Revitalizing a Vernacular Architectural Element Through Sustainability: Contemporary Applications of Mashrabiya*

Byan A. JETTO**, Semih G. YILDIRIM***

Abstract

Purpose: *Adequate natural lighting and thermal comfort, key components of sustainable spatial design, can be effectively managed using sunshades. There has been considerable interest in how mashrabiya, a traditional element of vernacular architecture that serves as a form of sun shading, is incorporated into contemporary designs. This study explores the integration of mashrabiya, a traditional architectural feature, into modern design practices, with a focus on sustainability.*

Conceptual Framework: *Currently, there is a growing demand for sustainable solutions across various design fields, with a particular emphasis on architectural elements that reflect cultural values and offer environmental advantages. The mashrabiya, which was originally used for shading and ventilation in hot, dry climates, serves as a prime example of sustainable design principles. This research explores the historical importance, technological developments, and possible uses of mashrabiya in both traditional and contemporary architecture, especially regarding its impact on daylighting design. It assesses how effective mashrabiya is in improving lighting quality, maximizing natural daylight, and enhancing the cultural identity of architectural settings in different parts of the world. By incorporating mashrabiya into modern designs, architects can pay tribute to traditional methods while tackling current environmental issues.*

Method: *This study employed qualitative research methods with data collected through document analysis. Within the framework of sustainability, buildings worldwide related to the subject were examined, focusing on the materials and methods used in both vernacular and modern applications of mashrabiya. The study evaluates sun-shading applications that control natural lighting and provide thermal comfort*

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** MSc. Architect, Istanbul Gelisim University, Institute of Graduate Studies, Istanbul, Türkiye.
E-mail: bayan.abdullah.3798@outlook.com; byan.jetto@ogr.gelisim.edu.tr
ORCID https://orcid.org/0009-0005-0503-0713
*** Corresponding Author, Asst. Prof., Istanbul Gelisim University, Faculty of Engineering and Architecture, Department of Architecture, Istanbul, Türkiye. E-mail: sgyildirim@gelisim.edu.tr
ORCID https://orcid.org/0000-0002-7832-6575

by analyzing the materials and construction methods used from the past to the present. Aspects of sun shading, including the type of pattern, whether it is fixed or movable, and whether it is two-dimensional or three-dimensional, were examined through various examples.

Findings: *In local architecture, designs are primarily categorized into two types: plain and projected mashrabiya. Although five distinct patterns are commonly recognized, there are instances in which these patterns are combined. The density of the patterns and textures directly influence the interior lighting and light direction. The patterns analyzed in vernacular architecture can be viewed as two-dimensional sunshades and fixed elements. In modern applications, two design types have been identified: shape-variable and parametric mashrabiya. The examples discussed include moving elements; in the first case, a two-dimensional moving sunshade is referenced, whereas in the second case, a three-dimensional moving sunshade is described. In vernacular architecture, sunshades are typically constructed from wood, whereas modern applications utilize a variety of materials including metal and wood.*

Conclusion: *Initially, thermal comfort was achieved using sunshades and water pots. In contemporary examples of mashrabiya, only sunshade features are used. Traditionally composed of two-dimensional fixed elements, mashrabiya have evolved to incorporate movement in modern applications. Today, it is not only referred to as a shading device but also as an adaptive facade system. With the incorporation of various materials and integration of moving components, these advanced versions differ significantly from traditional designs. In modern applications, shape-variable mashrabiya can be more closely associated with examples found in vernacular architecture.*

Keywords: *Mashrabiya, Shading Device, Daylighting, Vernacular Architectural Element, Sustainable Architecture*

Yerel Bir Mimari Öğenin Sürdürülebilirlik Yoluyla Yeniden Canlandırılması: Meşrebiyenin Çağdaş Uygulamaları

Öz

Amaç: *Sürdürülebilir mekânsal tasarımın temel bileşenleri olan yeterli doğal aydınlatma ve termal konfor, güneş kırıcılar kullanılarak etkili bir şekilde yönetilebilir. Yerel mimarinin geleneksel bir unsuru olan ve bir tür güneş kırıcı işlevi gören meşrebiyenin çağdaş tasarımlara nasıl dahil edildiğine dair kayda değer bir ilgi söz konusudur. Bu çalışma, geleneksel bir mimari özellik olan meşrebiyenin sürdürülebilirlik odaklı modern tasarım uygulamalarına entegrasyonunu araştırmaktadır.*

Kavramsal Çerçeve: *Günümüzde, kültürel değerleri yansıtan ve çevresel avantajlar sunan mimari unsurlara özellikle vurgu yapılarak, çeşitli tasarım alanlarında sürdürülebilir çözümlere yönelik artan bir talep söz konusudur. Başlangıçta sıcak ve kuru iklimlerde gölgeleme ve havalandırma amacıyla kullanılan meşrebiye, sürdürülebilir tasarım ilkelerinin en iyi örneklerinden biridir. Bu araştırma, meşrebiyenin tarihsel önemini, teknolojik gelişmelerini ve hem geleneksel hem de çağdaş mimarideki olası kullanımlarını, özellikle de gün ışığı tasarımı üzerindeki etkisini araştırmaktadır. Araştırma, meşrebiyenin aydınlatma kalitesini artırmada, doğal gün ışığını en üst düzeye çıkarmada ve dünyanın farklı bölgelerindeki mimari ortamların kültürel kimliğini geliştirmede ne kadar etkili olduğunu değerlendirmektedir. Mimarlar, meşrebiyeyi modern tasarımlara dahil ederek bir yandan geleneksel yöntemlere saygı gösterirken diğer yandan da güncel çevre sorunlarının üstesinden gelebilirler.*

