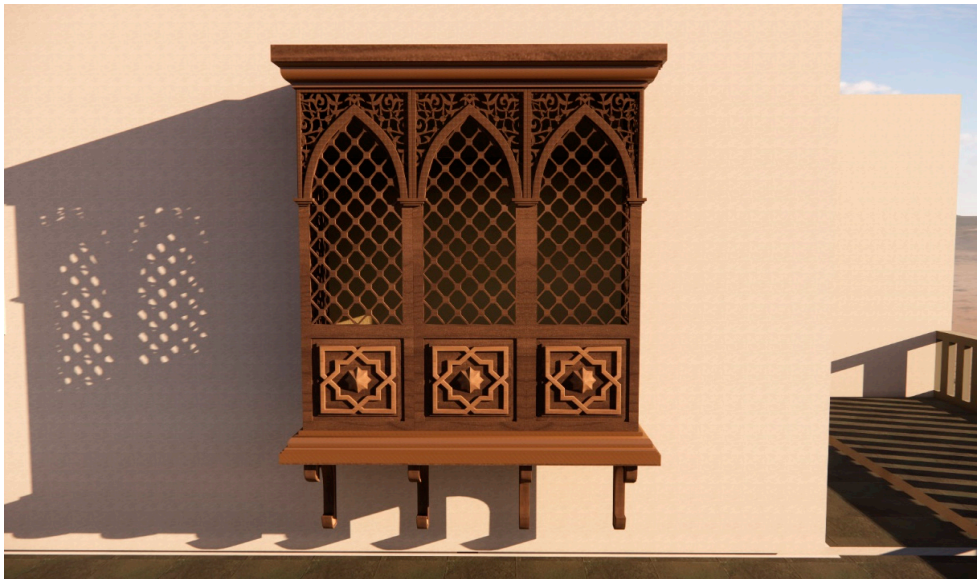


Figure 13. A 3D model of the existing Mashrabiya (Author).

The residents were able to experience the benefits of the Mashrabiya even with the presence of the internal window. They reported several advantages of having a room with a Mashrabiya, including:

1. The reduction in direct sunlight entering the room results in less need for additional lighting regulation measures, such as blinds or curtains (Figure 14). This is due to the intricate design of the Mashrabiya, which allows filtered sunlight to pass through, thus reducing glare and improving overall lighting conditions.
2. The lower operative temperature of the master bedroom compared to other rooms, as experienced by the residents, can be attributed to the ventilation provided by the Mashrabiya.
3. An optimal balance between natural light and privacy is ensured by the design of the Mashrabiya so that, even when the window is fully open without any privacy-enhancing devices such as blinds or curtains, the residents do not feel their personal privacy is being compromised.
4. Improved indoor air quality due to natural ventilation results in a less stuffy and more comfortable living environment. The residents reported experiencing significantly better air quality in the master bedroom with a Mashrabiya compared to other rooms due to its ability to facilitate natural ventilation for prolonged periods, which is not possible in other rooms due to privacy and security concerns.
5. According to residents, there was a significant impact on the regulation of interior operative temperature, reducing the dependence on mechanical air conditioning systems within the building.

Figure 14. Filtered natural light through the Mashrabiya in the master bedroom as, shown through 3D modelling (Author).

4.2. Mashrabiya House

The "Mashrabiya House" situated in the Palestinian Arab village of Beit Safafa, located between Jerusalem and Bethlehem, is a dwelling created as a modernized rendition of conventional elements of Arab vernacular architecture, simultaneously offering innovative and creative remedies for the evolving social and cultural environment of the village.

The Mashrabiya has been reinterpreted to create a striking floating effect through the use of a novel approach, where the wooden lattice is replaced with a layer of stone that covers the entire house. The Mashrabiya concept is merged with stone work, resulting in façades with no specific design parameters or patterns, where the focus is solely on the impact of light and porosity achieved through irregular spacing between large scale stone pieces. The playful design of the façades includes both small and large openings to maintain views from the inside to the outside while ensuring the necessary level of privacy. The architect also considers the Mashrabiya as an environmental element, recognizing that the stone layer that surrounds the building functions as a climatic buffer.

4.3. Comparative Analysis

1. A comparative analysis of the case studies (Table 2) reveals that the project under examination shares similarities with primitive designs utilizing the concept of Mashrabiya. However, it falls short of adhering to the specific terms and principles related to the functions, patterns, and design parameters of traditional Mashrabiya.
2. The design of walls filled with numerous openings requires a detailed examination of the issue of lighting. There appears to be insufficient study on how to ensure adequate lighting throughout the entire house, including areas that are readily accessible. Since the Mashrabiya screen is only an outer layer of stone covering the concrete and glass structure of the house, it does not appear to be an integral part of the main design.
3. The irregularity observed in the modern project is vastly different from traditional Mashrabiya in terms of daylight reduction. Traditional Mashrabiya effectively reduces glare and blocks direct light through a calculated spacing of the balusters. Similarly, the spacing between the stone pieces in the modern project facades may allow for some airflow movement, but it is not as effective as the spherical balusters in traditional Mashrabiya, which provide more comfortable airflow.
4. Regarding aesthetics, in contrast to traditional Mashrabiya, the modern project almost completely obscures the outside view, and it also lacks decorative features, such as carved decorations and ornamental patterns, that are typical of traditional Mashrabiya. Furthermore, the traditional Mashrabiya exhibits a more aesthetically pleasing

reflection of sunlight onto the internal walls and floors, unlike the contemporary iteration, which lacks a notable reflection. From the inside, it appears similar to any other modern house, resulting in a loss of Arab identity in this modern version.

5. Finally, it is crucial to consider the cost of the stone material. Although it may be cheaper, the costs of constructing double layers of walls in the Mashrabiya House should be considered. Furthermore, any alternative materials should possess similar properties to wood, such as durability, ease of production in quantity, the capacity to withstand extreme changes in both humidity and temperature, and the potential for conveying aesthetic worth.

Table 2. Comparative analysis of the case studies with traditional and modern Mashrabiya.

Comparative Factor	Mashrabiya House (Modern Mashrabiya)	Villa in Riyadh (Traditional Mashrabiya)
Material	Stone	Wood
Design	Irregular rectangular spacing between large scale stone pieces	Intricate wooden carvings with Islamic geometric patterns
Location	Along the whole front façade of the residential building, acting as a floating second skin.	As a window opening on the south façade of the building, in the Master bedroom.
Light Control	The design of the façade was characterized by the intentional integration of both large and small openings, which ultimately resulted in the creation of a dynamic interplay of light within the interior spaces of the building. It is important to note, however, that this design choice does not necessarily serve as a means of reducing the intensity of glare from the sun, as the primary function of the stone façade in this context was not intended to serve that specific purpose.	The intricate baluster designs within the Mashrabiya enables the entry of filtered light, with a marked reduction in glare, into the interior spaces of the building. The precise arrangement of these balusters allows for the controlled penetration of light, without hindering an excessive amount, thereby providing a harmonious balance between natural light and the desired level of illumination within the interior.
Airflow Regulation	Behind the stone Mashrabiya façade, which floats in front of the original façade of the building, is primarily concrete walls and glass windows that are not openable. Therefore, the Mashrabiya screen does not provide any airflow regulation into the building.	Even though a steel and glass window are fixed inside the Mashrabiya, since it is openable, the residents can use the Mashrabiya for Airflow regulation, as required. From the discussions with the residents, they made it evident that the Mashrabiya is regularly used for natural ventilation inside the room, as an attempt to bring down the energy consumption of the household.
Humidity Control	According to the architect, the stone serves as a means of climatic modulation through its ability to absorb thermal energy during the daytime and release it during the night-time, thereby functioning as a buffer against variations in temperature.	The utilization of wood as a construction material has been widely acknowledged and extensively studied for its ability to effectively regulate humidity levels within a structure. This has been discussed in the literature review.
Visual Privacy	It can be argued that the screen provides some level of visual privacy, but the irregular design of the façade leaves some rooms with glass facades completely visible to the outsiders. This completely invalidates the privacy function of the traditional Mashrabiya	The traditional Mashrabiya successfully provides privacy for the residents as they can view the outside through the openings without being visible from the outside. The Mashrabiya also maintains the privacy of the users when it is being used to regulate the temperature, airflow or lighting of the interiors without the help of any other privacy/shading devices such as curtains or blinds.

Table 2. *Cont.*

Comparative Factor	Mashrabiya House (Modern Mashrabiya)	Villa in Riyadh (Traditional Mashrabiya)
Temperature Regulation	The stone material protects the building against solar radiation as well as winter rain and winds. However, it is important to note that the stone layer alone does not serve as the sole means of protection for the building. In addition to the stone envelope, there is another layer of walling that is specifically engineered to protect the structure from the extreme heat and heavy precipitation that often occur during the winter season.	Wood in traditional Mashrabiya is an embodiment of the multifaceted properties it possesses in terms of temperature regulation and modulation. The intricate composition of varying baluster sizes and precisely calculated interstitial spaces not only enables control of air pressure and flow, but also plays a crucial role in maintaining optimal levels of humidity. This renders traditional Mashrabiya more efficacious than its contemporary counterparts.

5. Online Survey and Analysis

The online survey, consisting of 25 questions, both open-ended and closed-ended, aimed to assess the level of satisfaction of Saudi Arabian households with their current opening system and their willingness to adopt Mashrabiya in their homes. The survey further aimed to identify the factors that may impede households from installing traditional Mashrabiya, including cost, lack of information, and education.

The study participants were specifically recruited from different parts of the geographic region of Saudi Arabia, with the intention of obtaining a diverse representation of individuals residing in various types of residential structures, including detached homes, villas, and apartments. The data collection process was conducted entirely online, utilizing the Google Forms platform, and it was accompanied by informed consent and participant information forms. The goal of this recruitment strategy was to gather a representative sample of the population and gain insight into the perspectives and experiences of individuals living in different types of housing. A total of 107 responses were obtained from participants who were recruited solely based on their place of residence, i.e., Riyadh.

The survey adheres to the guidelines established by the Faculty Ethics Committee of the University, which conform to the legal regulations of the United Kingdom. The research protocol has been primarily approved by the ethics committee and places a strong emphasis on data protection and safeguarding the identity of participants. Prior to conducting the survey, the participants were fully informed about the research and gave their informed consent. They were also assured that their responses would be kept confidential, and their data would be used solely for research purposes. The participants also confirmed the authenticity of the transcribed data after the completion of the research. The ethical considerations were taken into account throughout the research process, in accordance with the guidelines set by the Ethics Committee.

5.1. Survey Results

5.1.1. Knowledge about Mashrabiya

The survey findings, as shown in Figure 15, indicate that an overwhelming majority of the respondents, amounting to 99.1%, were familiar with the concept of Mashrabiya. Additionally, from Figure 16, it can be observed that a significant proportion of respondents, representing 82.2%, strongly agreed that it serves as an architectural embodiment of Saudi Arabia's cultural and religious identity. However, only a minority of respondents, constituting 4.6%, demonstrated awareness of all the traditional Mashrabiya's functions, such as regulating lighting, ventilation, humidity, privacy, and aesthetics. Rather, the majority of respondents, accounting for 37.3% and 28.9%, perceived Mashrabiya as solely serving lighting and ventilation purposes, respectively. A mere 10.2% of the participants acknowledged the energy efficiency advantages associated with traditional Mashrabiya. These outcomes reveal a dearth of knowledge and comprehension concerning the manifold functions and benefits of the traditional Mashrabiya among the general populace, despite its widespread recognition as a cultural and architectural hallmark.

