AN EVALUATVE AND CRITICAL STUDY OF MASHRABIYA IN CONTEMPORARY ARCHITECTURE

A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES OF NEAR EAST UNIVERSITY

By
HIBA ALOTHMAN

In Partial Fulfillment of the Requirements for The Degree of Master of Science in Architecture

NICOSIA, 2017

HERE THE PAPER OF SIGNATURES

Approval page |

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last name: Hiba Alothman

Signature:

Date:

ACKNOWLEDGMENTS

Firstly, I would first like to thank my thesis advisor Dr. Ayten Özsavaş Akçay. The door to Dr. Akçay office was always open whenever I ran into a trouble spot or had a question about my research or writing.

She consistently allowed this paper to be my own work, but steered me in the right direction whenever she thought I needed it.

I would also like to thank the experts who were involved in the validation survey for this thesis, Assoc. Prof. Dr. Türkan Ulusu Uraz and Dr. Huriye Gürdallı. Without their passionate participation and input, the validation survey could not have been successfully conducted and I take this opportunity to express my gratitude to all of the department members for their help and support.

I would like to gratefully and sincerely thank the architect Hasan Fathy whose ideas inspired me to write these papers.

Finally, I must express my very profound gratitude to my mother for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without her. Thank you.

To my mother…

ABSTRACT

Finding the favorable trade-off between saving the architectural heritage, and assuring the development of modern architecture is a delicate and precise task, due to the lack of knowledge in the original criteria for the re-thinking of traditional architecture. As a tentative answer to this challenge, this thesis attempts to document the subject of Mashrabiya (Arab oriel windows as an environmental architectural element) with new, orderly arrangement to create a practical and theory-based resource. The history, functions, standards of design and construction , parameters, new updates in styles and materials of Mashrabiya and all aspects of the subject will be studied in detail, in order to explore a complete understanding of Mashrabiya which will give considerable help in evaluating important modern projects that have used contemporary versions of Mashrabiya. The first, and the most important step in preserving the identity of Mashrabiya is actually to start by skipping the repetition of theoretical discussion about this element and focus on the benefits of research in finding the best construction solutions and new, alternative materials, for making the Mashrabiya more dynamic, bearing in mind the most appropriate cost and safety, and keeping it in step with the renaissance of western architecture .

Keywords: Mashrabiya; Arab identity; functions; re-thinking traditional architecture; parameters; materials

ÖZET

Mimari mirasın korunması ile modern mimarinin gelişmesinin sağlanması arasındaki olumlu ilişkinin kurulması, geleneksel mimarlığın geniden düşünülmesi ve bilgi eksikliğinin giderilmesini gerektiren önemli ve hassas bir görevdir. Bu çalışma, geleneksel ve modern arasındaki tartışmaya cevap oluşturabilmek için Arap geleneksel mimari elemanı olan Maşrabiya ile ilgili pratik ve teori temeline dayanan bir kaynak oluşturmayı amaçlamaktadır. Maşrabiyanın tarihçesi, işlevleri, tasarım ve yapım standartları, parametreleri, malzemeleri, yeniden güncel değerlendirme şekilleri, ayrıntılı olarak incelenmiştir. Kapsamlı bir anlatım oluşturabilmek için moderm mimari projelerinde Maşrabiyanın çağdaş kullanımı incelenerek değerlendirilmiştir. Mashrabiya kimliğini korumanın ilk ve en önemli adımı, bu mimari öğe ile ilgili teorik tartışmaları tekrar etmek yerine en doğru yapım yöntemlerini ve yeni, alternatif malzemeler bulunmasına odaklanmaktır. Mashrabiyayı daha dinamik, uygun maliyetli, güvenli, bilinen ve batı mimarisinin rönesansına ayak uydurmasını sağlamaktır.

Anahtar Kelimeler: Mashrabiya; Arap kimliği; fonksiyonlar; geleneksel mimariyi yeniden düşünme; parametreler; malzemeler

TABLE OF CONTENTS

CHAPTER 3: FUNCTION, PATTERNS AND PARAMETERS OF MASHRABIYA

CHAPTER 4: MATERIALITY AND CONSTRUCTION OF MASHRABIYA

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CNC : Computer Numerically Controlled.

PF : Porosity Factor.

HAVC: Heat, Air Ventilation, and Cooling

AM: Additive Manufacturing

SVM: Shape Variable Mashrabiya

CHAPTER 1

INTRODUCTION

The Mashrabiya is an Arab architectural element, which always had something magical that attracted the western orientalists' attention and has subsequently been revived in many contemporary projects.

Some of the projects used the correct design criteria, some of them implemented the design using the latest technology, but with very high costs, and some projects, especially outside the Arab region, used it without even acknowledging the original name (Mashrabiya).

There might even be a marginalization of the original name of the Mashrabiya in projects in the Arab region too, and that began to pose a threat to the identity of Mashrabiya and its design integrity and standards.

These misconceptions are attributable to the lack of sufficient knowledge of the history, functions and design parameters of Mashrabiya.

1.1 Research Problem

The lack of a comprehensive and organized reference of Mashrabiya results in making the theoretical studies about Mashrabiya just scattered studies, piling up and repeating without most of them being taken seriously, especially when applied in real projects on the ground and when discussing the functions; the available explanations of Mashrabiya functions are so confused, even if they seem obvious in indices.

Consequently, there are many examples of modern projects that use the Mashrabiya just as a decorative aesthetic element without either usage of any other functional benefits, or relying on the design criteria of Mashrabiya.

Moreover other projects omit the original name of architectural element, and deal with it using new names like ‘geometric panels’ or ‘airflakes’. The lack of sufficient knowledge of the history of Mashrabiya and its concept does not provide an excuse to obliterate the identity of Mashrabiya. Knowledge about Mashrabiya is readily available, but it is scattered and confused. At this point the task is to collect and document the various studies, and create an integrated resource which can preserve the identity of Mashrabiya and present it as a powerful, environmentally-sensitive, architectural element.

1.2 The Aims and Scope of the Research

The thesis aims to provide a complete documented reference concerning Mashrabiya, with a new and logical arrangement of the subject, gathering together scattered studies, none of which have covered the topic in a comprehensive, integrated or sequential way. The research also seeks to evaluate important contemporary projects that have used Mashrabiya, and to discuss to what extent the precise criteria of Mashrabiya and the theoretical research relating to it, have actually been implemented.

1.3 Research Questions

This study tries to deal with some questions about the modern conversion of Mashrabiya, for example :

- What is the effect of Mashrabiya on the energy and optical comfort, especially the glare issue, in buildings? How does the efficiency of Mashrabiya compare to other cooling and shading devices? What are the evaluation or estimation guidelines for Mashrabiya, as an environmental, architectural element?

- Why are the theoretical studies and the proper design standards of Mashrabiya ignored during the implementation of modern projects? Why is the original name of this item marginalized or replaced with new nomenclatures in some recent projects?

- To what extent does the integration of modern technology with Mashrabiya affect the identity of Mashrabiya, its benefits and costs?

1.4 The Motivation and Importance of the Thesis

The motivation behind this research is to document all available data about Mashrabiya, the history, standards of design and construction, new updates and materials used for Mashrabiya, plus a comprehensive study of modern projects that have incorporated the Mashrabiya. The first and most important step is to preserve its identity and to avoid repetition of theoretical discussion about Mashrabiya and focus on the benefit of these studies to find the best construction solutions. This is in order to make the Mashrabiya more dynamic, with the most appropriate cost and safety, and to keep up with the renaissance of western architecture.

The East and West are two worlds who should be able to integrate together, without obliterating the identity of one or the renaissance of the other. Architecture represents the finest images of cultural integration, which benefits all sides.

1.5 Methodology of Research

The general research strategy depends on two approaches:

- First of all, to collect and document all the scattered studies of Mashrabiya, then present them in a new, obvious and comprehensible way, without any missing or repetitive explanations.

- Secondly, with reference to the integrated and powerful background of Mashrabiya, the research study will evaluate the modern versions of Mashrabiya, as found in contemporary projects.

The process seeks to insure full understanding and realization of the environmental functions and design parameters of Mashrabiya, along with preserving its original name, Arab architectural identity and cultural heritage (Figure 1.1).

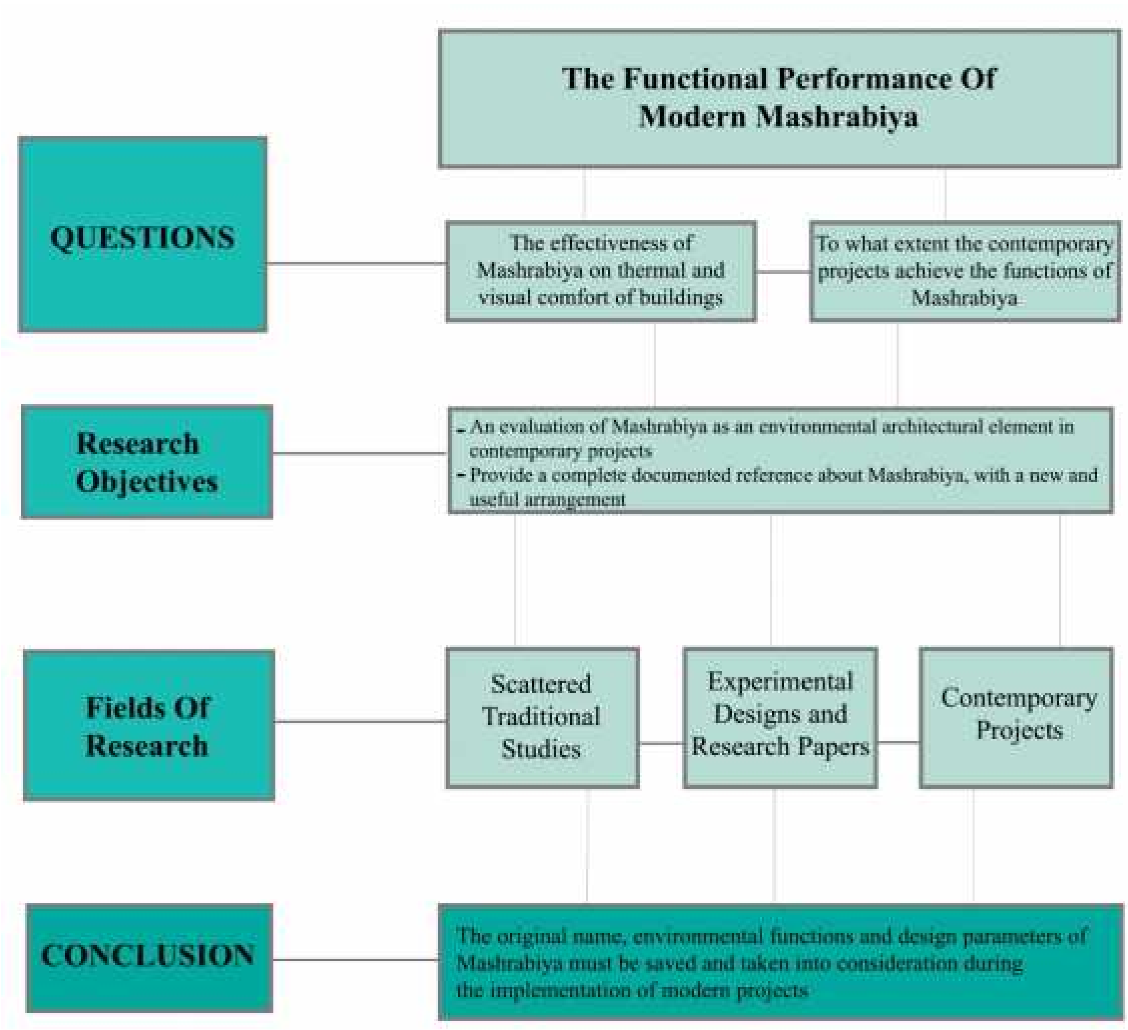


Figure 1.1: The methodology of research (Alothman, 2016)

1.6 Established Previous Studies

Up to the present time many important aspects of the Mashrabiya, have been studied scientifically within masters theses, research papers, journals and articles.

Hassan Fathy, in his book, (Natural Energies and Vernacular Architecture,1986) is considered the godfather of all published studies of Mashrabiya (Figure 1.2); but the subject of Mashrabiya itself was explained in only four pages in his book, which includes a comprehensive study of all traditional Arab architectural elements.

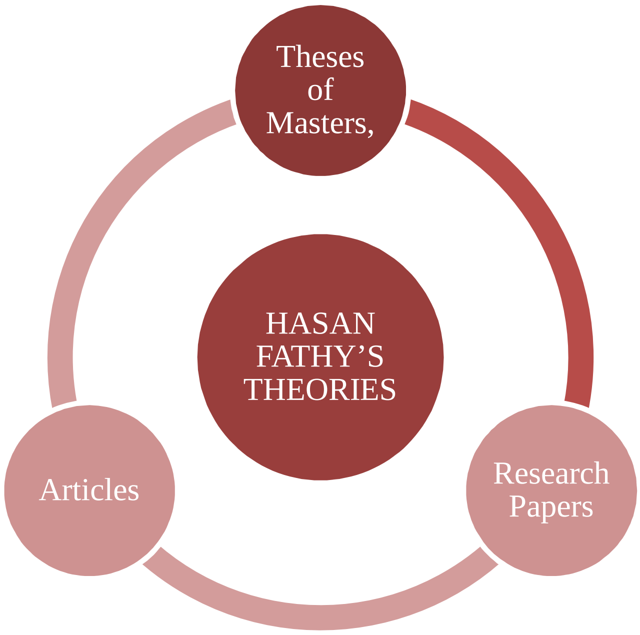


Figure 1.2: Through Fathy's theories, he has become the godfather of all published studies of Mashrabiya (Alothman, 2016)

To comply with the structural and economic variables of modern architecture, the need to develop the Mashrabiya has become necessary; therefore there have been numerous theoretical studies, and it has been revived in many contemporary projects.

But it is worth commenting on some available studies:

- Many studies provided good tables of contents with respect to the matter, but the important issues such as patterns, design rules, materials and functions, etc., are often found as interesting headlines without even a brief, adequate explanation, so even if some published research has motivating subtitles, the disappointment is that little help is provided to make any of them into powerful and comprehensive reference sources of Mashrabiya for foreign architects.
- Also some treatises did not go beyond being research papers and some articles shed limited light on the matter, sporadically and not sequentially, by examining one aspect and neglecting another, and without clear familiarity with the topic as a whole, thus failing to provide a thorough understanding of the Mashrabiya.
- To fill the gaps between the published studies and to present an integrated source, this thesis is based on a wide range of references.
- One way or another all the references were made by relying on ideas from Hasan Fathy, which he summarized in many pages where every line seemed to be a fact relating to Mashrabiya.

However, among the recent studies, three master theses have emerged and gained some importance (Figure 1.3):

- Performance and Permeability, An Investigation of the Mashrabiya for use within the Gibson Desert (Samuels, 2011).

- Determing Environmental Performance of Mashrabiya Façade for Modern Buildings in Pakistan (Batool, 2014).

- The Traditional Arts and Crafts of Turnery or Mashrabiya (Mohamed, 2015).

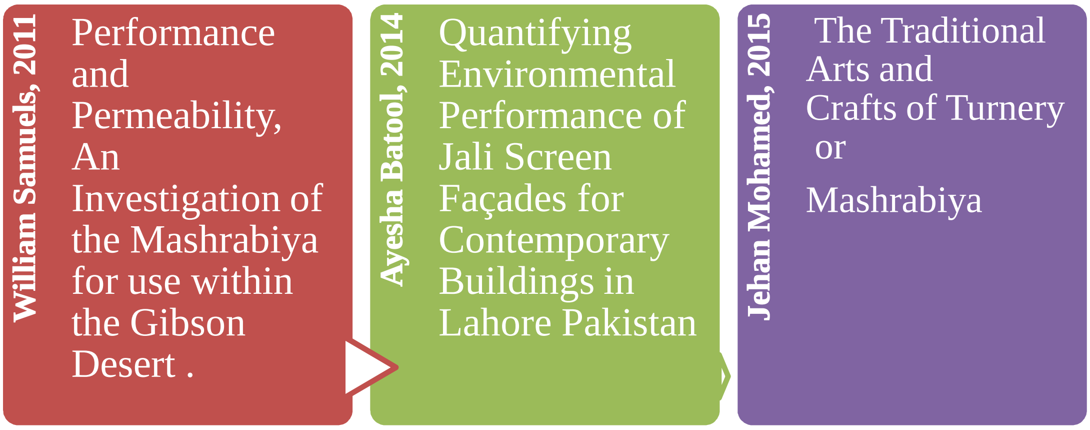


Figure 1.3: Important studies about Mashrabiya (Alothman, 2016)

Samuels's thesis was particularly important because he was among the very few to apply theoretical studies to practical projects, and he took advantage of the full functionality of Mashrabiya by emphasizing the importance of the correct design criteria. In addition he studied Fathy's theories and explored the parameters of Mashrabiya design to produce some hybrid patterns of modern Mashrabiya by using CIM and CNC technology. In fact, he was the first architect to benefit from digital design techniques to construct a new Mashrabiya, with costs as low as possible as well as developing the character of Mashrabiya.

Thereafter he was followed by Aisha Batool's thesis which studied Mashrabiya in Pakistan using a similar methodology to that found in Samuels's study.

Jehan Mohammed's thesis provided the subject with useful information about history, craftsmanship and woodwork, however, it is not a detailed enough study to be considered a complete reference, as it is not familiar with current innovations and empirical studies of the Mashrabiya.

It is worth mentioning that the credit should go to the Middle Eastern universities on the issue of preserving the Mashrabiya and working on its revival, because they are still teaching Mashrabiya as an important element of cultural heritage, and stressing the need to consider it as an effectively powerful, environmentally-sensitive component in sustainable architecture nowadays. This point has already been proven by a number of studies, in the same way they have proven the ability of Mashrabiya to integrate into other modern architectural trends.

Therefore there can be no excuse for an architect to invoke the weakness of the scientific and practical foundations of the Mashrabiya.

1.7 The Sequence of Research

The thesis starts in chapter two with a definition of Mashrabiya and in the etymology section, a review of the multiple names given by different countries. After that the chapter documents the history and spread of Mashrabiya around the world between the year 868 and the late 19^{th} century, finishing with a brief survey of the decline of the Mashrabiya (Figure 1.4).

Chapters three and four will offer a discussion of the main foundations of the function, patterns, parameters of design, materiality and construction of Mashrabiya, using new, simple explanations, free of confusion. The architect must have these prerequisite foundations in order to study the Mashrabiya in modern projects and to be able to evaluate it constructively and shed light on possible operational errors and suggest important recommendations in the development of Mashrabiya. Chapter 5 begins by explaining the reasons for the revival of Mashrabiya in modern architecture and discussion of contemporary projects.

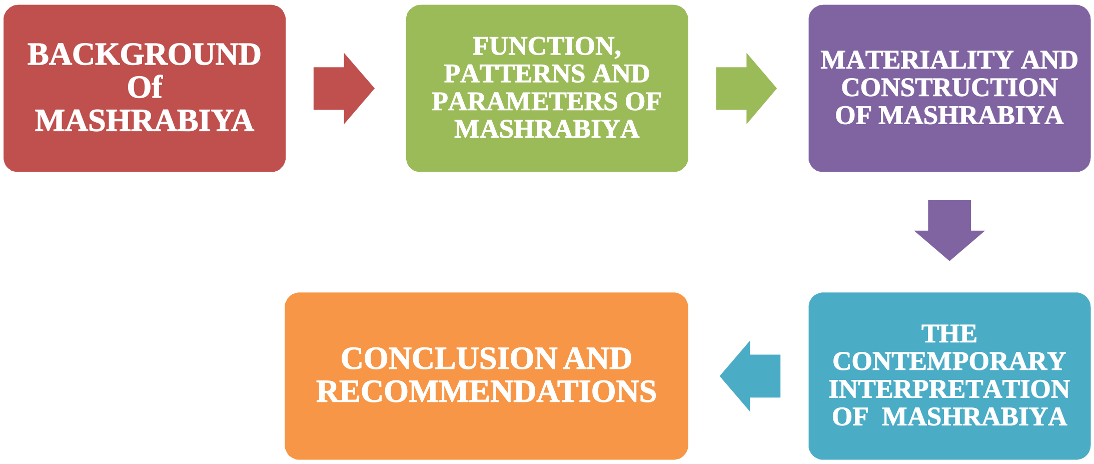


Figure 1.4: The sequence of research (Alothman, 2016)

CHAPTER 2

BACKGROUND OF MASHRABIYA

2.1. Definition of Mashrabiya

Mashrabiya is the prominent window that overlooks the street or the courtyard of traditional Arab houses. In the past Mashrabiya was the name given to the space, which is enclosed with wooden lattice openings (Figure 2.1), where jars of drinking water were put to cool. Cool air was created by the evaporation which is caused by the movement of air through the lattice openings (Fathy, 1986).

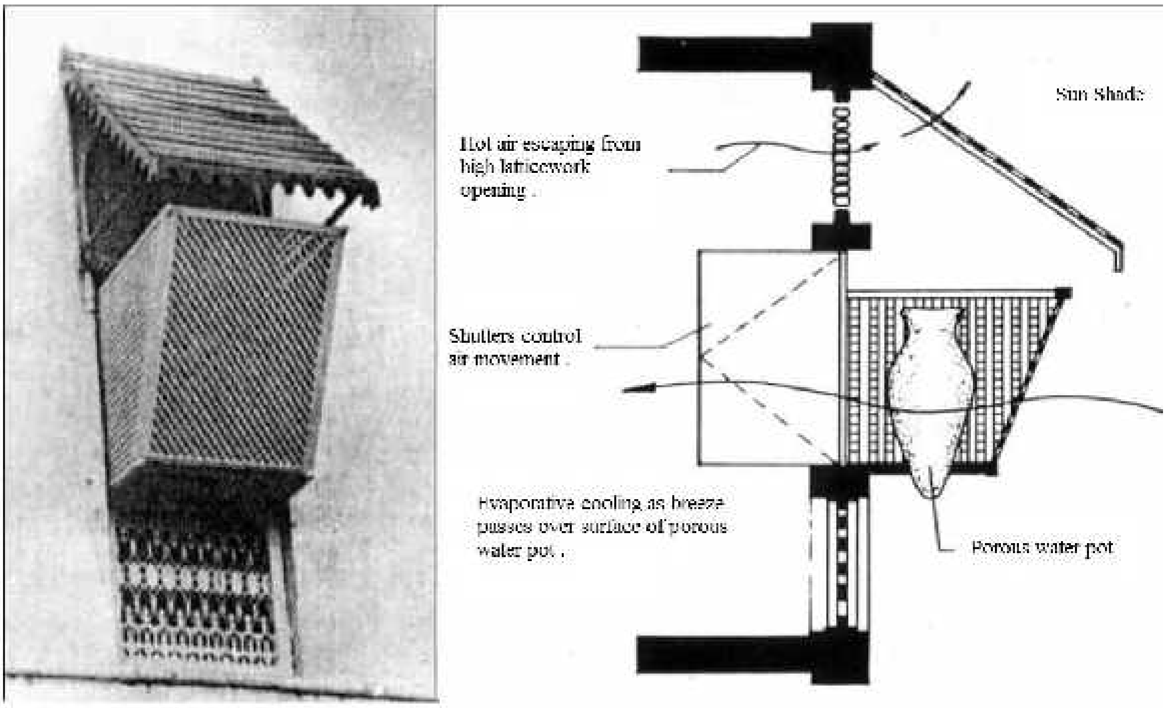


Figure 2.1: The cooling effect of Mashrabiya (Dayyoub, 2001)

Later, the name Mashrabiya was only given to the lattice screen, which is made of wooden balusters with a circular section (Figure 2.2), as a perfect condition to provide smoother airflow which contributes to the evaporation factor. This screen was completely hand-made and the design of the balusters was varied in different, artistic ways (Figure 2.3) for example, geometric and floral decorative forms or Arabic inscriptions (Figure 2.4) (Fathy, 1986)

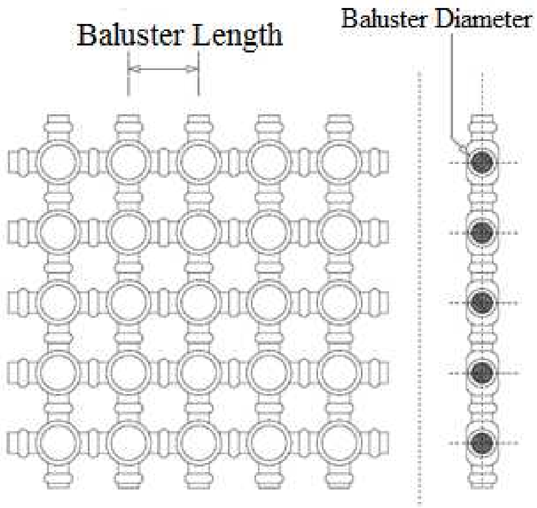


Figure 2.2: Traditional Mashrabiya typology (Samuels, 2011)

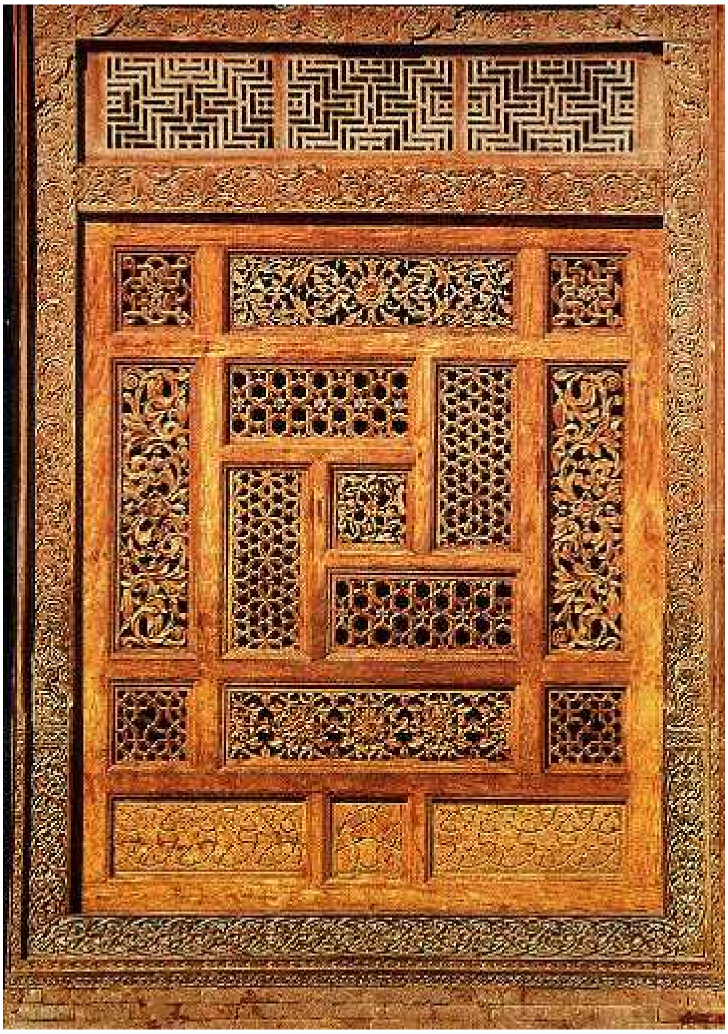


Figure 2.3: An old Mashrabiya in Pakistan decorated with floral forms (Orfali, 2015)

Figure 2.4: Mashrabiya with Arabic inscriptions and calligraphy designs from the Quran on the terrace of Gayer Anderson House in Cairo, Egypt (Alothman, 2016)

It can be seen that the Mashrabiya differs from other prominent windows or any random lattice screens; it was designed to respond specifically, effectively and dynamically to people's physical, environmental, social, physiological and religious requirements.

2.2 Etymology

The word Mashrabiya came from an Arab root meaning that is a place where the jars of drinking water were being put to cool, Mashraba is the noun form of a verb in Arabic "yashrab " meaning "drink" (Fathy, 1986).

It has also been said that Mashrabiya is a distortion of the word " Mashrafiya", taken from the verb in Arabic *yoshrif* meaning to overlook or observe, because the Mashrafiya is the prominent part of a window where the ladies of the house could observe the road outside in complete privacy (Figure 2.5).

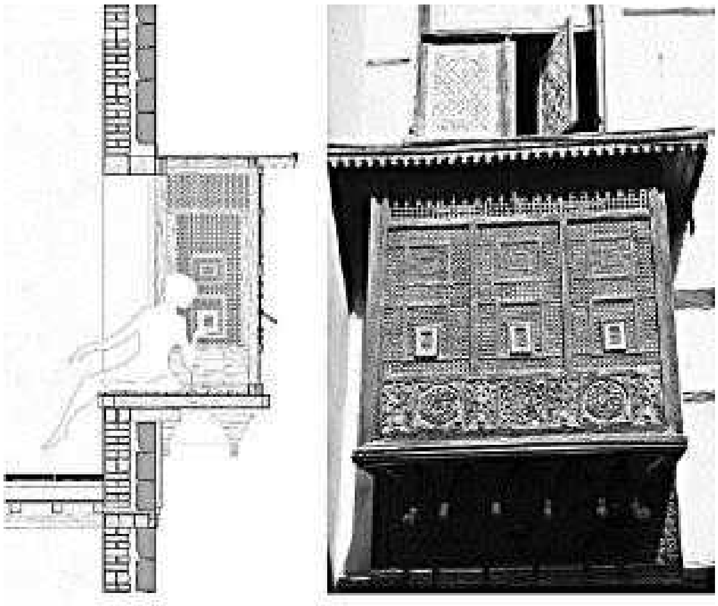


Figure 2.5: The ladies behind the Mashrabiya (Ficarelli, 2008)

There is a third view that says that the element was named by the Macherbah; it is an attribution to the kind of wood, called *Macherb* that was used in the manufacture of the screen. It is a good quality wood which is characterized by strength and the ability to withstand the heat of the sun and a harsh climate (Ben-Hamouche, 2013).

The Mashrabiya was widespread in Islam, but not only in Arab countries; consequently it has been given many names, like Roshan or Roche in the Arabization of the Persian word (Rosen), which means a window or a balcony (Almurahhem, 2009).

It also was known such as Cumba in Turkey; Cumba describes the prominent window that is enclosed by wooden lattice openings (Göçek, 2011). Jali in India, Shanshol in Iraq, Mushabak or Roshan in Iran, Roshan in Saudi Arabia also, Aggasi in Bahrain, Takhrima in Yemen, Barmaqli in Tunis. But the most commonly found name is Mashrabiya (Ashi, 2010) (Table 2.1).

It is worth mentioning that Mashrabiya is written in some studies as *Mashrabiyya* both expressions are correct, due to the grammar of the Arabic language which gives prominence to the Y letter in speaking or writing, as in the word Mashrabiyya.

Table 2.1: The Various Names of Mashrabiya Around the World (Alothman, 2016)

The Name	The Countries
Mashrabiya	Egypt, Syria, Palestine, Lebanon, Sudan, Australia, Spain, Peru …
Roshan/Roche	Arabian Gulf Countries , Iran
Shanshol	Iraq
Jali	India, Pakistan, Bhutan
Aggasi	Bahrain
Takhrima	Yemen
Mushabek	Iran
Barmaqli	Maghreb Countries
Cumba	Turkey

2.3 History and Spread

The history of Mashrabiya is dating back to the period when Arabs entered to Egypt, but when it first became used in particular, it is difficult to pinpoint because of the ever-evolving nature of architecture.

The British architectural historian author Briggs speculated (1974) that the origins of Mashrabiya could be found in the Coptic churches in Egypt. In a detailed explanation by the French Egyptologist Maspero (1914), (Manual of Egyptian Archaeology and Guide to the Study of Antiquities in Egypt) he discusses the process of the development of Mashrabiya and he points out that the Mashrabiya began to flourish during Tulunid era (868- 905) where they used a considerable amount of wood in their buildings, and Arab manufacturers benefited at the beginning of the industry, from the experience of the Copts, who were excellent woodworkers.

This wood work was inherited by Copts from the ancient Egyptians who used the wood for their doors and to build the roofing of their houses. The growth of Mashrabiya construction continued during the Abbasid era (750-1258), especially during the time of the Ayyubid (1171-1250) (Figures 2.6 - 2.7).

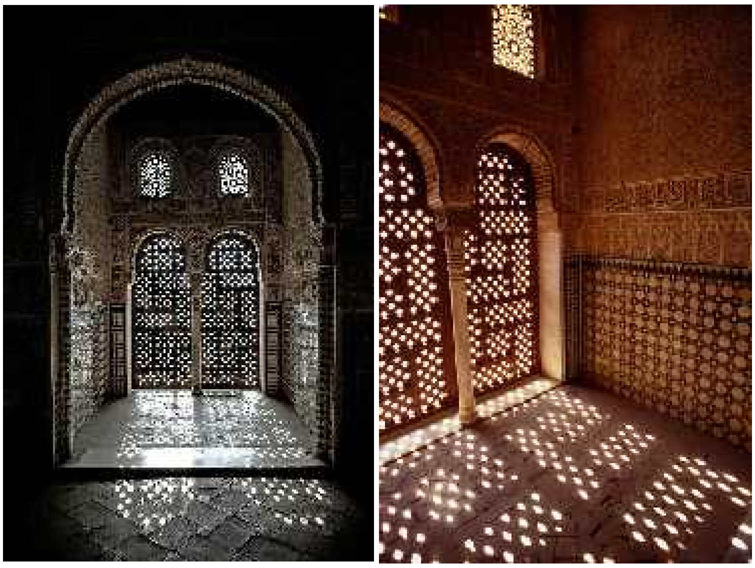


Figure 2.6: Two views of an amazing Mashrabiya in Alhambra palace in Granada, Spain (Hornsby, 2014)

Thereafter, during the Mamluk era (1250- 1517) the Mashrabiya industry grew and flourished artistically. The small screen openings, whether made of fine-turned wood or shading louvers with geometric shapes, allow the women to gaze outside and to be both unseen and unheard. If communication is required, most Mashrabiya, especially Egyptian ones, have smaller windows that can be opened upwards (Maspero, 1914).

Figure 2.7: Two Mashrabiyas with small windows that can be opened at Alsuhaimi House, in Cairo, Egypt (1648) (Kalpana, 2011)

The privacy requirement was a core value of the Islamic religion, so the Mashrabiya had widespread popularity throughout history, especially during the Islamic Ottoman era (1517- c1805) and it also continued later in various Arab regions, helping to adorn the streets, by giving it a beautiful artistic character (Maspero, 1974).

It should be mentioned that (Figures 2.8- 28) in this chapter are documented according to the chronology of the spread of Mashrabiya.