Yöntem: *Çalışmada nitel araştırma yöntemleri kullanılmış ve veriler doküman analizi yoluyla toplanmıştır. Sürdürülebilirlik çerçevesinde, dünya genelinde konuyla ilgili yapılar incelenmiş, meşrebiye özelliklerinin hem yerel hem de modern uygulamalarında kullanılan malzeme ve yöntemlere odaklanılmıştır. Doğal aydınlatmayı kontrol eden ve termal konfor sağlayan güneş kırıcı uygulamaların değerlendirildiği çalışmada, geçmişten günümüze kullanılan malzemeler ve yapım yöntemleri analiz edilmiştir. Desen türünün, sabit ya da hareketli olması, iki boyutlu ya da üç boyutlu olması gibi güneş kırıcı unsurlar çeşitli örnekler üzerinden incelenmektedir.*

Bulgular: *Yöresel mimaride düz ve çıkma meşrebiye olarak iki ana kategoride tasarımlar gruplandırılmaktadır. Yaygın olarak beş farklı desen tanınmakla birlikte, bu desenlerin birleştirildiği örnekler de vardır. Desenlerin ve dokuların yoğunluğu, iç aydınlatmayı ve ışık yönünü doğrudan etkiler. Yerel mimaride analiz edilen desenler, iki boyutlu güneş kırıcılar ve sabit elemanlar olarak görülebilir. Modern uygulamalarda iki tasarım türü tanımlanmıştır: şekil değiştirebilen meşrebiye ve parametrik meşrebiye. Ele alınan örnekler hareketli elemanlar içermektedir; ilk durumda iki boyutlu hareketli bir güneş kırıcıya atıfta bulunulurken, ikinci durumda üç boyutlu hareketli bir güneş kırıcı tarif edilmektedir. Yerel mimaride güneş kırıcılar tipik olarak ahşaptan inşa edilirken, modern uygulamalarda metal ve ahşap da dahil olmak üzere çeşitli malzemeler kullanılmaktadır.*

Sonuç: *Başlangıçta, termal konforu güneş kırıcılar ve su küplerinin kullanılması ile sağlayan meşrebiyenin günümüze yansıyan örneklerinde yalnızca güneş kırıcı özelliği kullanılmaktadır. Geleneksel olarak iki boyutlu sabit elemanlardan oluşan meşrebiye, modern uygulamalarda hareketi de içerecek şekilde evrim geçirmiştir. Günümüzde sadece bir gölgeleme elemanı olarak değil, aynı zamanda uyarlanabilir bir cephe sistemi olarak da anılmaktadır. Çeşitli malzemelerin bir araya getirilmesi ve hareketli bileşenlerin entegrasyonu ile bu gelişmiş versiyonlar geleneksel tasarımlardan önemli ölçüde farklılık göstermektedir. Modern uygulamalardaki şekil değiştirebilen meşrebiye, yerel mimaride bulunan örneklerle daha yakından ilişkilendirilebilir.*

Anahtar Kelimeler: *Meşrebiye, Güneş Kırıcı, Doğal Aydınlatma, Yöresel Mimari Eleman, Sürdürülebilir Mimari*

1. Introduction

Historically and currently, designs have been created to address needs influenced by climate conditions. Key principles of sustainable design, such as sun shading and natural ventilation, are crucial in the development of mashrabiya. These architectural elements, influenced by these design principles, also help shape the local architectural identity of a region. In today's sustainability framework, mashrabiya is classified as a passive system since it comprises non-active components and adheres to the principles of controlling daylight and facilitating natural ventilation. Contemporary adaptations of this traditional architectural feature are still present in modern designs. Mashrabiya is a key element of traditional Arabic vernacular architecture that has been used for centuries. Its primary function is to provide shade from direct sunlight and to prevent heat from entering the building. Typically made of

wood, mashrabiya take the form of a lattice window, often featuring geometric Islamic patterns (Taki & Kumari, 2023). Mashrabiya are typically positioned at the upper level of buildings facing the sun. In the past, rooms behind the mashrabiya were typically cooler than those in other parts of the building. These rooms are often used as living spaces or as welcoming guests (Abdelkader & Park, 2018). The reflection of mashrabiya, which are used as sunshades for natural lighting control in modern applications, is a subject of interest. Examining the materials and methods used in both vernacular and contemporary architecture can provide valuable guidance for designers in creating sustainable building facade elements that bridge the past and present. Therefore, the study examines the use of meşrebiye in both traditional and modern architecture, highlighting the differences in materials and construction methods, with a particular emphasis on natural lighting and sustainability.

2. Method

This study adopted qualitative methods to gather data through document analysis. Relevant buildings worldwide were examined in the context of sustainability, emphasizing the materials and techniques used in both traditional and contemporary mashrabiya applications. This study assesses sun-shading solutions that regulate natural light and enhance thermal comfort by exploring the evolution of materials and construction techniques over time. Various aspects of sun shading, such as pattern type, mobility (fixed or adjustable), and dimensionality (two-dimensional or three-dimensional), were analyzed through case studies. Three case studies related to Arabic architecture were examined, all of which featured modern applications of mashrabiya on the façade. In contemporary interpretations, two types have been identified: shape-variable mashrabiya and parametric mashrabiya. This study evaluated which modern practices are more closely associated with traditional approaches.