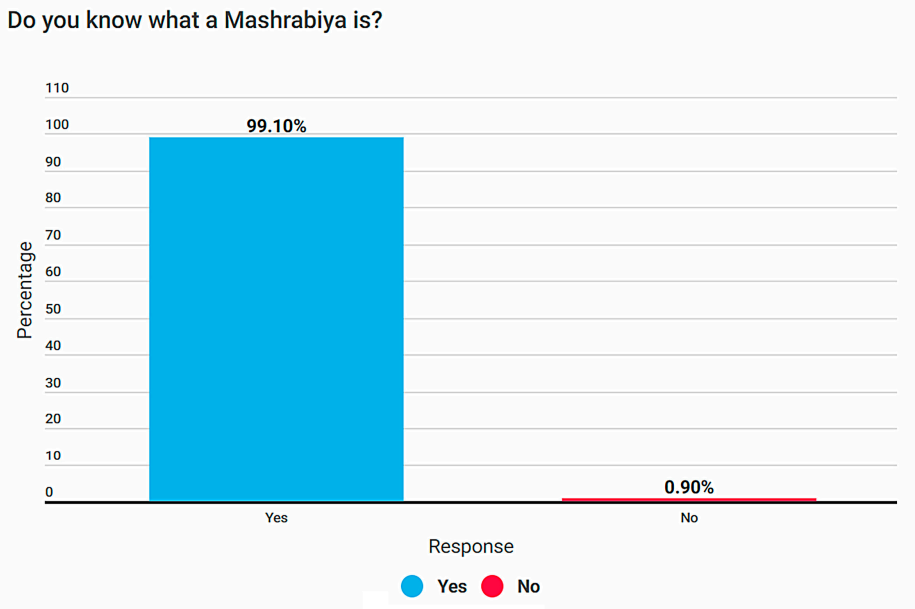


Figure 15. Survey results on public knowledge about Mashrabiya.

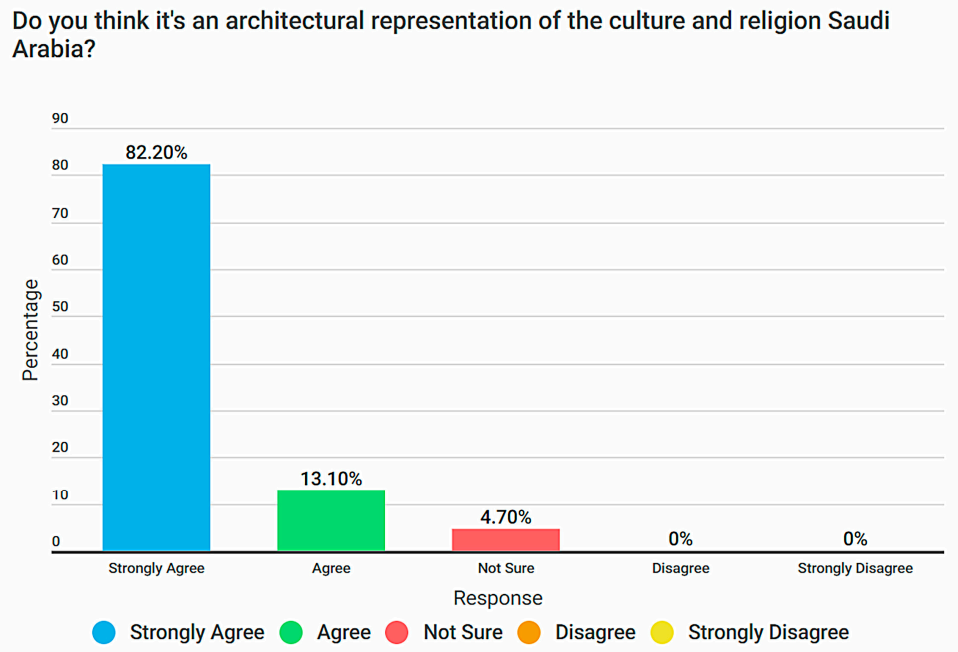


Figure 16. Survey results on the cultural and religious importance of Mashrabiya.

5.1.2. Type of Opening

The survey results of questions on types of openings present a nuanced perspective regarding the utilization of traditional Mashrabiya in Saudi Arabia (Figure 17). Notably, while 47.7% of respondents reported having Mashrabiya in their homes, a closer examination revealed that this was limited to a particular villa complex where contemporary forms of Mashrabiya were used solely for decorative purposes. This finding raises concerns about the degree to which respondents appreciate the practical functions of traditional Mashrabiya and if they are employing it for its intended purposes. Moreover, the fact that 51.4% of respondents had windows with shutters indicates a potential preference for this type of opening mechanism over traditional Mashrabiya.

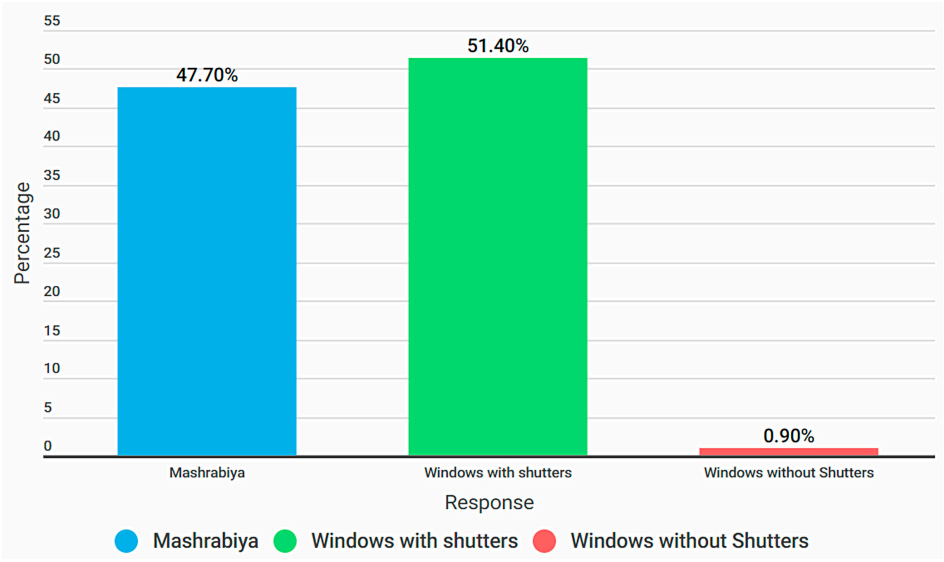


Figure 17. Survey results on types of openings.

5.1.3. Energy Consumption

The survey findings on energy consumption (Figure 18) reveal that the overwhelming majority of Saudi Arabian residents, 95.3%, have installed air conditioning systems in their homes to counter the extreme heat prevalent in the region. This overreliance on air conditioning units contributes significantly to the domestic energy consumption of Saudi Arabia, as evidenced by the 74.8% of respondents who reported monthly energy consumption between 2000 kWh and 4000 kWh. A minority of respondents, 15%, rely on natural lighting and ventilation to reduce their energy consumption, but this is limited by other factors, such as the occupancy period. Around 85% of the respondents expressed dissatisfaction with the current energy prices in the country, which aligns with the fact that a large majority of the respondents, 89.7%, are strongly willing and 8.4% could be persuaded to install a traditional Mashrabiya in their homes if it guarantees a reduction in energy consumption.

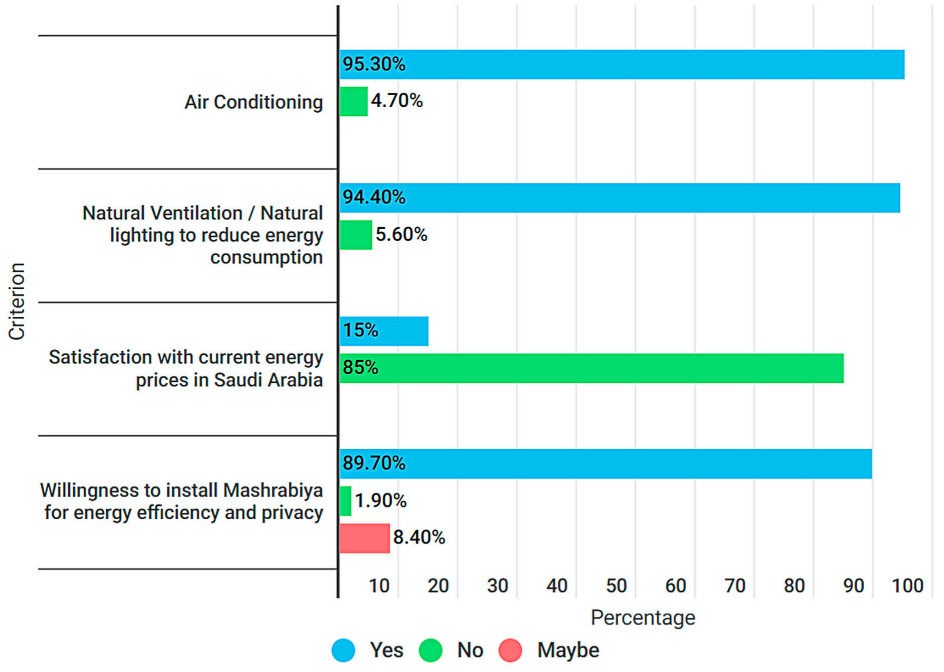


Figure 18. Survey results on energy consumption.

5.1.4. Functional Factors of Mashrabiya

This survey aimed to examine public perceptions regarding the functional aspects of Mashrabiya, which encompass natural light, natural ventilation, privacy, aesthetics, and energy efficiency, and the extent to which these factors were considered important by respondents. Results shown in Figure 19 indicate that a significant majority of participants rated all these factors as highly significant, with 84.1% assigning the highest level of importance to natural lighting, 83.2% assigning it to natural ventilation, 81.3% assigning it to energy efficiency, and 85% assigning it to privacy. Around 93.5% of respondents rated aesthetics as the most crucial factor. The mean values derived from the residents' ratings provide insights into the relative importance they placed on different functions of Mashrabiya. Aesthetics ranked highest, with a mean value of 4.779, followed closely by privacy (4.585). Natural ventilation and energy efficiency garnered mean values of 4.576 and 4.592, respectively, suggesting a considerable level of importance given to these factors. Lastly, natural light received a mean value of 4.569, reinforcing its relevance in the residents' evaluation.