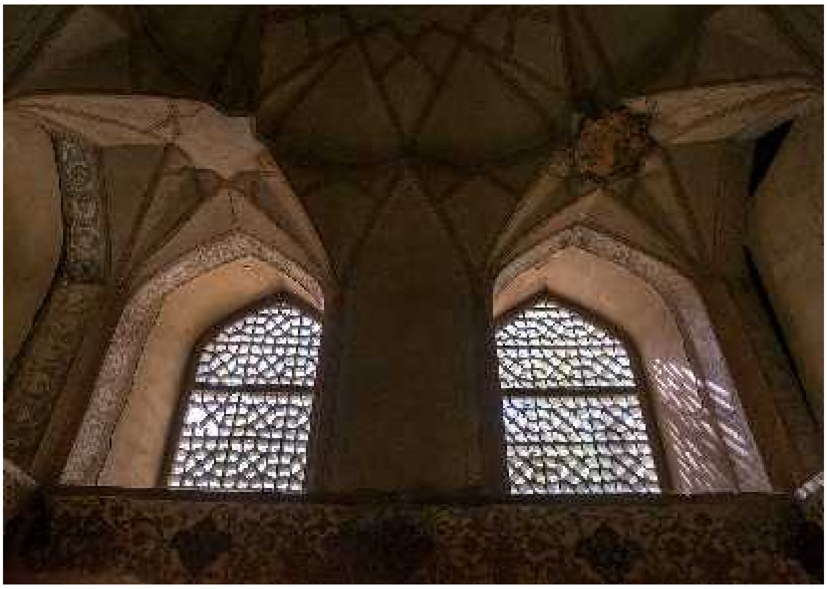


Figure 2.8: Mashrabiya at Hasht Behesht palace in Isfahan, Iran (1669) (http://www.akdn.org/architecture/project/ali-qapu-chehl-sotoun-hasht-behesht)

Figure 2.9: Mashrabiya in AlHrawi House (1731) in Cairo, Egypt (Ashi, 2011)

Figure 2.10: A painting shows the mashrabiya in Cairo (Vendedor de caballos) (Gérôme,1867)

Figure 2.11: Women behind Mashrabiya in a harem (Lewis, 1873)

Figure 2.12: An old image showing a street filled with Mashrabiyas in Cairo, Egypt (1860,1890) (https://tr.pinterest.com/eee7aaa/h-i-s-t-o-r-y/)

Figure 2.13: An old image showing a street filled with Mashrabiyas in AlQudis Jerusalem, Palestine (1900) (https://tr.pinterest.com/eee7aaa/h-i-s-t-o-r-y/)

Figure 2.14: Image of Mashrabiya overlooking the Courtyard of Camal Ed Din House in Cairo, Egypt (Landrock ,1910)

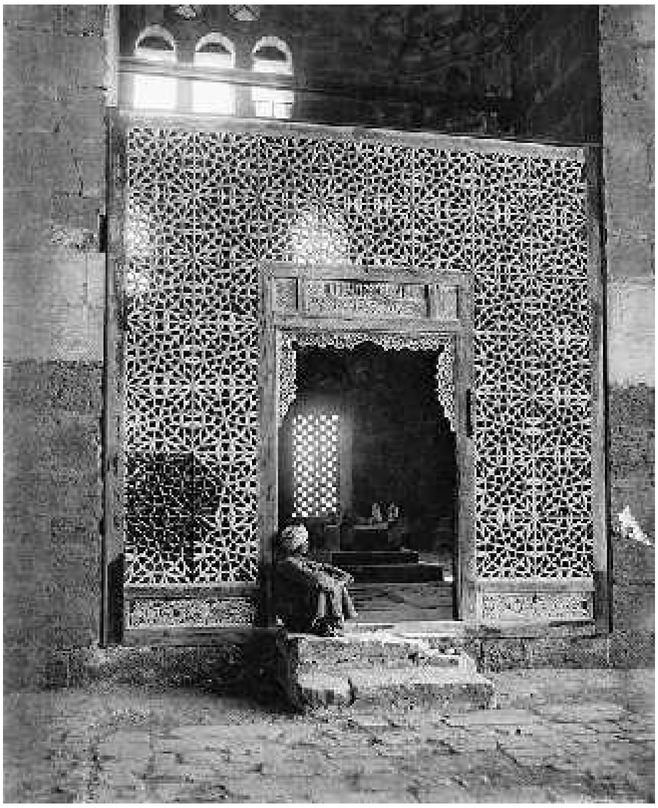


Figure 2.15: An old image showing the Mashrabiya in Faraj Ibn Berkuk Mosque, Cairo, Egypt in the 1920s (https://tr.pinterest.com/eee7aaa/h-i-s-t-o-r-y/)

Figure 2.16: Mashrabiyas beautifying the streets of Cairo, Egypt 1930's
(https://tr.pinterest.com/eee7aaa/h-i-s-t-o-r-y/)

Figure 2.17: Mashrabiya in Cairo, Egypt in late 19th century
(https://tr.pinterest.com/srshami/egypt-then-and-now/)

In the late 1900's entire Cairo street elevations were filled with Mashrabiyas, row upon row, level upon level (Feeney, 1974).

The spread of Mashrabiya was not confined to Egypt, but included Syria. Both countries had highly skilled woodworkers, especially in the use of finely turned wood, filled with Arabic and Islamic characters, and this soon spread to other countries (Dayyoub, 2001).

Figure 2.18: An old Mashrabiya in Damascus, Syria (Sretenova, 2013)

Subsequently this industry flourished in many Arab countries and the Islamic world as a whole, especially in the Arabian Gulf, in the architecture of Hijaz, Yanbu, Jeddah, Taif and Medina - Saudi Arabian cities where the Mashrabiyas are often found (Dayyoub, 2001).

Figure 2.19: An old image showing a street was crowded with Mashrabiyas in Jeddah, Saudi Arabia (1916) (https://tr.pinterest.com/eee7aaa/h-i-s-t-o-r-y/)

Figure 2.20: Image showing an ancient Mashrabiya in Bab elsharef, Jeddah, Saudi Arabia, in AlHijaz culture (1918) (https://tr.pinterest.com/eee7aaa/h-i-s-t-o-r-y/)

Figure 2.21: Image showing multiple, old Mashrabiyas in Makkah, Saudi Arabia (Khan, 2014)

Figure 2.22: Mashrabiya in Jeddah, Saudi Arabia
(http://www.saudicaves.com/gallery2001/oj08.jpg)

From the images of old Mashrabiyas in Saudi Arabia, one can observe that there is an extra layer surrounding the Mashrabiya, to increase the level of privacy required by the Saudi community.

Figure 2.23: Overcrowded Mashrabiyas in Jeddah, Saudi Arabia
(AramcoBrats, Inc., 2009)

Figure 2.24: An old residential quarter filled with Mashrabiyas in Jeddah Saudi Arabia 1979 (Lafforgue, 2010)

In Yemen, particularly Sana'a city and the surrounding area, Mashrabiya spread during the Ottoman era, therefore they were known as the Turkish windows (Figures 2.25- 2.26) (Dayyoub, 2001).

Figure 2.25: A derelict Mashrabiya in Zabid - Yemen (Lafforgue, 2010)

Figure 2.26: Another derelict Mashrabiya in Sana'a,Yemen (Lafforgue, 2010)

Mashrabiya also spread to the cities of Jerusalem, Tripoli in Lebanon, in Sudan, Iraq and in the Maghreb countries, as well as to India, Pakistan, Iran and Spain (Dayyoub, 2001). Some countries still preserve the heritage of Mashrabiyas, possibly due to the income generated by tourism; places like, the Maghreb countries, Egypt, Pakistan, India and Spain. On the other hand, there are some countries who neglect the Mashrabiya heritage, for example: Saudi Arabia, and some countries which have lost their valuable heritage due to wars, like Syria and Iraq (Figures 2.27- 2.39).

Figure 2.27: A luxurious Mashrabiya showing beautiful, complex patterns and decoration at Omar Hayat Palace in Chiniot, Pakistan (1935) (Niazi, 2015)

Figure 2.28: A façade of the Amber fort courtyard in Jaipur Rajasthan, India (1614) (https://en.wikipedia.org/wiki/File:Amer_Fort_Entrance.jpg)

Figure 2.29: An amazing marble Mashrabiya at the Amber Palace,in Jaipur Rajasthan India, 1614 (Moffatt, 2015)

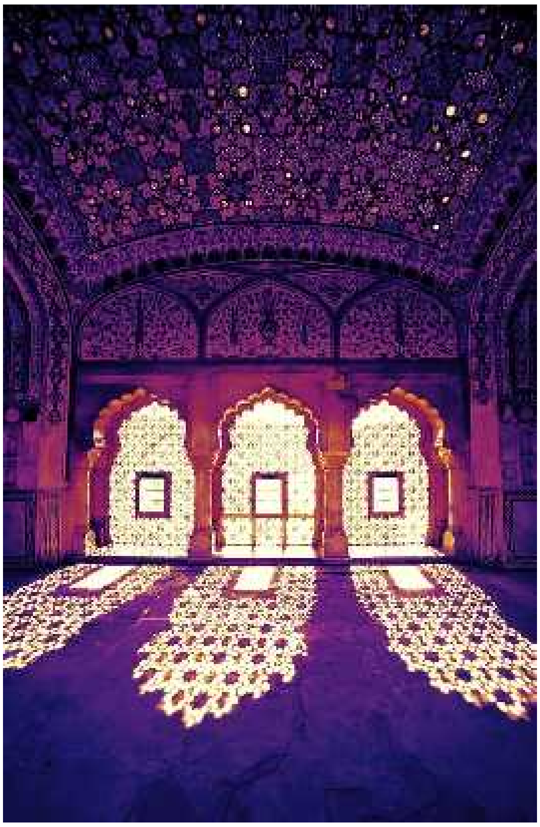


Figure 2.30: Picturesque image of an interior with Mashrabiya at Amber Palace, Rajasthan, India 1614 (Drishti, 2015)

Figure 2.31: Mashrabiya in Chiniot, Pakistan (Niazi, 2014)

Figure 2.32: Mashrabiyas in Punakha Dzong, Bhutan (Chandramowli, 2015)

Figure 2.33: A blue Mashrabiya with beautiful details in Nabeul, Tunis
(Sergio, 2015)

The architecture in Maghreb countries is distinguished by the use of the color blue, which draws the attention of tourists, and the attention of governments to preserve the deep-rooted Arab architecture. Mashrabiyas in these countries are still being rescued today.

Figure 2.34: Blue Mashrabiya in Morocco (Sweeney, 2015)

Figure 2.35: Mashrabiya dating back to 1922 in Plaza Mayor, Lima, Peru (Fotos, 2007)

Figure 2.36: Image of Mashrabiya in Plaza Mayor, Lima, Peru (1922) (Dmitry, 2012)

Figure 2.37: Shanshol in Basra, Iraq (Mohsen, 2014)

In Iraq, many houses have been abandoned and precious antiquities stolen. The Shanshol, as well as many other architectural features, has also been affected by the war.

Figure 2.38: A painting of a Turkish house with Mashrabiya (Cumba) in Istanbul, Turkey (http://www.allposters.com/-sp/Turkish-House-with-Cumba-Posters_i6835244_.htm?ac=true)

Figure 2.39: Very old Mashrabiya in Massawa, Eritrea (Lafforgue, 2010)

“ Mashrabiya is shrewdly designed, it not only subdued the strong desert sunlight but also cooled houses, water and people in lands from India to Spain where, at certain times of the year, people hide from the sun as others seek shelter from rain.” (Feeney, 1974) (Figure 2.40).

Figure 2.40: The spread of Mashrabiya between 868 and the late 19th century (Alothman, 2016)

2.4 Common Traditional Places for Mashrabiya

- Façades of traditional houses (Figures 2.41- 2.42).
- Mosques (Figure 2.43).
- Semi-public buildings like : agencies and caravansaries (Figure 2.44).
- Tombs (Figure 2.45) (Feeny,1974).
- Partition in interior design between rooms to increase ventilation from more than one side of the house, as seen in Jeddah, Saudi Arabia (Fathy, 1986).

> " Mashrabiyas were introduced into mosques too, often on a much larger scale, but serving the same purpose: filtering the intense sunlight flooding into the traditional courtyard and providing a cool shaded interior conducive to prayer and meditation. Others were created for large semi-public buildings like the wakalah, or caravansary, of el-Ghori, built in the 16th century to accommodate merchants coming into Cairo with caravans from the Red Sea. But the best examples were found in the great homes of Cairo, homes like el-Kretiliya, hard against the ninth-century walls of Ibn Tulun's great mosque, and el-Seheimy house, built in 1645." (Feeney, 1974) (Figure 2.46).

Figure 2.41: Mashrabiyas in Harem Room, Gayer Anderson House, Cairo, Egypt (Alothman, 2016)

Figure 2.42: Mashrabiyas on the terrace of Gayer Anderson House, Egypt (Alothman, 2016)

Figure 2.43: Mashrabiya in Faraj Ibn Berkuk Mosque, Cairo, Egypt (Alothman, 2016)

Figure 2.44: Mashrabiyas of Bazara Wakala in Cairo, Egypt (Alothman, 2016)

Figure 2.45: Tomb of Salim Chishti in India (Fatehpur, 2010)

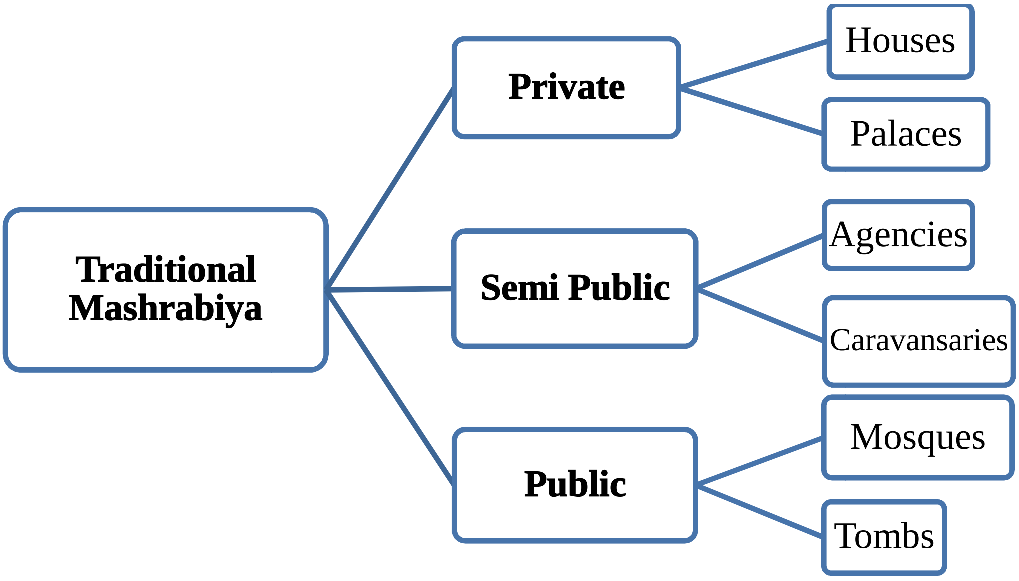


Figure 2.46: Common traditional places for Mashrabiya (Alothman, 2016)

2.5 Decline of the Mashrabiya

In the early 20 century Mashrabiyas started to decline in use due to many factors . For example, the result of cursory modernization, the growth of globalization, and the abandonment of vernacular traditions. Concurrent with this was a changing economic structure, which was born of the industrial revolution that made small craft-based manufacturing redundant. Therefore the reasons behind the decline in use of the Mashrabiya are twofold: due to both cultural and practical influences (Akbar, 1994) (Figure 2.47) .

Figure 2.47: The reasons for the decline in use of the Mashrabiya (Alothman, 2016)

2.5.1 Cultural

> ".. with the rapid growth of Europe and America in the 19th and 20th Centuries it became important for the slow developing economies of the Middle East to adopt the modern appearance of western values and, as such, architecture. " (Kenzari and Elsheshtawy, 2003).

Therefore architectural elements such as the Mashrabiya came to be considered as antiquated, too decorative, too expensive, and hampering the growth of the Arab economy at that time. Additionally the increase in globalization led to decline of Mashrabiyas, because the new technologies and styles of globalization, were encouraging simplicity and the avoidance of complex façades or decoration, both of which conflicted with the design and construction of Mashrabiyas (Figure 2.48).

> "It was symbolic because the image of villas and apartments was modern and thus, if the [Mashrabiya] was fixed on a villa or apartment, the modern image which people were keen to express would be distorted." (Akbar, 1994).

Figure 2.48: Egypt in the early 20 century (https://soundslikewish.com/tag/egypt/page/4/)

2.5.2 Practical

The industrial revolution of the 19^{th} century led to major economic changes which made traditional architecture financially unviable, so the Mashrabiya was considered labor-intensive, incredibly time-consuming and expensive. Consequently, architects were forced to avoid using the Mashrabiya due to its high costs. Air conditioners were used to replace them, but were unable to operate with the same efficiency as the Mashrabiya, especially in the hot, desert climate.

As a result of the Mashrabiya achieving widespread popularity around the old world for many decades, its construction flourished, especially in Egypt due to the arabesque design and woodwork being so popular in ancient times. Mashrabiya did not provide only a decorative and aesthetic element, but also it was designed to perform many environmental functions like adjustment of lighting, humidity and air flow control, reducing the heat, and playing an essential role in securing privacy. The next chapter will study all these functions and parameters of design, in addition it will expound the importance of commitment to the proper criteria of Mashrabiya, in order to fully exploit its functions.

CHAPTER 3

THE FUNCTIONS, PATTERNS AND PARAMETERS OF MASHRABIYA

As previously explained, the Mashrabiya has an inherent history, but this does not mean that it is just a culturally decorative element. It has also many important functions that helped to find solutions to contemporary variables and become a significant environmental element with design criteria and determined parameters of its own.

There are many available and valuable research studies about Mashrabiya, but none of them is thorough enough, and in general, all of them were written based on the theories of Hasan Fathy. As mentioned in the introduction, most of Fathy's ideas were summarized in four pages of his book (Natural Energies and Vernacular Architecture in 1986) where every line in those four pages was like a fact that Fathy related to Mashrabiya. As a result, William Samuels (2011) needed to expand the explanation of those ideas during his project in the Gibson Desert, in order to explore a number of rules and mathematical formulae for the optimal design of Mashrabiya lattice work.

Samuels, in his studies, achieved an important shift which had not been possible before, concerning the production of hybrid parameters of Mashrabiya by using CIM and CNC technology. But some problems lie in the sequence of subject presentation in Samuels's thesis, by going into details on some points at the expense of others, and by the description of the functions in a repetitive manner. So, for example, in the explanation of the issue of heat adjustment, the reader would have to proactively read about humidity and air flow control, then he would have to go back to review some points about direct light and then finally focus on the explanation of the heat setting, all the while going backwards and forwards trying to cross check a sentence, then read that chapter and again read that paragraph.

Therefore, even if the following chapter does depend on the ideas put forward by Fathy and Samuels, it has been rewritten to include all their points but offers them in a simple, obvious and comprehensive way that can help foreign architects and Arab junior architecture students. This is done by providing logically sequenced explanations, which do not confuse the functions, and takes into consideration that none of the modern projects successfully exploit all of the functions of Mashrabiya.

The fact that each function affects the other is true, but to accomplish full comprehension of Mashrabiya functions, each one has to be understood in a clear and simple manner. In addition, any evaluation of architectural projects needs to be based on strong scientific sources and provide a convincing background concerning design parameters and the importance of the mechanism used to implement the functions. As previously stated, these issues are often found as headlines in a lot of research studies, but the disappointment is that sometimes they remain simply as headlines, without a brief and coherent explanation.

3.1 Functions of Mashrabiya

The history of Mashrabiya is an important fact, but it cannot alone explain why the Mashrabiya became so widespread. Therefore it is necessary to know and study the role and functions of Mashrabiya within buildings.

Fathy asserted (in 1986) that Mashrabiya has, in general, five functions, and many models of these have been developed to describe ways of coping with the different conditions affecting one or more of these functions. The main functions are :

1 - Light Control. 2 – Airflow Regulation. 3 - Humidity Control. 4 - Temperature Regulation. 5 - Visual Privacy.

In addition, there are also the aesthetic, social and spatiality properties of the Mashrabiya which cannot be overlooked (Figure 3.1).

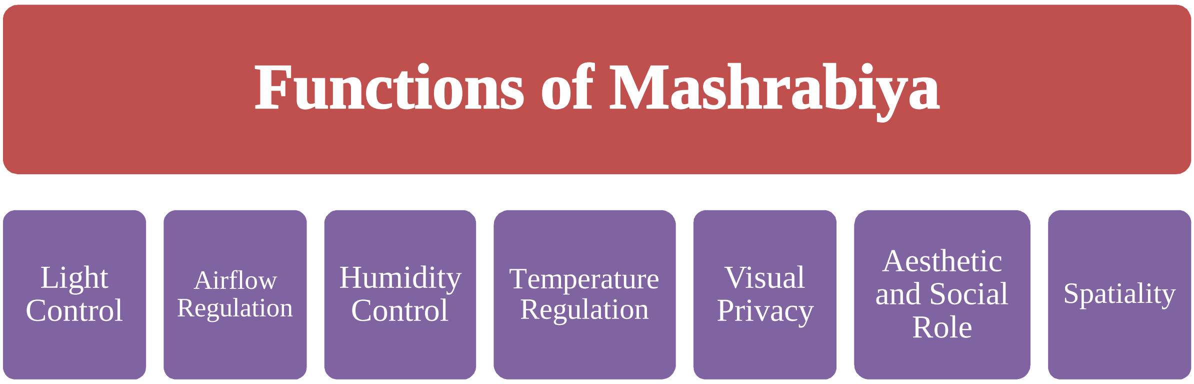


Figure 3.1: Functions of Mashrabiya (Alothman, 2016)

Fathy accepted wooden lattice as Mashrabiya, if it was able to provide some or all of these functions. He also suggested that to achieve any function, there are terms of design concerning the choice of the distances between adjacent balusters and the radius of each of them. According to the different designs, there are many models of Mashrabiya that are known by different names.

3.1.1 Light control

Natural light is one of the most important matters in architecture, as Louis Kahn described a room is not a room without natural light. But it is not only advantageous; there are three issues that need to be controlled:

- The heating caused by direct solar gain.
- The internal daylighting requirements.
- The visual qualities of light, such as glare.

There are three types of daylight:
1- Direct light
2- Diffuse skylight
3- Reflected glare
Mashrabiya can effectively deal with these three kinds and solve the problems by changing the light from something harsh and undesirable to a highly favorable and lovely feature of internal space. And it should be mentioned that the effect of internal daylight varies depending on the direction, for example it is preferable to block direct light entering from the southern openings, because it causes the surfaces to heat up inside the room, even though the glare from this direction does not cause any heat, it can cause an optical inconvenience (Figure 3.2).
Openings from the north do not cause any problems. Accordingly, the design of Mashrabiya with a south façade differs noticeably from the design in a northerly one. A Mashrabiya with a carefully calculated design is able to adjust exactly to what type of light should enter the building (Figure 3.3).

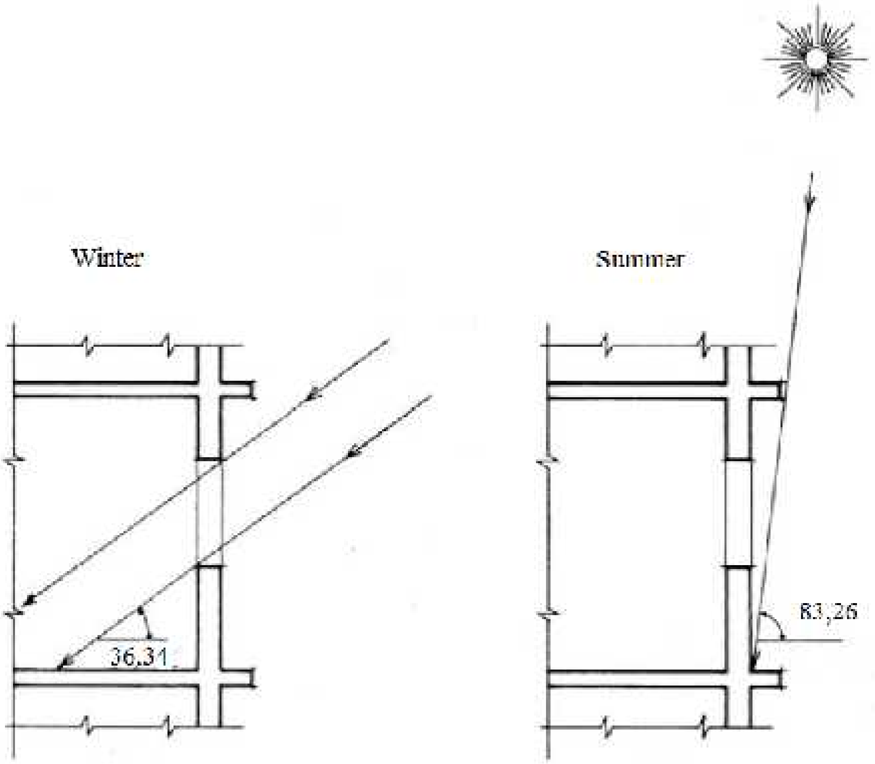


Figure 3.2: The angle of the sun above the horizon at noon (Southern Façade) (Fathy, 1986)

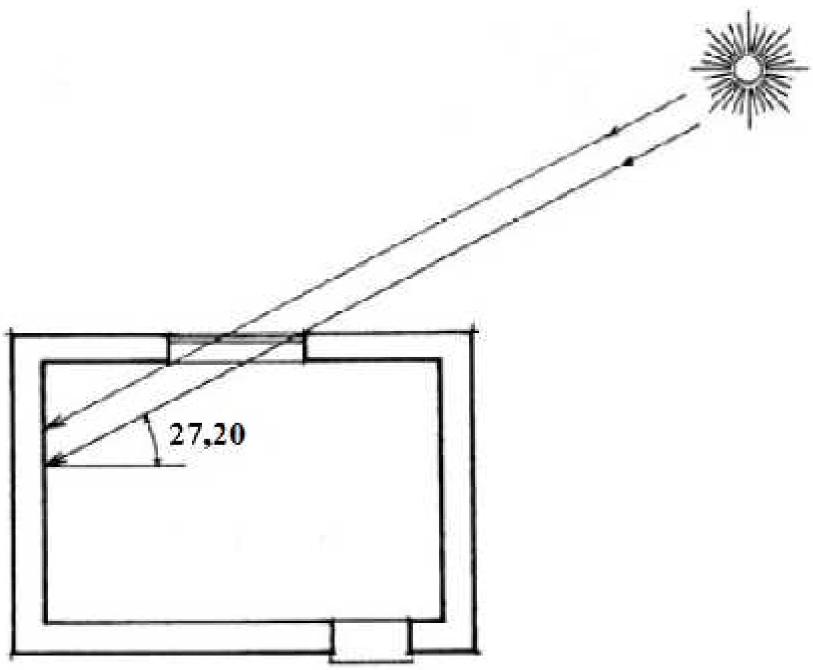


Figure 3.3: A plan of a room facing North, and the angle of the sun's rays falling from the North is 27, 20° (Fathy, 1986)

3.1.1.1 Direct light

Direct light is intensified light, which has an acute angle falling on the surface of the aperture level (Fathy, 1986). Mashrabiya is able to control when and how much direct daylight could enter the building during summer or winter according to the parameters of Mashrabiya design which the architect determines. It blocks the troublesome sun, decreases internal heat gain during summer and allows for a small amount of light to enter during winter (Figure 3.4).

Figure 3.4: Oriel Mashrabiya Room at Prince Mohammed Ali Tewfik Palace, in Cairo, Egypt (1899 - 1929) (Andrew, 2016)

According to Fathy’s principles (1986), this requires a lattice with small interval distances between the balusters at eye level, in order to prevent direct light in summer. While in winter it works in the opposite way, when the sun’s angle is lower in the sky and can pass through the interstices of the same Mashrabiya, and provide some warmth to the room . To compensate for the decrease in the amount of lighting in this design, it is preferable that the spaces between the balusters are made much wider in the upper parts of the façade, as shown in the example which is taken from Jamal al-Din alZahabi’s house in Cairo, Egypt Figure (3.5).

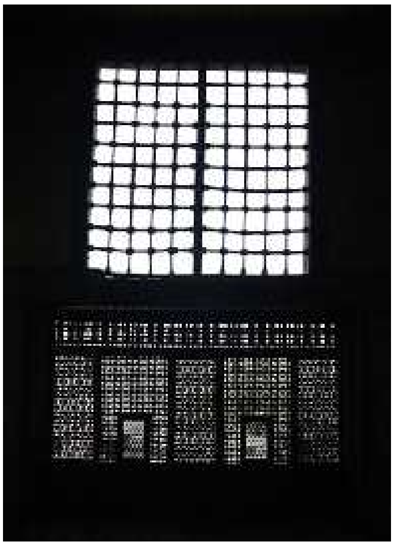


Figure 3.5: Mashrabiya at Jamal al-Din alZahabi’s house in Cairo, Egypt (Maher, 2015)

It is possible to install a small sunshade above the aperture to prevent direct sunlight from entering (Figure 3.6).

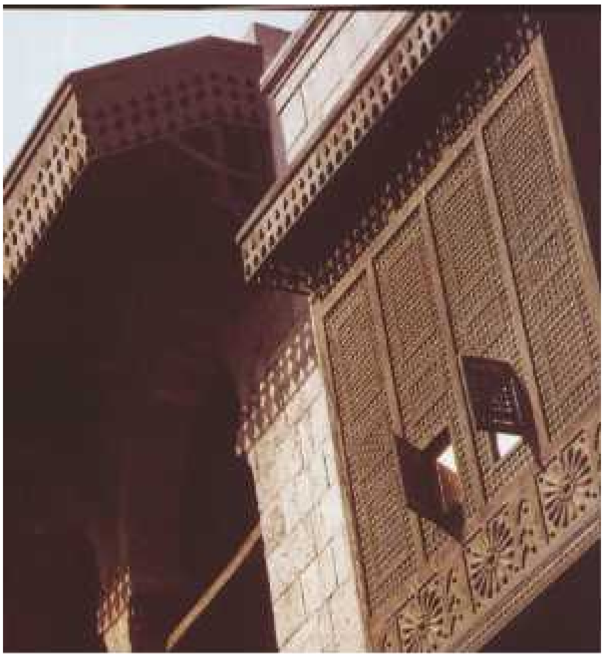


Figure 3.6: External view of Mashrabiya on the third floor of Suhaimi house in Cairo shows the prominent sunshade above (Fathy, 1986)

In north interfaces, where direct sunlight does not cause any problems, Fathy always preferred to make the separation distances between balusters wider, to provide adequate light for rooms.

3.1.1.2 Diffuse skylight

It is the required adequate daylighting which the internal spaces need to allow for regular activities, and it is essential in hot climates to create good internal situations without being bothered by excessive heat gain.

Even if we need to block direct sunlight in the troublesome times, we still need enough natural internal light for regular, daily activities. Mashrabiya is an important element that allows ambient light to pass into spaces without letting in direct sunlight. The quantity of diffuse skylight that goes into a room relies primarily on the important parameters that control how much ambient light can enter the building. These parameters, according to Samuels (2011) are: the size and porosity of the Mashrabiya, along with the reflectivity and materiality of the balusters.

3.1.1.3 Glare

It is less intense light and enters almost perpendicularly on the surface of aperture level (Fathy, 1986). Glare doesn't raise the temperature of the room, but it causes an optical inconvenience. To solve this problem Mashrabiya is one of the best effective choices. In this case the architect have to choose a Mashrabiya with a circular section for the balusters as a main condition.

> "The balusters, round in section, graduate the light reaching their surfaces, thus softening the contrast between the darkness of the opaque balusters and the brightness of the glare entering through the interstices... Therefore, with the Mashrabiya the eye is not dazzled by the contrast as in the case of the brise-soleil." (Fathy, 1986).

That means the gradual shadow which is created by rounded blusters, reduces any contrast, unlike the square sectional balusters, or any other similar shading devices.

This is a common mistake, which is repeated in some modern projects which use the Mashrabiya without taking into account this important condition, especially when using steel material in the construction of Mashrabiya (Figure 3.7).

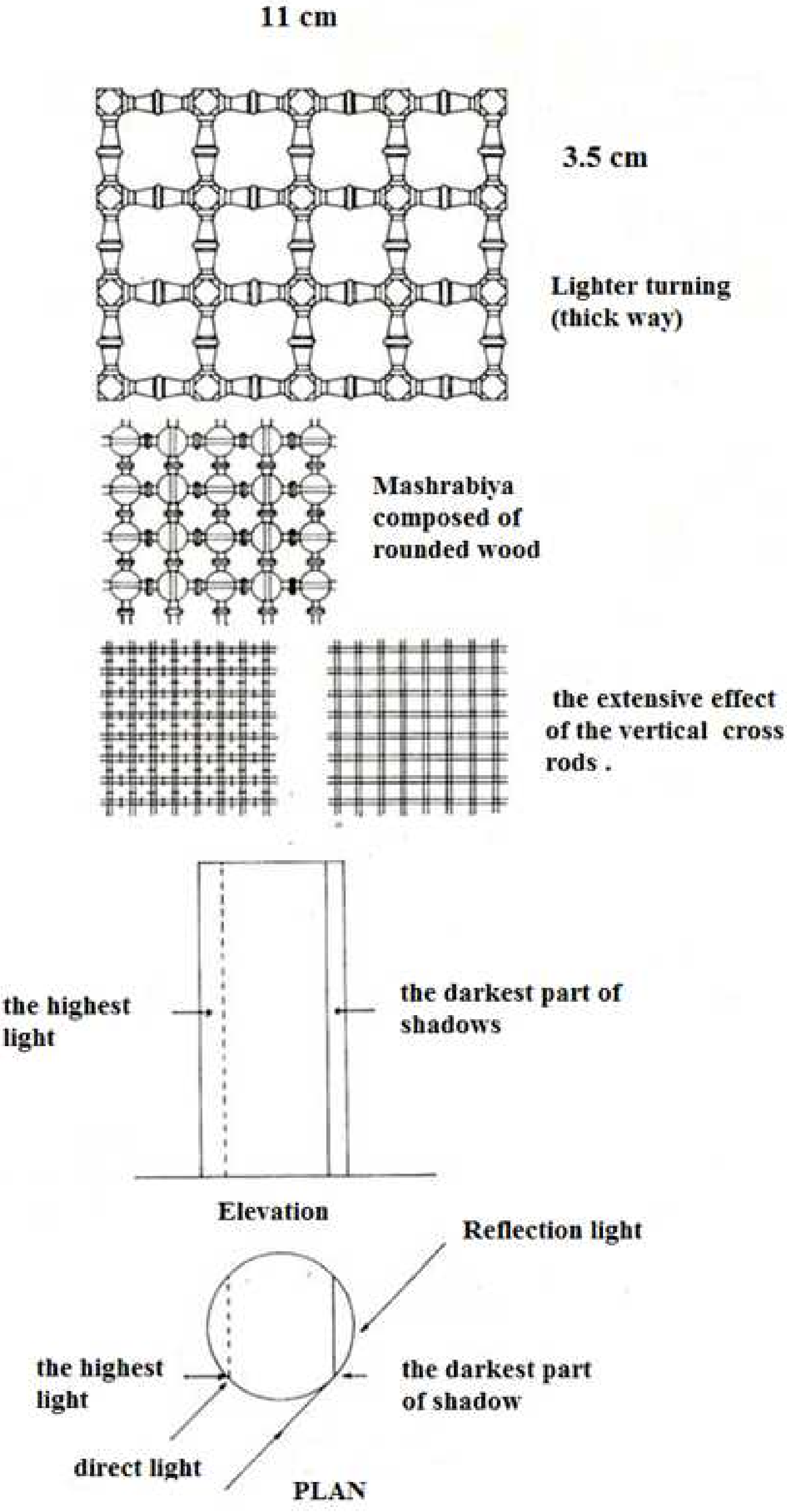


Figure 3.7: Analysis of the light falling on the Mashrabiya (Fathy, 1986)

Figure 3.8 shows the impact of Mashrabiya if there is a bright light, and how it produces a shaded image which moves the eye between the rods through spacing, horizontally and vertically, thereby invalidating the slashing effect which is caused by the flat slats used in brise-soleil Figure (3.9). Fathy (1986) also saw that Mashrabiya excelled in other types of window by working on matching the external views harmoniously through the full aperture, above the decorative pattern to the Mashrabiya, so Mashrabiya becomes like a piece of dark glass which is woven by ‘threads’ (Figure 3.10). In this way the view beyond is exposed, while maintaining privacy without any of the heat gain problems previously discussed.