3. Traditional Materials and Techniques Used in Mashrabiya

Historically, the term "mashrabiya" referred to an enclosed space with wooden lattice openings where vessels containing drinking water were placed for cooling purposes. Subsequently, the term evolved to denote solely the lattice screen (Alothman & Akçay, 2017). This architectural feature enables occupants to observe the streetscape or inner courtyard from the interior while maintaining privacy. The etymology of "mashrabiya" is rooted in Arabic, signifying the location where drinking water vessels were positioned for cooling. "Mashraba" is the nominal form of the Arabic verb "yashrab," which translates to "drink" (Alothman & Akçay, 2017). Clay vessels were situated on the inner shelf of the mashrabiya to passively cool the incoming air (Table 1). The mashrabiya is characterized by its circular wooden balustrades, which provide an optimal configuration for facilitating smooth airflow, thereby enhancing the evaporation process (Bagasi et. al. 2021). Traditionally, mashrabiya was constructed from wood due to its capacity to regulate humidity and enhance thermal comfort. As air traverses

the wooden mashrabiya, it experiences a reduction in moisture content owing to the absorption properties of the wooden balustrades (Table 1). Moisture absorption occurs during nighttime when air temperatures are lower. During daytime, as the mashrabiya is warmed by solar radiation, it releases the moisture absorbed at night, effectively humidifying and cooling the passing air. This technique has demonstrated the mashrabiya's distinctive efficacy in arid regions, as it increases the humidity of dry air during the day, contributing to the cooling of interior spaces during periods of elevated temperatures (Alothman & Akçay, 2017).

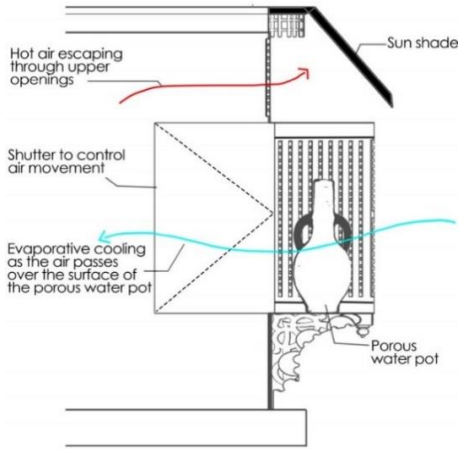
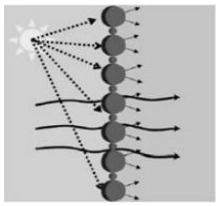
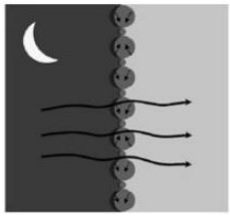
Mashrabiya Section	Passive cooling in the wooden mashrabiya through absorbing and discharging moisture
	Day time
	
	Night time
	

Table 1. Working principles of mashrabiya (Taki & Kumari, 2023; Alothman & Akçay, 2017)

3.1. Types and Patterns of Mashrabiya as Design Elements

Mashrabiya designs vary across Middle Eastern and North African regions, primarily due to differences in materials, construction methods, and local cultural significance. For instance, Yemeni mashrabiya sometimes incorporate stone elements (Abdelkader & Park, 2018). Despite regional variations in design, these structures generally feature similar geometric patterns and serve comparable purposes. Mashrabiya can be broadly classified into two main categories (Table 2): projected mashrabiya, which protrude from the wall surface, and plain mashrabiya, which are aligned with the wall (Bagasi et al. 2021; Bande et al. 2023).

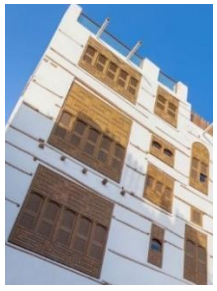
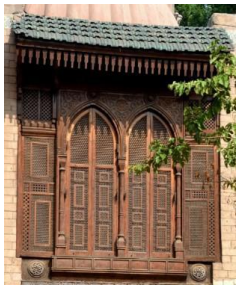
Projected Mashrabiya	   
Plain Mashrabiya	   

Table 2. Types of mashrabiya (Url 1; Url 2; Url 3; Url 4; Url 5; Url 6; Url 7; Url 8)

Mashrabiya is renowned for its complex and elaborate geometric designs, which showcase the skill of its creators and serve as distinctive characteristics of this traditional architectural element. These patterns were historically crafted by hand with great precision (Abdelkader & Park, 2018). While the latticework designs in mashrabiya differ across regions, some common patterns are listed in Table 3, including the cross, maymoni, hexagon, and church patterns, with the latter typically positioned at the mashrabiya's base (Taşkan & Ismaeel, 2022). The geometric patterns of mashrabiya serve both aesthetic and functional purposes, offering privacy while allowing air circulation and natural light penetration. Each style represents the rich artistic heritage and expert craftsmanship of various regions, contributing to the mashrabiya's status as a unique architectural feature (Khan & Rafi, 2019).

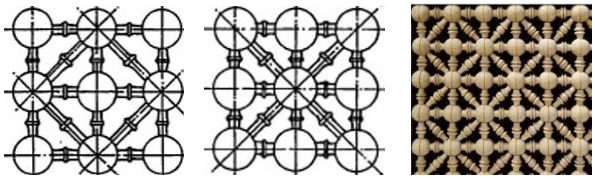
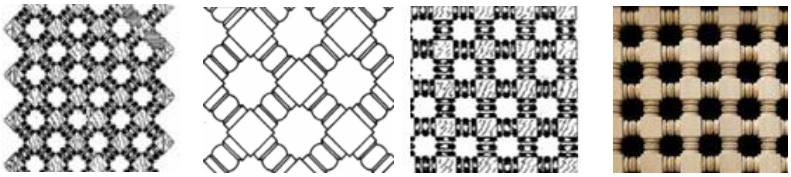
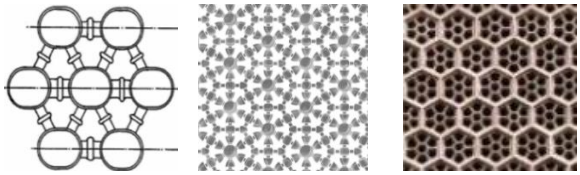
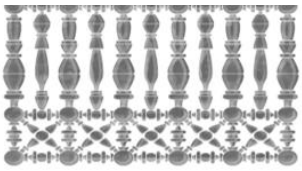
Name of the pattern	
The cross pattern	
The maymoni pattern	
The hexagon pattern	
The church pattern	