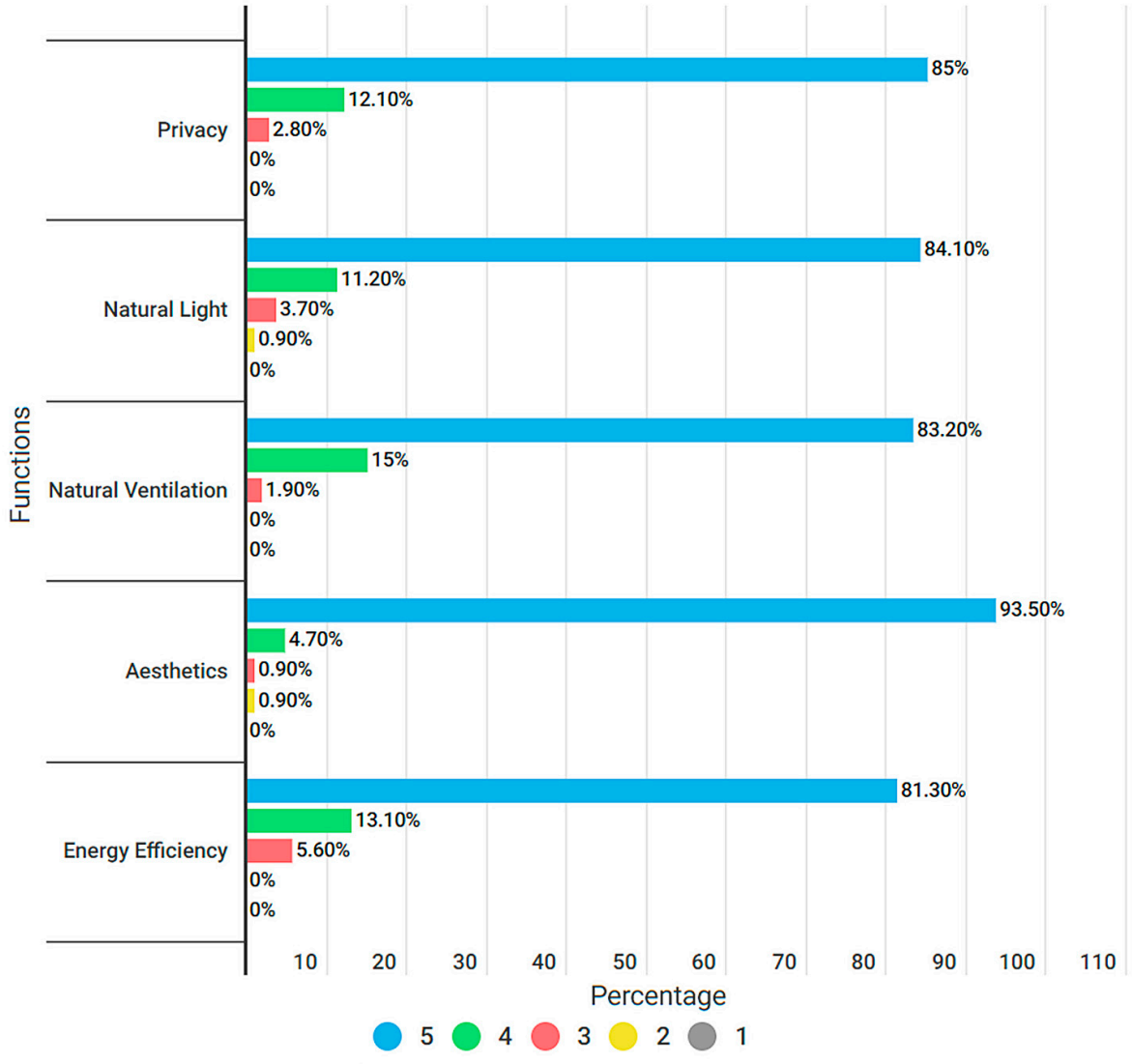


Figure 19. Survey results on the importance of the functional factors of Mashrabiya.

Regarding the means of achieving these functions (Figure 20), 45.8% and 46.7% of respondents used curtains or blinds and shutters, respectively, to regulate natural lighting in their homes. This finding was similarly reflected in responses regarding privacy, with

43% and 46.7% of respondents using curtains, blinds, or shutters, respectively. In contrast, only a small proportion of respondents, specifically 7.5% and 10.3%, reported that their Mashrabiya provided natural lighting and privacy. The majority of respondents, 95.3%, relied on shutters to regulate natural ventilation in their homes, with none of the respondents indicating that they used the Mashrabiya for this purpose.

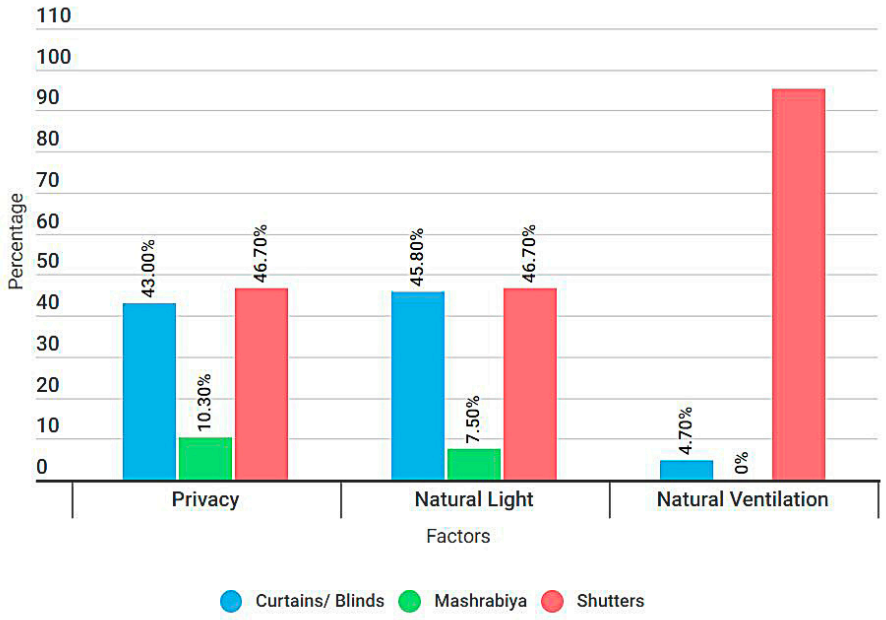


Figure 20. Survey results on the means of regulation.

5.1.5. Privacy

It is notable from the results of the survey on privacy (Figure 21) that 47.7% of respondents strongly feel as though their privacy is being compromised when using natural lighting or ventilation, and 14% of respondents sometimes feel the same. This suggests that the modern Mashrabiya found in the villa complex fail to achieve any of the basic functions of traditional Mashrabiya, and they are only used for aesthetic purposes. This is further supported by the fact that the majority of respondents use other means of regulating natural lighting, ventilation, and privacy, despite the presence of Mashrabiya in their homes.

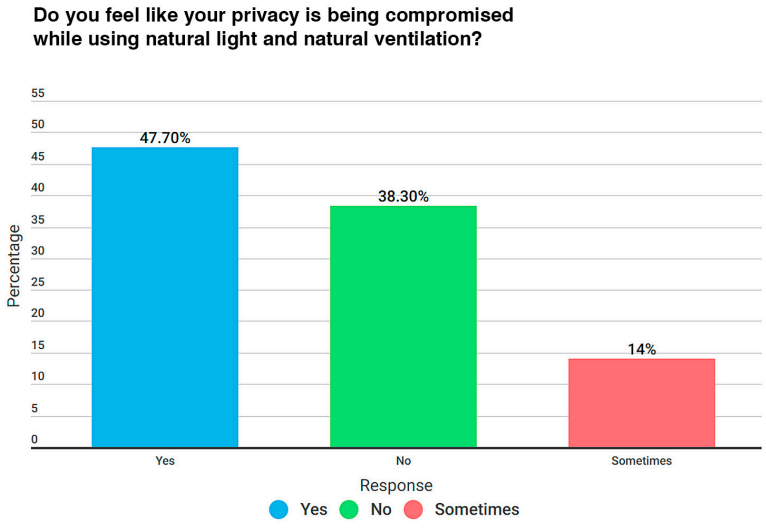


Figure 21. Survey results on privacy.

5.1.6. Factors Affecting Decision-Making

The results of the survey on factors affecting decision-making are shown in Figure 22. The majority of respondents identified cost as a major factor when deciding to install a Mashrabiya in their homes. While 89.7% were willing to install a Mashrabiya if it reduced energy consumption, 69.5% were dissuaded by the high initial cost of a traditional wooden Mashrabiya. Cost was identified as the most important factor by 55.1% of respondents. Aesthetics were a key factor for 16.8%, while 28% identified aesthetics, cost, and materials as driving forces. Material, on the other hand, was identified by only 1% as the sole decision-making factor.

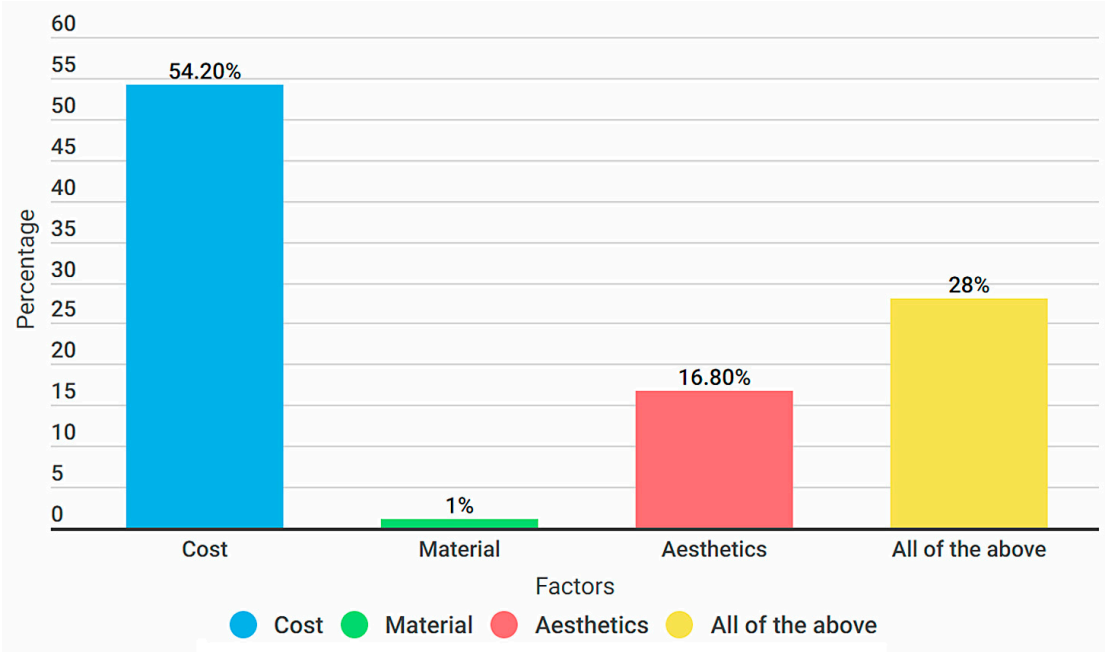


Figure 22. Survey results on factors affecting decision-making.

These findings demonstrate the importance of cost as a determining factor for homeowners when considering the installation of a Mashrabiya. Despite the potential benefits in terms of energy efficiency, privacy, and aesthetics, the high initial cost of installation remains a significant obstacle for many homeowners, and it is likely to remain a crucial consideration for future decision-making.