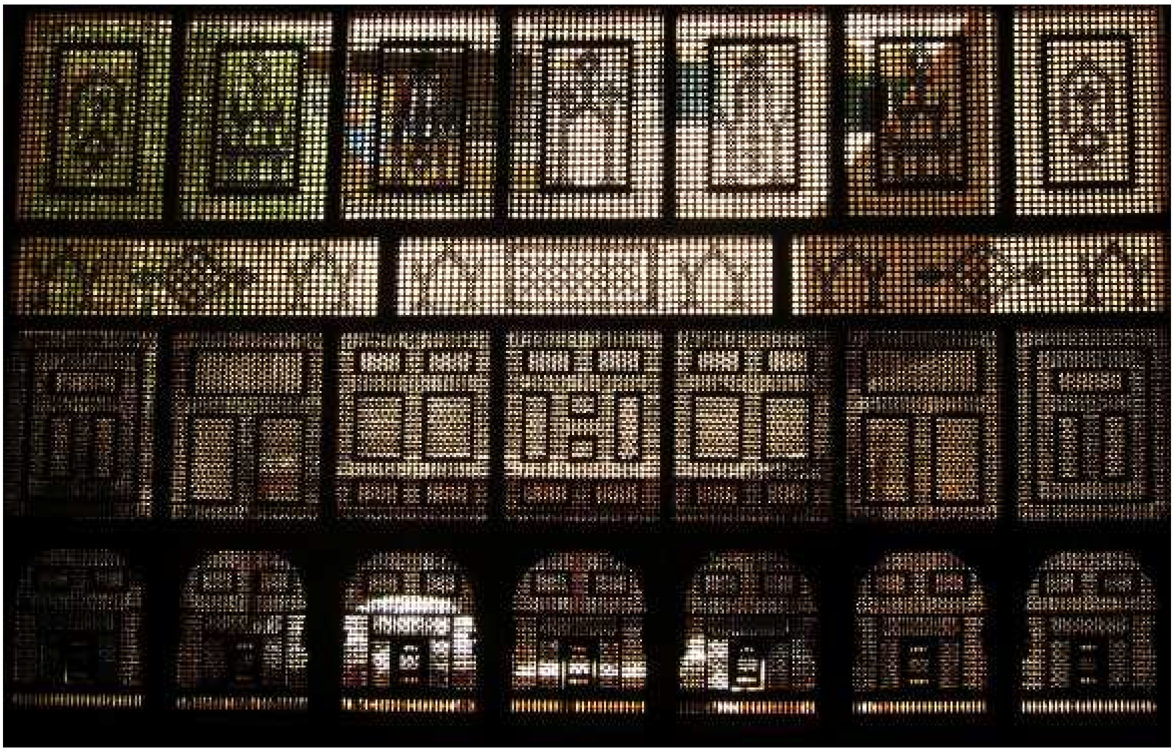


Figure 3.8: An interior view of Mashrabiya at al-Suhaymi House in Cairo, Egypt (Tolba, 2011)

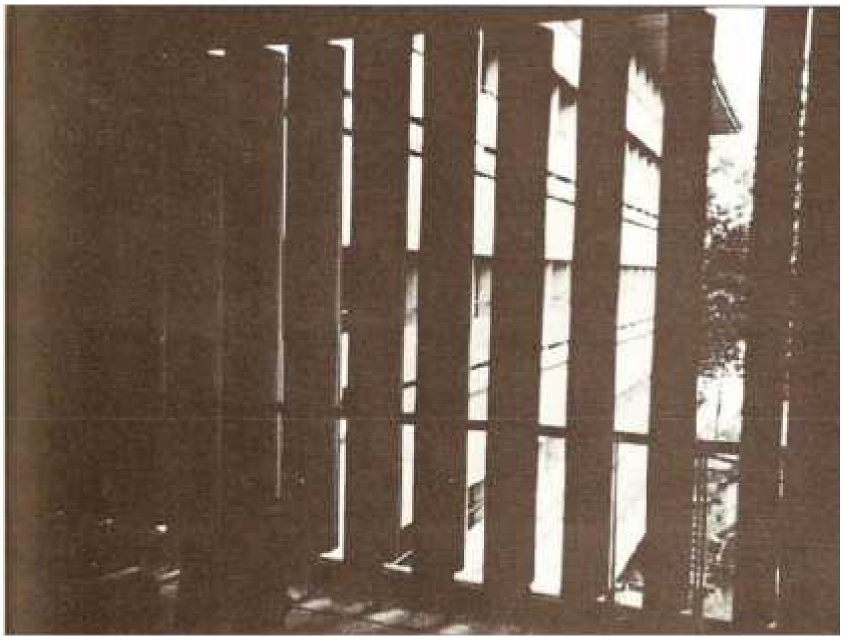


Figure 3.9: The Brise- Soliel in Boike - Cote d'Ivoire (Fathy, 1986)

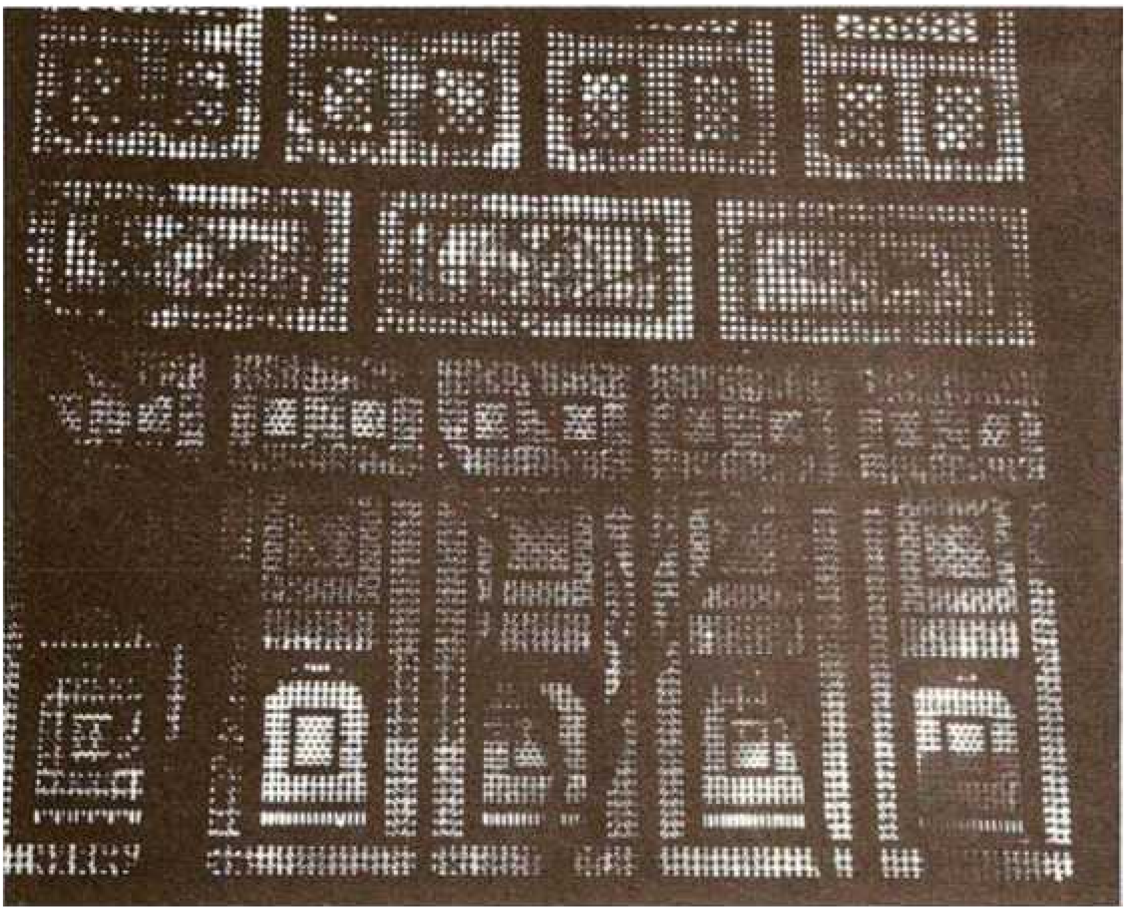


Figure 3.10: Mashrabiya at al Suhaimi House clearly shows the tree behind it (Fathy, 1986)

3.1.2 Airflow regulation

Evaporation is one of the most important techniques used to cool buildings in hot climates, and to make this process continuous and effective, the airflow needs to be strong enough to carry the released water vapor away, and thus provide heat transfer.
On this point it is important that buildings in harsh climates have a steady and uninterrupted internal airflow, so it is necessary to fully understand the effect of the design and the size of Mashrabiya. Further points concerning ventilation; Mashrabiya is used to ensure air circulation inside the building, air is pulled into the room through the small interstices of the Mashrabiya in the lower part and hot air is ejected out through the large interstices of the upper part. This technique not only enhances the air circulation but also speeds it into other indoor rooms.

When the temperature of the air diminishes, its size decreases, per contra the weight and density of it increase. The output rise in the air pressure drives the air to blow into the internal spaces through the small interstices. As the air temperature increases, the size of air increases also, while its weight and density decrease, therefore low pressure makes the air move upwards and out of through the large interstices in the upper part of the Mashrabiya. It is worth mentioning that the rounded surfaces of the latticework of Mashrabiya provide a smooth airflow. For the winter and in cold climates, the Mashrabiya can be prepared with glass shutters and solid wood (Lane, 1977).

To get more airflow, different pressures may be created between the inside and outside of the building, by openings on opposite walls of the room. The size of these openings and the porosity of the Mashrabiyas which enclose them are the decisive factors in the flow rate between the two. If the interstices constitute 80% of the total Mashrabiya area (Porosity Factor [PF or φ] = 0.8) then the airflow through the opening will be at 80% of what it would have been with no Mashrabiya in place (Gandemer and Alain, 1981).

A Mashrabiya with large interstices provides adequate airflow, when considerations relating to the light require narrow interstices and thus impedes sufficient air flow, in this case the architect can use the large open interstices pattern of Mashrabiya in the upper part, near the overhang, or increase the size of Mashrabiya, even to the point of covering the entire elevation of the room (Figure 3.11).

Sometimes the Mashrabiya was used by Fathy in interior design, between rooms, to supply the ventilation from more than one side of the building.

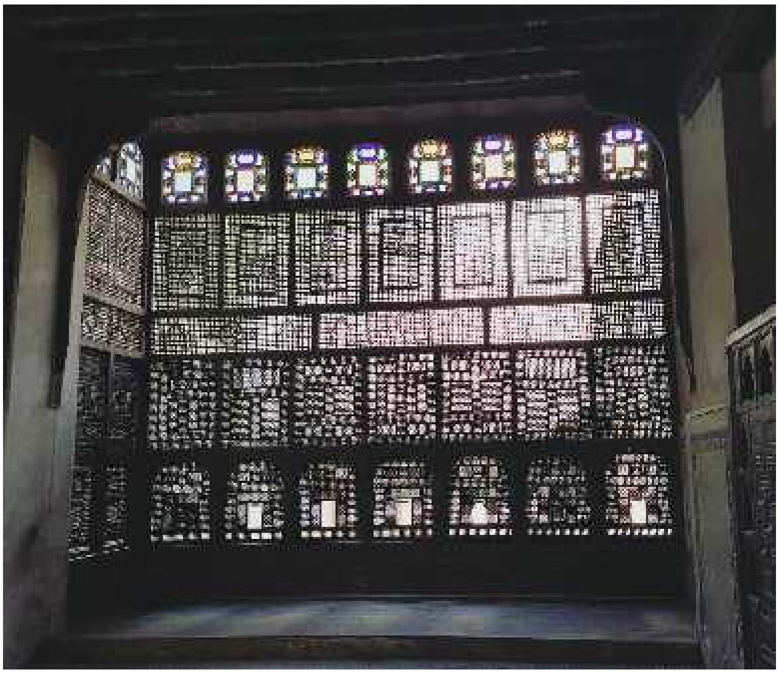


Figure 3.11: An old Mashrabiya at Al Suhaymi House in Cairo, Egypt (Marawan, 2016)

3.1.3 Humidity control

The air which passes through the wooden Mashrabiya, loses some of its humidity by the absorption property of the wooden balusters; if they are cold, as usual at night, and when the Mashrabiya is heated by direct sunlight, this humidity is absorbed by the air which flows through the porous wooden Mashrabiya (Figure 3.12). This technique is efficient in making dry air more moist in the heat of the day, humidifying and cooling it at a time when most needed.

> "The balusters and interstices of the Mashrabiya have optimal absolute and relative sizes that are based on the area of surfaces exposed to the air and the rate of at which the air passes through. Thus if the surface area is increased by increasing baluster size, the cooling and humidification are increased. Furthermore, a larger baluster has not only more surface area to absorb water vapor and serve as a surface for evaporation but also more volume, which means that it has more capacity and will therefore release the water for evaporation over a longer period of time." (Fathy, 1986).

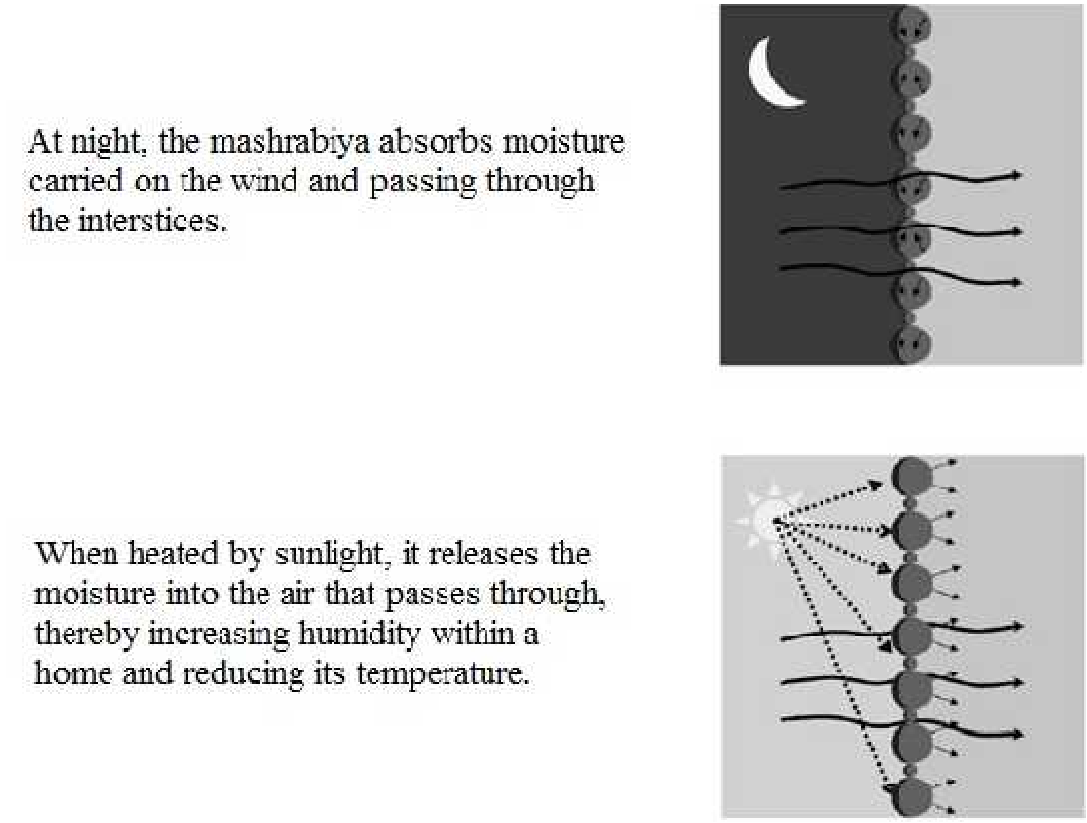


Figure 3.12: The cooling effect of Mashrabiya through the evapo-transpiration process (Fathy,1986, illustration by Gelil, 2014)

With regard to the foregoing, it should shed light on the importance of the wood chosen for the construction of Mashrabiya, and take into account that new alternative materials should have properties which are more or less similar to wood, in relation to absorption and evaporation matters.

For additional cooling by evaporation, the water jar can be used, placed behind the lattice of Mashrabiya, where the air flow gets cooled due to the evaporation of water from the jars, this process is known as evaporative cooling (Briggs, 1974) (Figure 3.13).

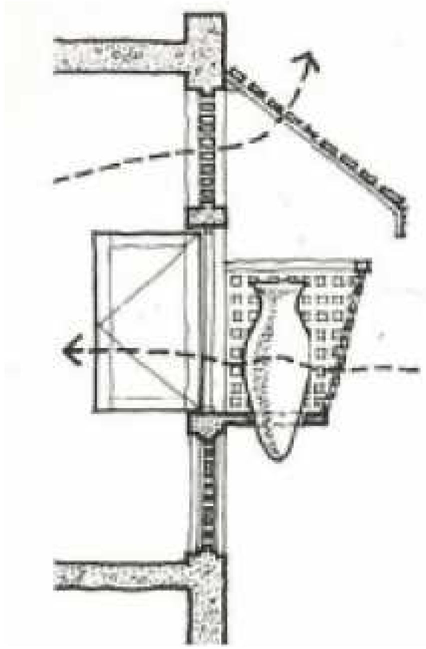


Figure 3.13: A porous clay water jar used to cool the air as it passes through the Mashrabiya and into the building behind (Ashi, 2010)

3.1.4 Temperature regulation

There are many recognized ways to adjust the temperature of buildings, like using walls with large sections and a high thermal inertia, shading the interiors, designing small apertures, and a smart combination of architectural elements that work together to reduce heat gains and create a perfect internal environment (Dayyoub, 2001).

We are all aware that direct sunlight is the reason for high temperatures, and the Mashrabiya limits the solar gain by shading the inner spaces during the hot summer months, but is able to supply some heat in the cooler months of the year, by allowing direct daylight to enter the building during winter. The cooling and heating processes rely on specific features of the lattice in terms of its sizing and porosity; a more porous lattice will allow for more direct light in the cold days but also raise the airflow through the space, and change the capacity of the evaporative cooling systems.

So it is important to fully understand each function separately, to determine the effects each have on the others, and how all of them work together to create comfortable thermal and visual conditions for internal spaces.

3.1.5 Visual privacy

As mentioned in chapter two, the widespread popularity of Mashrabiya in Islamic countries could be attributed to the visual privacy factor. Mashrabiya provides privacy for occupants from the outside, while allowing them, at the same time, to look out through the lattice. If the Mashrabiya is overlooking the street the distances between the balusters are preferably small at eye level, except for the upper part above eye level.

Figures 3.14 and 3.15 show an excellent example of how Mashrabiya can provide a view to the outside without losing the privacy factor which gives the resident a feeling of reassurance, as Fathy (1986) showed by focusing on the lattice, the Mashrabiya seems like a lighted wall, conversely, with the focus beyond the lattice, the external view is fully obvious, and only slightly obscured.

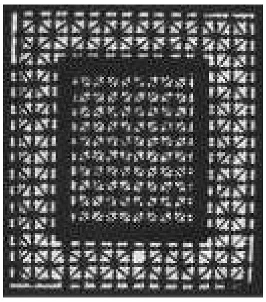


Figure 3.14: The focus is placed upon the individual balusters of a Mashrabiya in alSuhaimi House, creating a visual barrier in Cairo (Fathy, 1986)

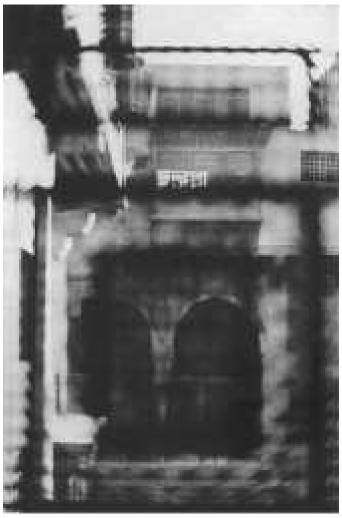


Figure 3.15: The same Mashrabiya but viewed from the inside and with the focus being placed upon the brightly lit external courtyard, becoming almost transparent as a result (Fathy, 1986)

This is an important feature of the Mashrabiya, but it is no longer possible when glazed windows are used, as they block the connection between internal spaces and outdoors.

3.1.6 Aesthetic and social role

The different patterns of Mashrabiya imbued life and vibrancy to the façades of traditional buildings which were previously extremely bare and gave a solid and harsh impression due to the heavy walls (Figure 3.16).

Figure 3.16: A Painting titled "Streets of Cairo" by the architect Owen Browne Carter, which shows the Mashrabiya in 1800's (https://tr.pinterest.com/pin/322288917055712886/)

The more complicated and detailed the Mashrabiya is, the more expensive it is; that is why it became highly desirable as a symbol of wealth. In this way the decorative features of the Mashrabiya became something of a social statement. Additionally, it should not be ignored that the Mashrabiya is an important expression of Eastern identity.

3.1.7 Spatiality

The traditional Mashrabiya provides an important property of being directional or maintaining a configuration, conformation, contour, form, shape and any spatial attributes (especially as defined by outline) to create a space which can be used for many functions as mentioned before, like a seat for the ladies to overlook outside , or to put a jar of water to get cool.

3.2 Design of Mashrabiya

Fathy (1986) pointed out that the name Mashrabiya previously was given to the prominent space enclosed by a lattice opening. Then it became used for the wooden lattice screen itself, made of small wooden rounded balusters that are coordinated at specific, regular intervals.

Gelil and Ali (2014) based on Fathy projects and Lane Edward Said's written representation (1977) gave a description of a typical design of Mashrabiya that consists of (Figure 3.17):

1. The main opening of Mashrabiya, which is composed of two parts:

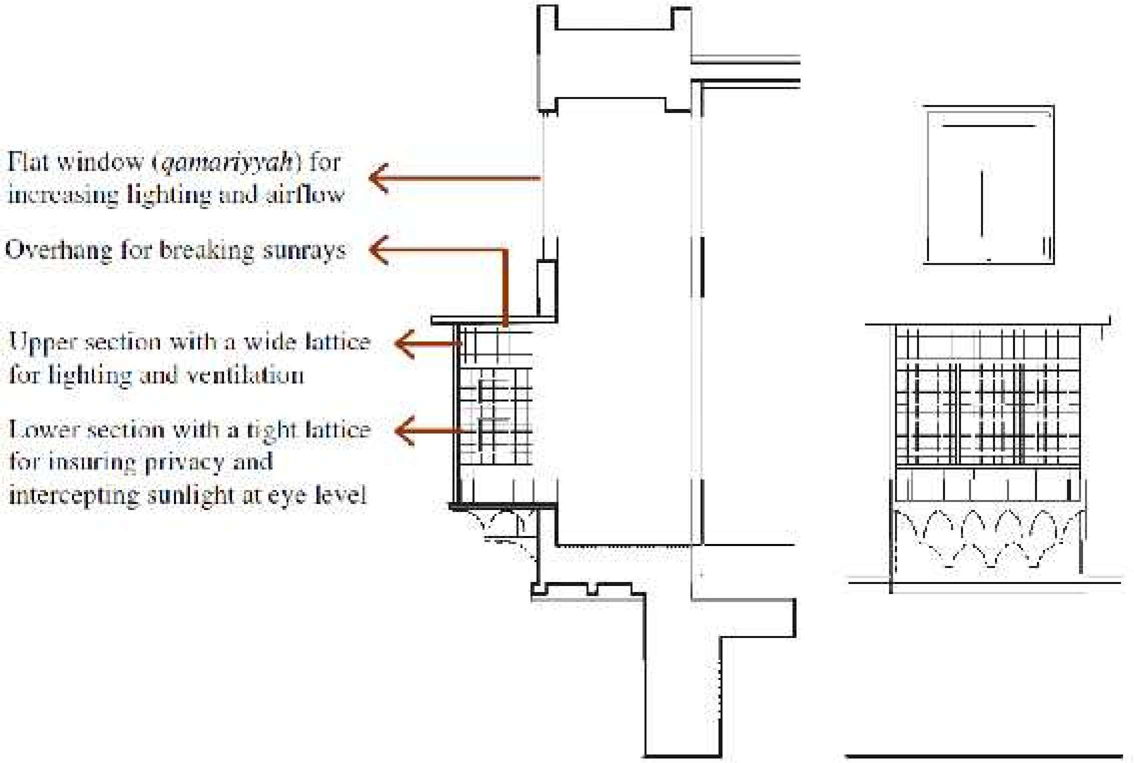
- A lower part below eye level with fine engraved balusters in a tight mesh pattern.
- An upper part above eye level filled with a more open mesh grill of engraved wood in a pattern called (Sahrigi) (Cistern turnery). The former enhances privacy and restricts the direct sunlight as mentioned before, and the latter insures the required airflow and lighting.

2. An overhang is located directly above the main opening to block the intense sunrays, which are prevented from passing through the wide upper part.

3. A flat window above the overhang is called the *qamariyyah*, and it is made of latticework of a wide pattern, made of wood, or stucco, and often filled with colored glass, this part was added to supply more light or airflow, in case the Mashrabiya was not able to provide enough.

(a) External View of a typical mashrabiyya in Zaynab Khatun House.

(b) Internal View of a typical mashrabiyya in Zaynab Khatun House.



(c) Illustration section of a typical Mashrabiya

Figure 3.17: A typical Mashrabiya in the Northern qa'a of Zaynab Khatun House (Gelil, 2014)

Mashrabiya also had additions of some or all of the following:

- Small niches extending out from the main lattice frame to hold drinking water jars (Fathy, 1986).
- Sliding or hinged parts in the main fixed lattice panels which could be opened for more ventilation and lighting (Lamei et al. 1996).
- Internal protecting glass to avoid dust or excessive coolness (Lane, 1977).
- External wooden shutters for more security and privacy.

> “In addition, while preserving its role, mashrabiyya’s typical form varied according to the household’s social class, the function of the space, and the orientation of the façade. For instance, mashrabiyya in lower class housing, or the less important spaces in a private house, were often without the upper window; and hanging shutters opening upwards replaced the fine latticework of the lower part. The façade’s orientation, on the other hand, influenced the size of the mashrabiyya’s opening, pieces, interstices, and overhang.” (Gelil, 2014).

3.3 Patterns of Mashrabiya

Speaking of patterns of Mashrabiya, Fathy confirmed the existence of different patterns of Mashrabiya and each has a name in his book, but these were not discussed in detail. It seems likely that the arabesque craft was so widespread that the names were traded just like fashion and at the time everyone knew these names. It did not occur to anyone that the day might come when Mashrabiya would go out of fashion and lose many of its features as well as the traded names.

While orientalists mentioned some names, architectural researchers referred to others and Fathy pointed out some others through his explanation of lighting. Also some theses mentioned the models, but only gave descriptions. However there was no subtitle to go under the title of Mashrabiya patterns that presents a clear, full and detailed explanation. Therefore this study aims, as far as possible, to bring together a total, documented and full reference for all the names of patterns that were previously mentioned randomly.

From the aforementioned, it is obvious that the functional role of the Mashrabiya requires a full understanding in order to choose the appropriate distances between the balusters and their diameter. Thus various patterns of Mashrabiya were produced, that were known by a variety of names.

Naturally, the names have regional variations, as with the detailing and style of Mashrabiya that changed between countries. However, it is important to note that functionally the Mashrabiya always performed the same role.

The lattice was distinctive in its intricacy and delicacy, creating the style which is most commonly recognized as true 'Mashrabiya'

The patterns of Mashrabiya were composed of simple geometric shapes, and often ewer or calligraphy designs from the Quran, because of the prohibition in the religion of Islam of the portrayal of any living being (Feeney, 1974). Besides, the simple shapes are easy to construct by manual way.

The major technical feature of the construction of the Mashrabiya as a climate regulator element, where the distances between the interstices, the size and volume of the balusters, all directly affect glare and temperature, as well as the level of humidity and airflow within the building (Fathy, 1986) .
Additionally, there is a close relationship between geometry and Islamic art in general, on the one hand, and calligraphy on the other.

> "The works of Islamic art…can be identified, described, and judged according to a relatively small number of principles which form their essence. One of these principles is geometry, which therefore became a whole book. The second premise is a reluctance to deal with history, to accept even incompatible varieties or irreversible changes as expressive of cultural wealth rather than a regrettable weakness." (Graber, 2006).

Some researchers, in referring to the names of some of the common patterns of lattices, have named the different design styles in the following way:

- The Hexagon (Figure 3.18) (Spencer, 1990).
- The Church or (Kanaysi in Arabic): the design consists of long, narrow balusters which are assembled vertically, and the shape of the turned baluster looks like the legs of a pigeon (Figures 3.19- 3.20) (Ashi, 2010).
- The Maymoni pattern is attributed to a town called Maymoniya in Egypt, it is a perpendicular mesh, and its balusters have squared sections in some areas and rounded sections in other areas (Figures 3.21- 3.22) (Ashi, 2010).

- The Cross pattern is made of short round balusters which are assembled diagonally, vertically and horizontally (Figures 3.23- 3.24) (Ashraf, 1983).
- The Sahrigi (Cistern turnery) pattern is attributed to a town called Sahrig in Egypt. This pattern includes large balusters in a wide mesh, and it is used in the upper part of the Mashrabiya, as mentioned in (3.2) (Fathy, 1986) (Figure 3.25).

In addition, depending on the relative skills of the craftsmen, there are some very complicated patterns of Mashrabiya that consist of up to 2000 pieces to one square yard. (Spencer, 1990) Figure 3.26 shows some of them.

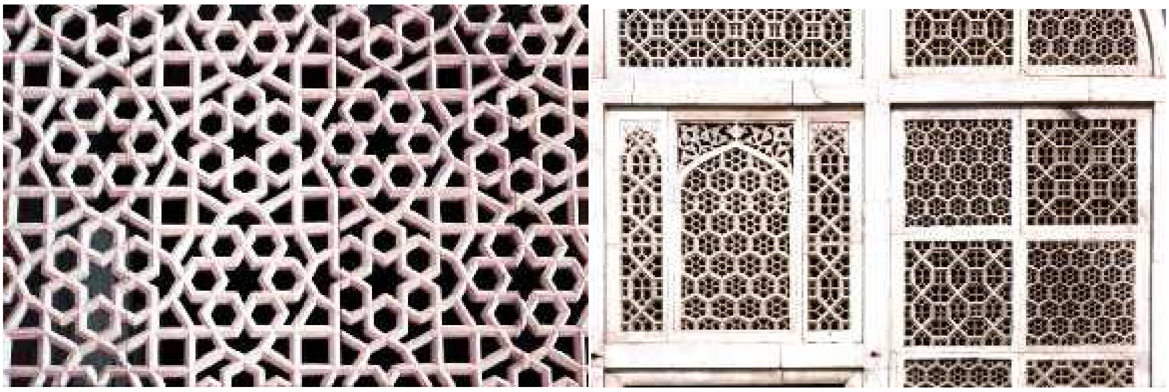


Figure 3.18: The Hexagon Pattern of Mashrabiya
(http://patterninislamicart.com/archive/main/2/india/ind0630)

Figure 3.19: The Church Pattern of Mashrabiya (Luxury crafts, 2011)

Figure 3.20: Notice the shape of the baluster in the Church pattern, how it looks like the legs of a pigeon (Luxury crafts, 2011)

Figure 3.21: The Maymoni Pattern of Mashrabiya (Luxury crafts, 2011)

Figure 3.22: The Maymoni Pattern works sometimes like the Sahrigi Pattern in the wide mesh that is provided, especially when it is used in the upper part of Mashrabiya (Luxury crafts, 2011)

Figure 3.23: The Cross Pattern of Mashrabiya (Luxury crafts, 2011)

Figure 3.24: The cross pattern with different colored wood and small spacing (Luxury crafts, 2011)

Figure 3.25: Mashrabiya at Jamal al-Din alZahabi's house which shows the increase in the spacing between the balusters in the Sahrigi Pattern in the upper part (Fathy, 1986)

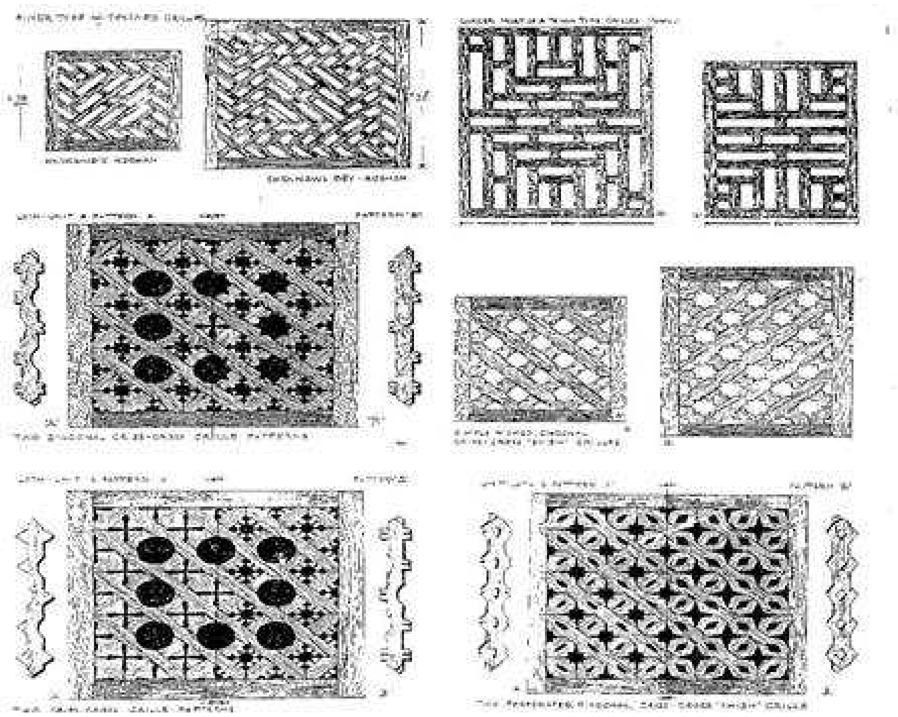


Figure 3.26: Some styles of screens (Jean, 1976)

Highly skilled craftsmen are able to integrate different patterns in the same Mashrabiya (Figures 3.27- 3.31).

Figure 3.27: Mashrabiya with the Maymoni and the Church Patterns (Luxury crafts, 2011)

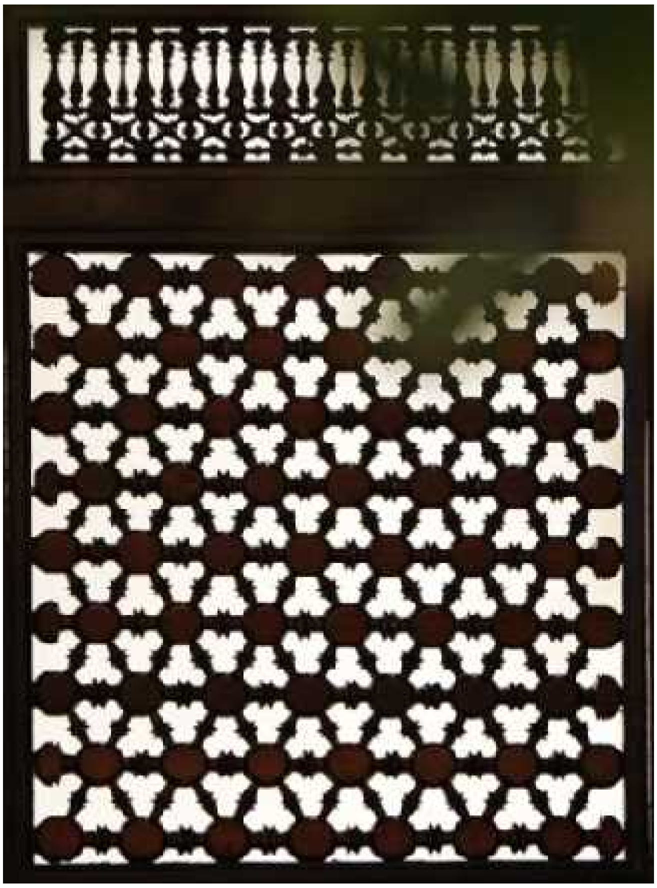


Figure 3.28: Mashrabiya with Cross and Church Patterns (Luxury crafts, 2011)

Figure 3.29: Mashrabiya with a Sahrigi pattern in the upper part and a Maymoni pattern in the lower one – Gayer Anderson House, Cairo-Egypt (Alothman, 2016)

Figure 3.30: Mashrabiya with different patterns at AlSuhaimi House in Cairo - Egypt (Alothman, 2016)

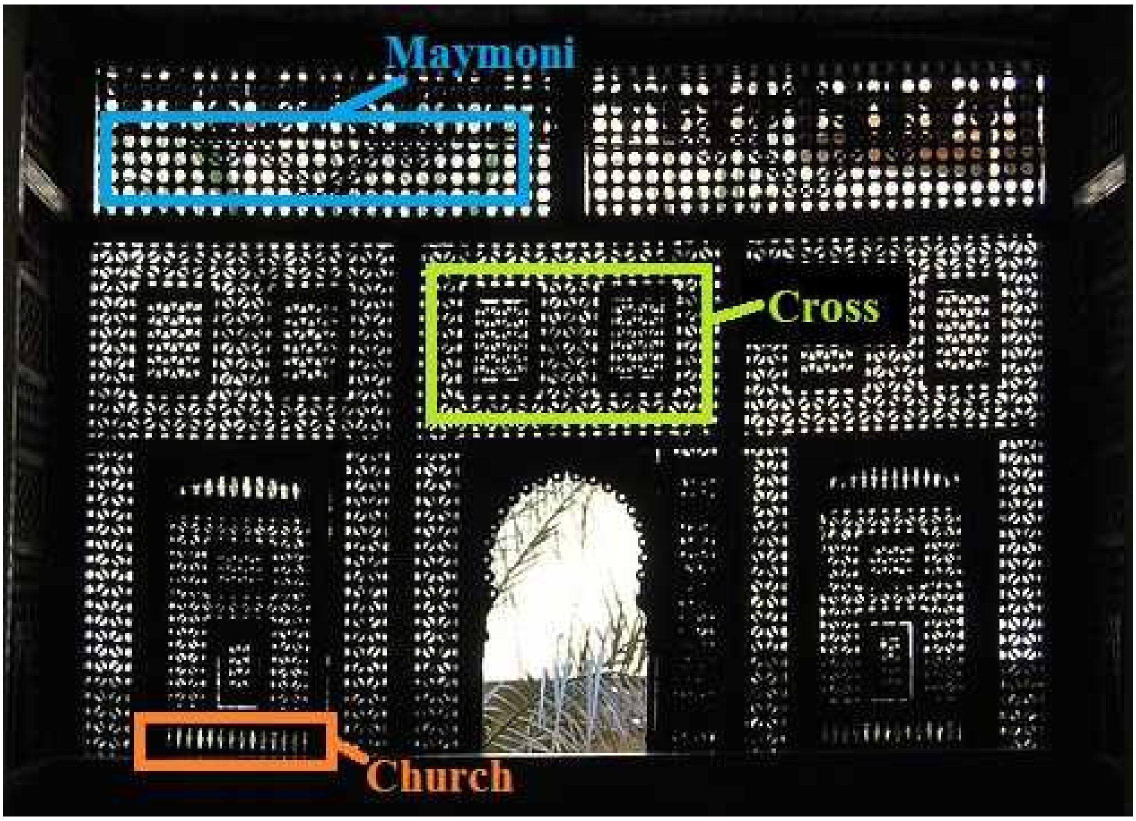


Figure 3.31: Mashrabiya with three types of patterns together (Alothman, 2016)

It is important to reaffirm that not all prominent windows are Mashrabiya. There should be one pattern at least, for example in the Figure 3.32 which is just a prominent window with normal wooden shutters, indicating that it has no Mashrabiya functions.