Table 3. Mashrabiya patterns (Taşkan & Ismaeel, 2022; Url 9; Url 10; Url 11)

Sometimes, mashrabiya screens may incorporate multiple types of inscriptions and patterns, as illustrated in Figure 1. This particular screen features three inscriptions—Maymoni, Cross, and Church—combined in a harmonious design. This sophisticated fusion reflects the rich dialogue among diverse cultural, religious, and artistic influences, highlighting the historical coexistence and mutual impact of various traditions within architectural design.

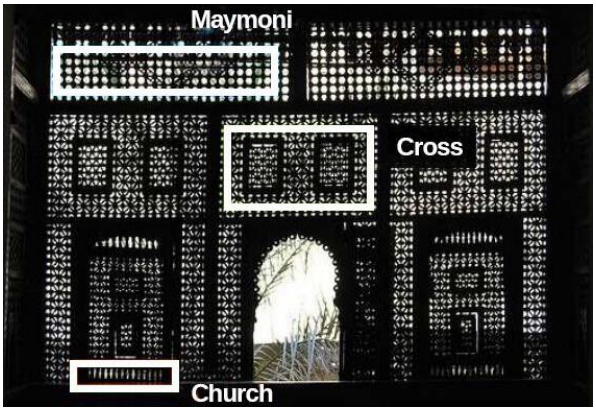


Figure 1. Interior view of combination of patterns in one mashrabiya (Alothman, 2024).

3.2. The Significance of Mashrabiya in Interior Lighting and Vernacular Architecture

Mashrabiya play a significant role in history by influencing interior lighting, particularly within the context of traditional architecture in the Middle East. Historically, mashrabiya screens were an innovative solution for mitigating intense sunlight and adapting to the region's hot climate. These intricately woven wooden lattices serve as sophisticated means of filtering natural light into interior spaces. One of the primary functions of mashrabiya in historical architecture is to regulate and control the entry of sunlight into buildings (Bayomy, 2016). The intricate patterns of the mashrabiya lattice diffuse harsh sunlight and cast beautiful patterns of light and shadow in interior spaces, as illustrated in Figure 2, adding depth and texture to the environment. In this way, they reduce glare and create a softer ambient illumination, which is conducive to indoor activities and comfort (Al-Karablieh et al., 2019).

Figure 2. Effects of shadow and lighting pattern in the indoor environment (Url 12; Url 13; Url 14)

Moreover, mashrabiya played a crucial role in enhancing privacy while still allowing natural light to penetrate the interior. By selectively obscuring views from the outside, these screens afforded occupants a sense of seclusion without completely blocking sunlight. This balance between privacy and illumination is essential for creating special and welcoming interior spaces, particularly in densely populated urban environments (Abdelkader & Park, 2018). In addition, the historical significance of mashrabiya in lighting extends its contribution to energy efficiency and sustainability. By harnessing the power of natural light, buildings adorned with mashrabiya screens were able to minimize their reliance on artificial lighting sources during the day. This not only reduced energy consumption, but also helped create more environmentally responsible architectural solutions that were in harmony with the natural surroundings (Fahmy et al., 2023).

3.3. Techniques for Adjusting Daylight Intensity and Direction

Mashrabiya provides architects with the opportunity to manipulate the intensity and direction of light within a space, enabling precise control over the ambiance and functionality of interior lighting. By strategically positioning mashrabiya panels or adjusting the spacing of balusters, architects can regulate the amount of sunlight that filters into a room, creating various zones of brightness. This dynamic approach to lighting not only enhances visual comfort but also improves energy efficiency by reducing reliance on artificial lighting during daylight hours (Fahmy et al., 2023). Furthermore, the adjustability of mashrabiya panels allows architects to respond to changing daylight conditions throughout the day, ensuring that interior spaces remain well-lit and comfortable at all times. In its design, Mashrabya takes into account the distance and size of openings to effectively manage lighting. As shown in Figure 3, the lower section features smaller openings positioned at eye level to filter and diffuse incoming sunlight, thereby enhancing privacy for the occupants. In contrast, the upper section includes larger openings situated high enough to permit natural light and cool air to enter the space while still preserving privacy. This thoughtful design creates a balanced and comfortable environment by facilitating the flow of light and air throughout the structure (Abdelkader & Park, 2018).