5.1.7. Current Condition of Mashrabiya

The survey results indicate that a large majority of the participants demonstrate a comprehensive awareness of the current developments and transformations in their local environment, particularly concerning the modernization of culture, religion, and architecture in their country (Figure 23). Specifically, 87.9% of respondents exhibit a recognition that the traditional architectural element of Mashrabiya has undergone significant alterations in its visual appearance, functionality, and construction materials. An overwhelming majority of 86.9% of the respondents acknowledge that these changes in architectural elements may undermine the cultural and religious integrity of Saudi Arabia's architecture. This recognition highlights the respondents' understanding of the essential cultural and religious significance of the Mashrabiya and its role in preserving the architectural heritage of the region. Around 86.9% express concern about the potential impact of these changes on the cultural and religious integrity of Saudi Arabian architecture, including the loss of identity and the erosion of architectural heritage. The results suggest that respondents have a deep understanding of the importance of preserving traditional architecture and cultural heritage in the region.

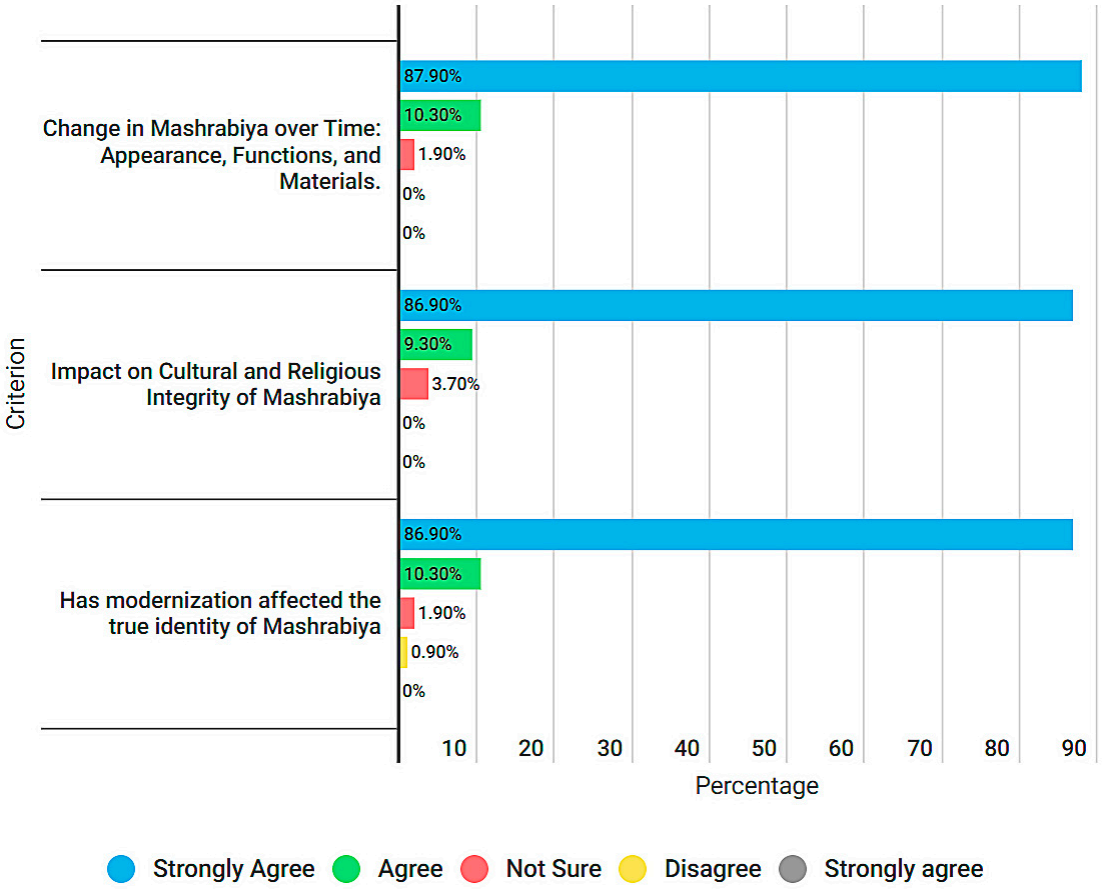


Figure 23. Survey results on the current condition of Mashrabiya.

5.2. Findings from the Survey Results

The survey results reveal a number of key findings that are crucial to understanding the current status and perception of Mashrabiya in Saudi Arabia.

1. It is clear that a large portion of the Saudi Arabian public is familiar with the concept of Mashrabiya and recognizes its cultural significance. While many respondents may not be fully aware of all the functions and benefits of this architectural element, they understand that traditional elements such as Mashrabiya are important parts of their cultural heritage.
2. The survey results suggest that the Saudi Arabian public is increasingly concerned about issues related to domestic energy consumption and the rising cost of energy. This is reflected in their willingness to consider alternative methods such as Mashrabiya for reducing energy consumption. However, the cost of installation is a significant factor that may deter many respondents from proceeding with this option, suggesting that, if an alternative, more affordable material that can effectively fulfil the functions of a traditional Mashrabiya is made available, it would likely be met with a high degree of acceptance among the public.
3. The survey results indicate that a group of respondents who have incorporated modern Mashrabiya into their villas can be considered a representative sample of users who are being influenced by modern designers and manufacturers who prioritize aesthetics over function in their contemporary versions of Mashrabiya. This can have a negative impact on the public's perception of this architectural element, and it further supports the research question that modernization and "revived" Mashrabiya are adversely affecting the functional, cultural, and religious values of traditional Mashrabiya.

6. Dynamic Thermal Simulations

A comprehensive 3D simulation and analysis of a villa located in Riyadh (a case study villa with the traditional Mashrabiya) is performed to evaluate the impact of the traditional Mashrabiya on the building, using EnergyPlus DesignBuilder software version 6.1.8.021, which allows for the analysis of various aspects of the residential building, such as operative temperature, daylight factor, solar gain, cooling load, energy consumption, etc.

The simulation is kept rather simple and is executed under two scenarios: one without the Mashrabiya and the other with the Mashrabiya. The building under consideration already has a traditional Mashrabiya installed outside its master bedroom, which is excluded from the first simulation. The second simulation takes into account the presence of both the existing traditional Mashrabiya and the proposed Mashrabiya in other rooms, such as the living room, drawing room, and guest bedroom.

The building layout, zones, and activities are assigned in the software in accordance with the plan of the existing villa, as shown in Figure 24.

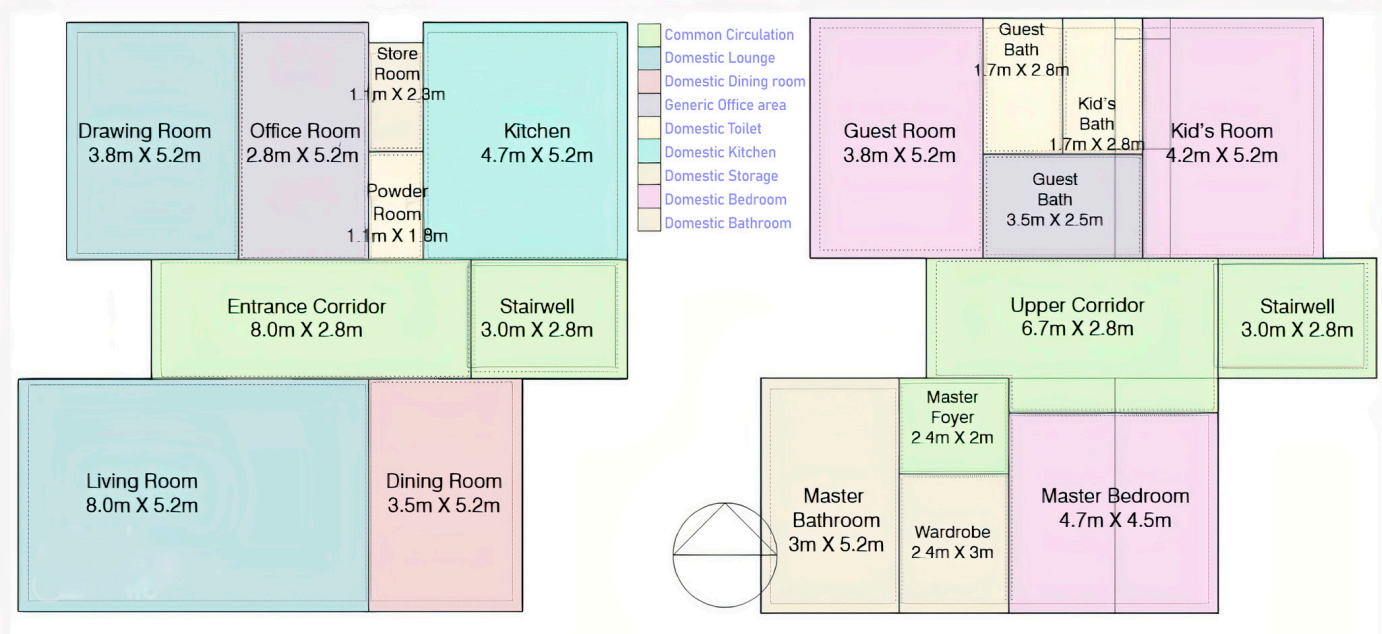


Figure 24. Floor plans drawn in DesignBuilder according to activity zones: (**a**) ground floor plan; (**b**) first floor plan.

- Location Details: The location on DesignBuilder is set to Riyadh, which is the original location of the villa (Figure 25). The simulation weather data is similarly set for Saudi, Riyadh in order to get accurate simulation results. Riyadh, as shown in Figure 9, belongs to the "BWh" subtype of the Köppen–Geiger climate classification, which is characterized by a hot desert climate [50].
- Template Details: The building's usage is considered residential with domestic circulation, and the construction template is customized for various building components such as walls, floors, ceilings, roofs, doors, and windows. The material used for the renovation of the villa is insulated concrete blocks, which form the majority of the building's construction material. The programme uses generic two-season clothing templates and mechanical cooling for HVAC. Window measurements and opening times for natural ventilation are determined based on the information and details given by the occupants. The LED lighting settings are used, with general lighting left on.
- Occupancy Details and Cooling Design: The occupancy details are set according to the schedule provided by the residents, as shown in Table 1 (Figure 26). The HVAC

schedule for the simulation is entered into the software for respective spaces as well (Figure 27). According to the residents, air conditioning is generally used from April to September, depending on the occupancy of the building.

- The proposed Mashrabiya incorporated in the DesignBuilder is modelled after the existing Mashrabiya on the residential building. It follows a traditional design of smaller openings on the lower part and larger openings on the upper part, with intricate detailing that has been replicated as accurately as possible using the DesignBuilder software. The Mashrabiya has been created as an assembly model (Figure 28) and has been added to the assembly library of DesignBuilder, subsequently incorporating it into the facade of the building. It is ensured that the surfaces of the Mashrabiya assembly object are properly connected to the surfaces of the building model, so heat transfer between them can be accurately calculated. Teak is specified as the assembly material, and default values for its properties are used in the software (Figure 29).