Figure 3.32: A prominent window with normal wooden shutters, therefore not Mashrabiya (https://totemscity.files.wordpress.com/2011/03/masjidaytimishareadsc_0674.jpg)

3.4 Geometry of Mashrabiya

- Perforation Ratio (PP): This is the ratio between the area of the opening and to the whole area of the screen (Sherif et al., 2012).
- Depth Ratio (DR): It is the ratio between the depth and the width of each perforation opening (Sherif et al., 2012).

3.5 Parameters of the Mashrabiya

After learning about the importance of functions and patterns of Mashrabiya, it is necessary to understand what are the determined terms of its parameters relating to length, angle and section of each baluster, along with the sectional layers and baluster offset (Figure 3.33).

Samuels (2011) offered a number of rules and mathematical formulae for the optimal design of the Mashrabiya lattice, by analyzing traditional construction methods. This constituted an important step towards catching up with the variable production methodology nowadays, as we will see in next chapter. These rules can be used to design the perfect lattice of Mashrabiya to ensure the optimum internal conditions, regardless of the geographic location or programmatic requirements.

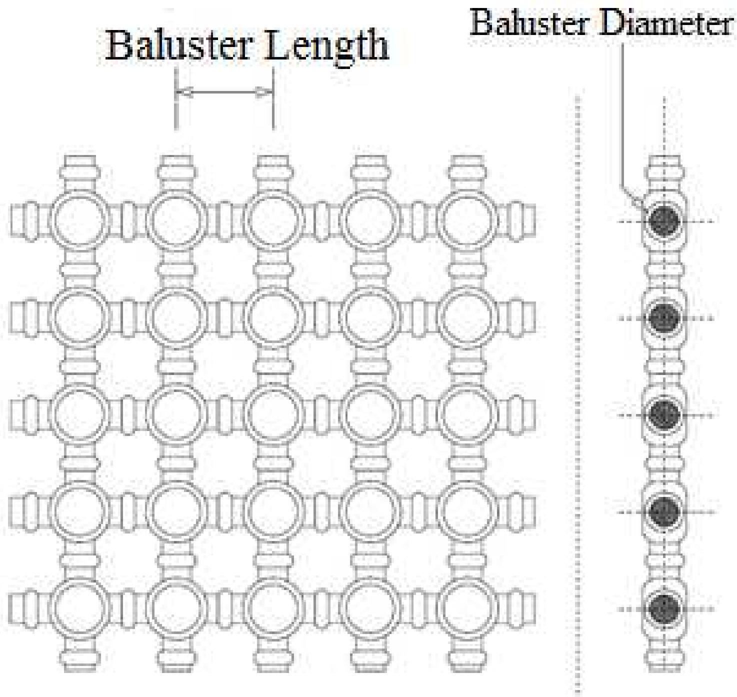


Figure 3.33: Traditional Mashrabiya Typology. (Samuels, 2011)

3.5.1 Baluster Diameter/Length ratio

The ratio between the baluster (Figure 3.34) diameter and length (D/L Ratio) was traditionally used to determine two important issues:

- The functional features of the Mashrabiya, and the porosity of the lattice are directly influenced by this.

- The exact time of year in which direct sunlight enters the internal space, which defines the critical moment when the temperature of room switches from cool to hot.

If this is too soon in the year, the internal space will become dramatically overheated and uncomfortable. If it is too late, the internal space will be bitterly cold during the winter – and equally uncomfortable.

It is well known that direct sunlight controls the thermal environment of a building, and the porosity of the lattice adjusts it. The porosity is subservient to the D/L Ratio which is calculated through the formula [D/L =Cosθ1]; a sun altitude angle is (θ1) (Figure 3.35) (Samuels, 2011).

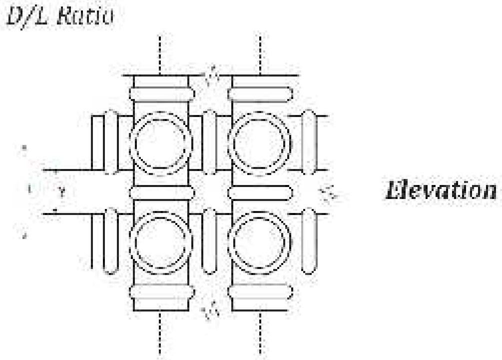


Figure 3.34: Illustration of (D/L Ratio) (Samuels, 2011)

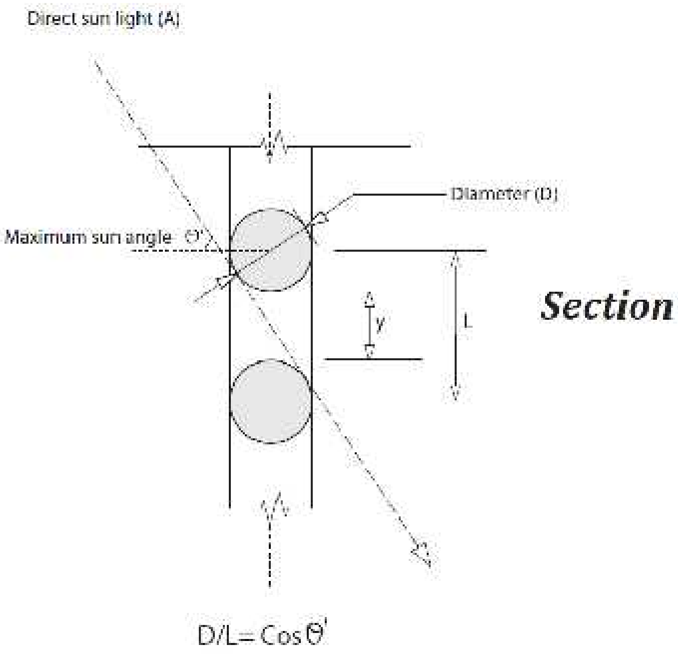


Figure 3.35: Illustration of the formula [D/L =Cosθ1] for baluster design (Samuels, 2011)

3.5.2 Baluster angle

Mornings are generally a lot cooler than the rest of day, so it is necessary to introduce sunlight into the room during the morning. The calculation of the precise angle on both the horizontal and the vertical balusters determines what time of day the sunlight enters the room, thus ensuring the correct daily solar gain. But the determination of the established angle was not something that was possible or easy to achieve in the traditional construction of the Mashrabiya, as it depended on the skills of the craftsman and 'trial and error' testing.

Samuels in his research explored exactly what angle is required, providing an accurate example in his case study (information coming from the Giles Weather Station in Australia), by using shading masks, which he changed from a symmetrical shape to one that favors the morning or evening sun, then he applied this to the stereographic temperature graph (Figure 3.36).

> " .. and by incorporating the established D/L ratio an accurate shading diagram can be formed which will precisely map the times of the year in which complete shading is provided by the Mashrabiya." (Samuels, 011).

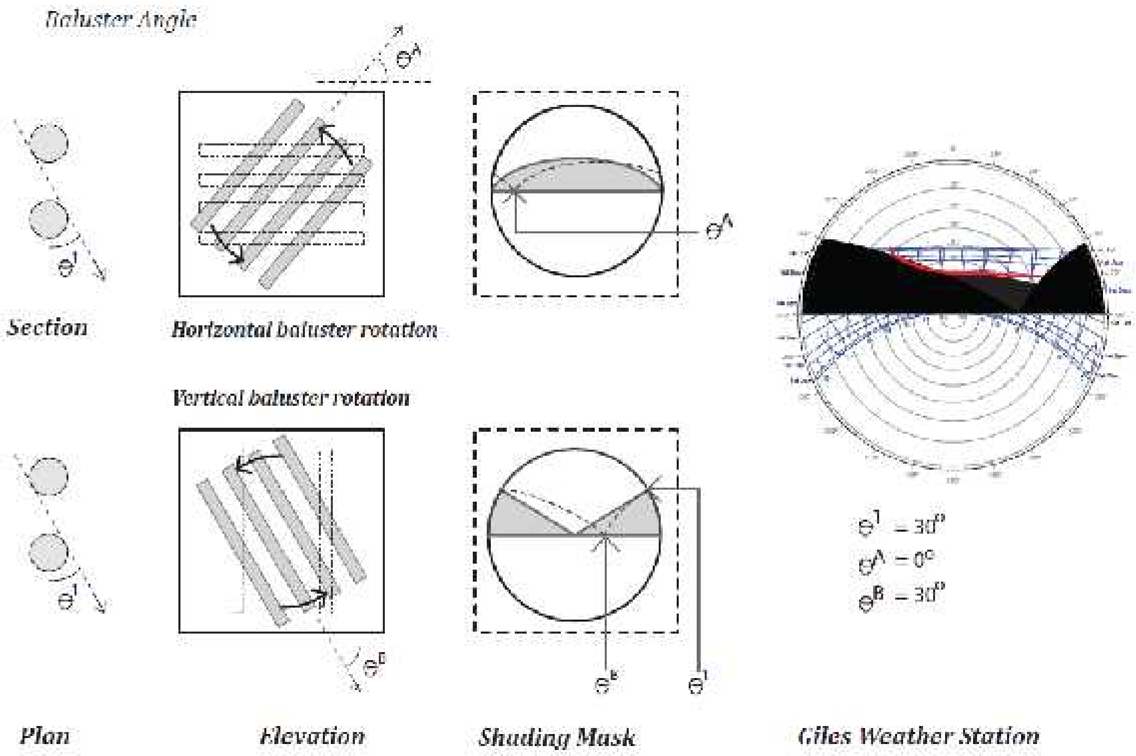


Figure 3.36: Baluster angle analysis in Samuels's study (in Giles Weather Station-Australia) (Samuels, 2011)

3.5.3 Baluster section

According to traditional construction, the section of the baluster should be circular for many functional requirements which are related to the adjustment of glare and airflow (Fathy, 1986). Therefore any alterations in the shape of the baluster section should be derived from the circular section to provide the same important requirements. It should be noted that changing the section of each baluster alters the angle at which sunlight enters the room, meaning modifications must be made to the D/L ratio calculations in order to compensate.

> “A reduction in the baluster width will increase the PF value, increasing the amount of ambient light and air passing through the screen. The PF value has to be high enough to allow adequate ambient light to enter the space for normal activities to occur.” (Samuels, 2011)

As mentioned before, the porosity of the Mashrabiya lattice controls the solar gain, glare and the airflow. In addition, this porosity factor (PF or φ) describes the ratio of open lattice to that which is filled with balusters (Figure 3.37).

> “ PF can be calculated by dividing the total area of the opening by the total area of the interstices. A PF of 1 is equivalent to an opening without a Mashrabiya, i.e. 100% porosity.” (Samuels, 2011).

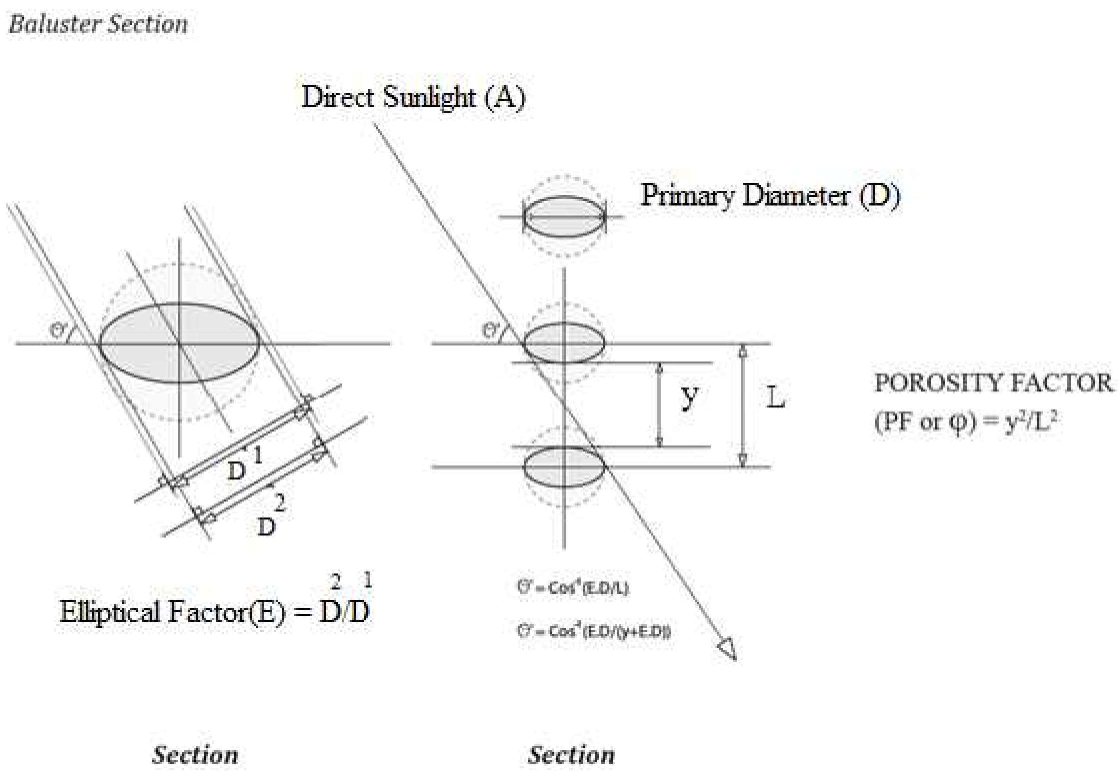


Figure 3.37: Baluster section analysis (Samuels, 2011)

3.5.4 Sectional layers

Traditionally Mashrabiya consisted of just one layer of lattice, but nowadays (Figure 3.38) with contemporary processes of construction, it has become possible to produce new models of Mashrabiya with double layers using a computer numerically controlled (CNC) router. After many tests, much research, 3D modeling and computer simulations, it became apparent that:

- The optimal number of layers is two.
- The important benefits of the extra layer are:

1- An increase in the amount of solar gain within the building:

It alters the way light passes through the lattice during winter, although it is still possible to use the previously defined D/L ratio, baluster angle and sectional shape as a basis for the lattice.

> “in winter there are points at which the interstices of each layer directly line up with the angle of the sun.” (Samuels, 2011).

2- A reduction in glare

> “The first layer of balusters, that which is closest to the outside, benefits from light reflected off the second layer of balusters, thus reducing the amount of shadows across its surface. This creates a two-tiered transition between the interior and exterior, greatly reducing both the visual contrast and the glare.” (Samuels, 2011).

3- Creation of a more visually dynamic surface

> “The intricacy and delicacy of the screens were a visual wonder, and any contemporary interpretation must express those qualities to do any level of justice to the original form. The use of additional layers within the Mashrabiya comfortably achieves that by adding to the visual intrigue and spectacle of the screen.” (Samuels, 2011).

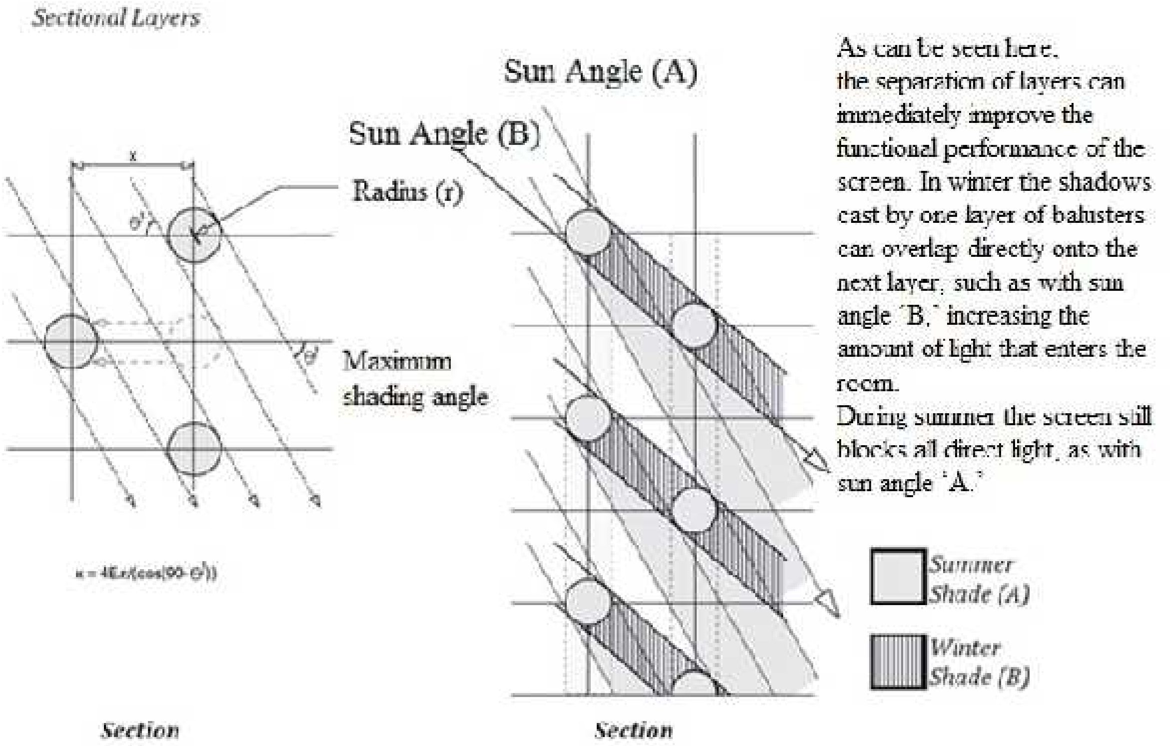


Figure 3.38: Sectional layer analysis (Samuels, 2011)

3.5.5 Baluster offset

This describes the degree to which the two layers of the lattice line up. The possible offset of the layers is a way in which the airflow or lighting in the room is not directly affected, in contrast to the privacy matter; the offsetting gives more or less control to the designer. Whereas the visual porosity in this case changes, relying upon the position in which a person stands and the angle at which he looks at the lattice (Figure 3.39).

"For the offset to ensure that the direct light is not affected precision is required. The vertical offset needs to be matched by a horizontal offset, the ratio of which has been found to be determined by the equation [X1 /X2= 2Y1 /(Y1+Y2)] , ensuring that the solar gains are kept constant." (Samuels, 2011).

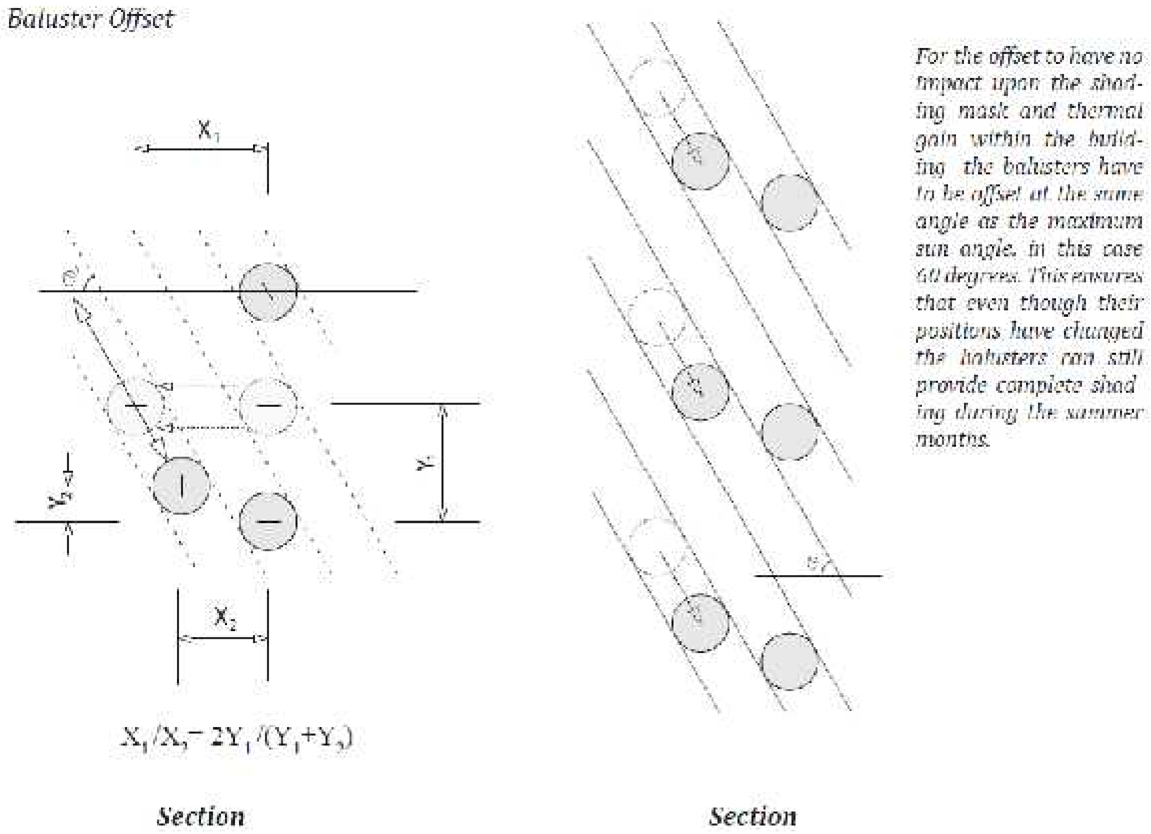


Figure 3.39: Baluster offset analysis (Samuels, 2011)

3.5.6 Supplemental parameters of Mashrabiya related to the potentiality of reflected sunlight

Aljofi (2005) published a research study concerning the effects of the Mashrabiya screen on reflected sunlight. The results of the experiment were:

- The effect of the baluster shape in the screen:

The light is lower in the case of the rounded shape than in other complicated shapes.

- The effect of the size of the screen baluster:

In both vertical and horizontal positions of the balusters, the contributed reflected light is increased in the lattice with large diameter balusters, than in the lattice with smaller diameter balusters. This is due to the ratio of open to closed parts of the lattice.

- The effect of surface reflection of the screen:

The contributed light from the light Oak wood lattice is more than in other types of wood, by an average of 17% .

3.5.7 An extra review of several researchstudies about the function of Mashrabiya

Batool (2014) presented an important literature review of a number of research studies concerning the performance of Mashrabiya and the impacts of its parameters.

Table 3.1 summarized the views:

Table 3.1 : Researches Review (Batool,2014)

SOURCES	PARAMETERS	IMPACTS
2012 Sherif et al.	--- Orientation --- Perforation Rate --- Depth/Opening Ratio	--- Cooling Energy --- Heating Energy --- Window Transmitted Solar Energy --- Lighting Electricity
2010 Sherif et al.	--- Orientation (south, west, east) --- Perforation Rate	--- Cooling energy
2011 Sherif et al.	--- Location --- Depth – Perforation Ration	--- Energy --- Daylighting
2008 Raymond et al.	--- Vertical spacing /perforation --- Thickness / density	--- Cooling load --- Shading --- Privacy
2001 Datta	--- Slat length --- Slat tilt / angles	--- Cooling load --- Heating load
2010 Alzoubi et al.	--- Room geometry --- Shading elements --- Orientation	--- Lighting energy --- Illuminance level
2011 Borg	--- Materiality (steel)	--- Daylighting --- Thermal performance
2006 Chow et al.	--- Depth --- Materiality --- Air temperature	--- Ventilation --- Heat gain --- Energy saving
1994 CIBSE	- Wood (10 – 50% reflectance)	--- Glare
2011 Sabry et al.	--- Rotation angles --- Light shelves	- Daylighting
1990 Spencer	--- Light intensity --- Geometry: Sahgiri (square grid) --- Geometry: Musadass (hexagon)	--- Glare --- Pattern
1983 Ashraf	--- Cress- Crossed --- Diagonal crossed --- Rounded strips	--- Pattern

Table 3.1 Continued		
2010 Lockyear	--- Algorithm/Generative --- Layered screens / sectional study --- Materiality --- Opacity	--- Pattern
2010 Sherif	--- Materiality (wood) --- Perforation ration --- Screen geometry	--- Daylighting (illuminance) --- Privacy
2001 Al-Shareef et al.	--- Parallel shading device --- Position and tilt angles	--- Daylighting --- Venetian blinds
2002 Athienitis & Tzempelikenos	--- Automated controlling (outdoor test room)	--- Daylighting --- Transmission
2008 Tzempelikos	--- Blind geometry / shape --- Tilt angle / reflectance --- Curved / rotation surface	--- View --- Direct light transmission --- Illuminance
1990 Allyali	--- Air velocity --- Orientation --- Wind speed	--- Air movement
1988 Hassan	--- Materiality (wood) --- Geometry	--- Humidity --- Pattern

CHAPTER 4

MATERIALITY AND CONSTRUCTION OF MASHRABIYA

4.1. The Traditional Materiality and Construction of Mashrabiya

Wood is the main traditional material used for the construction of Mashrabiya, as can be seen in chapter 3, due to its advantages in the adjustment of internal shadows, reduction of glare, toleration of high temperatures and finally, its effect on humidity buffering and cooling the airflow. In Egypt, where wood turnery in general and Mashrabiya in particular is considered a deeply-rooted craft, the Egyptian government website displays information about the different types of wood used and the craft of word turning.

4.1.1. Craftsmanship

As mentioned in chapter 2, the Copts in 13^{th} century Egypt inherited the craft of wood turnery, especial the Mashrabiya, from their forefathers. Later the craft was developed by master craftsmen who exhibited woodwork of their own creativity using artistic or geometric shapes.

In Rashid (Rossetta) houses, the Mashrabiya was decorated on the side walls with beautiful ornamentation; the craftsmen also partitioned the Mashrabiya into numerous turned woodwork units with fanciful designs, which display Islamic words or symbols (Figure 4.1) (Wood Turnery. SIS Publications, 2014).

Figure 4.1: Image of Mashrabiya at Gayer Anderson Museum House, with Arabic writing, in Cairo, Egypt (Alothman, 2016)

4.1.2 Different types of wood

The Mashrabiya was made originally from one of three kinds of wood, pine, walnut or beech; but the craftsmen did not only use local types of wood, they also imported various other types, like : Walnut, oak and walnut from Europe and West Asia and ebony wood from Somalia, South Sudan and Ethiopia (Wood Turnery. SIS Publications, 2014).

There are many types of wood which are used in traditional Mashrabiya (Figure 4.2):

Types of wood according to their origin:

1- Local wood:

- Sant wood is tough, rigid and has a reddish color, which changes in time. It is similar to ebony.
- Mulberry wood has a yellowish color and contains red circles. It is tough and has condensed fibers. It may be be used in turnery as its surface can be polished.
- Tamarind wood has a white, yellowish color.
- Nut wood and Nabk wood were considered the favored types for Mashrabiya.
- Guava, lemon, sycamore, olive, date and willow wood are used in turnery as well, having different ornamental colors.

2- Imported wood:

Imported wood includes mild workable types and tough rigid types.

A- Mild Workable: Known as Mosky or Swedish, it is a practicable wood comprised of red pine and yellow pine.

B- Tough Rigid wood: This includes beech and ebony.

- Beech wood is preferred because it is flexible; it is essentially white, yellowish in color, but turns to reddish yellow after dehydration.
- Ebony has many types with different colors: black, brown, red and green. It is a solid, hard wood and used in the turnery of Mashrabiya.

Types of wood according to turnery size:

1- Large Turnery : This type of turnery contains Cistern turnery (Sahrigi pattern) which is used in the Mashrabiya in order to allow air and light to enter inside the building. 2- Fine Turnery: known as Mashrabiya Turnery.

Mashrabiya Turnery is of different sizes; the names of the patterns are explained in the previous chapter.

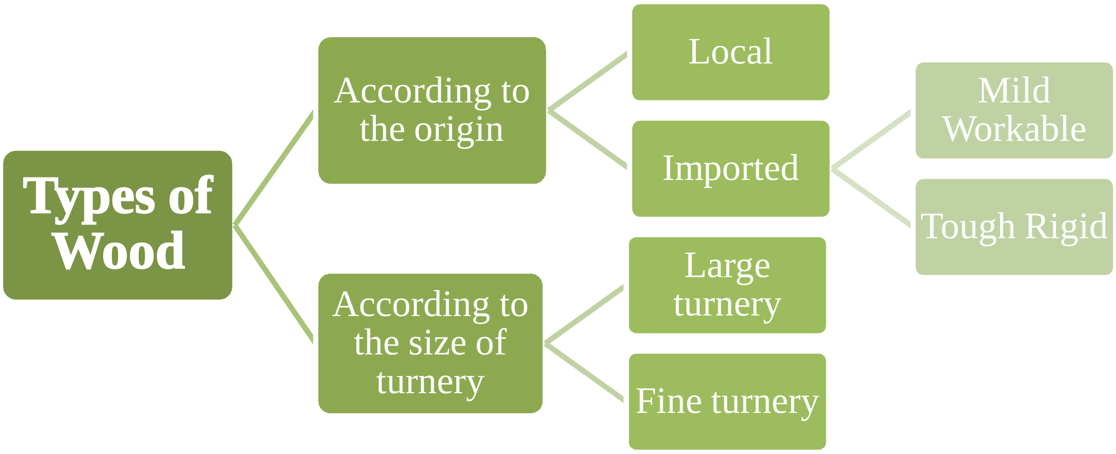


Figure 4.2: Types of wood which were used in construction of traditional Mashrabiya (Alothman, 2016)

4.1.3 Traditional tools and machinery

During ancient times, Mashrabiya were constructed manually using various types of chisels (Figure 4.3), along with an important machine which is called a bow lathe, the machine had a primitive shape (Figures 4.4- 4.6). The craftsman used only the skew chisel to model a piece of wood, while turning it on a lathe (Figures 4.7- 4.8).

Figure 4.3: Manual Turning Tools, the chisels (http://www.robert-sorby.co.uk/)

Figure 4.4: Image of the first evidence of a lathe
(http://www.theegyptianchronicles.com/Article/KHIRAATAH.html)

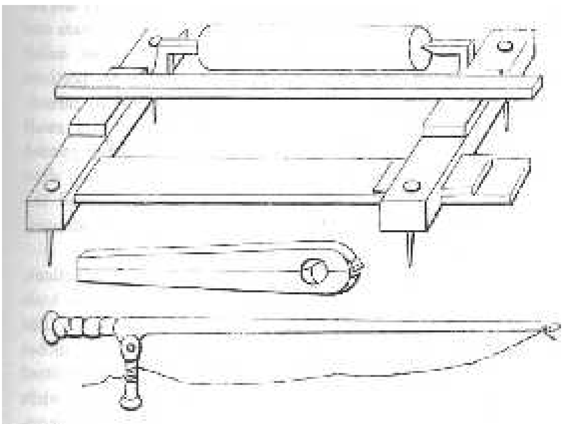


Figure 4.5: a bow lathe illustration (Usher, 1929)

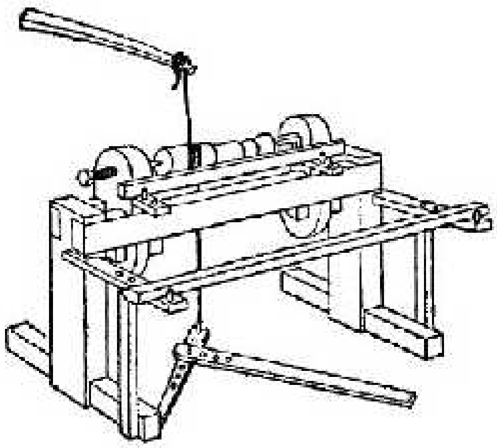


Figure 4.6: a more developed bow lathe (Usher, 1929)

Figure 4.7: A craftsman in Cairo turning the long primary balusters on a lathe (Samuels, 2011)

Figure 4.8: The traditional craft of Mashrabiya depended on the use of lathing tools (http://qanzaman.blogspot.com.cy/2013/01/blog-post_9979.html)

The machine was replaced later by an electric version (Figure 4.9), to keep up with the concept of design sophistication and mass production. Even an electric lathe is considered a traditional tool (Figure 4.10), compared with the digital design and CNC milling tools which are used nowadays to construct the Mashrabiya, using a setup program without the need of a worker nearby.

Figure 4.9: The electric lathe (http://www.preetlathe.com)

Figure 4.10: An image of an electric lathe machine (Almerbati et al., 2016)

4.1.4 The traditional construction

The craftsman turned each rod with the lathe to the length and thickness required, starting with a chain of long elementary balusters which could be between 100 mm to a meter in length, depending on the details and the scale of the final Mashrabiya, in this way he would establish the basic framework of the lattice (Figures 4.11- 4.14) (Akbar, 1994).

Figure 4.11: A sketch showing the traditional craftsman's position during the wood turning process (Ishinan, 1979)

Figure 4.12: A sketch of the craftsman using his bare foot to turn the baluster on the lathe (Ishinan, 1979)

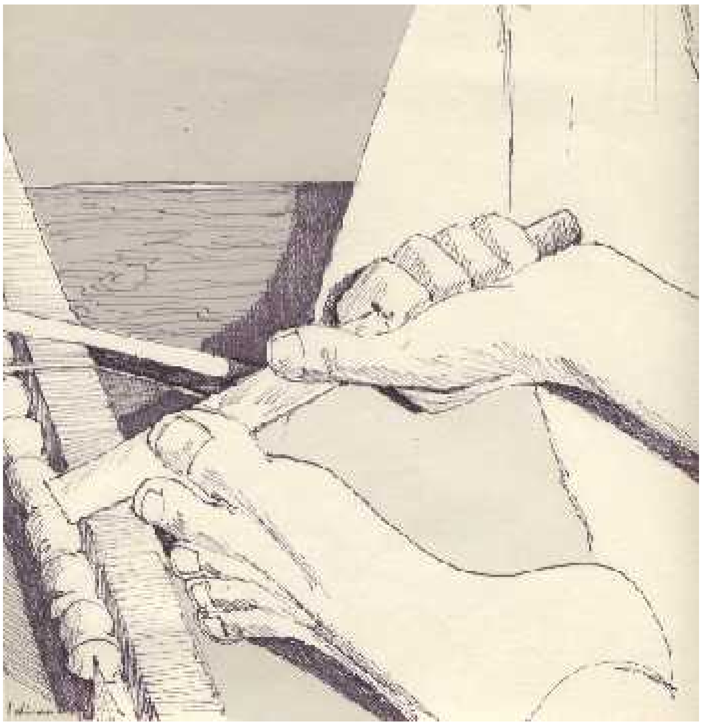


Figure 4.13: A sketch of a detail of turning work (Ishinan, 1979)

Figure 2.14: A sketch of latticework (Ishinan, 1979)

The turned balusters were used to make a series of cylindrical lengths which were peppered periodically with connection points to the lateral balusters. These points are shaped as larger cubic pieces (Maymoni pattern), spherical pieces (Sahrigi pattern) or mixed peices (cross pattern). The craftsman would drill a hole into each of the connection points, where the shorter secondary baluster fitted (Figure 4.15). As a result a connection was created without using nails or glue, (Figures 4.16- 4.17) (Briggs, 1974).