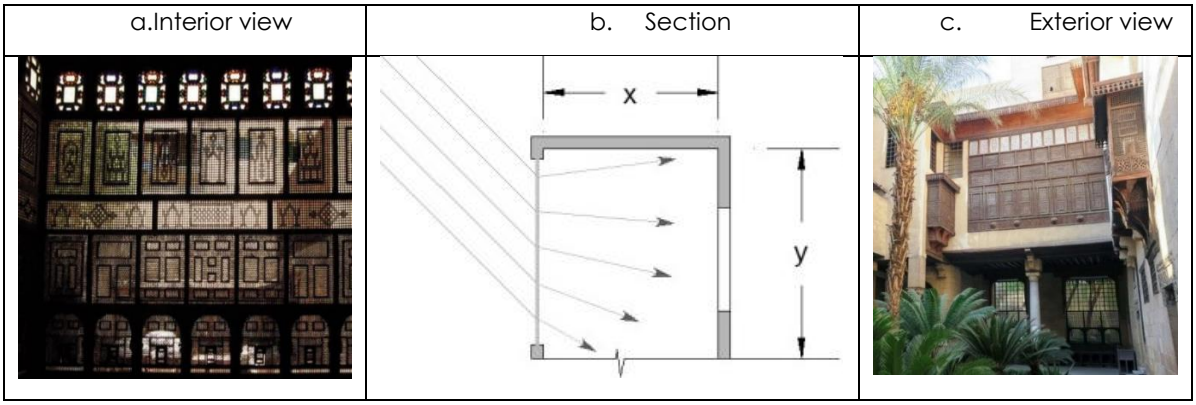


Figure 3. Light directing at interior space at Al-Suhaymi house, Egypt (Al-karablieh et al., 2019; Abdelkader & Park, 2018)

In the Suhaimi house, as illustrated in Figure 3, the room's layout emphasizes the relationship between spatial dimensions and the mashrabiya. The mashrabiya panels, which are nearly the same height as the room's walls, effectively enhance the distribution of light. The height of the mashrabiya is approximately equal to the room's height, denoted as y. The room's height slightly exceeds its width, ensuring that sunlight penetrates deeper into the space. Consequently, the combined height and width of the mashrabiya facilitate the maximum influx of sunlight throughout the room. This design not only optimizes natural light within the house but also adds aesthetic value and functionality to the interior space (Al-Karablieh et al., 2019).

3.4. Creating Visual Effects with Mashrabiya

The arrangement of light and shadow on the surface of the mashrabiya is influenced by its cylindrical shape, which helps to soften the contrast between light and dark, resulting in more diffused illumination. The shapes and apertures of mashrabiyas vary significantly, affecting both the quantity and pattern of light that enters the interior space, as well as the quality of light, which can range from soft dimness to harsh glare (Bayomy, 2016). The spacing between the bars of the mashrabiya and their diameters are critical factors that influence the primary source of light. Increasing the spacing between the bars enhances the amount of light that enters, while decreasing the spacing reduces it. Figure 4 presents a detailed illustration of a mashrabiya, categorizing the regions into two types: one representing areas with limited light penetration (negative area) and the other representing open spaces that allow light to enter (positive area). The negative area consists of solid wood that obstructs light entry and appears to occupy a larger total area compared to the positive area (Al-Karablieh et al., 2019). The area featuring positive space is illustrated in Figure 4, which showcases openings that allow light to filter through, creating intricate patterns and decorative effects within the space. This interplay of light and shadow produces a visually appealing aesthetic and enhances the

artistic value of the environment. The balance and control of light interacting with the mashrabiya structure foster a harmonious and graceful atmosphere, utilizing natural light as a fundamental element in the architectural expression of Islamic design principles (Al-Karablieh et al., 2019). Understanding the difference between negative and positive space in mashrabiya design is crucial. This knowledge enables designers to optimize natural light, ensuring that interiors are well-lit without excessive glare. Additionally, it aids in managing thermal comfort, helping to keep indoor spaces relatively cooler in hot climates by blocking direct sunlight. Furthermore, the strategic placement of negative spaces enhances privacy, allowing light to enter while obstructing external views. This thoughtful design of negative areas adds aesthetic value, making the overall design visually appealing. The balance of light and shadow contributes to its beauty. Mastering this balance is essential for developing innovative, functional, and attractive architectural designs.

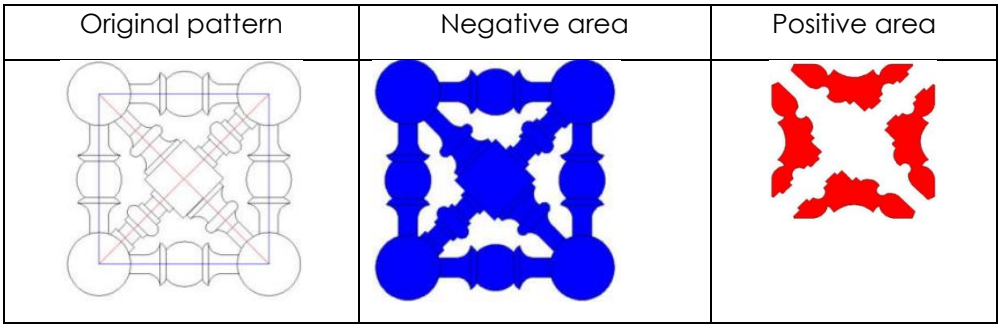


Figure 4. The negative and positive areas (Al-karablieh et. al., 2019)

4. Contemporary Materials and Methods of Mashrabiya

In recent years, extensive research has been conducted on adaptive façade systems. Belek and Yamaçlı (2022) explored various design solutions that align with sustainable design criteria using these systems. In contemporary applications, mashrabiya has also been integrated into adaptive façade systems. Designers are transforming traditional mashrabiya into advanced daylighting systems through the use of computer technology. These modern mashrabiyas have evolved into sophisticated systems capable of adapting to varying light and shadow conditions within spaces. Traditional mashrabiya lacks the ability to adjust to changing environmental conditions. A significant innovation in this field is the shape-variable mashrabiya, which is designed for both lighting and shading. This concept, along with parametric mashrabiya, provides architects and designers with enhanced flexibility and an unprecedented ability to generate interactive mashrabiya patterns and configurations.