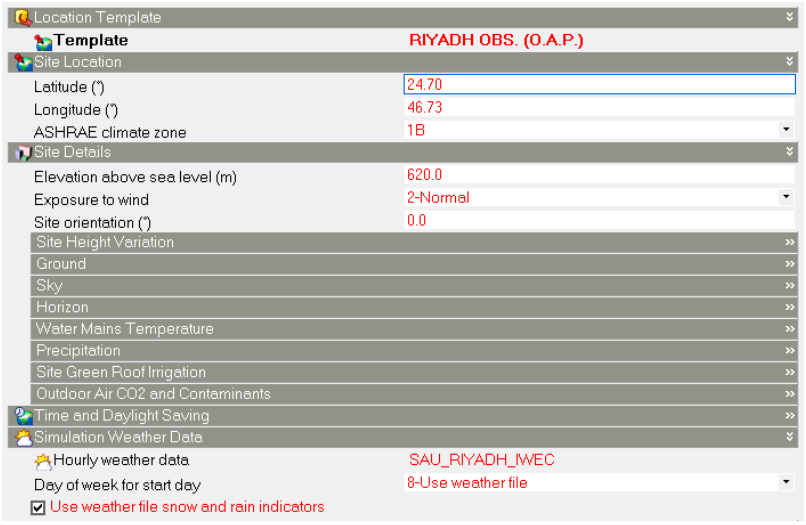


Figure 25. Location template used in the DesignBuilder software.

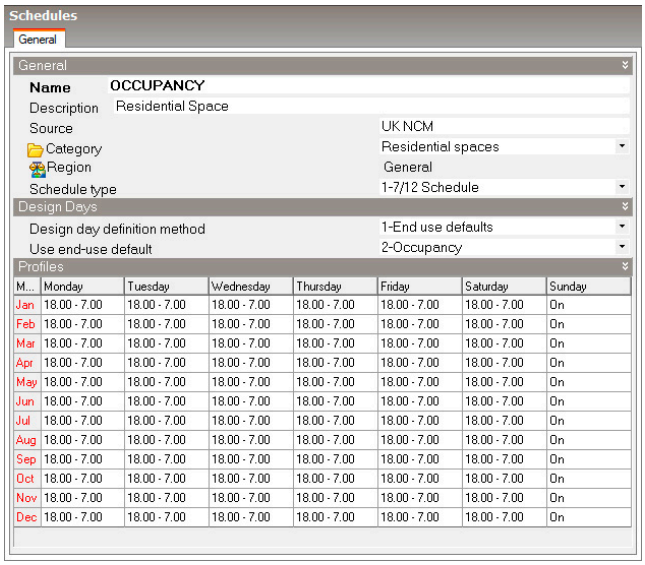


Figure 26. The occupancy schedule entered into the software, according to the details from the residents.

Schedules

General

General

Name	**COOLING DESIGN**
Description	Residential Space
Source	UK NCM
Category	Residential spaces
Region	General
Schedule type	1-7/12 Schedule

Design Days

Design day definition method	1-End use defaults
Use end-use default	6-Cooling demand

Profiles

M...	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Jan	Off	Off	Off	Off	Off	Off	Off
Feb	Off	Off	Off	Off	Off	Off	Off
Mar	Off	Off	Off	Off	Off	Off	Off
Apr	18.00 - 7.00	18.00 - 7.00	18.00 - 7.00	18.00 - 7.00	18.00 - 7.00	18.00 - 7.00	On
May	18.00 - 7.00	18.00 - 7.00	18.00 - 7.00	18.00 - 7.00	18.00 - 7.00	18.00 - 7.00	On
Jun	18.00 - 7.00	18.00 - 7.00	18.00 - 7.00	18.00 - 7.00	18.00 - 7.00	18.00 - 7.00	On
Jul	18.00 - 7.00	18.00 - 7.00	18.00 - 7.00	18.00 - 7.00	18.00 - 7.00	18.00 - 7.00	On
Aug	18.00 - 7.00	18.00 - 7.00	18.00 - 7.00	18.00 - 7.00	18.00 - 7.00	18.00 - 7.00	On
Sep	18.00 - 7.00	18.00 - 7.00	18.00 - 7.00	18.00 - 7.00	18.00 - 7.00	18.00 - 7.00	On
Oct	Off	Off	Off	Off	Off	Off	Off
Nov	Off	Off	Off	Off	Off	Off	Off
Dec	Off	Off	Off	Off	Off	Off	Off

Figure 27. The HVAC schedule entered into the software, according to the data provided by the residents.

(**a**) (**b**)

Figure 28. Proposed Mashrabiya models in EnergyPlus DesignBuilder software: (**a**) the assembly model of proposed the Mashrabiya in DesignBuilder, which was used for the second set of simulations; (**b**) individual panels used in the assembly.

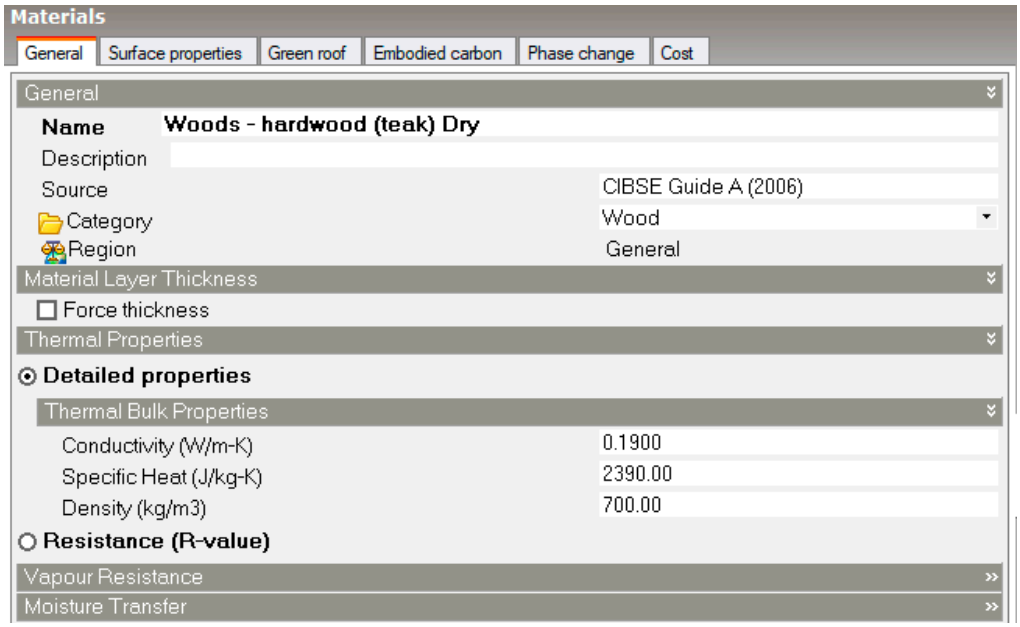


Figure 29. Default material details of teak in the EnergyPlus DesignBuilder software.

6.1. Simulation Results

- Existing Villa Design

The 3D model of the villa with the existing Mashrabiya, made in DesignBuilder, is shown in Figure 30. The pre-existing traditional Mashrabiya has been ignored in the first set of simulations in order to produce results that are reflective of the typical performance of a modern-day residential structure in Saudi Arabia.

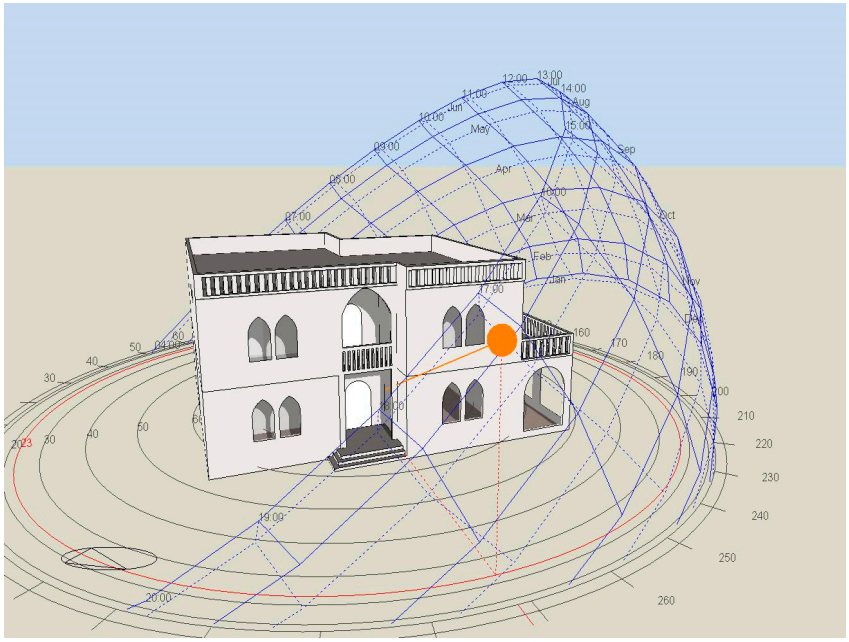
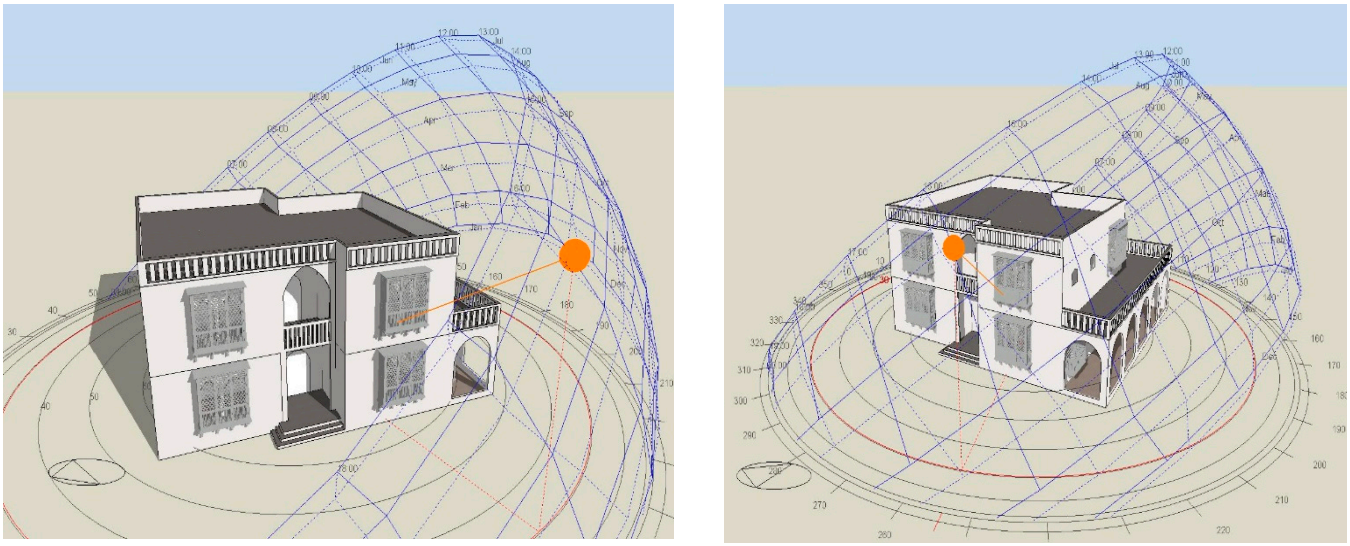


Figure 30. DesignBuilder model of the villa without the Mashrabiya.