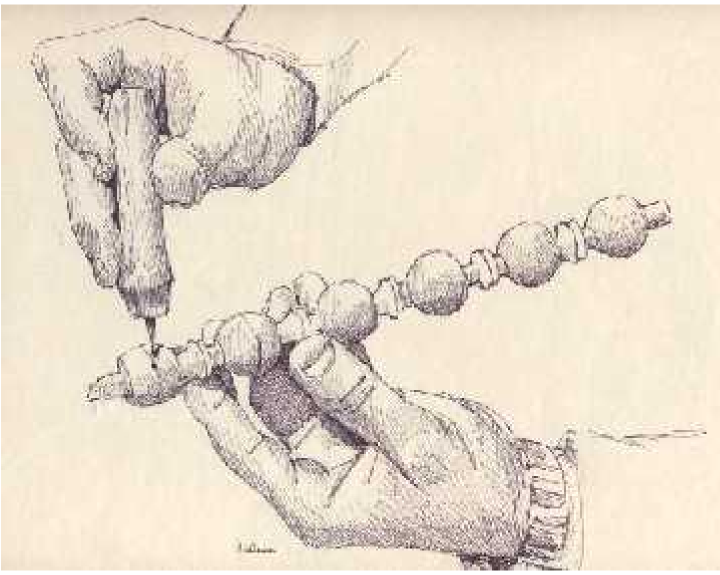


Figure 4.15: How the craftsman drills a hole into each connection point (Ishinan, 1979)

Figure 4.16: A small part of Mashrabiya is connected inside without glue or nails (Luxury crafts, 2011)

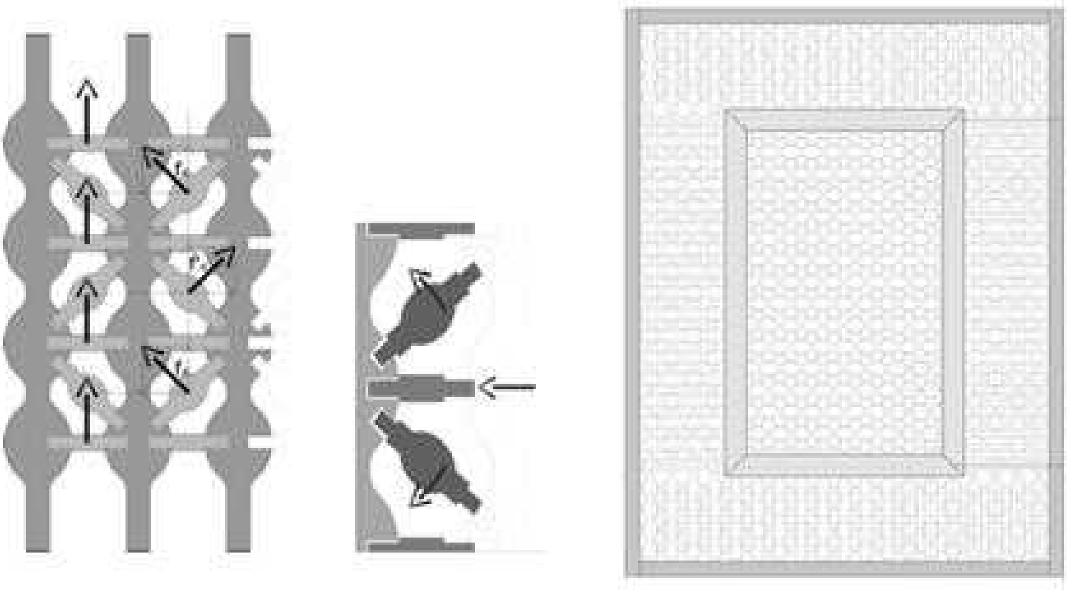


Figure 4.17: The complex geometric structure of the Mashrabiya screen
(Benedetti et al., 2010)

Once a mesh of balusters had been made, it was enclosed within a frame to strengthen it. The frame works also as a structural element, since the gravity is spread and the stress of wind blowing throughout the length of the lattice avoids damaging any individual balusters. By altering the diameter and length of each baluster, the craftsman can adjust the climatic conditions of the internal space. The determination of these sizes was decided by the individual craftsman using his experience of the traditional production process.

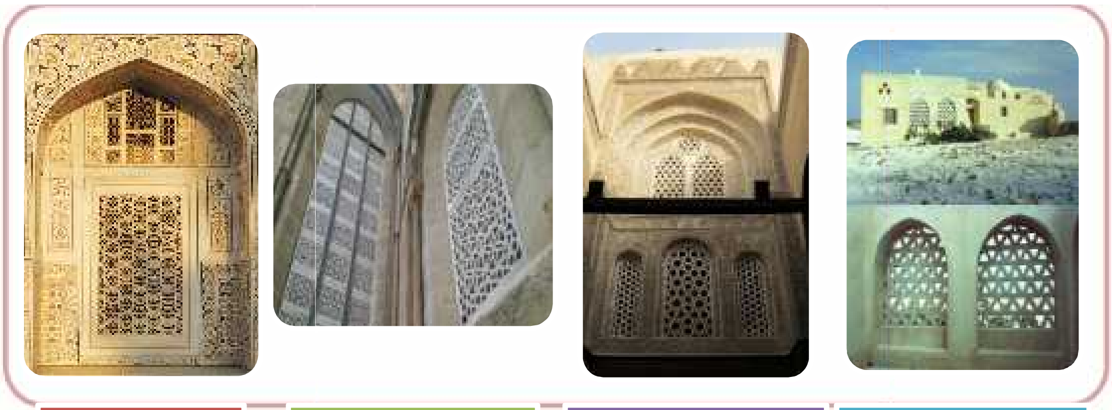
4.2 Other Materials For Mashrabiya

Given that the basic material to construct Mashrabiya is wood, any alternative material needs to have similar properties to wood; it should to be strong, easily reproduced in quantity, and able to cope with extremes of humidity and temperature, at the same time capable of expressing a certain softness.

However, there are many examples of Mashrabiya which were made of different materials like:

- Marble, in Indian tombs (Figure 4.18a); it was effective in the cooling function and light adjustment, but concerning humidity control it does not have the same properties as wood.
- Natural stone is used in Mashrabiyas of mosques and old castles in Spain, Iran and Cyprus (Figure 4.18b).

- Plaster can be found in some palaces in Egypt (Figure 4.18c).
- Brick, which Fathy used it to construct Mashrabiya in some projects in Egypt (Figure 4.18d). In his books he does not mention brick as an alternative material for Mashrabiya. However he frequently used brick in the façade designs of his projects, which were described as Mashrabiya.



(a) Marble in tombs.

The tomb of Itimad ud Daulah in India. (Rogers, 2014)

(b) Stone is used in Mashrabiya of mosques and old castles.

Stone Mashrabiya, Selimiye Mosque in Old city , Lefkosa , North Cyprus. (Author, 2015)

(c) Plaster in some palaces.

Mashrabiya in complex of Sultan Qalawun at Al-Muʾizz al-Din Street in Cairo , Egypt. (Albadawy, 2010)

(d) Brick in some of Fathy's other projects.

Brick Mashrabiyas at Sidi Krier House in Egypt, designed by Hasan Fathy. (http://archnet.org/sites/200/publications/6623)

Figure 4.18: Other Materials for Mashrabiya (Alothman, 2016)

Samuels (2011) proposed ceramic as a new construction material for Mashrabiya, pointing out that ceramic is not influenced by temperature and it is also waterproof, very strong and has the ability to be produced with a semblance of semi –translucence. This is an interesting characteristic which can reduce glare, when it is used within the Mashrabiya context, and it can create a soft, glowing effect. Furthermore the use of ceramics can reduce the labor and overall costs.

4.3 Hybrid Parametric of Mashrabiya and the 3D Digital Craftsmen

Technology nowadays causes alterations in the methodology of constructional pruduction, thus creating a major number of variables in Mashrabiya manufacture.

> "The use of computer numerically controlled (CNC) milling devices, now a common form of digital fabrication, gives a much higher degree of accuracy, speed and versatility than was previously possible using hand driven lathes. By using a flip-bed CNC system, where a block is cut, flipped and a matching cut is made on the other side, a screen of almost any possible shape can be made. This means that the individual section, shape and dimension of each baluster can be precisely defined to provide the optimal climatic and spatial control." (Samuels, 2011).

This means that more advanced turning machines are available in the design and production process, such as CNC Wood Turning Lathe, (Figure 4.19) which allows a choice of design by entering numeric values to the computerized memory for turning wood. This cuts the need for expending a great deal of time and manpower, as found in the tradional fabrication process (Figure 4.20).

Figure 4.19: The CKX-600/1300/1600 CNC Wood Turning Lathe
(http://en.intorex.com/1674/cnc-wood-turning-lathes-ckx-600-1300-1600#ad-image-2832)

Figure 4.20: The CNX is a fully automatic CNC wood turning lathe (http://en.intorex.com/1674/cnc-wood-turning-lathes-ckx-600-1300-1600#ad-image-2832)

Almerbati et al. (2016) in their research about the hybrid Mashrabiya, supported the importance of CIM and CNC Mashrabiya model of Samuels's thesis (Figures 4.21- 4.23) and his final result:

> "Even if the final result was not aesthetically significant, the process and the product created utilized modern CIM and CNC technology that was not available to local craftsmen." (Almerbati et al., 2016).

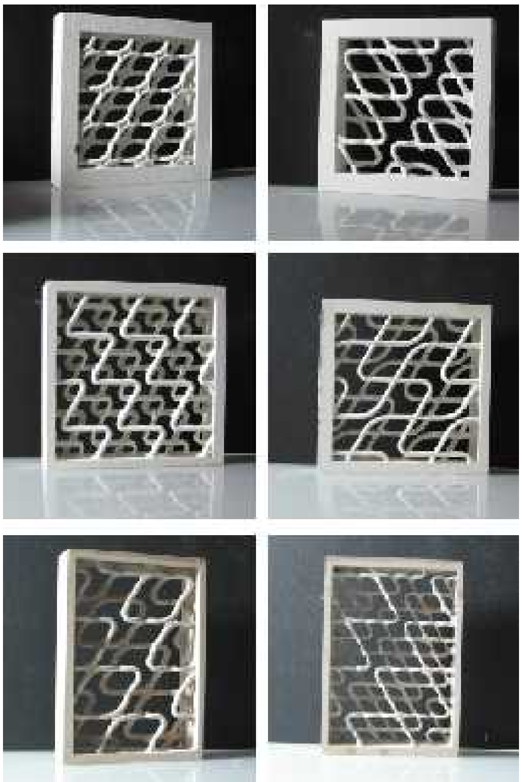
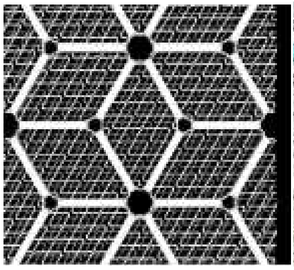
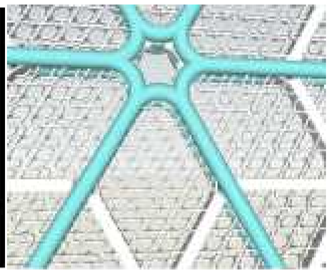


Figure 4.21: Test patterns by William Samuels (Samuels, 2011)

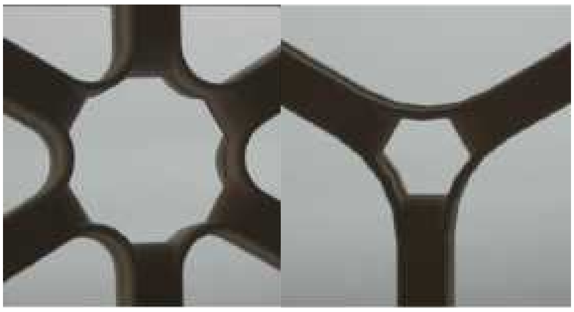
(a) Basic Mashrabiya component.



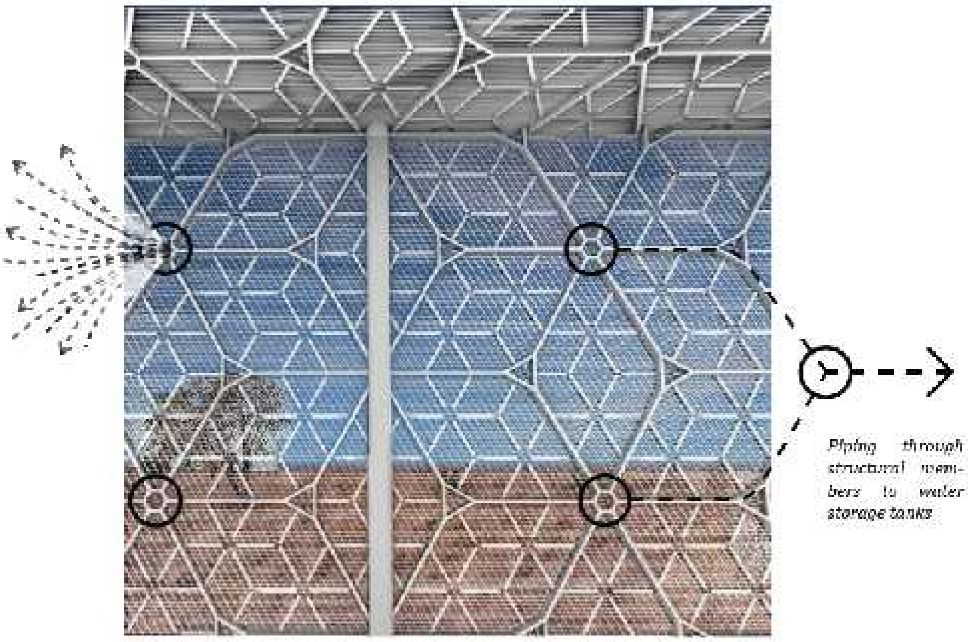
(b) Component tiling arrangement.



(c) 3D Structural bracing layer.



(d) Joint connection detail.



(e) Misting Spray Points.

Figure 4.22: Development of Samuels' CIM and CNC Mashrabiya Component (Samuels, 2011)

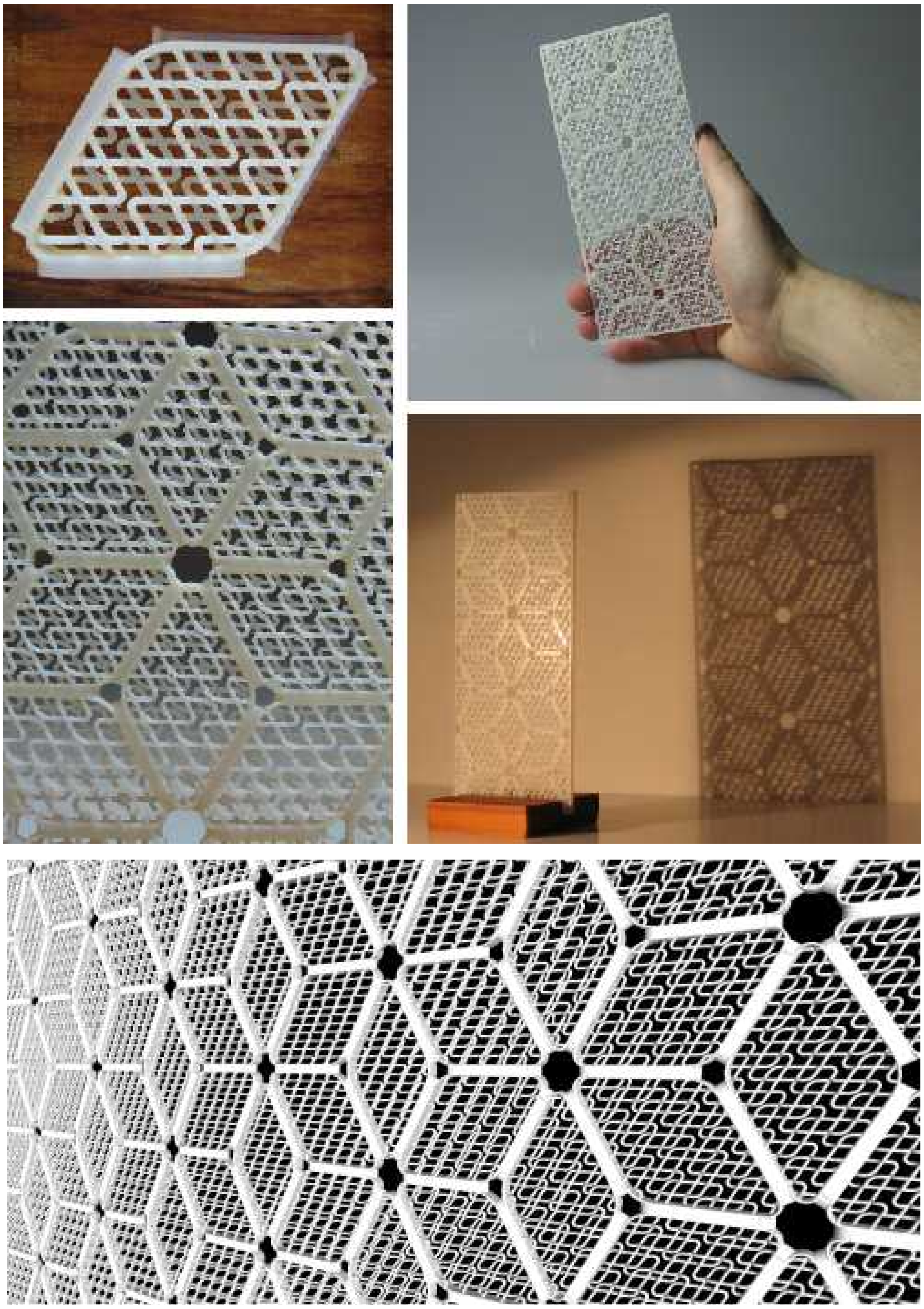


Figure 4.23: Component Tessellations of development of Samuels' CIM and CNC (Samuels, 2011)

Almerbati et al. (2016) followed Samuels' experience to explore new hybrid parametrics of Mashrabiya, and they pointed out that as traditional craftsmen persevered in understanding the kinds of wood and tools to be used, digital craftsmen seek to master the art of how to convert the functional limitations of different types of technology and new machines, into the contemporary digital construction that controls their careers. When digital craftsmen study the history of Mashrabiya, they can inform the traditional mathematical and geometrical patterns with functional design parameters which can be controlled by graphic algorithmic modelers. The geometric dimensions are improved through the use of T-Splines (Figures 4.24- 4.25)

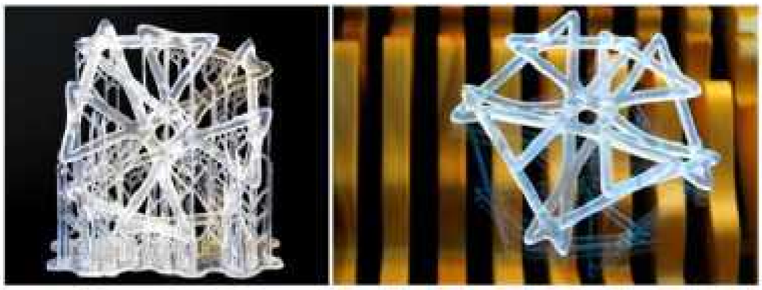


Figure 4.24: 3D printing enables the production of parts that cannot be made in any other fashion, 10 cm by 10 cm test prints of Mashrabiya screen modular units using Form 1 printer (Almerbati et al., 2016)

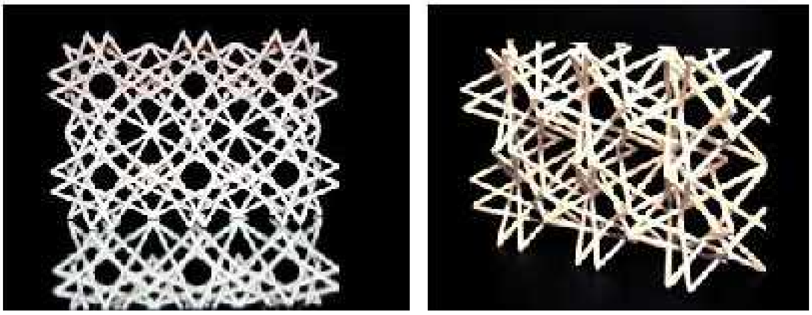


Figure 4.25: Images of 3D-printed Laser Sintered Plastic for Focus Group Consideration in Bahrain (Almerbati et al., 2016)

> “3D printing is selected as the ideal manufacturing process, as, at times, these constructions achieve a complexity that extends beyond multi-axis CNC milling…. since these parameters have been programmed dynamically, the culture is able to evolve through the dynamic modification of the parameter model. Furthermore, as more cultural or functional variables (architectural programming, for example) emerge and are programmed into future instantiations of the Parameter Mashrabiya, the resultant forms will continue to evolve alongside the culture. In addition, the advantage of the units’ shape is linked to the fact that they can be digitally crafted to fit various patterns from both 2D surfaces and complex 3D interlaced geometries, some of which are too highly complex to be created using other mould-based manufacturing techniques.” (Almerbati et al., 2016).

4.4 The Additive Manufacturing (AM) of Mashrabiya

AM is the procedure of solidifying powder or liquid by using a melting laser or a binding agent (Jon and Nathan, 2010). This process has some advantiges :

- It saves time and transporation costs related to importing fundamental materials.
- It provides the ability to produce three dimentionl elements or objects from models, or from computer controlled additive processes.
- It provides mass customization, flexible shapes and affordability (Wittbrodt et al., 2013).

Almerbati et al. (2014) in the research titled “The value of additively manufactured window screens in Middle Eastern dwellings” described by Postler and Ferguson Company as pioneers in the AM field (Figures 4.26- 4.27).

> “the company proposed using additive manufacturing or 3D printing as a substitute for the intensive tooling needed and to free the design from any milling constraints. Their final sand products for public space usage were based on a three-dimensional interpretation of a Mashrabiya latticework design… Postler and Ferguson have hinted that AM Mashrabiyas have never been produced before or researched.” (Almerbati et al, 2014).

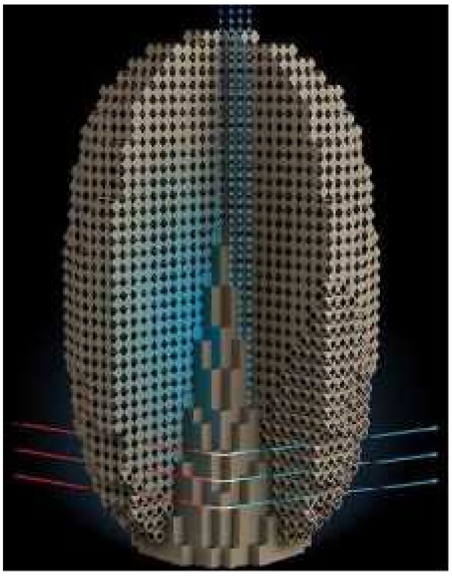


Figure 4.26: The giant 6m bed D-shape printed (Almerbati et al., 2014)

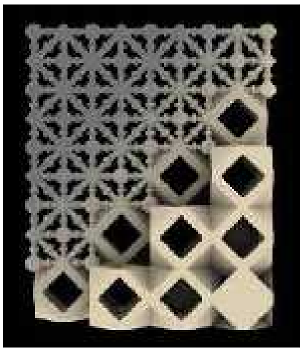
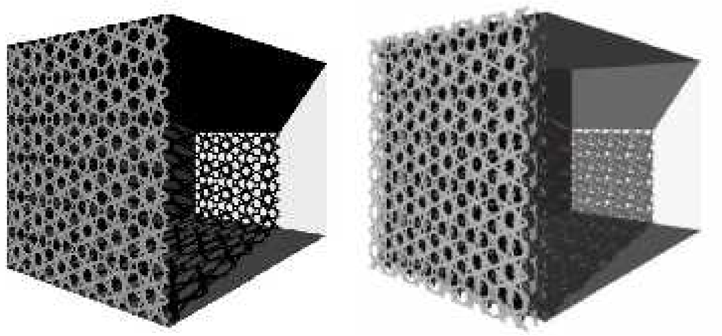


Figure 4.27: The Microclimates (Almerbati et al., 2014)

4.5 Shape – Variable Mashrabiya (SVM)

This is a system which is formed by three identical opaque backscattering shields, filled with a pattern inspired by the Mashrabiya. It is considered an adaptive daylighting and shading system, due to the ability of its shields to move relative to each other, in order to switch between a closed situation in the case of direct sunlight (Figure 4.28a) and an open situation when skylight prevails (Figure 4.28b) (Giovannini et al., 2015).



(a) Closed configuration. (b) Opened configuration

Figure 4.28: Images of the SVM (Giovannini et al., 2015)

The SVM advantages:

- It effectively blocks direct light, along with converting a part of it into diffuse reflected light, so as to enhance the comfortable daylight in the room space.
- It diminishes the overheating problem, therefore it performs better than other technologies used for the control of sunlight, especially in Middle East region.
- It provides good visual comfort, in terms of glare adjustment; moreover it offers some aesthetic value (Giovannini et al., 2015).

CHAPTER 5

THE CONTEMPORATY INTERPRETATION OF MASHRABIYA

This chapter seeks to study the modern Mashrabiya in many contemporary projects to evaluate its performance according to the environmental functions that are suggested by Hasan Fathy (light adjustment, airflow and humidity control and reduction of temperature), along with visual privacy and aesthetic role, including the materials used, costs and difficulty of structural details. Before this important step it would be wise to shed light on the reasons for the revival of Mashrabiya.

5.1 The Revival of Mashrabiya in Contemporary Architecture

Architecture passed through many notable changes since the beginning of the twentieth century; the industrial revolution and the globalization movement have played a key role in shifting away from the important elements in traditional architecture, like Mashrabiya.

Some of these changes were helpful and others were unfavorable, in particular with regard to globalization, which damaged the cultural identity of peoples, along with the industrial revolution and the trend for the use of materials and structural systems which were not considered eco-friendly.

In recent decades these issues have forced a lot of architects to find alternative solutions to keep pace with modernity and yet benefit from the cultural heritage. Thus Mashrabiya became one of the leading environmental traditional and architectural elements that have been revived. This has meant a re-focusing on the study of its concept and functions to employ it through the most effective images, and thus adopting it in contemporary projects, by using a high-tech interpretation of the original model, or through a contemporary expression of the original model.

5.1.1 Factors of Mashrabiya revival

There are three main factors that have led to the re-use of Mashrabiya in the field of architecture, which is widespread, but especially found in Arab Gulf countries which have a hot, harsh climate (Figure 5.1).

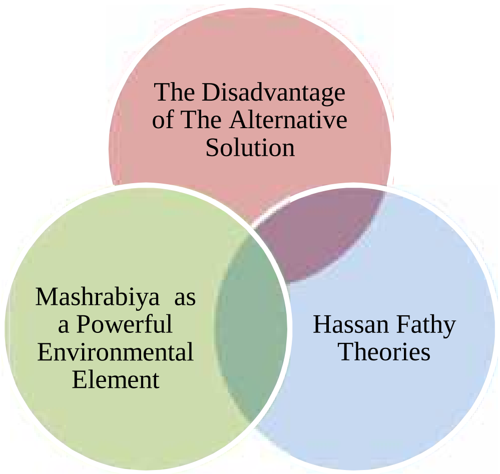


Figure 5.1: Factors influencing the Mashrabiya revival (Alothman, 2016)

5.1.1.1 The disadvantage of the alternative solution

As mentioned in the first chapter, air conditioners were alternative solutions to the Mashrabiya at the beginning of the industrial revolution and the spread of the globalization movement. But the idea, unfortunately, has failed in some way, due to the fact that air conditioners require a lot of energy and have expensive running costs, compared to Mashrabiya, that have proven highly effective for many years in several fields. They were not limited to the task of cooling alone, but also controlling the light, humidity, airflow, visual privacy, along with aesthetic and social properties, which mechanically driven cooling cannot provide.

In many of these [hot climate] countries, air-conditioning accounts for more than 70% of the national electrical power consumption. However, less than a century ago, the inhabitants of these countries lived in buildings that incorporated only natural-cooling (i.e. far cheaper) techniques for achieving thermal comfort (Batty et al. 1991).

> “When the modern architect replaced these decorative elements with air-conditioning equipment, he created a large vacuum in his culture. He has become like a football player playing football with a cannon. If the purpose of the game is scoring goals, then assuredly he can score a goal with every shot. But the game itself will disappear, and so will any diversion for the spectators, except perhaps in the killing of the goalkeeper.” (Fathy, 1986).

5.1.1.2 Hassan Fathy theories

Thanks to the revered architect Hassan Fathy (Figure 5.2), a resurgence of interest in Mashrabiya has taken place. He did a great deal of research on the origins of traditional architecture and he extracted many important lessons and ideas, which he benefited from later in his architectural applications. Fathy worked on reviving the heritage values and concepts at the level of the foundations, not only as modal vocabularies, but he included in his methodological philosophy the study of history and the advantages of the old tradition in its ability to adapt these principles and experiences intergenerationally, while not losing sight of the present and its requirements, and thus his methodology is logical, acceptable and valid.

He also praised the necessity of dealing with the appropriate technology in order to maintain development, and the need avoid neglecting social factors, as well as the importance of the role of heritage, and the need to re-dedicate the national and local identity through architecture.

Many of his writings reflect his own philosophy towards heritage, the contemporary Arabic architecture and modernity in general, which can be summarized in a set of main points:

- To Fathy, heritage means all inherited experiences and a group of "decisions" that have been taken to solve specific problems in a certain period of history, then those decisions were developed and adapted to serve a community purpose, and the community accepted them unanimously, in stages. Thus they became a relatively constant part of the heritage.

- In Fathy’s vision of modernity, he believed that modernity does not necessarily mean vitality, and that change is not always for the better. Modernity versus heritage as seen by Fathy is to “co-exist at the same time with the other". This concept is in line with the theses of many thinkers in the philosophy of tradition and modernity. It means that modernity does not necessarily include a conscious choice and the exclusion of traditional solutions does not always create evolution (Alsayied, 2010).

- Fathy considered that there is considerable confusion and misuse of the idea of modernity based on chronology; Western architecture subscribed to modernity because it was the most recent in time, compared to Arab architecture to which is attributed the idea of failure, due to its ancient history and originality.

- With the appearance of the sustainable architecture trend, Fathy gave a strong foundation for the return of traditional architectural elements, especially the Mashrabiya. He deemed that traditional architecture is closer to the natural environment rather than the global architecture that swept through the Arab world. The traditional one, in his view, respects and observes the natural environment and all spatial, temporal and social circumstances; it also reflects the requirements and needs of the cultural and civilizational reality.

- In his book (Natural Energies and Environmental Architecture,1986) he shows many of the experiments that he conducted using the traditional vocabularies in the Arab house, like the Mashrabiya; from a scientific basis he studied wind speed and temperature in different parts of Arab houses as examples. He worked hard in his research to include the extent of the complexity of the thermal problems and capabilities of thermal insulation which were achieved in the simplest traditional houses. These buildings efficiently took into account the harsh climatic nature and at the same time preserved the cultural values of local communities and reduced the adverse effect on the environment.

Figure 5.2: The Architect Hassan Fathy (Alsayied, 2010)

5.1.1.3 Mashrabiya as a powerful environmental element

There is multiple, duplicated research concerning the green roof, that makes it seem that it is the only environmental element in current sustainable architecture, while in fact, the Mashrabiya can also play an important part in this field.

This fallacy is partly due to the fact that the studies regarding Mashrabiya were mostly historical and regurgitated theory, scattered and not focused, instead of being practical and more related to direct implementation.

Modern Mashrabiya, the magic of the East and the dynamism of the West, will become an architectural element that is capable of becoming a new feature in sustainable architecture.

The economic and the socio-cultural variables in the Arab region within the recent years, and the ideological and cultural openness to the Western world, has led to sustainability becoming an unavoidable trend in Arab countries.

This trend has taken different modes of expression, which were known as sub trends: modern technology, the neo-traditional, and the contemporary interpretation trend (Abdelsalam and Rihan, 2012). These trends have had a noticeable effect on the Arab architectural identity.

At this point, it is important to point out that the Mashrabiya is presented through contemporary sustainable designs in three ways:

Firstly; it is offered in its original traditional style, using the traditional shape, materials, and characteristics.

Secondly; its concept is displayed through a high-tech solution, where the main function is achieved by using advanced technological means.

Thirdly; a contemporary interpretation of the traditional model is presented relying on new materials, styles and features, while maintaining its original concept (Abdelsalam and Rihan, 2012).

5.2 Discussions of modern Mashrabiya in contemporary projects

The scope of this study includes eight projects which have been completed using modern versions of Mashrabiya; five of them will only be reviewed, while another three projects will be discussed in detail to explore important notes to assist in evaluating them.

Arab world Institute was the first project that used a developed version of Mashrabiya, and even if at first sight its facade might seem as an Arabic decorative, but it is not at the same level with the high perfection in style and craftsmanship of the traditional version .

Compared to the Mashrabiya House in Palestine, there is a huge difference in details, patterns and concept. While in Masdar City, UAE, the modern Mashrabiya was similar to traditional Mashrabiya, without high technology, but by using the large section for balusters. Modern Mashrabiya in many shapes and expressions met with great popular in UAE through a lot of projects such as Abu Dhabi Central Market and Al Bahar Towers / Mashrabiya Towers. The new Mashrabiya has also a widespread within Arab Gulf countries like Doha Tower in Qatar and Ali Mohammed T. Al-Ghanim Clinic in Kuwait.

And the interesting project is Manish Restaurant in Brazil which used the concept of Mashrabiya and mentioned to the Arab inspiration of its facade design.

The five projects will only be reviewed:

- Arab World Institute which is designed by Jean Nouvel (1987) in France.
- Abu Dhabi Central Market which is designed by Foster + Partners (2014) in United Arab Emirates.
- Doha Tower is designed by Jean Nouvel (2012) in Qatar.
- Ali Mohammed T. Al-Ghanim Clinic is designed by AGi architects (2014) in Kuwait.
- Manish Resturant is designed by ODVO architects (2011) in Brazil.

Then the study will be focus on three important examples, they will be discussed in detail, and supplied with general important comments to evaluate the various modern versions of Mashrabiya. Often the modern Mashrabiya has been re-used in accordance with three notable forms, including: the primitive form, the sustainable form, and the form provided with advanced technology. Using these categories, the three projects under discussion are selected as examples (Table 5.1).

Table 5.1: Notable forms of modern Mashrabiya and the chosen examples (Alothman, 2016)

Chosen Examples		
Primitive Form	Sustainable Form	The form which is provided with adv. technology
Mashrabiya House is designed by Senan Abdelqader in Palestine (2011).	Masdar City is designed by Foster+ Partners architects in United Arab Emirates (2015).	AlBahar Towers/ Mashrabiya Towers are designed by Aedas architects in United Arab Emirates (2012).

The methodology of study of chosen examples will be as following (Figure 5.3):

The architect's openions about his project will be displayed firstly, and supplied with important figures of project to compare them to traditional examples of Mashrabiya, and to assist in evaluating each project according with the explanations of functions, patterns, materials and different aspects of optimal Mashrabiya.

The results of this process are recommended to take seriosly, because there are numerous contemporary projects which are under construction and are using the modern Mashrabiya in various ways. These projects are designed by very famous architects like Foster, Zaha and Nouvel, and have an acceptability related to these famous architects; but that only gives an excuse for an abundant number of small, local projects to copy the same mistakes of these well-known projects with regard to the misuse of Mashrabiya and its conversion to a purely decorative element, given that none of the large projects achieve all the functions of Mashrabiya, as will be seen in the discussions of these projects.