4.1. The Shape Variable Mashrabiya (SVM)

The shape-variable mashrabiya (SVM) is an innovative sun protection system inspired by the traditional mashrabiya concept, specifically designed to enhance efficiency in arid and hot climates. The primary objective of this system is to minimize solar gain and direct sunlight while maximizing natural daylight. The SVM consists of three identical shields arranged in a specific pattern, as illustrated in Table 4. These patterns are meticulously crafted to achieve an optimal balance between sun protection and daylight. The shields are constructed from durable, lightweight materials such as aluminum, which facilitates easy maintenance. This system dynamically adjusts in response to external factors, including sunlight, temperature, and wind (Giovannini et al., 2015).

A central computer manages the system and continuously monitors environmental conditions and user preferences. Based on this data, the mashrabiya adjusts its panels to enhance airflow, lighting levels, and privacy (Giovannini et al., 2015). The SVM system consists of three identical shields: the first shield remains fixed, while the second and third shields can move independently along both the vertical and lateral dimensions (the x- and y-axes) by half of the motif length (L/2). The SVM is designed to respond to changing solar angles throughout the day. It dynamically adjusts its configuration to optimize protection from direct sunlight while providing diffused daylight and maintaining a connection to the outdoor environment. By adapting to outdoor conditions, the SVM system ensures maximum comfort for building occupants while preserving a well-lit and pleasant indoor atmosphere (Karamata & Andersen, 2014).

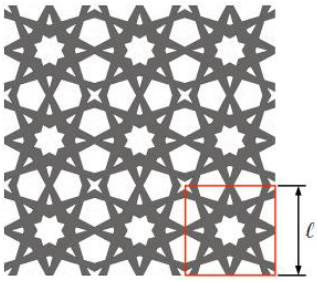
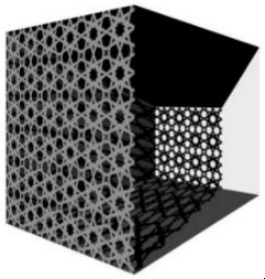
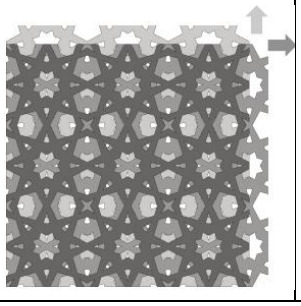
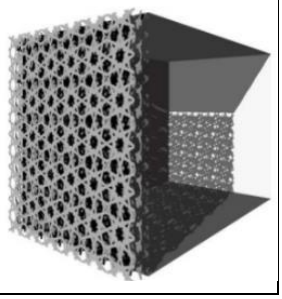
Open		Closed	
Elevation	3D view	Elevation	3D view
			

Table 4. The pattern and the positioning of shape variable mashrabiya (SVM) (Giovannini et. al., 2015; Karamata & Andersen, 2014)

Recently, the SVM system was compared to standard Venetian blinds. The study revealed that the SVM system demonstrated superior performance, particularly in terms of

providing adequate lighting in the space. Additionally, it significantly conserves energy, with potential savings of up to 65.7% compared to reflective glazing (16%) and 30.7% compared to Venetian blinds. While these results were derived from simulations, further insights into the effectiveness and aesthetic appeal of the SVM system could be obtained through real prototypes (Taki & Kumari, 2023).

4.2. The Parametric Mashrabiya (PM)

In the design field, the term refers to variable design. It is a method of creating and designing various models and structures through the application of multiple algorithms and mathematical operations. This technology enables the development of complex, self-modifying designs that autonomously respond to diverse inputs, including climatic conditions, required functionalities, and aesthetic preferences. Advanced software tools are frequently employed in parametric design to model and optimize these mathematical relationships, which in turn influence innovative and efficient architectural solutions (Bayomy, 2016; Sharaidin et al., 2012).

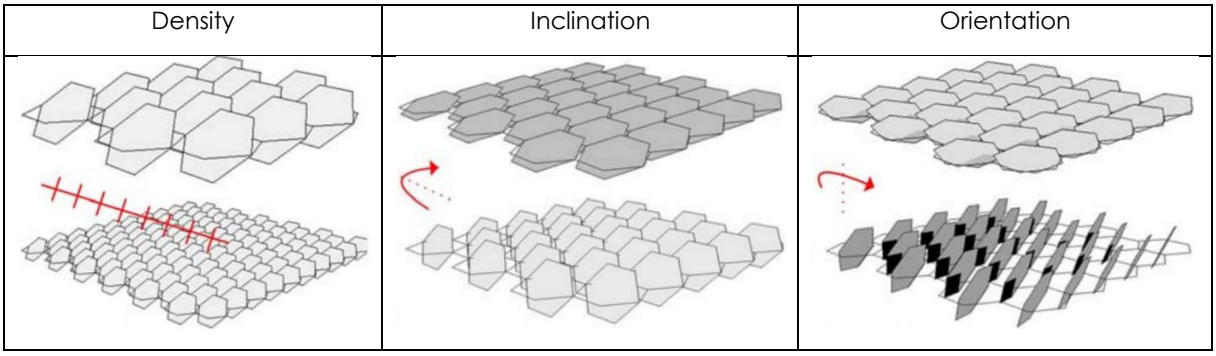


Figure 5. Variables of the parametric model (Turrin et al., 2011)

In the parametric design of a mashrabiya, factors such as the required levels of light and heat are crucial. Based on these parameters, the opening and closing of the parametric mashrabiya are regulated. This system ensures balanced lighting within the building and enhances comfort by adjusting heat and light levels according to specific needs (El Semary et al., 2017). The parametric mashrabiya represents a contemporary interpretation of a traditional architectural element, seamlessly blending ancient artistry with modern technology. In parametric design, architects can adjust pattern density, panel orientation, and shading angles to optimize the design and enhance its visual appeal (Figure 5). This level of customization allows architects to create mashrabiyas tailored to the unique characteristics of each building and its surrounding environment. By integrating advanced materials and manufacturing technologies, the parametric mashrabiya improves building performance while preserving a connection to its historical and cultural roots (Fahmy et al., 2023).