The second set of simulations incorporates the impact of not only the pre-existing traditional Mashrabiya but also the proposed addition of similar wooden Mashrabiya in key areas of the residential structure, as shown in Figure 31. The proposed Mashrabiya are designed in accordance with the dimensions and aesthetic qualities of the pre-existing

traditional Mashrabiya, ensuring consistent architectural and stylistic cohesion within the building.



(**a**) (**b**)

Figure 31. DesignBuilder model with the proposed Mashrabiya: (**a**) view from the north-west; (**b**) view from the south-west.

6.1.1. Operative Temperature and Solar Gain

- Simulation 1: Without Mashrabiya

Cooling calculations are performed, for the whole building, to determine the interior operative temperature of the villa under the hottest summer conditions at the site, the results of which are shown in Figure 32. The HVAC system is turned off to determine free-floating temperatures and natural ventilation effects. July 15th is identified as the hottest day, with a peak temperature of 38.31 °C at 14.00, resulting in an interior operative temperature range from 34.96 °C to 38.31 °C, exceeding the human comfort range of 21 °C to 27 °C. On the same day, solar gain is highest through the windows, with a peak hourly gain of 8.68 kW.

- Simulation 2: With Mashrabiya

The simulation is run under the same conditions as the first one, and the results (Figure 32) showed a reduction in the operative temperature from the previously observed elevated levels to a range from 29.89 °C to 32.91 °C, which can be considered a significant improvement in thermal comfort. The solar gain during peak hours decreases from 8.68 kW to 2.99 kW. This decline in the quantity of heat transmitted through the windows can be attributed to the integration of Mashrabiya. By providing shading to the exterior of the windows, the Mashrabiya helps to regulate the amount of heat that enters the interior, contributing to the maintenance of a suitable and comfortable thermal environment within the villa.

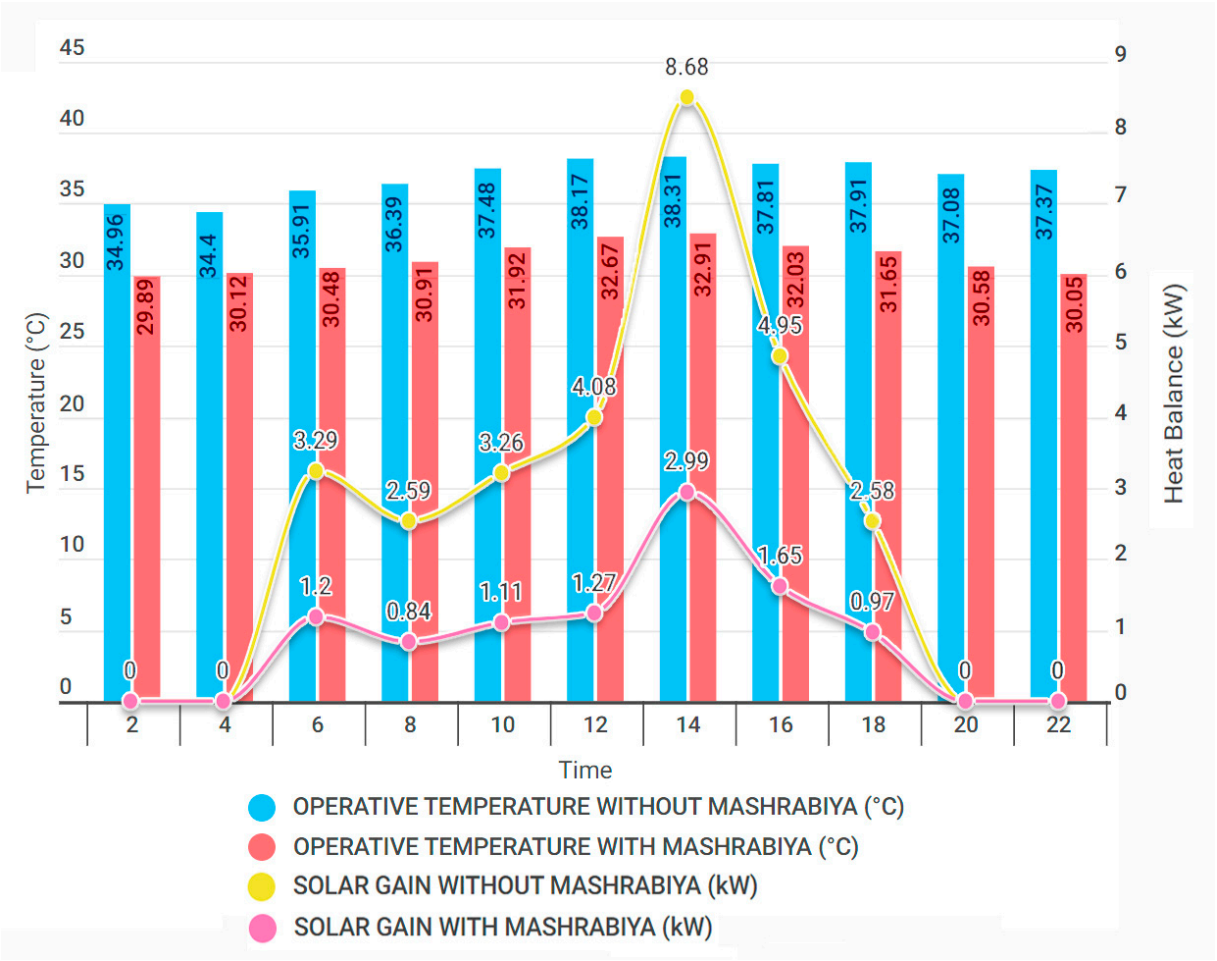


Figure 32. Graph showing the comparison of operative temperature and solar gain with and without Mashrabiya.

6.1.2. Cooling Load

- Simulation 1: Without Mashrabiya

The cooling load is the energy used to counterbalance the heat gained through the building envelope, or through infiltration or ventilation in a hot climate, which is identified by running the fuel breakdown simulation on the software for the whole residential building. The results focus specifically on the hottest month, July, which results in high demand with regard to the use of AC, which draws more energy to cool the interior. The energy consumed to counterbalance the internal heat gain in July was 3702 kWh (Figure 33).

- Simulation 2: With Mashrabiya

The optimization of thermal comfort as a result of the utilization of Mashrabiya has a direct correlation with the energy consumption of the villa. The decrease in internal operative temperature and the solar gain reduces the amount of energy required to maintain a comfortable interior temperature, which, in turn, makes a positive impact on the reduction in the energy consumption of the villa. The energy consumed by the villa to counteract the interior temperature rise in the month of July has decreased from 3702 kWh to 3492 kWh (Figure 33).

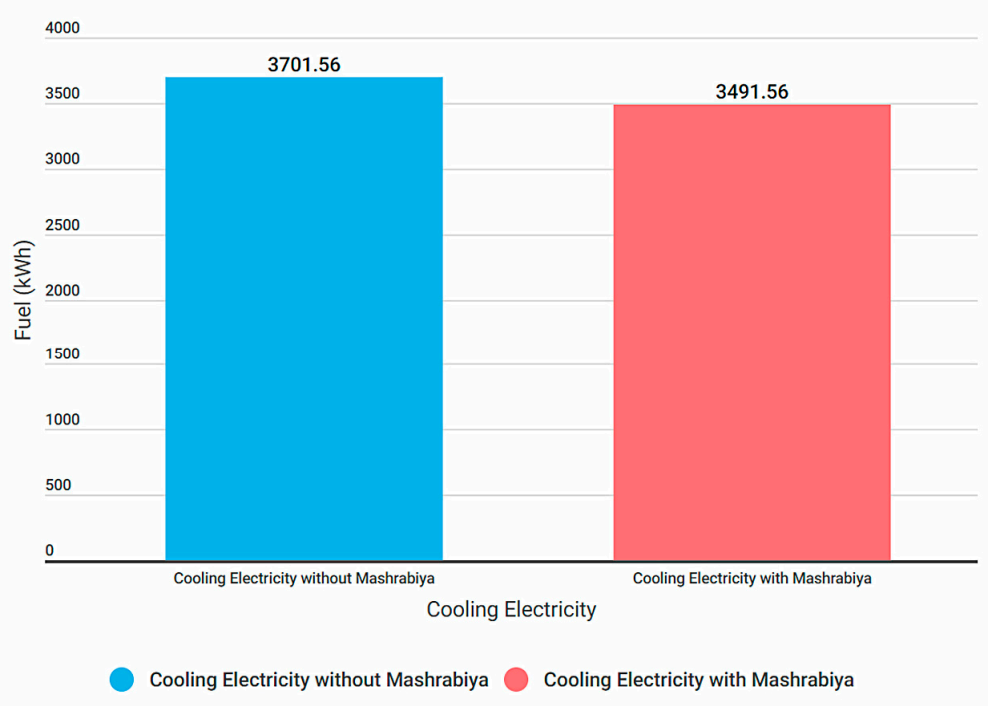


Figure 33. Graph showing the results of cooling load simulations with and without Mashrabiya.

6.2. Comparison of Simulation Results

The side-by-side comparisons of the simulation results are shown in Table 3. Along with operative temperature, solar gain, and cooling load, a daylight simulation based on the BREEAM Health and Wellbeing Credit HEA 0 was conducted to assess the impact of daylight. The table provides the variations in the average daylight factor values of the residence. The comparison shows that the addition of a Mashrabiya significantly improved all the factors that were studied in the simulation. This demonstrates that a Mashrabiya has a positive effect on the temperature, thermal comfort, lighting, and energy efficiency of the building. The results of the simulation provide strong evidence of the positive impact that a Mashrabiya can have on a residential building, and they underscore the importance of incorporating traditional building elements such as a Mashrabiya into contemporary architecture.

Table 3. Comparative table of the simulation results with and without Mashrabiya.

Comparative Factor	Simulation without Mashrabiya	Simulation with Mashrabiya	Reduction in Percentage
Operative Temperature during the hottest day of the year (°C)	34.96 °C to 38.31 °C	29.89 °C to 32.91 °C	approx. 14%
Average Daylight Factor	3.1	2	35.5%
Peak Solar Gain during hottest day of the year (kW)	9	2	77.8%
Cooling Load during the hottest month of the year (kWh)	3702	3492	5.7%

7. Results and Discussion

The research encompasses various aspects, including literature reviews, case studies, surveys, and simulations, and the results obtained through each of the research techniques

are carefully compared and synthesized to arrive at the ultimate aim of the study, providing a robust and meaningful contribution to the field.

The comparison between the two case studies revealed that contemporary Mashrabiya designs often prioritize aesthetic factors over their functional capabilities. This can be seen by the loose usage of the term Mashrabiya to describe any facade featuring voids and light-and-shadow play, regardless of whether it adheres to the traditional designs and patterns of Islamic architecture. Furthermore, the use of alternative materials, such as stone, can detract from the energy-efficient properties that made the traditional Mashrabiya so effective in the first place.