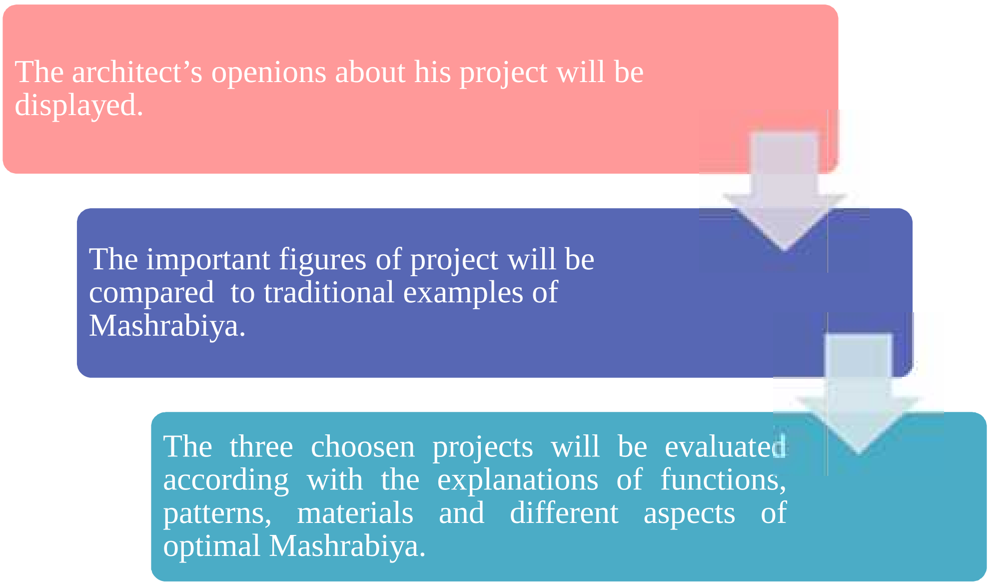


Figure 5.3: Methodology of the evaluative study (Alothman,2016)

This section also sheds light on some projects still under construction :

- Hotel and Residential Tower is designed by Zaha Hadid, and it is scheduled to be completed in 2020 in Qatar.
- The King Abdullah Financial District Metro Station is designed by Zaha Hadid, and it will be completed in 2017 in Saudi Arabia.
- Louvre Museum is designed by Jean Nouvel, and it is supposed to be completed in 2017 in United Arab Emirates.

Besides to a survey of some examples of projects which are located outside the Arab region and which use façades with the same concept as Mashrabiya, but without mentioning the original name.

5.2.1 Arab World Institute

The project is located in Paris, France, completed in 1987 and designed by Jean Nouvel, Architecture-Studio, Pierre Soria and Gilbert Lezenes (Figure 5.4). The main reason to construct this institute was to create a destination devoted to the relationship between Arab culture and France (Figure 5.5).

Figure 5.4: Arab World Institute in Paris, France (Fessy, 2011)

Nouvel was inspired by the details of façades from Mashrabiya, he used its concept to create a shield for the building which uses a technological system containing 27,000 light sensitive diaphragms (Figures 5.6- 5.10). The function of these diaphragms is the same as the Mashrabiya lattice function that regulates the amount of light which can enter the building.

Figure 5.5: The screen is inspired by Mashrabiya in the Arab World Institute, Paris, France (Michler, 2010)

" Visible behind the glass wall, a metallic screen unfolds with moving geometric motifs. The motifs are actually 240 photo-sensitive motor-controlled apertures, or shutters, which act as a sophisticated brise soleil that automatically opens and closes to control the amount of light and heat entering the building from the sun. The mechanism creates interior spaces with filtered light — an effect often used in Islamic architecture with its climate-oriented strategies." (Architecture studio, 2013)

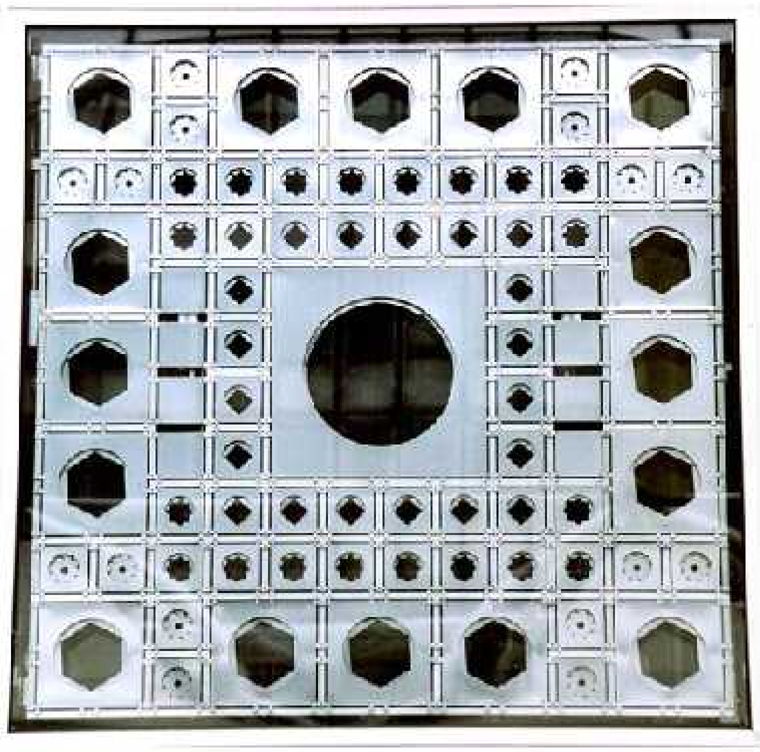


Figure 5.6: Detail illustration of one unit in the façade of the Arab World Institute (Michler, 2010)

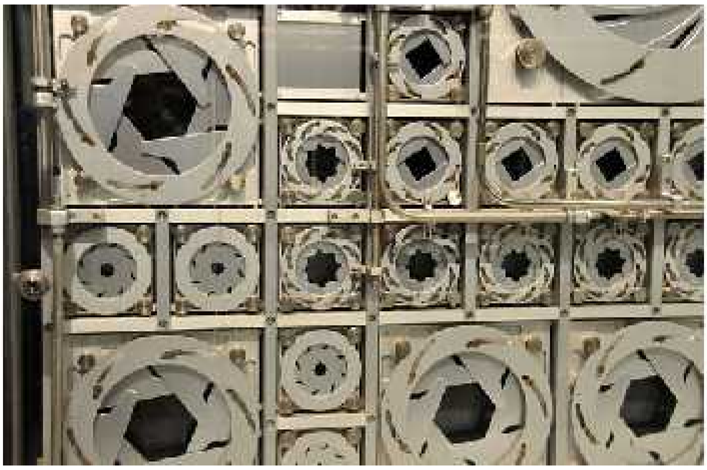


Figure 5.7: An image showing the complex details of the construction of one part of the façade of the institute (James, 1987)

Figure 5.8: An internal detail of the façade (James, 1987)

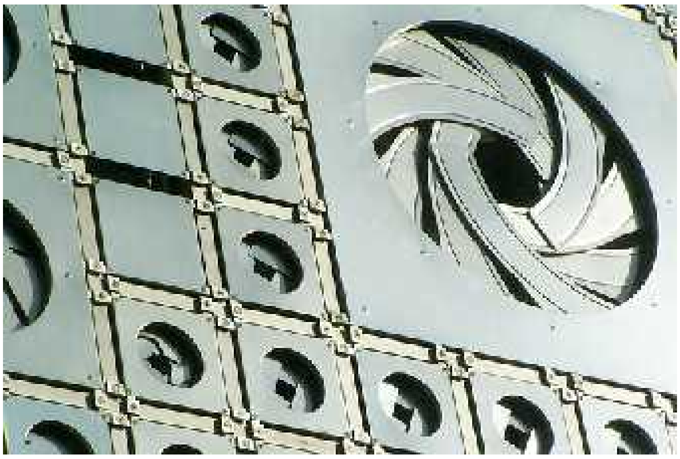


Figure 5.9: An external detail of the façade (James, 1987)

Figure 5.10: A detail of the light sensitive diaphragm (James, 1987)

The architect in this project benefited from the Mashrabiya only in the intricacies and patterns, though the façades with the sensitive diaphragms can filter the light and ensure the visual spectacle. However, they did not play the same efficient role as the traditional Mashrabiya, with regard to the other important functions of airflow and temperature adjustment.

The use of glass walls prevents the airflow through the building (Figure 5.11), and that gives rise to static thermal zones; consequently the internal spaces are required to be climatically adjusted by HVAC units "cooling devices".

At first the structure of the building might seem like an Arabic embellishment, but its functions derive from filtering the daylight dynamically, depending on certain weather conditions (Figures 5.12- 5.13).

Figure 5.11: An image showing the glass curtain walls (Fessy, 2011)

Figure 5.12: Interior view of the library in Arab World Institute (Fessy, 2011)

In this image it can be seen that electric light is used along with natural light during the day, while in the past the traditional Mashrabiya provided enough light for all daily activities.

Figure 5.13: An interior view of one unit in the Arab World Institute (Fessy, 2011)

5.2.2 Abu Dhabi Central Market

The project is located in Abu Dhabi, United Arab Emirates, and was designed by Foster + Partners (2014). This Central Market is one of the oldest sites in the city (Figure 5.14).

The objective of the design was to create a market building inspired by the traditional architecture of the Arab Gulf (Figures 5.15- 5.16), to give the city a new civic heart, by presenting an alternative to the globalised one-size-fits-all shopping mall it, and to provide a featured contemporary interpretation of the local vernacular (Foster + Partners, 2011) (Figure 5.17).

> " Inspired by the traditional architecture of the Middle East,.. different experiences are brought together in a sensory interior palette of dappled sunlight, warm woods, colours and running water. An intimate sequence of streets, alleys, courtyards, balconies and colonnades dissolve barriers between inside and outside, with flexible sliding roofs and walls to enable control of internal environments.... Layers of internal shading on the towers control glare and solar gain." (Foster + Partners , 2011) (Figures 5.18- 5.19).

Figure 5.14: Abu Dhabi Central Market, designed by Foster + Partners (Young, 2014)

Figure 5.15: A view of Abu Dhabi Central Market shows the wooden overlapping façades (Young, 2014)

Figure 5.16: A view showing the pattern which Foster developed with a scholar of Islamic arts (Young, 2014)

Figure 5.17: An image displaying how modern office and residential towers sprout out of The Central Market (Young, 2014)

Figure 5.18: The beautiful interior of Abu Dhabi Central Market (Young, 2014)

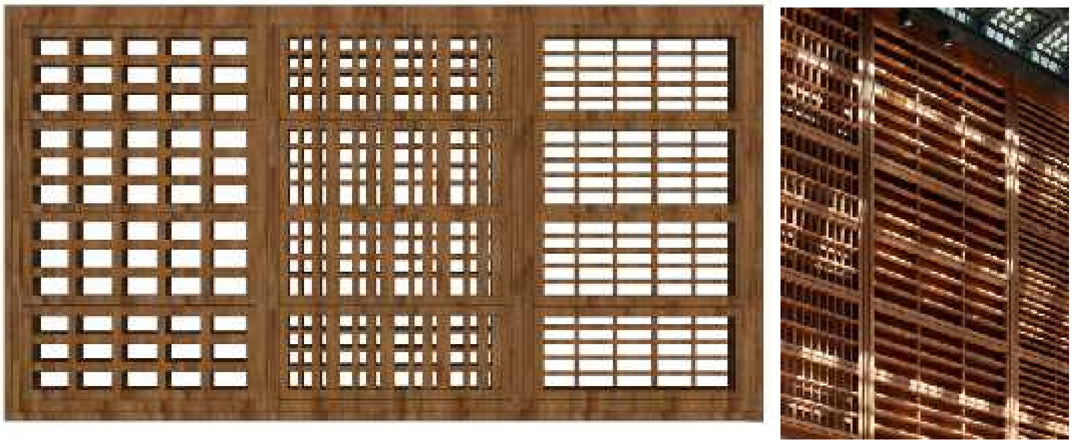


Figure 5.19: Details of Mashrabiya in Abu Dhabi Central Market (Young, 2014)

It is important to state that the architect did not mention façades in this project using the name Mashrabiya, although it seems that he found inspiration and a lot of functional advantages in the traditional Mashrabiya.

5.2.3 Doha Tower

The project is located in Doha, Qatar, completed in 2012 and designed by the French architect Jean Nouvel (Figure 5.20). The building is a massive, rounded cylindrical skyscraper that is characterized by internal reinforced concrete dia-grid columns, while the entire façade is covered with metal brise-soleil based on traditional Mashrabiya.

Figure 5.20: Doha Tower in Qatar (Garrido, 2010)

Nouvel created an innovative design for the façade by using the linear patterns of Mashrabiya and rotating its geometry module then flipping it (Figures 5.21- 5.22), to create a massive screen which can fracture the sunlight and insure maximum shading for the internal spaces (Figures 5.23- 5.24).

> "The design for the system involved using a single geometric motif at several scales, overlaid at different densities along the façade. The overlays occur in response to the solar conditions: 25% opacity was placed on the north elevation, 40% on the south, and 60% on the east and west. From afar, the screen appears as a uniform density, but the intricacy of the layering and scaling of the screens becomes apparent at a closer viewpoint, lending the building multiple textural experiences. Behind the shading layer is a typical curtain wall system that is accessed for maintenance from walkways in the cavity between the two layers. User-operable solar shades are also available behind the glazed curtain wall. The overall façade system is estimated to reduce cooling loads by 20%. At night, an integrated lighting system enhances the delicate screen with programmable light shows." (The skyscraper Center, 2012) (Figures 5.25- 5.29).

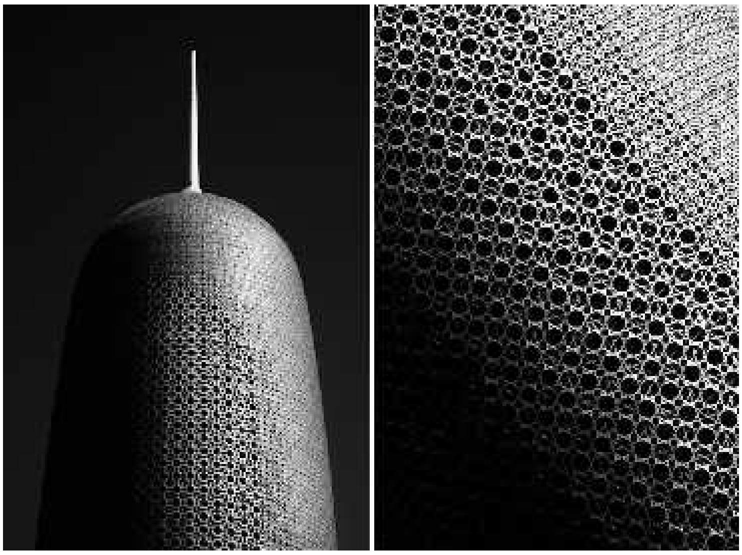


Figure 5.21: Close shots of Doha Tower façade (Courtesy of HBS, 2010)

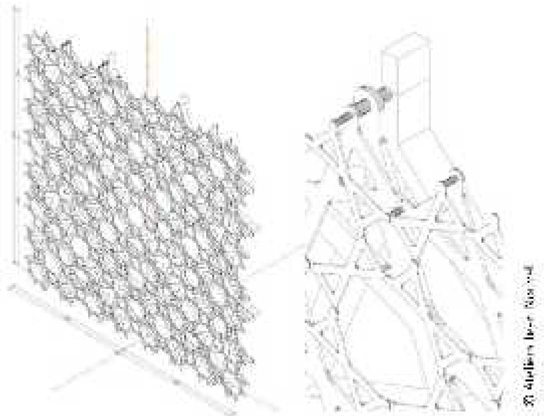


Figure 5.22: Details of the Mashrabiya screen of Doha Tower (Nouvel, 2014)

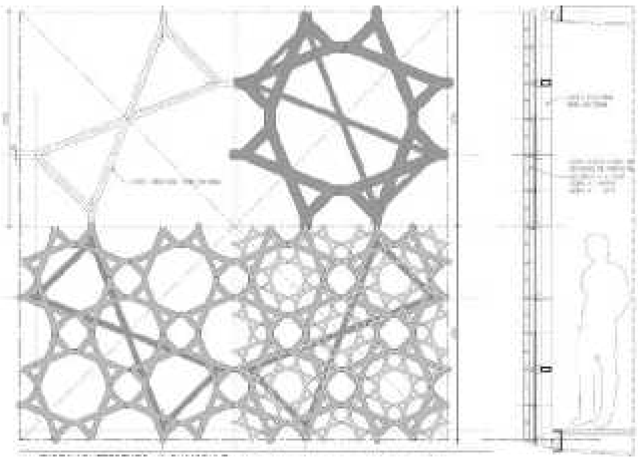


Figure 5.23: Construction details of the screen (Nouvel, 2014)

Figure 5.24: Details of the screen (Garrido, 2014)

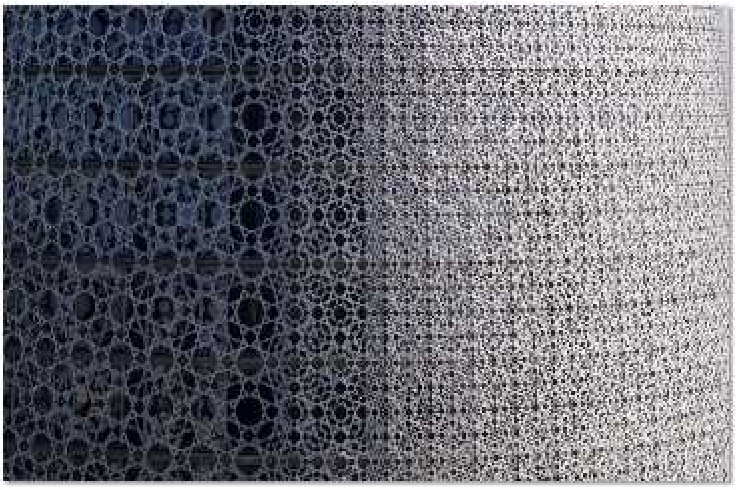


Figure 5.25: An image showing the variation in density in Doha Tower Mashrabiya (Garrido, 2014)

Figure 5.26: Inside the air corridor (Garrido, 2014)

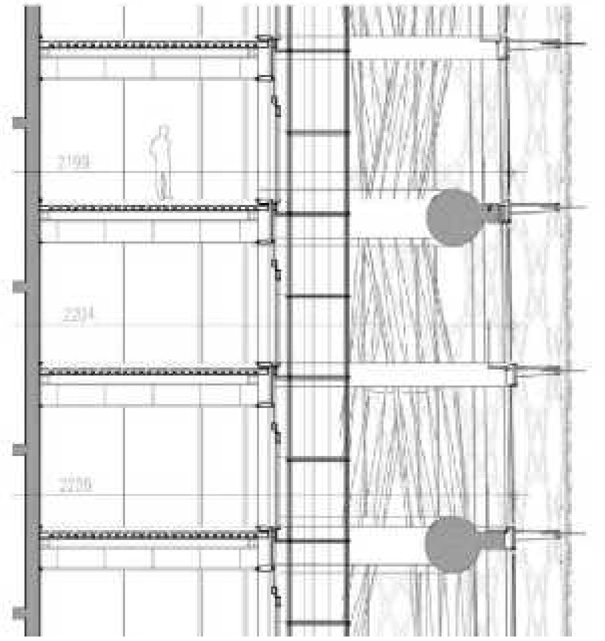


Figure 5.27: Sectional View of Doha Tower (Nouvel, 2014)

The fixed Mashrabiya screen is situated more than a meter from the high performance curtain wall. This is to allow for cleaning access to the space. The metal grating on each floor provides additional shading for the glass.

Figure 5.28: Interior View of Doha Tower Summit (Courtesy of HBS, 2010)

Figure 5.29: A bright interior of Doha Tower (Courtesy of HBS, 2010)

5.2.4 Ali Mohammed T. Al-Ghanim Clinic

The Clinic is located in Kuwait, completed in 2014 and designed by AGi architects (Figure 5.30). The project is characterized in the healthcare sector by addressing matters such as privacy and security through a modern model (AGi, 2014).

Figure 5.30: Ali Mohammed T. Al-Ghanim Clinic (Garrido, 2014)

The concept of the façade seems to be inspired from Mashrabiya, despite the architects not mentioning it by name, they just talked about the role of the façade in generating light, views, ventilation and cultural identity. The same functions provided by traditional Mashrabiya (Figures 5.31- 5.34).

Figure 5.31: A view of the clinic façade (Garrido, 2014)

Figure 5.32: Internal view of the clinic façade (Garrido, 2014)

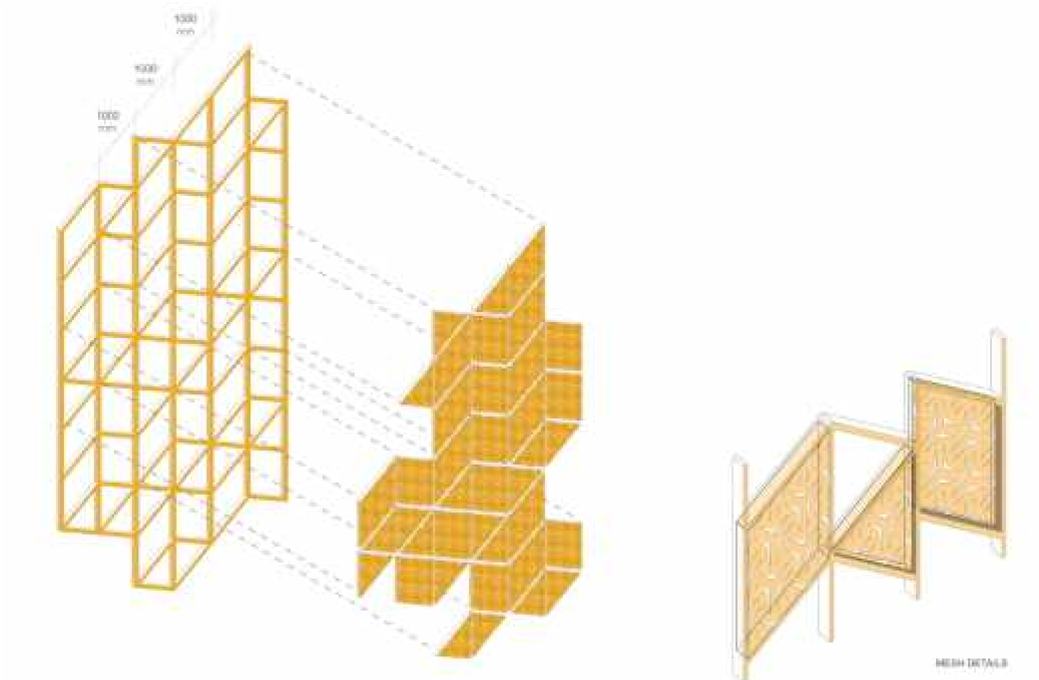


Figure 5.33: Diagram of mesh details (AGi, 2014)

" The metal sheet is split into 1m segments where the punctured mesh is placed into, and works to maintain sufficient sunlight in the interior spaces. When struck by sunlight, the mesh, casts patterned shadows on the courtyards, which give the spaces a calmer tone. The contemporary mesh connects also to the cultural identity of end users.” (AGi, 2014).

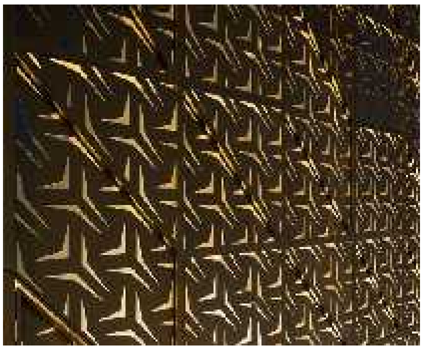


Figure 5.34: A close view of façade (Garrido, 2014)

5.2.5 Manish Restaurant

The project is located in Sao Paulo, Brazil, completed in 2011 and designed by (ODVO arquitetura e urbanismo, Mínima) architects (ODVO, 2011) (Figure 5.35).

Figure 5.35: Manish Restaurant in Brazil (Pregnolato and Kusuki Studio, 2011)

The design of main façade is derived from Arab culture, the whole frontispiece is covered by a muraxabi, an imposing concrete arabesque, which decreases the natural light in small frames and focuses the shadows of the busy street (Figures 5.36- 5.40) (ODVO, 2011)

The architects asserted that they benefited from the functions and decoration of an Arab architectural element, they called it "muraxabi frame," instead of mentioning it by its original name "Mashrabiya" (Figure 5.41).

Figure 5.36: An internal view of the restaurant façade (Pregnolato and Kusuki Studio, 2011)

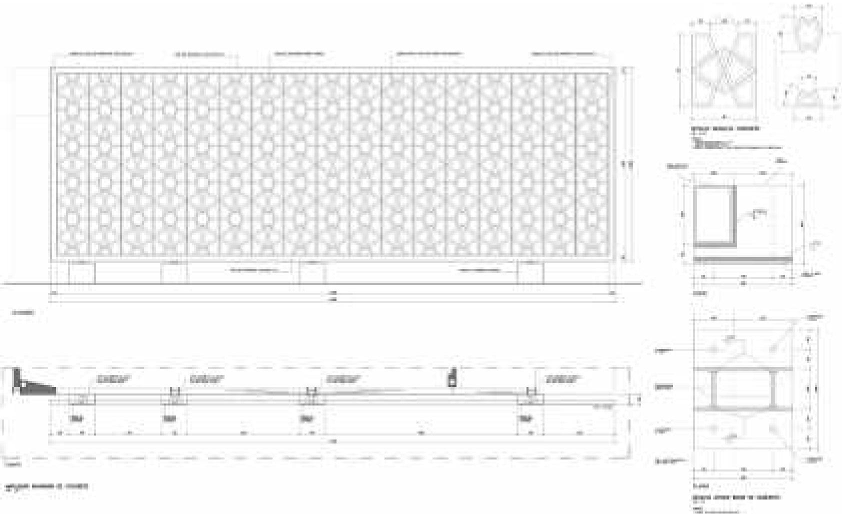


Figure 5.37: Elevation details of the Manish Restaurant (ODVO, 2011)

Figure 5.38: The interior of the restaurant is lit by another glass façade (Pregnolato and Kusuki Studio, 2011)

Figure 5.39: A view shows the courtyard with the decorative façade (Pregnolato and Kusuki Studio, 2011)

Figure 5.40: The interior of the restaurant (Pregnolato and Kusuki Studio 2011)

"We were inspired by the basic elements of Arab architecture, and we tried to translate such traditional elements into a contemporary language and application. The architectural part is thus centered around the development of the components of this kind of architecture: the courtyard, the balcony, the muraxabi frame." (ODVO, 2011).

Figure 5.41: A night view of the restaurant demonstrates the decorative function of the façade (Pregnolato and Kusuki Studio, 2011)

5.2.6 Mashrabiya House

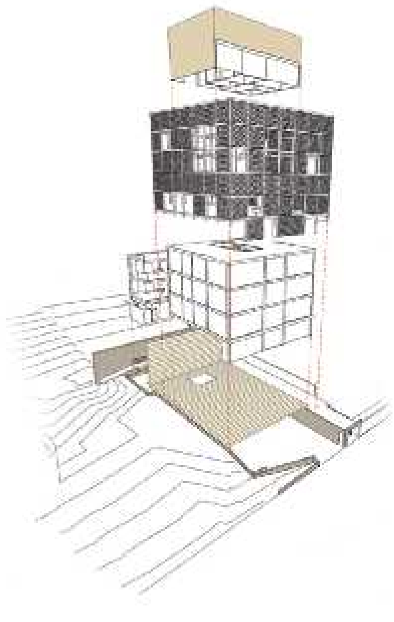
The project is located in the Arab Palestinian village Beit Safafa between Jerusalem and Bethlehem. It was completed in 2011, and designed by the architect Senan Abdelqader (Figure 5.42). The architect asserts that:

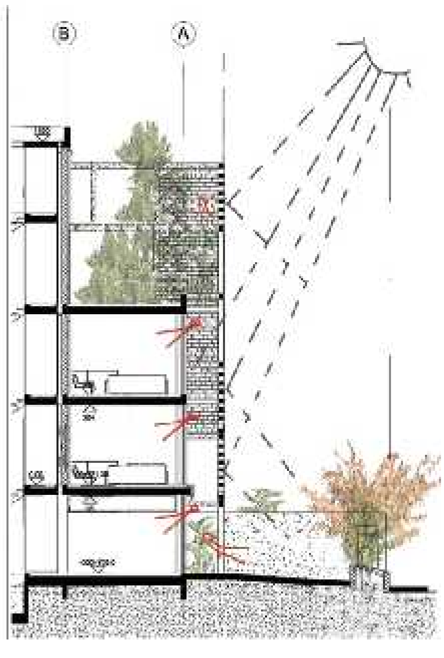
Figure 5.42: The Mashrabiya House in Palestine (Amit, 2011)

The Mashrabiya is employed to provide a floating effect by using a new interpretation, where the wooden lattice is re-imagined in the structure of a stone layer that covers the whole house. The façades are formed using the Mashrabiya concept merged with stone work without any design, parameters or consideration of patterns. The architect, in his use of Mashrabiya just focused upon the effect of light and porosity by adopting irregular spacings between large scale stone pieces. The playful design of the façades by creating small and large openings, ensures views from inside to outside while retaining the required privacy. The architect also considers the Mashrabiya to be an environmental element in this project, he understands that the stone layer which surrounds the whole building works as a climatic buffer (Figure 5.43).

“It helps to absorb heat during the day and release heat during the cool Jerusalem nights. Thus it protects the building against solar radiation as well as winter rain and winds. The gaps between the stones ensure a constant flow of fresh air. A further element of passive cooling is the 1m gap between outer and inner envelop. Not only does it ensure constant circulation of fresh air around the building the fact that it remains open towards the top of the building generates a suction effect like that of a chimney: Hot air travels upwards and fresh air is sucked into the gap from below.” (Abdelqader, 2011).

(a) Illustration of the Mashrabiya House





(b) Illustration of the building layers (c) Section through the Mashrabiya.

Figure 5.43: Illustrations of Mashrabiya House (Abdelqader, 2011)

Table 5.2: Comparison of the Mashrabiya House project to traditional Mashrabiya (Alothman, 2016)

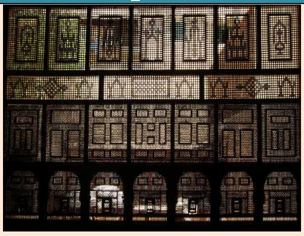
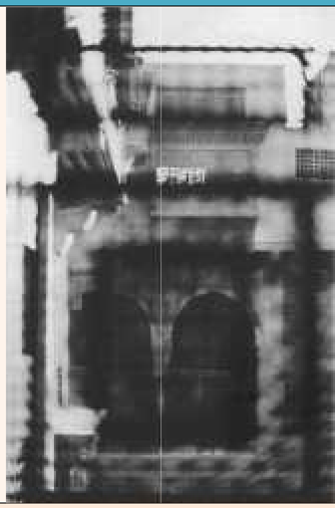
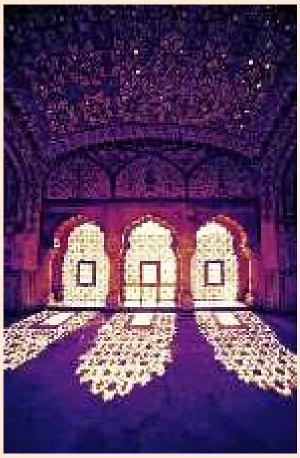
According to	The Detail of Façade of Mashrabiya House	Traditional Examples for Comparison
Light Control		 
Airflow Regulation		
Humidity Control	The stone mass of the outer envelope acts as a climatic buffer because it helps to absorb heat during the day and release heat during the cool night.	Wood is the best material to control humidity, as explained in the previous chapter.
Temperature Regulation	The stone material protects the building against solar radiation as well as winter rain and winds. The constant air flow through the gaps also helps. But that does not mean the stone layer is the main protection, there is another wall formed around the building to protect it from high temperature and winter rain. 	There are many reasons related to the valuable properties of wood that make it the best material for temperature control and adjustment. Plus, the varied sizes of balusters, and calculated spaces between them control the different pressure, airflow and the humidity, all making the traditional Mashrabiya more effective than modern versions, despite the complex details.

Table 5.2 Continued		
Visual Privacy		
Aesthetic Role	  	 

Discussion:

Based on scientific sources and the background information discussed in previous chapters, and comparing to the traditional version (Table 5.2), it is possible for an informed architect to evaluate and discuss any project that includes Mashrabiya, and in discussion of the "Mashrabiya House" project, some important comments can be made:

- The project in general looks like a primitive project using the concept of Mashrabiya; but it does not apply the correct terms which are related to the functions, patterns and design parameters of Mashrabiya. It is much closer to the designs of Tropical Space architects that use terracotta and baked-brick materials, positioning the blocks in irregular spacings, as seen in the Termitary House and Terracotta Studio projects in Vietnam.

- The special design of the walls filled with a lot of holes needs careful examination of the light issue, it would seem that there is no study to into how to provide light to all corners of the house, even in the easiest-to-access areas, because the project is a fully-fledged house with concrete walls and glass windows, which has then been coated with a layer of stone. As a result, the outer layer does not seem to be part of the main design.

- Daylight is only reduced in irregular ways, compared to traditional Mashrabiya which creates an effective reduction of glare and blocks direct light by careful calculation of the spaces between the balusters in the façade.

- The irregular spacing between the stone pieces in the façades of modern projects provide airflow movement, but it is still not as efficient as the studied spacing between the balusters in the traditional Mashrabiya, which provides more appropriate, comfortable airflow.

- Wood is known to be more efficient than stone in the absorption and evaporation processes.

- The use of a confused arrangement of spacing and large openings between the stone panels creates the gaps which provide the airflow, but conversely they are not able to help in cold or wet weather, or even in situations of direct sunlight. This means the internal spaces need another layer for protection.

- It is important to notice how the view to the outside is almost completely closed off in the modern project, while it is clearly obvious in the traditional Mashrabiya.

- In the modern project there are no aesthetic decorative features, like patterns or carved decorations, which distinguishes the traditional Mashrabiya.

- For the internal aesthetic effect, traditional Mashrabiya draws the most beautiful reflection of the sun onto the interior floors and walls, while the modern version in this project has no featured reflection. From inside it seems like any modern house. More importantly, the Arab identity of the style is lost in this modern version.

- The modern details seem so simple and modest compared with traditional details.
- The cost of stone might cheaper, but it should take into account the costs of construction of the double layers of walls in Mashrabiya House.

- As mentioned in the previous chapters, any alternative materials need to have similar properties to wood; it should be durable, easily produced in quantity, and able to cope with extremes in humidity and temperature, along with the possibility of expressing some aesthetic value.

5.2.7 Masdar City

The project is located in the city of Abu Dhabi, in the United Arab Emirates (2007, 2015), and designed by architects Foster + Partners. Masdar city is considered the first sustainable city in the Arab world (Figure 5.44), providing superb examples of the use of advanced technology in sustainable architecture while attempting to preserve Arab identity in some aspects, especially in the design of the apartments (Figure 5.45).

Figure 5.44: Masdar City in UAE (Courtesy of Foster + Partners, 2010)

Figure 5.45: The Residential Units in Masdar City, UAE
(Foster + Partners, 2010)

"The buildings have self-shading façades and are orientated to provide maximum shade as well as sheltering adjacent buildings and the pedestrian streets below... Windows in the residential buildings are protected by a contemporary reinterpretation of Mashrabiya, a type of latticed projecting oriel window, constructed with sustainably developed, glass-reinforced concrete, colored with local sand to integrate with its desert context and to minimize maintenance. The perforations for light and shade are based on the patterns found in the traditional architecture of Islam." (Foster + Partners, 2010) (Figure 5.46-5.48).

Figure 5.46: Terracotta façade of student dormitories (Caine , 2014)

Figure 5.47: A detail of one apartment façade before fixture to the building (Foster + Partners, 2010)

Figure 5.48: A public courtyard framed by student dormitories for Masdar (Caine, 2014)

The buildings at Masdar combine various materials and construction strategies to reduce heat gain, for example, including terracotta cladding, metal screening and air-filled wall panels, like Foster's metal screen for solar shading inspired by Mashrabiya. While metal screens are used to filter sunlight, air-filled wall panels were designed to minimize the thermal mass of a building's exterior envelope and reflect the light away (Foster + Partners, 2010) (Figure 5.49).