5. Examples of Innovative Mashrabiya Applications in Modern Architecture

In contemporary architecture, three notable examples are examined: The Arab World Institute in Paris, the Doha Tower in Qatar, and the Al Bahar Towers in the United Arab Emirates. These buildings, evaluated within the context of adaptive facade systems, also incorporate active kinetic systems (Belek & Yamaçlı, 2022). The first system, designed with an emphasis on natural lighting, was implemented on a single-skin facade, whereas the second and third examples feature a double-skin facade. Double-skin facade systems also facilitate natural ventilation. Unlike traditional systems, contemporary designs utilize a variety of materials, and kinetic systems can be developed instead of relying solely on static designs. Consequently, it is possible to incorporate design elements inspired by vernacular architecture while employing advanced techniques and design patterns. This approach allows for the integration of traditional cultural techniques with modern innovations.

5.1. Arab World Institute in Paris, France

The Arab World Institute in Paris, France, was designed by Jean Nouvel and completed in 1987. The southern façade functions as a massive mashrabiya, measuring 30 × 80 meters, which seamlessly integrates modern technology with traditional Arabic architectural principles (Bagasi et al., 2021). This contemporary mashrabiya serves as a dynamic screen that filters light while being both functional and aesthetically pleasing. The southern façade comprises 240 square units that open and close automatically, resembling camera lenses (Gamal et al., 2022). This advanced system is calibrated to regulate and filter the amount of light and heat entering the building (Figure 6). Interface elements continuously change throughout the day, presenting a new appearance that adapts to external environmental conditions and evolving needs (El Semary et al., 2017). From an environmental perspective, the adjustable mashrabiya openings in this design have significantly reduced the need for artificial lighting and enhanced the building's energy efficiency. This technique illustrates how traditional elements can be reinterpreted to suit modern architectural contexts while preserving their cultural significance (Gamal et al., 2022). The Arab World Institute creates a unique and culturally meaningful space that connects the past with the present.

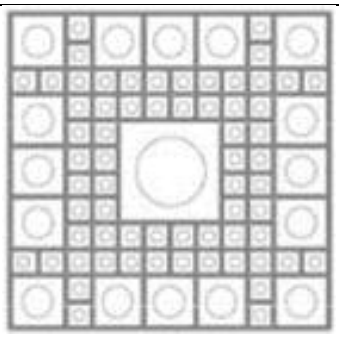
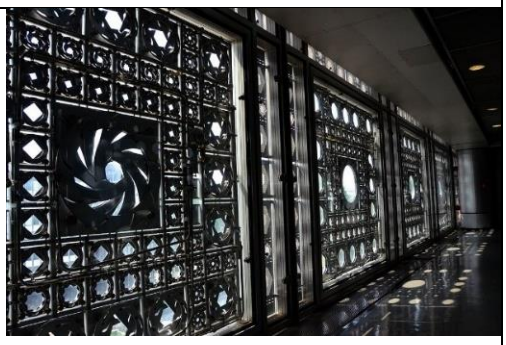
South facade	Pattern	Positioning (open and closed)
		

Figure 6. Arab World Institute in Paris, France (El Semary et. al., 2017; Url 15; Url 16)

5.2. Doha Tower (Burj Qatar) in Doha, Qatar

The tower's design is inspired by Islamic motifs and geometric patterns, seamlessly blending cultural heritage with contemporary architecture. Completed in 2012, the tower stands 231 meters tall and comprises 46 floors. Known as Doha Tower or Qatar Tower, it was designed by Jean Nouvel. The building's cylindrical shape, complemented by a mashrabiya-inspired façade, makes it a distinctive landmark in the area. The façade functions as a multi-layered system featuring a complex grid design (Bayomy, 2016). It is adorned with four layers of metallic patterns that provide both aesthetic appeal and functional benefits. The design incorporates a single geometric shape at multiple scales, overlaid with varying densities across the façade. Overlays are applied based on solar conditions: 25% opacity is designated for the north elevation, 40% for the south, and 60% for the east and west (Bagasi et al., 2021). The façade system contributes to a 20% reduction in cooling loads. This technology aids in decreasing energy consumption by regulating the light and heat that enter the building (Figure 7) (Khan & Rafi, 2019).

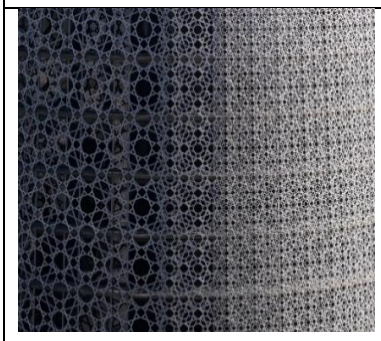
Building elevation at west	North façade pattern	South façade pattern
		

Figure 7. Doha Tower in Qatar (Bayomy, 2016; Url 17)

5.3. Al-Bahar Towers in Abu Dhabi, UAE

The evolution of the mashrabiya screen into contemporary architecture is exemplified by the twin towers in Abu Dhabi, United Arab Emirates. These structures serve as a landmark, showcasing a harmonious blend of cultural heritage and modern innovation. The traditional vernacular element has been transformed into a dynamic façade system. This façade features a parametric shading system composed of umbrella-like elements (Khan & Rafi, 2019). These umbrella-like panels are installed on three façades: the eastern, southern, and western façades. The northern portion of the façade remains exposed without shading (Table 5).