The integration of contemporary Mashrabiya designs, which often involve the implementation of a glass layer behind the primary facade, results in an obscuring of the relationship between individuals and the exterior environment. This design characteristic, known as a double skin façade, eliminates the visual privacy aspect inherent to traditional Mashrabiya. This also blocks natural airflow into the building, hindering the airflow regulation, as well as the humidity control properties, of the Mashrabiya.

The survey provided insights into the general public's perception of the Mashrabiya and its current state. The results revealed that the respondents were aware of the changing face of the Mashrabiya and the impact it has on the cultural and architectural identity of the region, but they were largely uninformed about ways to preserve its true essence. Moreover, the participants, being dissatisfied with the current energy prices in Saudi Arabia, expressed a strong interest in reviving traditional Mashrabiya designs if cheaper alternatives to traditional wood materials could be made available. This highlights the need for further research in this area, specifically focusing on identifying materials that can effectively mimic the properties of wood while being more affordable.

Lastly, the survey results indicated that a lack of understanding regarding the various functions of Mashrabiya could hinder its popularity, with respondents perceiving it solely as a decorative element. This could result in an increase in the production and usage of cheap, imitation Mashrabiya designs, which would not only detract from the authenticity of this important architectural element but also compromise its effectiveness.

The results from the simulations carried out on a case study villa, which can serve as a representative sample of the domestic sector in Saudi Arabia, have proven to be highly favourable. The simulations demonstrated a significant improvement in thermal comfort and energy efficiency due to the integration of traditional Mashrabiya into the building's openings.

The traditional architectural feature of Mashrabiya holds potential as an energy-efficient element that can be seamlessly integrated into the Saudi Arabian government's Vision 2030 plans. The Vision Realization Programs (VRPs), devised to translate the goals of Vision 2030 into tangible actions [17], include the 'Housing Program' and 'Quality of Life Program', both of which present suitable avenues for the incorporation of Mashrabiya. The Quality of Life Program specifically targets objectives such as 'Boosting Saudi contribution to arts and culture' and 'Preserving and introducing the Kingdom's Islamic, Arab, and national heritage,' [17] both of which can be greatly enhanced by the integration of traditional Mashrabiya. In alignment with the overarching Vision 2030, the Housing Program aims to deliver 1.5 million houses by 2030. Incorporation of traditional Mashrabiya into this housing program could have a profound impact on the cultural and architectural identity of the country, given the sheer number of houses that would be carrying Mashrabiya on their facades as a symbol of the country's heritage. Thus, the incorporation of Mashrabiya into the government's plans could play a key role in reversing the decline of cultural and religious values in Saudi Arabia.

However, this could present some drawbacks or trade-offs. Among these drawbacks, one is the cost implications, as the intricate craftsmanship and specialized construction techniques involved in Mashrabiya can lead to higher expenses compared to modern methods. Maintenance and durability are important considerations, as Mashrabiya made of natural materials may require regular upkeep and protection from weathering. Compatibility

with contemporary design can be a challenge, as Mashrabiya may not always seamlessly integrate with modern architectural styles. Accessibility, standardization, scalability, and the accommodation of evolving lifestyle needs are further considerations. Traditional architectural elements may not always resonate with contemporary tastes or preferences. Public reception, acceptance, and understanding of the cultural significance and value of Mashrabiya might vary, requiring efforts in education, awareness, and social acceptance. A balanced approach that addresses these drawbacks while preserving cultural elements will contribute to the successful incorporation of Mashrabiya in policies and initiatives.

8. Output and Impacts

The research presents a promising prospect for addressing the challenges related to housing and domestic energy consumption in Saudi Arabia, while also safeguarding the cultural heritage of the country.

This research highlights the significance of Mashrabiya in terms of its impact on a building's energy consumption. A return to traditional Saudi Arabian architecture can offer a solution to the country's growing energy consumption and consequent environmental concerns through decreased energy bills and heightened occupant satisfaction. Integrating Mashrabiya not only promotes privacy but also enhances energy efficiency, thus contributing to sustainable development initiatives.

The study underscores the critical role of Mashrabiya in providing privacy in traditional Middle Eastern architecture, which has been overlooked in modern architecture, leading to a decline in the cultural values associated with privacy. The research serves as a reminder of the importance of privacy and how it is integral to the cultural identity of the Middle East. The results allow for essential recommendations that can guide architects and designers to integrate functional features of Mashrabiya, such as privacy, into contemporary buildings, thus preserving the cultural identity of the region.

The methodology established in this research can serve as a strong framework for adoption in other regions, with different cultural aspects and variations that would affect the use of Mashrabiya, to enhance occupants' satisfaction while minimizing energy consumption. By virtue of this, not only can the environmental impact be reduced but cross-cultural understanding and dialogue can also be fostered. This can promote collaboration and exchange between different regions and societies, thus contributing to a more sustainable and interconnected world.

9. A Set of Guidance

The recommendations derived from the research are as follows:

1. The primary recommendation is to prioritize the preservation of the traditional identity of the Mashrabiya while emphasizing the identification and implementation of construction solutions that maximize its benefits in terms of cost-effectiveness, safety, and adaptability to changing architectural trends.
2. The arbitrary application of the term "Mashrabiya" requires regulation to prevent the devaluation and distortion of the traditional significance of the architectural element. A structure or element should be scrutinized and deemed to conform to a substantial proportion of the functional characteristics of a traditional Mashrabiya before being assigned the label.
3. The introduction of new materials does not mean traditional design elements, such as intricate carvings and Islamic geometric patterns, need to be compromised as well. The traditional designs and craftsmanship of Mashrabiya can be maintained through modernization, utilizing innovative technologies such as 3D printing and additive manufacturing.
4. Preserving the cultural values of existing buildings and considering environmental indicators are important for achieving sustainable outcomes [52]. Adaptive reuse of existing traditional buildings that incorporate Mashrabiya and adapting them to modern energy-efficient standards can be an effective way of preserving traditional

architecture, as well as enhancing energy efficiency, while reducing the environmental footprint of the building.

5. Raising the political profile and developing attractive financial incentives are important for promoting preservation practices [52]. Government incentives, such as tax breaks or grants, can encourage property owners to preserve existing traditional structures, as well as incorporate traditional structures such as Mashrabiya into their buildings.
6. Incorporating traditional architecture into government housing projects can also encourage the public to follow suit.
7. The findings of Karytsas et al. [43] suggest that individuals with a stronger environmental consciousness are more likely to show interest in sustainable solutions. Raising consciousness and educating the general public, regarding the significance of safeguarding traditional architecture and its contribution to energy efficiency, can motivate community members to actively participate in its conservation.

10. Conclusions

The research was aimed at exploring the impact of modernity and the re-emergence of Mashrabiya on the preservation of traditional architecture and culture, as well as the energy efficiency of households in Saudi Arabia. The driving force behind the study was the pressing need to address the housing crisis and escalating domestic energy consumption in Saudi Arabia. This research addresses these critical issues.

The study has shown the mutually dependent nature of energy efficiency and cultural preservation. Integrating traditional Mashrabiya into Saudi Arabia's housing plans has the potential to mitigate the country's escalating domestic energy usage. The results of the dynamic thermal simulations showed notable enhancements in thermal comfort and energy efficiency by incorporating traditional Mashrabiya into building designs. The study observed an approximate 14% reduction in operative temperature and a 77.8% reduction in solar gain, alongside a 5.7% decrease in monthly cooling load and a 35.5% improvement in the daylight factor. These findings indicate that integrating Mashrabiya can effectively improve building performance, leading to a more sustainable and comfortable indoor environment. The proposed solution requires the extensive use of Mashrabiya in the facades of 1.5 million houses as part of the government's plan to tackle the housing crisis by 2030. Such an approach would also help preserve the country's architectural and cultural heritage, which is presently under threat. This proposal, therefore, completes a circle by addressing both pressing concerns simultaneously. However, implementing this solution requires overcoming challenges, such as the high cost of constructing traditional wooden Mashrabiya, which, as per the survey, can influence public choice.

In summary, the relationship between the preservation of traditional architecture and culture and energy efficiency is a complex and interdependent one. The incorporation of traditional Mashrabiya designs in the housing plans of Saudi Arabia is a crucial step in the direction of finding a sustainable solution to these pressing issues.

Future Research

Further research is required in the area of affordable materials and construction methods for Mashrabiya to make this solution more accessible and implementable. Research can explore the use of eco-friendly materials, such as bamboo or cork, other recycled materials, and bio-based materials to create Mashrabiya screens, ensuring sustainability while maintaining aesthetic appeal and performance.

To achieve an enhanced and sustainably built environment, it is crucial to strike a balance between technological advancements and technical considerations. This involves prioritizing the research and development of innovative techniques, systems, and components that improve sustainability and ensure resilience to future challenges [52]. The significance of a comprehensive and integrated approach to the building envelope, encompassing active solar energy systems, glazing systems, and vegetation, have been studied by

researchers, and this combined approach was found to maximize the positive impacts of each system [53]. To further enhance the potential of traditional Mashrabiya, future research should explore the integration of advanced technologies such as Building Integrated Photovoltaics (BIPV), smart sensors, responsive systems, and adaptive control mechanisms. By incorporating these technologies, a Mashrabiya can be optimized in terms of functionality and energy efficiency, allowing it to adapt effectively to changing environmental conditions.

Author Contributions: Conceptualization, A.T. and H.K.; methodology, A.T. and H.K.; software, A.T.; validation, A.T.; formal analysis, H.K.; investigation, A.T. and H.K.; resources, H.K.; data curation, H.K.; writing—original draft preparation, H.K.; writing—review and editing, A.T.; visualization, H.K.; supervision, A.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee of DE MONTFORT UNIVERSITY, LEICESTER (protocol code 528602 and date of approval 6 December 2022).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

SVM	Shape Variable Mashrabiya
RG16	Reflective glazing with 16% light transmittance
VB	Venetian Blinds
DDT	Direct to diffuse light transformation
AM	Additive Manufacturing
GRC	Glass fibre Reinforced Concrete
BWh	The Köppen–Geiger climate classification for hot deserts
HVAC	Heating, Ventilation and Air Conditioning
LED	Light Emitting Diode
AC	Air Conditioning
VRP	Vision Realization Program
BREEAM	Building Research Establishment Environmental Assessment Method
BIPV	Building Integrated Photovoltaics