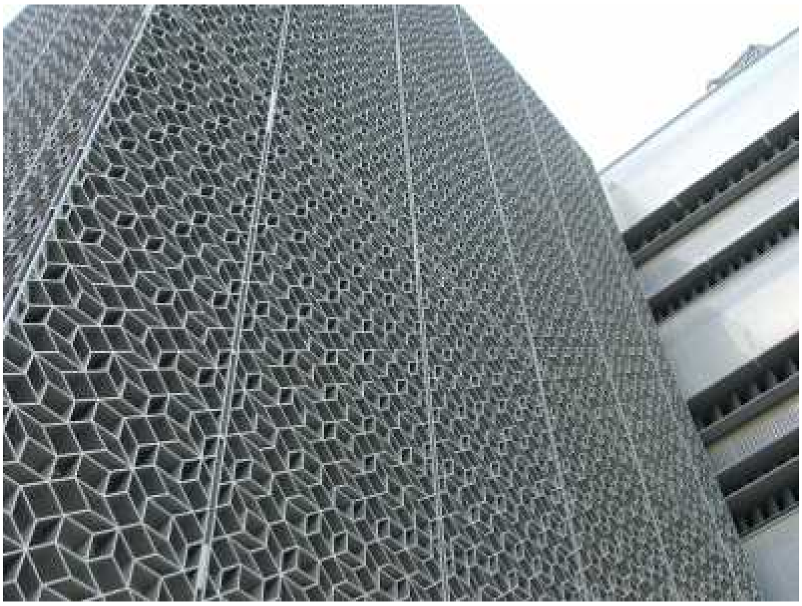


Figure 5.49: Foster's metal screen for solar shading inspired by iconography of local culture (Caine, 2014)

Table 5.3: Comparison of Mashrabiya in Masdar City to traditional Mashrabiya (Alothman, 2016)

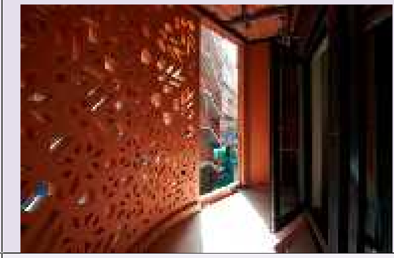
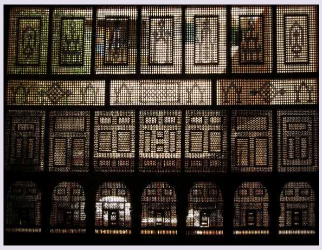
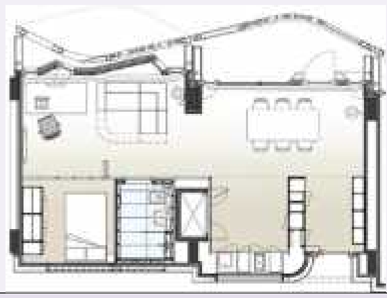
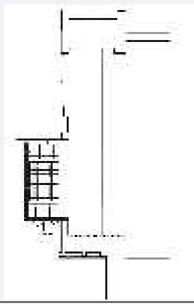
According to	The Detail of Façade of Masdar City	Traditional Examples for Comparison
Light Control	 	 
Airflow Regulation	 	 
Humidity Control	The materials chosen to deal with humidity are effective, especially the use of palm wood along with the terracotta cladding.	Wood is the best material to control humidity.
Temperature Regulation	The project relies on material and construction strategies for reducing heat gain, including terracotta cladding, metal screening, air-filled wall panels and timber for screens in some areas . In addition the use of a courtyard concept works effectively with the Mashrabiyas around it . In the atria, a thermal stack and exposed thermal mass, help to provide passive cooling.	Many reasons related to the beneficial properties of wood make it the best material for temperature adjustment, additionally the studied sizes of balusters, and calculated spaces between them to control the different pressure , airflow and humidity makes the traditional Mashrabiya more effective than modern versions despite the complex details.

Table 5.3 Continued		
Visual Privacy		
Aesthetic Role	   	 

Discussion:

Even if the aims of the project were seek to revive Arab identity by using some architectural elements inspired by Arab heritage, the Mashrabiya in this case has not been constructed using the correct terms.

In accordance with explanations of the functions, patterns, materials and different aspects of optimal Mashrabiya (Table 5.3), it is important to mention the following points:

- Although direct sunlight is blocked in the modern project, the problem of glare seems not to have been considered, especially in the use of the large sections for the Mashrabiya layer details, compared to traditional Mashrabiya which efficiently reduces the glare through the use of fine rounded balusters.

- The Mashrabiya in the modern project covers the balcony area, so the airflow is reasonably well dealt with, but in the internal spaces of the building this is somewhat reduced because of the other wall behind the Mashrabiya. The traditional Mashrabiya uses sliding internal shutters which can be opened or closed without blocking the airflow.

- The modern project tries to emulate the traditional version in the humidity adjustment function, thanks to the use of palm wood and the terracotta cladding.

- A careful study of traditional techniques in cooling was obvious in the modern project, despite using some technological systems, the merging of the methods was creative.

- It is worth noticing how the view to the outside is not clear enough, as found in the traditional Mashrabiya.

- The modern version of Mashrabiya relies on large sized partitions and large spacing, compared to the fine rounded balusters of traditional Mashrabiya.

- The perforations for light and shade in modern Mashrabiya are based on the patterns found in the traditional architecture of Islam, but because of the use of large sizes in the design, the internal aesthetic effect is less successful, while the traditional Mashrabiya draws the most beautiful reflection of the sunrays and shadows on the internal floors and walls through its fine, beautiful lattice.

- As for the beautiful carving design of the modern Mashrabiyas, it emulates the aesthetic of ancient models.

- The modern version of this project re-uses the spatiality factor of traditional Mashrabiya by creating a prominent space that is similar to the space of an optimal Mashrabiya .

5.2.8 Al Bahar Towers / Mashrabiya Towers

The towers are located in Abu Dhabi, United Arab Emirates, completed in 2012 and designed by Aedas Architects (Figure 5.50). The project aims to create an outstanding landmark which to express the Arab architectural heritage, conjointly with contemporary and sustainability principles by using modern technology.

Figure 5.50: Al Bahar Towers/ Mashrabiya Tower in Abu Dhabi, UAE (Aedas, 2012)

The Architects designed for this project a creative, responsive façade which is derived from the cultural cues taken from Mashrabiya (Figure 5.51). The computational design team at Aedas developed the shading system based on traditional Mashrabiya, and have created a real innovation in the design of an interesting external, automated shading system which encases the building as a dynamic façade, imagined as a modern interpretation of Mashrabiya. The system contains about 2000 umbrella-like modules per tower controlled by photovoltaic panels (Figure 5.52). The team used a parametric depiction of traditional Mashrabiya for the geometric design of the actual façade panels, and they made these panels responsive to sun exposure and able to alter the angles of incidence during the different times/days of the year (Cilento, 2012).

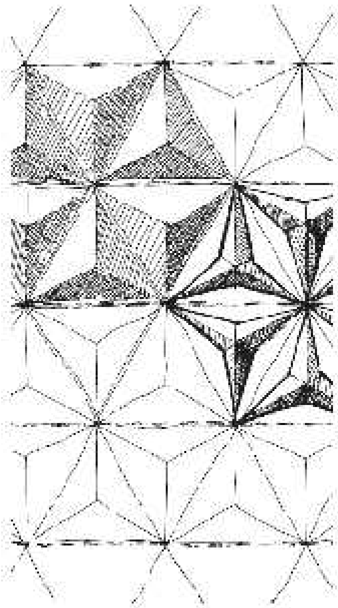


Figure 5.51: Initial Design Sketch of Al Bahar Towers Façade (Aedas, 2012)

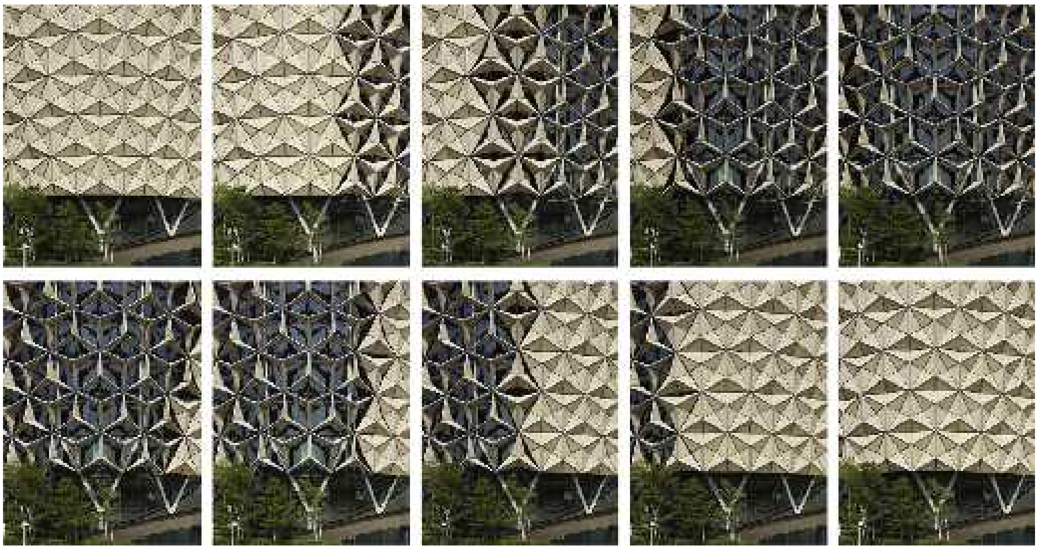


Figure 5.52: The Opening Sequence of Mashrabiya Towers Façade (Richters, 2012)

The façade works as a curtain wall, positioned two meters around the buildings' exterior on a separate frame. Each triangle is plated with fiberglass and programmed to respond to the movement of the sun as a method of decreasing solar gain and glare. In the evening, all the units of the façade close (Figure 5.53) (Cilento, 2012).

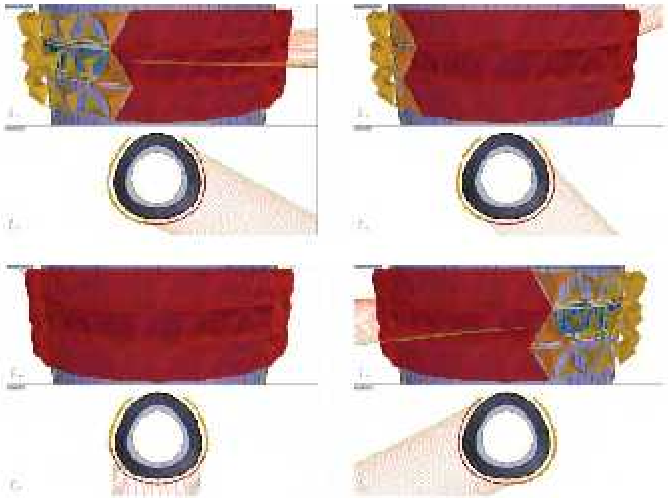


Figure 5.53: Solar analysis diagrams (Aedas, 2012)

> "At night they will all fold, so they will all close, so you'll see more of the facade. As the sun rises in the morning in the east, the Mashrabiya along the east of the building will all begin to close and as the sun moves round the building, then that whole vertical strip of Mashrabiya will move with the sun." (Oborn, 2012) (Figure 5.54).

Figure 5.54: A night view of Al Bahar Towers (Aedas, 2012)

The Mashrabiya façade at Al Bahar Towers includes a series of transparent umbrellas that could be opened and closed in response to the sun's path. Each of the two towers has over 1,000 independent shading devices that are driven by the building management system, forming an intelligent façade (Figures 5.55-5.56) (CTBUH, 2012).

Figure 5.55: Comparison of shading units fully closed (left) and fully open (right) (Aedas, 2012)

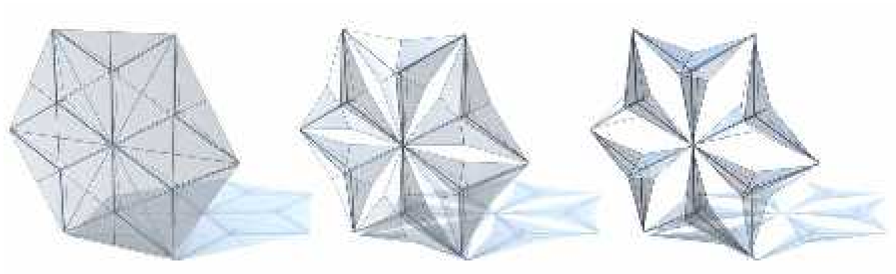


Figure 5.56: Responsive Façade (Aedas, 2012)

Each unit consists of a series of stretched PTFE (polytetrafluoroethylene) panels, and it is operated by a linear actuator that will gradually open and close once per day in response to a pre-programmed succession that has been calculated to block direct sunlight and to limit direct solar gain to a maximum of 400 watts per linear meter (CTBUH, 2012) (Figures 5.57-5.61).

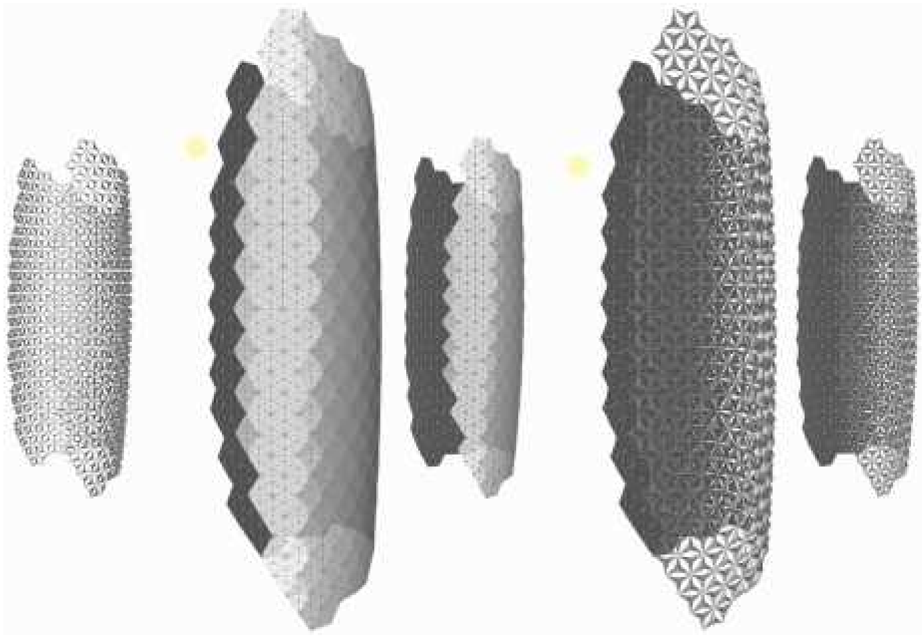


Figure 5.57: Responsive Façade (Aedas, 2012)

“The advantage of this approach is the avoidance of dark tinted glass which inevitably restricts incoming light all of the time rather than just problematic direct sunlight at certain times of day. Instead, these dynamic shades let daylight in for part of the day allowing the use of artificial lighting and air conditioning in the interior can be significantly reduced. The result is a 50% reduction in energy consumption within the twin towers and an 80% reduction in solar gain." (Welch, 2013) (Figure 5.62).

Figure 5.58: Overall view from the north (Aedas, 2012)

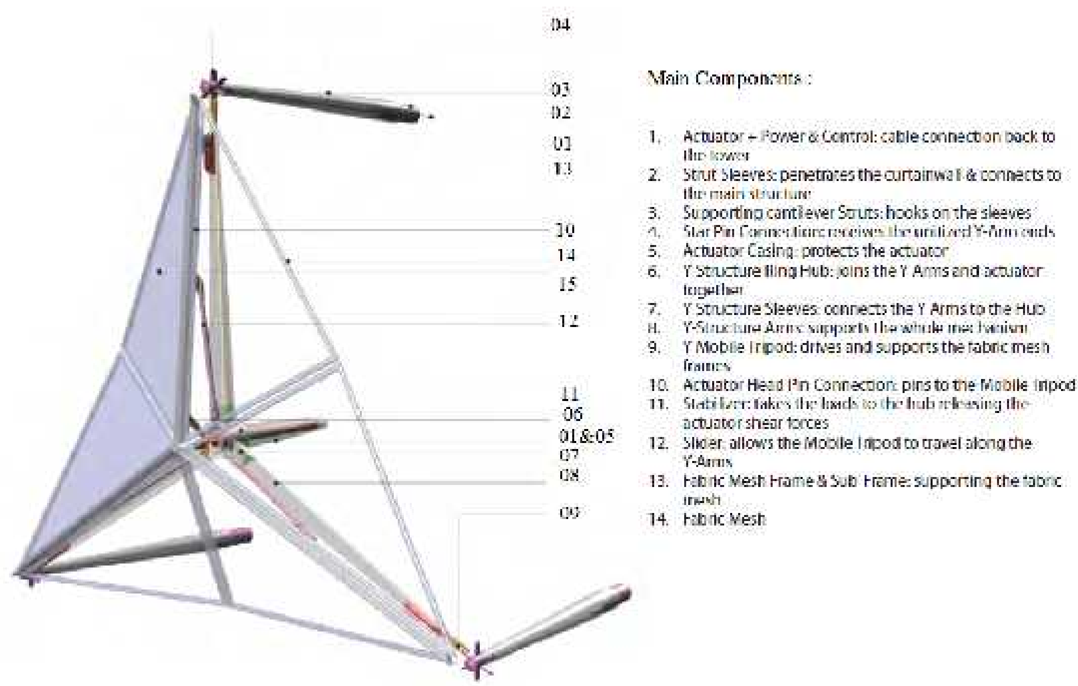


Figure 5.59: Detailed diagram of an individual shading device (Aedas, 2012)

Figure 5.60: Detail View of Shading Units (Aedas, 2012)

Figure 5.61: Detailed view of shading units showing the inspired pattern (Aedas, 2012)

The impact of this system includes :

- Decreased glare.
- Improved daylight permeation.
- Less dependence on electrical lighting and cooling.
- Over 50% reduction in solar gain, which leads to a reduction of CO_2 emissions by 1,750 tonnes per year (CTBUH, 2012).

> ”It (the screen) allows us to use more naturally tinted glass, which lets more light in so you have better views and less need of artificial light. It’s using an old technique in a modern way, which also responds to the aspiration of the emirate to take a leadership role in the area of sustainability.” (Oborn, 2012).

Figure 5.62: 3D View shows double layers that cover the building (Aedas, 2012)

Table 5.4: Comparison of Mashrabiya in Al Bahar Towers to traditional Mashrabiya (Alothman, 2016)

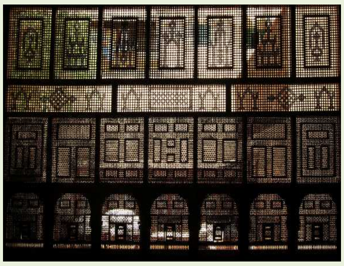
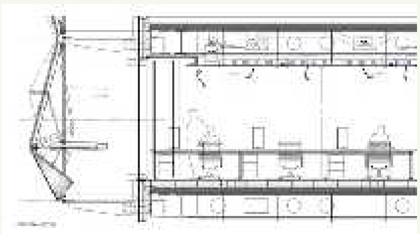
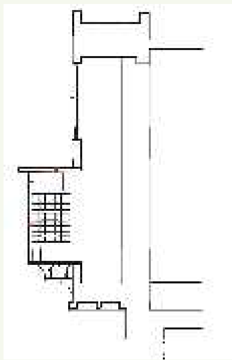
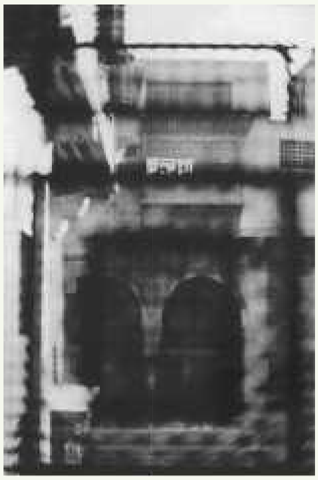
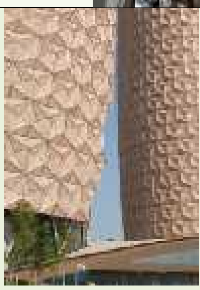
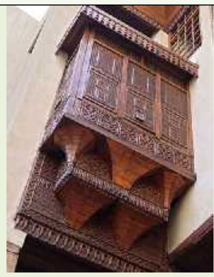
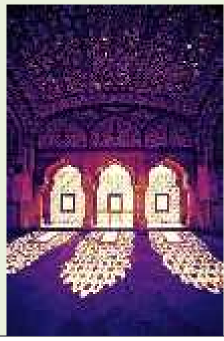
According to	The Detail of Façade of Al Bahar Towers	Traditional Examples for Comparison
Light Control	 	 
Airflow Regulation	   The best use of the Mashrabiya concept in this project is the façade, was designed to protect the entire installation by a variety of sensors that will open the units in the event of overcast conditions or high winds.	 

Table 5.4 Continued		
Humidity Control	Steel material which is formed the façade doesn’t have any effect on humidity control factor. Besides the research study of this project did not mention any humidity considerations .	Wood is the best material to control humidity.
Temperature Regulation	The project is based on advanced technology and an intelligent system to reduce excessive heat gain and block direct sunlight to minimize the resulting rise in temperature, but it should pay more attention to the properties of the materials used concerning heat gain; normally the use of steel and glass materials cause a rise in temperature.	Many reasons related to the beneficial properties of wood make it the best material for temperature adjustment, additionally the studied sizes of balusters, and calculated spaces between them to control the different pressure, airflow and the humidity makes the traditional Mashrabiya more effective than modern versions, despite the complex details.
Visual Privacy	 	
Aesthetic Role	  	 

Discussion:

This project has widespread popularity within architectural magazines, but that does imply that it is a perfect project. The evaluation of any project should not be dependent on popularity alone, but it should rely on its validity and the application of correct design standards, as well providing the required functionality without an exaggeration in construction cost. Unfortunately, in accordance with the functions and rules that have been explained before in chapters 3 and 4, and comparing to the optimal version of Mashrabiya (Table 5.4), there are many important comments that ought to be made in order to wisely evaluate the modern version of Mashrabiya in this project:

- The modern Mashrabiya succeeded in reducing incoming daylight at all times, but by a solar-responsive dynamic shading screen which was very expensive, due to the advanced technology, compared to the traditional version that has a high efficiency in light/heat control and it is considered a a difficult rival in this field .

- When the shade units close the airflow moves through them, but the fixed glass layer behind, blocks it completely, therefore creating static thermal zones, meaning the internal spaces need to be climatically regulated by means of HVAC units.
- When the units stretch and form a curtain wall, the airflow is almost completely blocked, as compared to the traditional Mashrabiya lattice which is always open, and supplied with sliding internal shutters of glass which can be opened for more ventilation or closed to avoid dust or excessive coolness.

- The modern project does not benefit from the humidity adjustment function of traditional Mashrabiya.

- The modern Mashrabiya in this project is considered a creative suggestion for more responsive and dynamic solutions to climactic conditions, especially in the reduction of heat gain and the creation of a more comfortable internal environment for occupants. But this is achieved at a high cost, compared to traditional Mashrabiya techniques, apart from which air conditioners are still required in the modern project.

- The view to the outside is obvious enough when the units are folded back, and is blocked when they are stretched, while it is always visible and clear through the traditional Mashrabiya .

- The modern interpretation of Mashrabiya provides a powerful visual impact, at first sight it might seem like an Arabic decorative design in the folded units, but the opposite is true as the buildings appear to be to solid masses that are coated with a parameter surface.
- For the internal aesthetic effect, the traditional Mashrabiya draws the most beautiful reflection of the sunrays and shadows on the internal floors and walls, compared to the modern version.

- The details of the modern Mashrabiya seem more complex and much more expensive, compared to traditional design, despite the fact that modern Mashrabiya does not achieve all the traditional functions, which are achieved at a lower cost and with simpler techniques, even though they may seem primitive.

- As mentioned in previous chapters any alternative materials need to have similar properties to wood; they should to be strong, easily produced in quantity, able to cope with extremes in humidity and temperature, as well as capable of expressing certain aesthetic values.

5.2.9 Projects under construction

5.2.9.1 Hotel and residential tower in Qatar

The hotel and residential tower is designed by Zaha Hadid, and scheduled to be completed in 2020, with subsequent phases of the Lusail City Master plan to be announced at a future date (Lynch, 2016) (Figure 5.63).

Figure 5.63: Hotel and Residential Tower in Qatar
(Courtesy of Zaha Hadid Architects, 2013a)

The façade design is derived from the traditional Mashrabiya element, to protect the building from temperatures by decreasing solar gain. The tower's fluid form and calligraphic, geometric patterns also gain inspiration from the Arab architectural heritage, creating innovative relationships between program elements by connecting domes to ceilings, ceilings to walls, and walls to floors (Lynch, 2016) (Figure 5.64).

Figure 5.64: The base of the tower (Courtesy of Zaha Hadid Architects, 2013a)

5.2.9.2 The king Abdullah financial district metro station in Saudi Arabia

The project is located in Riyadh, Saudi Arabia, and designed by Zaha Hadid. It will be completed in 2017 (Figure 5.65). The façades seem to be inspired by Mashrabiya in their patterning, and also providing the same functions of Mashrabiya, with regard to reducing solar gain (Figure 5.66) (Rosenfield, 2013).

Figure 5.65: The King Abdullah Financial District Metro Station in Saudi Arabia (Courtesy of Zaha Hadid Architects, 2013b)

Figure 5.66: The Façades of the King Abdullah Financial District Metro Station (Courtesy of Zaha Hadid Architects, 2013b)

5.2.9.3 Louvre museum in United Arab Emirates

The project is located in Abu Dhabi, United Arab Emirates, and designed by Jean Nouvel. It is supposed to be completed in 2017 (Figures 5.67- 5.68).

Figure 5.67: Louvre Museum in United Arab Emirates (Nouvel, 2013)

It is a project founded on a major concept of Arab architecture related to the dome and Mashrabiya. However, there is an evident shift from tradition, to a modern perspective (Castro, 2016).

> "The museum is covered by a white dome of 590 feet (180 meters) in diameter, which is an emblematic feature of Arabian architecture, evoking mosque and mausoleum. The dome's seemingly random but carefully designed arrangement of geometric openings was inspired by the interlaced palm leaves traditionally used as roofing material. The apertures will make it possible to control the light and temperature inside. The interior will be illuminated by an enchanting, shifting 'rain of light', reminiscent of Mashrabiya and the beams of light that illuminate souks." (louvre Abu Dhabi.ae, 2014) (Figures 5.69- 5.76).

Figure 5.68: Roof plan with dome (Nouvel, 2013)

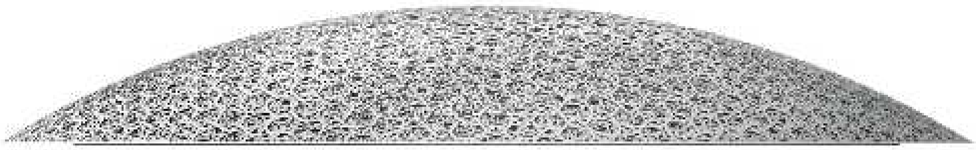


Figure 5.69: Dome exterior elevation (Nouvel, 2013)

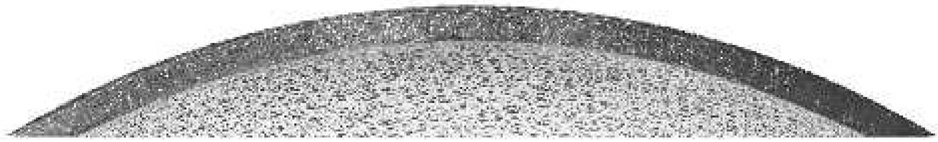


Figure 5.70: Dome transverse section (Nouvel, 2013)

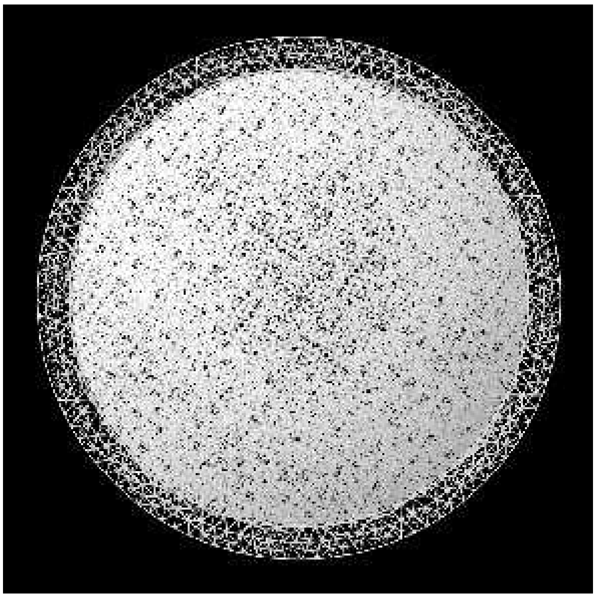


Figure 5.71: Dome pattern (Nouvel, 2013)

Figure 5.72: A view of the dome under construction (Nouvel, 2013)

Figure 5.73: A woven double dome creates an interior skin of dappled light (Nouvel, 2013)

Figure 5.74: Bursts of sunlight permeate interior galleries (Nouvel, 2013)

Figure 5.75: The interior air circulation promotes a cool, garden effect (Nouvel, 2013)

Figure 5.76: Interior view (Nouvel, 2013)

Figure 577: The spread of modern Mashrabiya (Alothman, 2016)

5.3 Projects using geometric panels

As previously mentioned, there are many modern projects that have benefited from the concept and functions of Mashrabiya without mentioning it by name, like the Central Market Abu Dhabi, Al-Ghanim Clinic, Manish restaurant, The King Abdullah Financial District Metro Station and the Hotel and Residential Tower in Qatar. The architects of these projects just pointed out that their inspiration for these façades came from traditional local culture (Figure 5.77). On the other hand, the same façades, with the same functions have been used in countries outside the Arab region using totally different names and without even any mention of Arab culture, like the façades of the Birmingham Library in United Kingdom (Figures 5.78- 5.81). It was designed by Mecanoo architects in 2013.

Figure 5.78: Birmingham Library designed by Mecanoo Architects (Richters, 2013)

Concerning their research about the façade design, in an article in Archdaily Magazine published on 29 August 2013, the architects explained:

> “The Library is a transparent building, it maintains energy efficiency through the buffering capacity of the building mass and the atria. Sun shading and reflective materials within the façades block the harsh rays of the sun during the height of afternoon while allowing natural daylight into the interiors. The building will incorporate a mixed mode and natural ventilation strategy. The façade will respond to external conditions and openings which will allow fresh air intake and outflow.” (Mecanoo architects, 2013).

This means that the interfaces achieve the same functions as Mashrabiya and have the same concept and features, except for the convergent decorative features, but without any mention of Mashrabiya .

Figure 5.79: A view of the library (Richters, 2013)

The views show how the library and its façades seem not to belong to the cultural environment, regarding the traditional style of the surrounding buildings. It seems more like an Arab decorative building.

Figure 5.80: A close shot showing the details of the façade pattern (Richters, 2013)

Figure 5.81: Interior view of the library (Richters, 2013)

In the evaluation of the project described in the following Figures 5.82- 5.88, similar to the discussion of the Birmingham Library, it can be seen that the use of the Mashrabiya concept to design the interfaces, either in the functions or decorative patterns or both, are referred to by the architects as simply geometric panels.

Figure 5.82: Hamersley Road Residence in Australia 2014, designed by Studio53 (Sprogoe and Maher, 2014)

Figure 5.83: The interface of Mozza restaurant in Sao Paulo was designed by the Brazilian architect Arthur Casas in 2010 (Fernando Guerra FG+SG , 2010)

Figure 5.84: Interior view shows the light adjustment through the façade (Fernando Guerra FG+SG, 2010)

Figure 5.85: Blairgowrie House in Australia in 2013 by Wolveridge Architects (Swalwell, 2013)

Figure 5.86: W-House in Netherlands in 2005, designed by/ VMX Architects (Musch, 2013)

Figure 5.87: La Tallera in Mexico (2010), designed by Frida Escobedo (Gamo, 2010)

Figure 5.88: An interior View of La Tallera (Gamo, 2010)

By comparing the façades of the previous projects to the Mashrabiya, many critical questions need to be considered in order to distinguish the difference between the real thing and the ‘fake’.

Who is the inventor of the geometric panels? How did the idea start? What is the country of origin? In which year? What are their rules and design criteria?

The absence of any references may give us an answer to these axiomatic questions; it makes the idea of geometric panels closer to being an example of high fashion in architecture, not as an environmental architectural element in itself!

How did people wake up to find these screens in the architectural markets? To what extent do the geometric panels help to create a new trend in architecture with original criteria and a documented history? However, nothing compares with the authenticity of Mashrabiya, as evidenced in the documented studies in the previous chapters, therefore the main reason for this gap in the geometric panels issue, may be due to the fact that they are obviously inspired by the heritage of Mashrabiya, but are not prepared to admit it !

5.4 Comments and important points

This section raises many comments with reference to the previous discussions of the modern projects, each comment as a discrete, important point needs to be taken into account.

- Any modern Mashrabiya is acceptable even if it doesn’t achieve all the functions, but it should provide effective, calculated light regulation with one other environmental function as a minimum. Nowadays there is a prevalent misuse of Mashrabiya through a lot of small, local projects in the Arab region, where Mashrabiya has been transformed into a merely decorative, aesthetic element, such as the project shown in the following figures. This is Al Hokair administration building in Riyadh, Saudi Arabia, its façades full of Mashrabiyas (Figures 5.89- 5.90).

Figure 5.89: Al Hokair administration building in Riyadh, Saudi Arabia (Alothman, 2016)

Figure 5.90: A close view of the Mashrabiya (Alothman, 2016)

The Mashrabiya in this project acts as a decorative element designed with a uniform pattern using large scale interstices between the balustrades, covering the entire aperture from top to the bottom. This is not consistent with the function of light adjustment found in traditional Mashrabiya, which relies on the diversity in scale between the narrow interstices at eye level and the wider ones in the upper section. As mentioned before, this criterion not only controls the light, but also supplies airflow circulation between the different zones of pressure through a variety of lattice density. In the same way the airflow rate is directly affected by changes to the porosity of the lattice (See chapter 3).

- Modern projects have revived the concept of Mashrabiya but also changed many of its parameters, and it is probably worth noting that the architects have sometimes ignored the implementation of proper standards, especially regarding the baluster section which needs to be circular, or should be based upon a derivation of the circular section, to ensure that shadow diffusion is retained.

In some modern designs the Mashrabiya is no longer composed of those fine rounded balusters, it has been replaced by a massive, perforated wall inspired by Mashrabiya style, but is nothing like the fine wooden lattice that looks like a layer of lace.

Therefore, glare reduction through the square section of these massive Mashrabiya is unrealized, except in cases where glass is used.

- For the visual privacy aspect, the relationship between people and the outdoors is no longer evident in the use of modern Mashrabiya, where a glass layer is placed behind the main façade, creating what is known as double skin façades.

- Traditional Mashrabiya covered a space that had functions such as a stand for water jars or a seat for ladies to look outside. But the modern version, in using a double skin façade system, simply creates a narrow space without any function.

- Modern projects mostly rely on the double skin façade system (Figure 5.91) that blocks any airflow and creates static thermal zones, meaning the buildings still need to be climatically regulated by means of cooling devices; while the traditional Mashrabiya uses sliding internal shutters which can be opened for more ventilation or closed to avoid dust or excessive coolness, and fixed glazed panels are located in the upper section, just to provide more daylight without any effect on airflow rate (Figure 5.92).

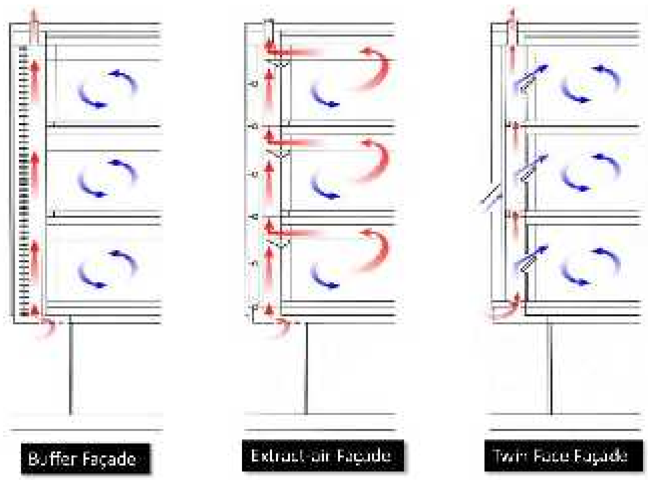


Figure 5.91: Double Skin Façade Types (Boake, 2014)

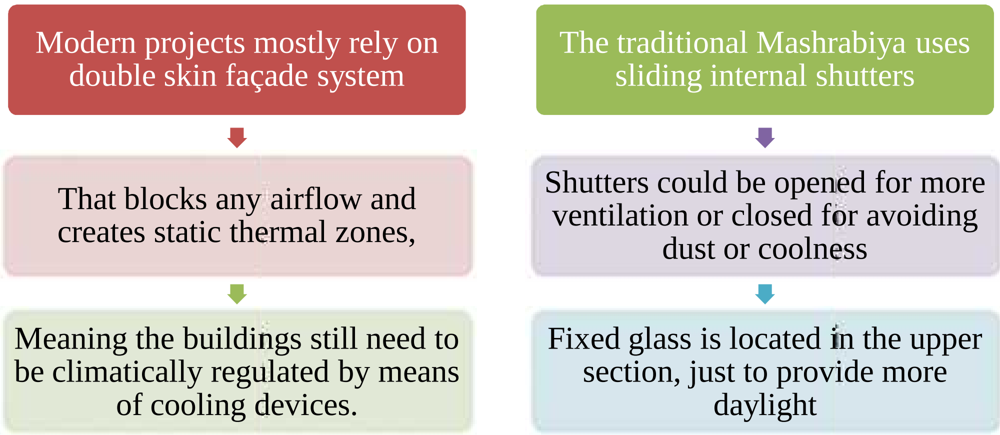


Figure 5.92: Double skin system versus traditional Mashrabiya (Alothman, 2016)

- One of the most difficult environmental issues in the Arab region that must be addressed is the combination of high humidity and steel materials and metal structures which are used to construct the modern Mashrabiya. They do not ensure humidity adjustment, the factor that was efficiently provided by wooden Mashrabiya.