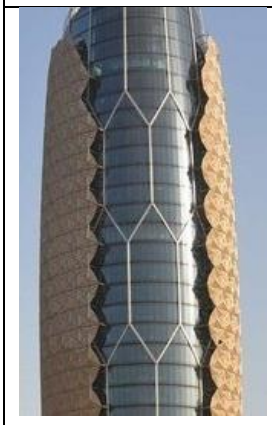
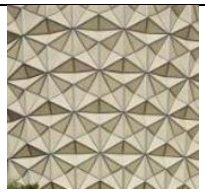
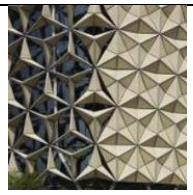
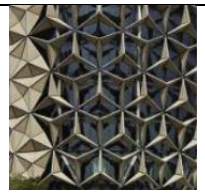
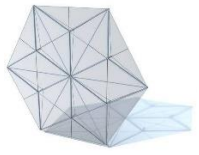
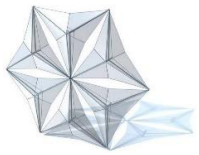
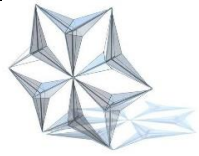
Building facades		Mashrabiya patterns		
North facade	South facade	max. shading	half shading	min. shading
				
		closed	semi-open	max. open
				

Table 5. Al-Bahar Towers in Abu Dhabi, UAE (El Semary et. al., 2017; Url 18; Url 19)

The two towers consist of over 1,000 individual units that are electronically controlled by the building management system to create a smart façade. This adaptive mashrabiya takes on a triangular shape when fully expanded. All six units are interconnected at a common point, forming a hexagonal configuration. These umbrella-like components are constructed from semi-transparent materials that illuminate and diffuse sunlight while minimizing glare and heat from direct exposure (Gamal et al., 2022). By utilizing complex algorithms, the relationships between design elements can be defined through specific parameters, resulting in a façade that automatically adapts to changing external environmental conditions (Khan & Rafi, 2019). This shading system adjusts according to the movement of the sun. At sunrise, the east-facing section of the facade closes to block the intense morning sunlight. As the day progresses, the shading elements dynamically change in response to the sun's position, resulting in a unique and evolving facade throughout the day (Bayomy, 2016). By regulating the amount of sunlight entering the building, this technology effectively reduces glare and heat gain, thereby decreasing reliance on artificial cooling systems and creating a comfortable indoor environment for occupants. Studies indicate that this innovative approach can reduce solar gain by up to 50%, significantly lowering cooling costs and energy consumption (Bayomy, 2016).

6. Conclusion and Discussion

This research focuses on the fundamental concepts related to mashrabiya as a local architectural vernacular element in the Middle East, with a primary emphasis on its revival in contemporary applications. Traditionally, thermal comfort was achieved through the use of sunshades and water pots. In local architecture, designs are mainly divided into two categories: plain and projected mashrabiya. There are five commonly recognized patterns, and they can sometimes be combined. The density of these patterns and textures affects the interior lighting and its direction. The patterns found in traditional architecture can be seen as two-dimensional sunshades and fixed features. The principles embedded in the traditional mashrabiya align with contemporary sustainable architecture, promoting daylighting, natural ventilation, and reduced energy consumption. Traditionally, mashrabiya consisted of static two-dimensional elements; however, they have now evolved to incorporate moving parts in contemporary applications. The integration of diverse materials and dynamic components has resulted in significant differences between these advanced versions and traditional designs. In contemporary mashrabiya designs, the sunshade function is predominantly emphasized. Traditional sunshades are usually made of wood, whereas modern designs incorporate various materials, including metal and wood. Current interpretations incorporate advanced materials and technologies to showcase the mashrabiya's adaptability in improving the environmental performance of buildings. In modern applications, it is primarily employed on the southern

facade as a shading device, offering both natural lighting and thermal regulation. Today, they are recognized not only as shading devices but also as adaptive façade systems. In contemporary designs, two types have emerged: SVM and parametric mashrabiya. SVM refers to motion in a two-dimensional plane, such as the x and y axes, whereas parametric mashrabiya describes motion in a three-dimensional space, including the x, y, and z axes. From this perspective, parametric mashrabiya unveils a design pattern that transcends traditional mashrabiya. Examples include dynamic facades and parametric designs that respond to environmental conditions in real-time, demonstrating that the mashrabiya can be innovatively integrated into contemporary architecture. The examples mentioned include movable elements; the first refers to a two-dimensional moving sunshade, while the second describes a three-dimensional version. In contemporary applications, SVM can be more closely associated with examples found in vernacular architecture.

It is important to note that conducting a comprehensive study on SVM as a valuable direction for future research. Additionally, it is evident that a separate investigation is necessary to explore the design relationship between traditional patterns and those selected in modern applications. This text reflects the modern adaptation of mashrabiya, which integrates variable shapes and dynamic features. Additionally, further research is needed to assess the performance of daylighting and natural ventilation in mashrabiya within adaptive facade systems. This area of research may open new opportunities for SVM in optimizing building performance concerning energy efficiency, daylight manipulation, and thermal comfort, while also maintaining a connection to traditional architectural identity.

Author Contribution and Conflict of Interest Declaration

This article has two authors. The entire manuscript has been written and approved by both authors and presents original, unpublished work. This research did not receive any specific grants from funding agencies in the public, commercial, or non-profit sectors. The authors declare that they have no conflicts of interest.

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