References

1. Middle East. Available online: https://www.climatecentre.org/wp-content/uploads/RCCC-ICRC-Country-profiles-Region_Middle_East.pdf (accessed on 12 May 2023).
2. Binzagr, S.M.O.S. Vernacular Saudi Arabian Architectural Techniques: Revival to Modern Saudi. *WIT Trans. Built Environ.* **2020**, *197*, 99–111.
3. Alelwani, R.; Ahmad, W.M.; Rezgui, Y. Public Perception of Vernacular Architecture in the Arabian Peninsula: The Case of Rawshan. *Buildings* **2020**, *10*, 151. [CrossRef]
4. Fathy, H. *Natural Energy and Vernacular Architecture: Principles and Examples with Reference to Hot Arid Climates*, 5th ed.; University of Chicago Press: Chicago, IL, USA, 1986; pp. 105–117.
5. Al-Naim, M.A. Identity in Transitional Context: Open-Ended Local Architecture in Saudi Arabia. *Int. J. Archit. Res.* **2008**, *2*, 125–146.
6. Bardeesi, B.; Muhrji, D.; Gutub, G.; Al-Ahdal, H.; El-Shorbagy, A.M. The Lost Identity of Jeddah. *Civ. Eng. Archit.* **2022**, *10*, 2180–2186. [CrossRef]
7. Eljaouhari, K.; Amhamdi, L.; Bouayad, L. Mashrabiya Contemporary Design: Cultural Anchor and Environmental Performance. *Impact Int. J. Res. Eng. Technol.* **2020**, *8*, 1–12.
8. Provinces Map of Saudi Arabia. Available online: https://www.orangesmile.com/travelguide/saudi-arabia/country-maps-provinces.htm (accessed on 12 May 2023).
9. Alrashed, F.; Asif, M. Trends in Residential Energy Consumption in Saudi Arabia with Particular Reference to the Eastern Province. *J. Sustain. Dev. Energy Water Environ. Syst.* **2014**, *2*, 376–387. [CrossRef]

10. Dehwah, A.H.; Asif, M.; Rahman, M.T. Prospects of PV application in unregulated building rooftops in developing countries: A perspective from Saudi Arabia. *Energy Build.* **2018**, *171*, 76–87. [CrossRef]
11. Saudi Arabia: Total Population from 2018 to 2028. Available online: https://www.statista.com/statistics/262467/total-population-of-saudi-arabia/ (accessed on 12 May 2023).
12. Al-Sur, M.; Trigunarsyah, B. *Analyzing the Literature for the Link between the Conservative Islamic Culture of Saudi Arabia and the Design of Sustainable Housing*; Queensland University of Technology: Brisbane, QL, Australia, 2012.
13. Shehri, A. Electricity Industry in Saudi Arabia: An Overview. In Proceedings of the Saudi Water and Power Forum, Jeddah, Saudi Arabia, 1–4 November 2008.
14. Statista. Available online: https://www.statista.com/statistics/975281/saudi-arabia-residential-electricity-consumption/#:~:text=As%20of%202021%2C%20the%20volume,around%20120.65%20terawatts%20per%20hour (accessed on 12 May 2023).
15. Vision 2030. Available online: https://www.vision2030.gov.sa/ (accessed on 25 January 2023).
16. Saudi Census. Available online: https://saudicensus.sa/ (accessed on 27 January 2023).
17. Almerbati, N.; Ford, P.; Taki, A.; Dean, L. From Vernacular to Personalised and Sustainable. In Proceedings of the Across: Architectural Research through to Practice: 48th International Conference of the Architectural Science Association, Genoa, Italy, 10 December 2014.
18. Bagasi, A.A.; Calautit, J.K.; Karban, A.S. Evaluation of the Integration of the Traditional Architectural Element Mashrabiya into the Ventilation Strategy for Buildings in Hot Climates. *Energies* **2021**, *14*, 530. [CrossRef]
19. El Semary, Y.M.; Attalla, H.; Gawad, I. Modern Mashrabiyas with High-tech Daylight Responsive Systems. *Acad. Res. Community Publ.* **2017**, *1*, 11. [CrossRef]
20. Abdelkader, R.; Park, J.-H. Sustainable Building Façades: Modern Usages of The Traditional Mashrabiya. *Open House Int.* **2018**, *43*, 69–76. [CrossRef]
21. Abdelkader, R.; Park, J.H. The Evolving Transformation of Mashrabiya as a Traditional Middle Eastern Architecture Element. *Int. J. Civ. Environ. Eng. IJCEE IJENS* **2017**, *17*, 15–20.
22. Sabry, H.M.K.; Mohammad, S.K. "Mushrabiyya" Patterns and Parameters: An Experimental Analysis for Daylighting Performance. In Proceedings of the International Conference of Sustainable Energy Technologies and Asessments, Katowice, Poland, 20 January 2011.
23. Alothman, H.; Akçay, A.Ö. A Theoretical Framework for the Evaluation from the Traditional Mashrabiya to Modern Mashrabiya. *J. Hist. Cult. Art Res.* **2017**, *6*, 107–121.
24. Ashour, A.F. Islamic Architectural Heritage: Mashrabiya. *WIT Trans. Built Environ.* **2018**, *177*, 245–253.
25. Alothman, H. An Evaluate and Critical Study of Mashrabiya in Contemporary Architecture. Master's Thesis, Near East University, Nicosia, Cyprus, October 2017.
26. Baarimah, A. Redefining the Traditional Mashrabiya Improving Daylight Performance, Privacy, And Radiant Heating Utilizing Adaptive Diffused Shading in Hot Arid Climate. Master's Thesis, University of Arizona, Tucson, AZ, USA, 12 November 2019.
27. Aljawder, H.M.; El-Wakeel, H.A. Evaluating the Performance of a Daylighting Traditional Device, The Mashrabiya, In Clear Sky Conditions: Case Study of a Traditional Bahraini House. *WIT Trans. Built Environ.* **2019**, *191*, 395–409.
28. Salama, H.M. Mashrabiya in Islamic architecture between idea authenticity and applying novelty. *J. Archit. Arts Humanist. Sci.* **2019**, *4*, 704–731.
29. Giovannini, L.; Lo Verso, V.R.; Karamata, B.; Andersen, M. Lighting and energy performance of an adaptive shading and daylighting system for arid climates. *Energy Procedia* **2015**, *78*, 37–375. [CrossRef]
30. Karamata, B.; Giovannini, L.; Verso, V.L.; Andersen, M. Concept, Design and Performance of a Shape Variable Mashrabiya as a Shading and Daylighting System for Arid Climates. *Energy Procedia* **2015**, *78*, 370–375.
31. Taşkan, D.; Ismaeel, A.B. An Architectural Element: Mashrabiya. *Art Sanat.* **2022**, *17*, 475–496. [CrossRef]
32. Madan, B.S.; Saxena, S. Islamic Architectural Heritage: Mashrabiya, from Tradition to Innovation. *Res. Rev. J. Archit. Des.* **2021**, *3*, 1–13.
33. Bagasi, A.A.; Calautit, K.J. Experimental Field Study of the Integration of Passive and Evaporative Cooling Techniques with Mashrabiya in Hot Climates. *Energy Build.* **2020**, *225*, 110325. [CrossRef]
34. Taleb, H.M.; Antony, A.G. Assessing different glazing to achieve better lighting performance of office buildings in the United Arab Emirates (UAE). *J. Build. Eng.* **2019**, *28*, 101034. [CrossRef]
35. Nasr, A.E.H.; Baioumy, N.F.; Elwahed, A.G.A. Application of the Mashrabiya philosophy in contemporary architecture. *J. Archit. Art Humanist. Sci.* **2020**, *7*, 103–118.
36. Abiya. Available online: https://www.abiya.ae/knowledge-nehal/3d-printing-the-ideal-manufacturing-process (accessed on 2 May 2023).
37. Almerbati, N.; Headley, D.; Ford, P.; Taki, A. From Manual to Hybrid, Parametric Mashrabiya. *Int. J. Architecton. Spat. Environ. Des.* **2016**, *10*, 29–39. [CrossRef]
38. Excell, J.; Nathan, S. The Rise of Additive Manufacturing. *Engineer* **2010**, *24*.
39. Beyond the Façade. Available online: https://allaccessarts.com/beyond-the-facade-mixed-use-architecture-the-mashrabiya-system/ (accessed on 3 May 2023).
40. Mashrabiya, A. Day of Art and Adventure. Available online: http://www.touregypt.net/featurestories/mashrabiya.htm (accessed on 3 May 2023).

41. Headley, D.; Almerbati, N.; Ford, P.; Taki, A. From Research to Practice: Exploring 3D Printing in Production of Architectural Mashrabiya. In *Living and Learning: Research for a Better Built Environment*; University of Melbourne: Melbourne, VIC, Australia, 2015; pp. 1009–1017.
42. Crolla, K.; Williams, N. Smart Nodes: A System for Variable Structural Frames with 3D Metal-Printed Nodes. In Proceedings of the ACADIA 14: Design Agency, the 34th Annual Conference of the Association for Computer Aided Design in Architecture, Los Angeles, CA, USA, 23–25 October 2014; pp. 311–316.
43. Karytsas, S.; Choropanitis, I. Barriers against and actions towards renewable energy technologies diffusion: A Principal Component Analysis for residential ground source heat pump (GSHP) systems. *Renew. Sustain. Energy Rev.* **2017**, *78*, 252–271. [CrossRef]
44. Wüstenhagen, R.; Wolsink, M.; Bürer, M.J. Social acceptance of renewable energy innovation: An introduction to the concept. *Energy Policy* **2007**, *35*, 2683–2691. [CrossRef]
45. Karytsas, S.; Vardopoulos, I.; Theodoropoulou, E. Factors Affecting Sustainable Market Acceptance of Residential Microgeneration Technologies. A Two Time Period Comparative Analysis. *Energies* **2019**, *12*, 3298. [CrossRef]
46. Elwan, M.M. The role of traditional Lattice window "Mashrabiya" in delivering singlesided ventilation- A CFD Study. *Int. J. Eng. Trends Technol.* **2020**, *68*, 154–161.
47. About: Al Batha, Riyadh. Available online: https://dbpedia.org/page/Al_Batha,_Riyadh (accessed on 12 May 2023).
48. Beck, H.E.; Zimmermann, N.E.; McVicar, T.R.; Vergopolan, N.; Berg, A.; Wood, E.F. Present and Future Köppen-Geiger Climate Classification Maps at 1-km Resolution. *Sci. Data* **2018**, *5*, 1–12. [CrossRef]
49. Google Maps—Saudi Arabia. Available online: https://www.google.com/maps/place/Saudi+Arabia/@24.5896989,44.575968,7.5z/data=!4m6!3m5!1s0x15e7b33fe7952a41:0x5960504bc21ab69b!8m2!3d23.885942!4d45.079162!16zL20vMDF6MjE1 (accessed on 12 May 2023).
50. Google Maps—Al Bathaa. Available online: https://www.google.com/maps/place/Al-Bathaa,+Riyadh+12652,+Saudi+Arabia/@24.6218768,46.7190339,18z/data=!3m1!4b1!4m6!3m5!1s0x3e2f05920fa18ca3:0x9f309c0705908d39!8m2!3d24.6221233!4d46.7197548!16zL20vMGRxaDU3 (accessed on 12 May 2023).
51. Climate Change Knowledge Portal. Available online: https://climateknowledgeportal.worldbank.org/country/saudi-arabia (accessed on 2 February 2023).
52. Vardopoulos, L.; Tsilika, E.; Sarantakou, E.; Zorpas, A.A.; Salvati, L.; Tsartas, P. An Integrated SWOT-PESTLE-AHP Model Assessing Sustainability in Adaptive Reuse Projects. *Appl. Sci.* **2021**, *11*, 7134. [CrossRef]
53. Italos, C.; Patsias, M.; Yiangou, A.; Stavrinou, S.; Vassiliades, C. Use of double skin façade with building integrated solar systems for an energy renovation of an existing building in Limassol, Cyprus: Energy performance analysis. *Energy Rep.* **2022**, *8*, 15144–15161. [CrossRef]