- Projects mostly moved away from the use of wood and turned the Mashrabiya to metal or glass interfaces or other materials that do not have the properties of wood, with respect to various environmental functions. While the most important recommendations made in published research in this field of study, states and stresses that any alternative material needs to have similar properties to wood; it should to be strong, easily produced in quantity, able to cope with extremes in humidity and temperature, along with capable of expressing a certain aesthetic value.

- If the use of wood has been ruled out in the new Mashrabiya construction, because of expense, the advanced technology that is used instead, to operate the contemporary Mashrabiya, would seem to cost more money and energy, and the structural details are more complex both in their construction and maintenance.

Advanced technology and the modern systems which are used, do not obviate the need for familiarity with the required design parameters of Mashrabiya, bearing in mind the importance of their functionality.

Moreover the effort involved in designing these systems, could be focused on important processes in the field of construction materials and their properties, to invent new structural materials which have comparable advantages to that of wood, and provided at an affordable cost.

At this point it is important and worth highlighting an amazing new material that has been invented by Chao Chen (2015) a student at the Royal College of Art in London, who got his inspiration from a pine cone, that opens and closes in reaction to water, to design a powerful new architectural skin (Figure 5.93).

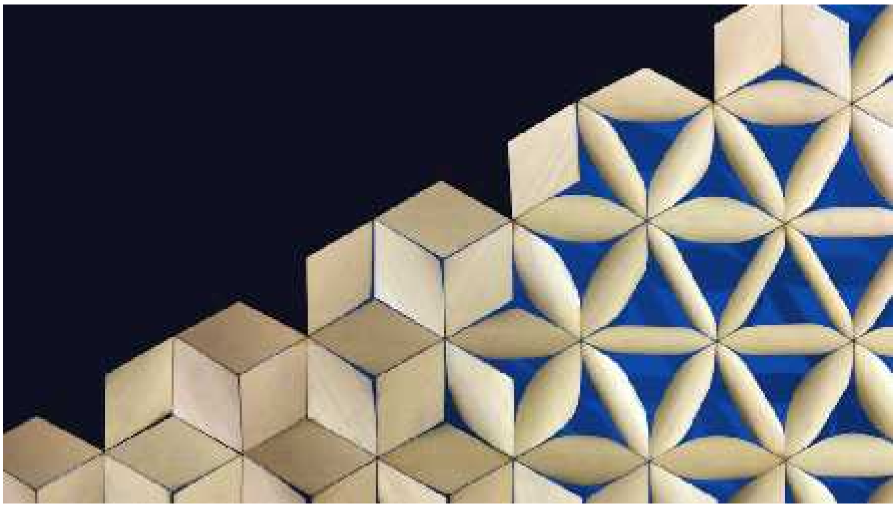


Figure 5.93: Water reaction, a new material as an architectural surface (Chen, 2015)

The surface consists of: lime veneer, nylon and styrene (Chen, 2015). On the official web site of the college product design program, it is announced that:

> "Imitating this natural phenomenon has resulted in a laminate water-reacting material. Utilizing its own property, this bio-mimicry material detects water and changes shape automatically without mechanical structures or electrical elements. According to different scenarios, the material has been applied to objects related with water, illustrating a purity of functionalism and aesthetics." (Chen, 2015).

The response of the new architectural surface to water can be seen in the following Figures 5.94- 5.99, where it starts to progressively open in the rainy weather, and comes back to close in the brighter weather.

Figure 5.94: The surface before the water reaction (Chen, 2015)

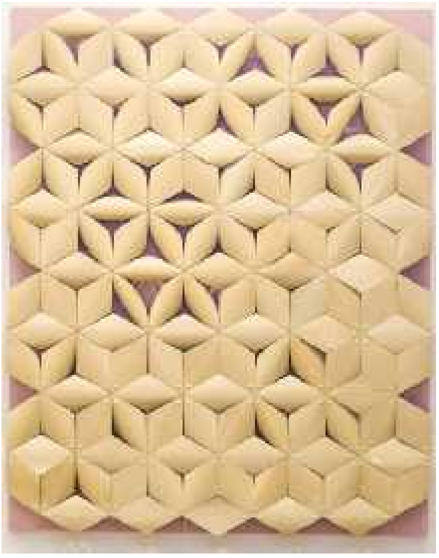


Figure 5.95: The gradual response of the surface to the water (Chen, 2015)

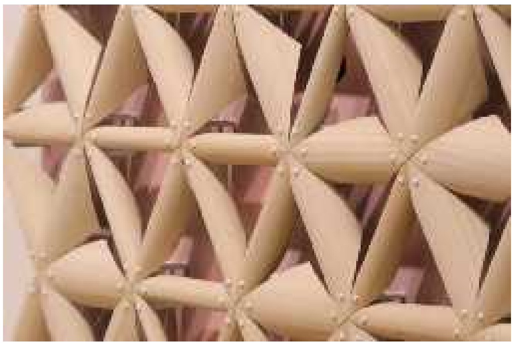


Figure 5.96: A detail open view of the surface (Chen, 2015)

Notice how the parts start converting to shapes resembling the rounded balusters of the traditional Mashrabiya.

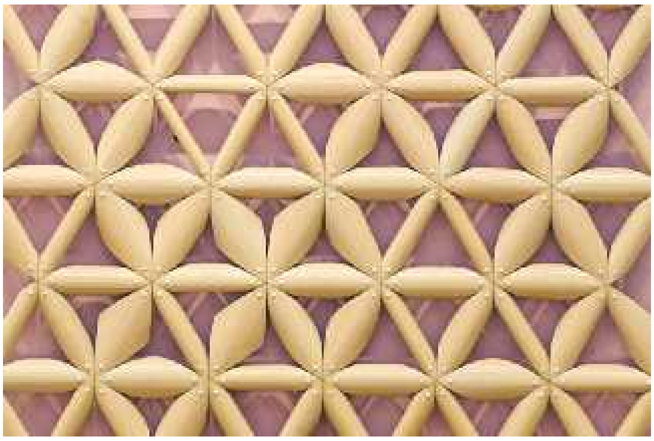


Figure 5.97: A view of the surface while opening (Chen, 2015)

Figure 5.98: A detail after finishing the water reaction (Chen, 2015)

It is noticeable that the response of this hybrid material competes with the properties of wood in connection with climate changes.

As for the form of these units, the movement is similar to the designed reaction system of Al Bahar towers, using a similar pattern. All these powerful aspects sound simple, efficient and at a lower cost compared with any advanced technological system.

Further to its amazing ability in the transformation of its parts, it achieves the required rounded baluster shape during the response.

Figure 5.99: Another style of the new material reaction with different color (Chen, 2015)

- Finally it is easy to say that all the contemporary projects which have been studied, are clearly inspired by the Mashrabiya, but it is difficult to decide which is better; insisting those façades should be called “Mashrabiya”, or ignoring the name and merely describing them as panels that have been derived from Mashrabiya (Table 5.5).

The first might lead to loss of the design parameters, since not one of those projects took the real importance of the Mashrabiya parameters into consideration, and the latter would obliterate the original name of this creative, traditional element and replace it with fabricated names such as ‘Geometric Panels’ and ‘Airflakes’ (Figure 5.100).

Figure 5.100: An Airflake designed by Borselius Stefan, and produced by abstracta (Borselius, 2016)

The airflake is considered a hanging screen, and can be used in many ways to create partitions within a room, and to diffuse unpleasant light reflections. Airflakes are now available in different size and various patterns.

Table 5.5: The projects and the original name “Mashrabiya” (Alothman, 2016)

The Project Name	Architect Name	Location and Year	The original name according to the architect
Mashrabiya House	Senan Abdelqader	Palestinian (2011)	Mashrabiya
Masdar City Institute	Foster + Partners.	United Arab Emirates (2015)	Mashrabiya
Al Bahar Towers / Mashrabiya Towers	Aedas Architects	United Arab Emirates (2012)	Mashrabiya
Arab World Institute	Jean Nouvel	France (1987)	Mashrabiya
Abu Dhabi Central Market	Foster + Partners	United Arab Emirates (2014)	The architect didn’t mention the façades in this project as Mashrabiya, but said they were “a pattern developed with a scholar of Islamic arts”
Doha Tower	Jean Nouvel	Qatar (2012)	Mashrabiya
Ali Mohammed T. Al-Ghanim Clinic	AGi architects.	Kuwait (2014)	The architects didn’t mention it by the name Mashrabiya, but they asserted that: “The contemporary mesh that connects to the cultural identity of Arab”
Manish Restaurant	(ODVO arquitetura e urbanismo, Mínima) architects	Brazil (2011)	The architects called the façade "muraxabi frame", although they denoted that : “We were inspired by the basic elements of Arab architecture”
Hotel and Residential Tower in Qatar	Zaha Hadid	Qatar (2020) Under construction	Mashrabiya
The King Abdullah Financial District Metro Station in Saudi Arabia	Zaha Hadid	Saudi Arabia (2017) Under construction	The architect called the façade a “a three-dimensional lattice”
Louvre Museum in United Arab Emirates	Jean Nouvel	United Arab Emirates (2017) Under construction	Mashrabiya

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

Mashrabiya is an architectural element of the intellectual and re-thinking heritage elements. It is the prominent window that overlooks the street or the courtyard of traditional Arab houses. In the past the name Mashrabiya was given to the space, which is enclosed with wooden lattice openings, where jars of drinking water were placed to cool by evaporation which is caused by the movement of air through the lattice openings. Later the name Mashrabiya was given to the wooden lattice screen itself.

It had widespread popularity in countries of the Arab and Islamic world and the countries of the countries of south Asia, such as India and Pakistan and even reached Peru and Spain. It had been used in Islamic countries for privacy reasons, while in the countries of south Asia it was used for its powerful functions in light adjustment, humidity and airflow control and temperature reduction.

In that time, the specific dimensions and parameters of Mashrabiya were not documented, but Fathy recommended some important design observations, like making the section of Mashrabiya baluster rounded and making the interstices between Mashrabiya balusters narrow at eye level and making them wider in the upper part.

With the advent of the industrial revolution and later, globalization, Mashrabiya begun less popular and were replaced by air-conditioning units in the beginning of the twentieth century. Thereafter there has been a revival, again by Fathy in 1980's, and because of its aesthetic property and being a clear expression of Arab identity, attention was focused on Mashrabiyas in some contemporary projects. However, it was soon misused due to the important environmental functions being ignored in many local projects, which turned it into a mere aesthetic, decorative element. Nevertheless it has subsequently achieved widespread popularity in many architectural sectors such as modern houses, mosques, markets, administrative towers, libraries, educational buildings and restaurants.

Additionally, in ignoring the important functions, and the correct standards of design, architects moved away from the utilization of wood and replaced it with minerals and double skin façades, which are equipped with fixed panels of glass that prevent the airflow and thus cause static thermal zones inside the rooms, which then require the use of HVAC cooling units, which eliminate the environmental role of Mashrabiya.

In the past, several materials were used in Mashrabiya construction such as marble, stone, plaster, brick and wood as well. But all Hassan Fathy’s theoretical studies about Mashrabiya recommended wood as essential for the Mashrabiyas, thanks to the special properties of wood in fulfilling the desired functions of Mashrabiya.

In modern enterprise, in addition to the decline of the issue of environmental functions and lack of familiarity with the design parameters and theoretical studies, it has been found that sometimes architects ignore the original name of the element "Mashrabiya", and simply allude to the style of façades inspired by Arab heritage.

It is easy to say that all contemporary projects which have been studied, are inspired by the Mashrabiya, but it is difficult to decide which is better, asserting that those façades should be called “Mashrabiya”, or ignoring the name and only mentioning that the panels have been derived from Mashrabiya .

The first might lead to the loss of design parameters, due to the fact that not one of those projects took the importance of Mashrabiya parameters into consideration, and the latter would obliterate the original name of this creative traditional element and replace it with fabricated names such as ‘Geometric Panels’ and ‘Airflakes.’

The advanced technology which is used for the implementation of contemporary Mashrabiya has many disadvantages related to the high construction costs and the cost of energy, plus the structural details are much more complex.

However, these modern systems do not obviate the need for familiarity with the required design parameters of Mashrabiya, the importance of their functionality and the need for a diversity of patterns in the façade to provide a beneficial functional performance.

Moreover the efforts to design digital systems that use high energy and a lot of money, could focus on an important process in the field of construction materials and their properties, to invent new structural materials that have comparable advantages to wood, at an affordable cost.

In addition, the original name must be preserved and the architect has to recognize it and have a full understanding of all the environmental, social and cultural functions .

Two critical questions arise:

- Does hiring a foreign architect provide justification for a lack of familiarity with and a lack of knowledge about Mashrabiya?
- Why is it that contemporary Arab projects do not adopt the new generation of Arab architects who are studying hard to learn about their heritage and are fully aware of its development methodology?

The first and most important recommendation is to preserve its identity and to avoid repetition of theoretical discussion about Mashrabiya and focus on the benefit of these studies to find the best construction solutions. This is in order to make the Mashrabiya more dynamic, with the most appropriate cost and safety, and to keep up with the renaissance of western architecture.

The East and West are two worlds who should be able to integrate together, without obliterating the identity of one or the renaissance of the other. Architecture represents the finest images of cultural integration, which benefits all sides.

In general, the best way to achieve this coexistence, is a revival of Fathy’s principles, especially by talking about his vision of modernity, he believed that modernity does not necessarily mean vitality, and that change is not always for the better. In architecture, if the design was for human comfort, we can talk and debate, but if it was for other purposes such as trade, politics or blind emulation, it is not “architecture” at all.

REFERENCES

Abdelqader, S. (2011). The architect of Mashrabiya House. Retrieved April 07, 2016 from http://www.senanarchitects.com/al-mashrabiya-building

Abdelsalam, T. (2002). Unity in Architectural Composition and Language (pp. 210-219). Almakkiya Residence, Saudi Arabia: Riyadh Press.

Abdelsalam, T. (2006). Courtyard Housing in Saudi Arabia, Past, Present & Future (pp. 147-163). London, England: Taylor & Francis Press.

Abdelsalam T., and Rihan, G. (2012). The impact of sustainability trends on housing *design identity of Arab cities. Housing and Building National Research Center of HBRC Journal*, 9(2), 159-172.

Aedas architects (2012). The architectural design team of AlBahar Tower. Retrieved Septemper 22, 2015 from http://www.archdaily.com/270592/al-bahar-towers-responsive-facade-aedas

AGi architects (2014). The Architectural design team of Ali Mohammed T. Al Ghanim Clinic. Retrieved September 22, 2015 from http://www.arch2o.com/ali-mohammed-t-al-ghanim-clinic-agi-architects/

Akbar, S. (1994). The diminishing role of windows from traditional to modern. *In Proceeding of the International Conference on the Role of Windows in Saudi Arabia* (pp. 16-21). Jeddah, Saudi Arabia.

Albadawy, A. (2010). Mashrabiya in complex of Sultan Qalawun at Al-Muʿizz al-Din street in Cairo, Egypt. Retrieved July 12, 2015 from https://tr.pinterest.com/pin/418764465324066111/

Aljofi, E. (2005). The potentiality of reflected sunlight through Rawshan screens. *In Proceeding of the International Conference on Passive and Low Energy Cooling for the Built Environment* (pp. 817-822). Santorini, Greece.

Almerbati, N., Ford, P., Taki, A., and Dean, L. (2014). From Vernacular to Personalised and Sustainable. The value of additively manufactured window screens in Middle Eastern dwellings. *In Proceeding of the 48th International Conference of the Architectural Science Association* (pp. 479-490). The Architectural Science Association & Genova University.

Almerbati, N., Headley, D., Ford, P., and Taki, A. (2016). From Manual to Hybrid. Parametric Mashrabiya Digital Workflow for the Re-envisioning and Conservation of Eastern Architectural Screens and the Engagement of Digital Tectonics. *The International Journal of Architectonic, Spatial, and Environmental Design,* 10(2) 29-37.

Almurahhem, F. (2009). Behind the Roshan. *PhD Thesis*, *University of Brighton*, Brighton, England.

Alothman, H. Different photos have been taken by Hiba Alothman.

Alsayied, W. (2010). The thinker readings in the philosophy of heritage at the thought of Hassan Fathy. *Journal Of Lonaard,* 6(1) 72-91.

Amit, G. (2011). The photographer Mashrabiya House in Palestine. Retrieved September 23, 2015 from http://www.archdaily.com/175582/the-mashrabiya-house-senan-abdelqader/50160dac28ba0d1598000902-the-mashrabiya-house-senan-abdelqader-photo

Andrew, A. (2016). Oriel Mashrabiya Room at Prince Mohammed Ali Tewfik Palace in Cairo, Egypt. Retrieved August 28, 2016 from https://www.flickr.com/photos/2007828/30389533495

Aramco Brats, Inc. (2014). Overcrowded Mashrabiyas in Jeddah, Saudi Arabia. Retrieved March 15, 2015 from https://www.flickr.com/photos/aramcobrats_inc/4737088715/in/photostream/

Architecture studio. (2013). Exhibition centre dedicated to Arab culture. Retrieved September 13. 2013 from http://www.archello.com/en/project/arab-world-institute

Asfour, K. (1998). Cultural crisis: Cut and paste leads to disaster in the Middle East. *In Proceeding of the International Conference of the Architectural Review of the Middle East* (Vol. 1, pp. 52-60).

Ashi, A. (2010). Theories and History of Architecture. Homs, Syria: Al Baath University Press.

Ashraf, S. (1983). Elrawashin of Jeddah, Saudi Arabia: Passive and low energy. *International Journal of Architectural Research, 1(1), 9-12.*

Batool, A. (2014). Quantifying Environmental Performance of Jali Screen Facades for contemporary Buildings (pp. 30-33). *Master Thesis, School of the University of Oregon*, Lahore, Pakistan.

Batty, W., Al-Hinai, H., and Probert, S. (1991). Natural cooling techniques for residential buildings in hot climates. *Journal of Applied Energy*, 39(4), 301-337.

Ben-Hamouche, M. (2013). Leftover spaces versus sustainability in Arab Gulf cities. *Urban Design International*, 18(2), 114-130.

Benedetti, C., Marco B., Giuliana L., Tanja, M., and Paglialonga, G. (2010). Wood Technology for Passive Cooling. *In Proceedings of the 11th World Conference on Timber Engineering.* (pp. 2-3).

Boake, T. (2014). Hot Climate Double Facades. *Journal of Façade Tectonics*, 14(1) 4-16.

Borselius, S. (2016). The designer of Airflake in abstracta company. Retrieved April 20, 2016 from https://abstracta.se/product/airflake/

Briggs, S. (1974). Architecture in Egypt and Palestine (pp. 213-214). New York, NY: Da Capo Press.

Caine , T. (2014). The photographer of Masdar City. Retrieved March 23, 2016 from http://www.archdaily.com/517456/inside-masdar-city/539b46d9c07a805cea000834-inside-masdar-city-photo

Castro, F. (2016). In Progress: Louvre Abu Dhabi, Jean Nouvel. Retrieved August 12, 2016 from http://www.archdaily.com/793182/inprogress-louvre-abu-dhabi-jean-nouvel

Chandramowli, D. (2015). Mashrabiyas in Punakha Dzong, Bhutan. Retrieved Septemper 22, 2015 from http://simplysiri.tumblr.com/post/118431414639/lotusunfurled-by-dhillan-chandramowli

Chen, Ch. (2015). Water Reaction, new material by a student of Royal College of Art in London, England. Retrieved February 20, 2016 from https://www.rca.ac.uk/students/chao-chen/

Cilento, K. (2012). Al Bahar Towers Responsive Façade, Aedas. Retrieved September 05, 2015 from http://www.archdaily.com/270592/al-bahar-towers-responsive- facade- aedas

Courtesy of HBS. (2010). Group of photographers of Doha Tower. Retrieved April 20, 2016 from http://www.arch2o.com/doha-tower-jean-nouvel/

Courtesy of Zaha Hadid Architects. (2013a). 3D Group of Zaha Hadid Architects of hotel and residential tower in Qatar. Retrieved September 22, 2015 from http://www.archdaily.com/791240/zaha-hadid-architects-to-design-hotel-and-residential-tower-in-qatar

Courtesy of Zaha Hadid Architects. (2013b). 3D Group of Zaha Hadid Architects of the King Abdullah Financial District Metro Station in Saudi Arabia. Retrieved July 15, 2015 from http://www.zaha-hadid.com/architecture/king-abdullah-financial-district-metro-station/

CTBUH, (2012). Council on Tall Buildings and Urban Habitat: Innovation Award Winner. Retrieved April 20, 2016 from http://www.ctbuh.org/

Dayyob, T. (2001). History of Arab Architecture. Homs, Syria: AlBath University Press.

Dmitry, Sh. (2012). Mashrabiya in Plaza Mayor, Lima, Peru. Retrieved July 15, 2015 from https://www.flickr.com/photos/dmitry_shakin/8398936916/in/photostream

Drishti, L. (2015). An interior with Mashrabiya at Amber Palace in Rajasthan, India. Retrieved April 22, 2016 from http://undercoverdiva.tumblr.com/post/5641983258/amber-palace-rajasthan-india

Edgar, G. (2007). Suggestions for Local Sustainability Initiatives. *Master Thesis, Federal Ministry for the Environment*, Berlin, Germany.

Edgar, G., and Lahham, N. (2008). A Future Vision for Sustainable Egyptian Cities. *In Proceeding of the International Conference of Vision for the Future* (pp. 56-58). Ain Shams University, Cairo.

Fatehpur, S. (2010). Tomb of Salim Chishti in India. Retrieved September 28, 2010 from http://jacobgines.blogspot.com.cy/2010/09/light-shadow-in-architecture.html

Fathy, H. (1973). Architecture for the Poor (pp. 39-42). Chicago, USA: The University of Chicago Press.

Fathy, H. (1986). Natural Energies and Vernacular Architecture, *Mashrabiya* (pp. 46-49). Chicago, USA: The University of Chicago Press.

Ficarelli, L. (2008). The Domestic Architecture in Egypt between Past and Present. The Passive Cooling in Traditional Construction. *In Proceedings of the Third International Conference on Construction History* (Vol.2, pp. 54-72). Cottbus, Germany: University of Technology.

Feeney, J. (1974). The Magic of Mashrabiya. *Journal of AL Riyadh, 25(4) 32-36.*

Fernando Guerra FG+SG. (2010). Group of photographers of Mozza Bar and Restaurant in Sao Paulo. Retrieved July 15, 2016 from http://www.knstrct.com/architecture-blog/2014/5/13/sao-paulos-mozza-an-italian-jewel-on-a-brazilian-boulevard

Fessy, G. (2011). The photographer of Arab World Institute, Paris, France. Retrieved September 22, 2015 from http://www.archdaily.com/162101/ad-classics-institut-du-monde-arabe-jean-nouvel/50381c0228ba0d599b000f18-ad-classics-institut-du-monde-arabe-jean-nouvel-image

Foster + Partners. (2010). Architects office of Masdar City. Retrieved November 25, 2014 from http://www.archdaily.com/91228/masdar-institute-foster-partners

Foster + Partners. (2011). Architects office of Abu Dhabi Central Market. Retrieved November 25, 2014 from http://www.fosterandpartners.com/design-services/interiors/aldar-central-market-interiors/

Fotos, Ch. (2007). Mashrabiya in Plaza Mayor in Lima, Peru. Retrieved July 15, 2015 from https://www.flickr.com/photos/galeriachimi/2926277805/#/photos/galeriachimi/2926277805/lightbox/

Gamo, R. (2010). The photographer of La Tallera in Mexico. Retrieved September 22, 2015 from http://www.archdaily.com/320147/la-tallera-frida-escobedo

Gandemer, A., Jacques, C., and Guyot, A. (1981). Protection against the wind (p. 132). Paris, France: Centre Scientifique et Technique du Bâtiment Press.

Garrido, N. (2010). The photographer of Doha Tower Project. Retrieved July 15, 2015 from http://www.archdaily.com/69449/in-progress-doha-office-tower-qatar-ateliers-jean-nouvel-nelson-garrido/jean_nouvel_high_rise_office_building_qatar0000

Garrido, N. (2014). The photographer of Ali Mohammed T. Al-Ghanim Clinic. Retrieved from April 20, 2016 http://www.archdaily.com/611323/ali-mohammed-t-al-ghanim-clinic-agi-architects/550a4834e58ece151100009a-agi_clinic_kuwait_071214_1145_clean-jpg

Gelil, N. (2006). A new Mashrabiyya for contemporary Cairo. Integrating traditional latticework from Islamic and Japanese cultures. *Journal of Asian Architecture and Building Engineering*, 5(1) 37-44.

Gelil, N., and Ali, W. (2014). Traditional Residential Architecture in Cairo from a Green Architecture Perspective. *In Proceeding of the International Conference of Art and Design Studies* (Vol. 14, pp. 6- 23). Egypt- 6th of October City: October University for Modern Sciences and Arts ,MSA University.

Gérôme, J. (1867). A painting of mashrabiya in Cairo: Vendedor de caballos. Retrieved July 15, 2015 from https://es.pinterest.com/pin/336784878366664340/

Giovannini, L., Valerio, M., Verso, B., Karamata, B., and Andersen, M. (2015). Lighting and energy performance of an adaptive shading and daylighting system for arid climates. *In Proceeding of the International Building Physics Conference on Energy Science* (Vol. 78, pp. 370-375). Lausanne, Switzerland: Energy Procedia.

Graber, O. (2006). Islamic Art and Beyond, *Constructing the Study of Islamic Art* (pp. 81-155). New York, *NY:* MacLehose and Company Limited Press.

Göçek, G. (2011). The Transformation of Turkey: Redefining State and Society from the Ottoman Empire to the Modern Era. London, England: I.B.Tauris & Co Ltd.

Hamuda, O. (1987). Architectural Character Between Authenticity and Modernism. Cairo, Egypt: Al-Dar Al-Masriah Al-Lubnaniah Press.

Hensen M. and Hoes, P. (2009). User behavior in whole building simulation. *Journal of Energy and Buildings*, 41(3), 295–302.

Hornsby, L. (2014). Mashrabiya at Alhambra Granada palace in Spain. Retrieved July 15, 2015 from https://www.khanacademy.org/humanities/ap-art-history/early-europe-and-colonial-americas/ap-art-islamic-world-medieval/a/the-alhambra

Ishinan, A. (1979). Sketches of traditional craftsman’s positions during the wood turning process. Retrieved October 12, 2016 from http://www.theegyptianchronicles.com/Article/KHIRAATAH.html

James, H. (1987). History of Innovation, The World Arab World Institute. Paris, France. Retrieved October 4, 2015 from https://aehistory.wordpress.com/1987/10/04/164/

Jean, P. (1976). The coral buildings of Suakin. London, England: Oriel Press.

Jon, E., and Nathan, S. (2010). The rise of additive manufacturing. Retrieved February 10, 2014 from https://www.researchgate.net/publication/295307192_The_rise_of_additive_manufacturing

Kalpana, G. (2011). Mashrabiyas with small windows at Alsuhaimi House in Cairo, Egypt. Retrieved July 15, 2015 from https://totemscity.wordpress.com/2011/03/10/mashrabiya/

Khan, I. (2014). old Mashrabiyas in Makkah, Saudi Arabia. Retrieved September 22, 2015 from https://tr.pinterest.com/pin/739716307515626513/

Kenzari, B., and Elsheshtawy, Y. (2003). The ambiguous veil: On transparency, the Mashrabiy'ya, and architecture. *Journal of Architectural Education,* 56(4) 17–25.

Kultermann, U. (1999). Contemporary Architecture in the Arab States, *Renaissance of a Region.* London, England: McGraw-Hill Press.

Kuban, D.(1983). Modern versus Traditional. A False, Conflict. *Journal of Mimar Architecture in Development,* 9(1), 54-58.

Lafforgue, E. (2010). An old residential quarter filled with Mashrabiyas in Saudi Arabia. Retrieved July 15, 2015 from https://www.flickr.com/photos/mytripsmypics/6995992321/sizes/l/in/photostream/

Lafforgue, E. (2010). Very old Mashrabiya in Massawa, Eritrea. Retrieved July 15, 2015 from https://www.flickr.com/photos/mytripsmypics/412412797/in/photostream/

Lamei, S., Fahmi, A., Zeinhom M., and Nagib E. (1996). Light Screens: The Arabian Turned Wood Work Mashrabiya and Stucco Coloured Glass Windows in Egypt. Cairo, Egypt: Ministry of Culture Press.

Lane, E. (1977). Orientalism (pp. 4-93). New York, NY: Pantheon Press.

Landrock, L. (1910). Mashrabiya overlooking the Courtyard of Camal Ed Din House in Cairo, Egypt. Retrieved Februray 22, 2015 from https://tr.pinterest.com/pin/334533078544637217/

Levine, R., and Hughes, M. (2008). Sustainability Over Time. *In Proceeding of the International Conference on Vision for the Future* (pp. 27-31). Cairo, Egypt: Ain Shams University.

Lewis, J. (1873). An image of women behind Mashrabiya in a harem room. Retrieved July 15, 2015 from http://www.iiste.org/Journals/index.php/ADS/article/viewFile/10288/10493

Lim, S., Buswell, A., Le, T., Austin, A., Gibb, F., and Thorpe, T. (2012). Developments in construction-scale additive manufacturing processes. *Journal of Automation in Construction*, 21(5) 262–268.

Louvre Abu Dhabi.ae. (2014). Louvre Abu Dhabi: Universal Museum. Retrieved April 20, 2016 from http://louvreabudhabi.ae/en/about/pages/a-universal-museum.aspx

Luxury crafts (2011). An Egyptian company for wooden craftsmanship. Retrieved September 10, 2016 from https://www.youtube.com/watch?v=JFiaVEWG3gs

Lynch, P. (2016) . Zaha Hadid Architects selected to design Hotel and Residential Tower in Qatar. Retrieved July 12, 2016 from http://www.archdaily.com/791240/zaha-hadid-architects-to-design-hotel-and-residential-tower-in-qatar

Maher, A. (2015). Mashrabiya at Jamal al-Din alZahabi's house in Egypt. Retrieved September 22, 2015 from http://picssr.com/tags/%D9%85%D8%B4%D8%B1%D8%A8%D9%8A%D8%A9/page5

Marawan, R. (2016). An old Mashrabiya at Al Suhaymi House in Cairo, Egypt. Retrieved December 8, 2016 from http://www.imgrum.org/media/1203558523401670886_340619099

Martin, A. (1997). The Global Age, *State and Society Beyond Modernity*. Stanford , USA: Stanford University Press.

Maspero**,** G. (1914). Manual of Egyptian Archaeology and Guide to the Study of Antiquities in Egypt. New York, NY: Putnams Sons Press.

Mecanoo Architects, (2013). Architects Of Library of Birmingham. Retrieved August 29, 2013 from http://www.archdaily.com/421970/library-of-birmingham-mecanoo

Michler, M. (2010). A photographer of Arab World Institute. Retrieved from http://www.architecture-studio.fr/en/projects/pastb1/arab_world_institute.html

Moffatt, M. (2015). A marble Mashrabiya at the Amber Palace in Jaipur Rajasthan, India. Retrieved June 6, 2015 from http://emilialua1.tumblr.com/post/13551300483/myfotolog-jaisalmar-rajasthan-india

Mohamed, J. (2015). The traditional arts and crafts of turnery or Mashrabiya (pp. 12-28). *Master Thesis, The State University of New Jersey*, Camden, New Jersey.

Mohsen, A. (2014). Shanshol in Basra, Iraq. Retrieved January 10, 2014 from http://algardenia.com/2014-04-04-19-52-20/qosqsah/8506-2014-01-24-16-38-28.html

Musch, J. (2005). The photographer of W-House in Rieteiland, Netherlands. Retrieved October 10, 2015 from http://www.archdaily.com/329864/w-house-vmx-architects

Niazi, Sh. (2015). Mashrabiya in Chiniot, Pakistan. Retrieved June 6, 2015 from https://www.flickr.com/photos/shaukatniazi/7122028375/

Niazi, Sh. (2014). Mashrabiya in Chiniot, Pakistan. Retrieved June 6, 2015 from http://petitcabinetdecuriosites.tumblr.com/post/10286773016/agoodthinghappened-balcony-by-shaukatniazi-on

Nouvel, J. (2013). Louvre Museum in United Arab Emirates. Retrieved January 12, 2015 from http://www.archdaily.com/298058/the-louvre-abu-dhabi-museum-ateliers-jean-nouvel

Nouvel, J. (2014). Doha Tower Illustrations. Retrieved January 21, 2015 from https://s-media-cache-ak0.pinimg.com/originals/ca/c1/ac/cac1ac3d0cff9bda62363cd0163f56e3.jpg

Oborn, P. (2012). The deputy chairman of Aedas Archirect: Towering triumph for unusual pair of buildings in Abu Dhabi. Retrieved October 10, 2015 from http://www.thenational.ae/business/industry-insights/property/towering-triumph-for-unusual-pair-of-buildings-in-abu-dhabi

ODVO arquitetura e urbanismo + Mínima. (2011). The Architectural Design Team of Manish Restaurant. Retrieved March 18, 2013 from http://www.archdaily.com/345428/manish-restaurant-odvo-arquitetura-e-urbanismo

Orfali, H. (2015). An old Mashrabiya in Pakistan. Retrieved December 2, 2015 from http://www.imgrum.org/media/1001194244862397361_1493093089

Pregnolato and Kusuki Studio. (2011). Group of Photographers of Manish Restaurant. Retrieved March 18, 2013 from http://www.archdaily.com/345428/manish-restaurant-odvo-arquitetura-eurbanismo/5747d386e58ece3d40000183-manish-restaurant-odvo-arquitetura-e-urbanismo-photo

Richters, Ch. (2012). Photographer of Mashrabiya facade at Al Bahr Towers. Retrieved November 12, 2015 from http://www.archello.com/en/project/abu-dhabi-investment-council-new-headquarters-al-bahr-towers

Richters, Ch. (2013). Photographer of Library of Birmingham in United Kingdom. Retrieved March 9, 2015 from http://www.archdaily.com/421970/library-of-birmingham-mecanoo/521f4b14e8e44e56b5000003-library-of-birmingham-mecanoo-photo

Rogers, P. (2014). The tomb of Itimad ud Daulah in India. Retrieved October 11, 2015 from http://evenfewergoats.blogspot.com.cy/2014/05/agra-7-itimad-ud-daulahs-tomb-and-chini.html

Rosenfield, K. (2013). Zaha Hadid Architects selected to design the King Abdullah Financial District Metro Station in Saudi Arabia. Retrieved September 22, 2015 from http://www.archdaily.com/374198/zaha-hadid-architects-selected-to-design-the-king-abdullah-financial-district- metro-station-in-saudi-arabia-2

Samuels, W. (2011). Performance and Permeability: An Investigation of the Mashrabiya for Use within the Gibson Desert in Australia (pp. 42-57). Master Thesis, School of Architecture and Design of Victoria University, Wellington, New Zealand.

Sergio, E. (2015). A blue Mashrabiya in Nabeul, Tunis. Retrieved January 10, 2016 from https://www.superstock.com/stock-photos-images/1792-38602

Sherif. A, Sabry, H., Rakha, T. (2012). External perforated Solar Screens for daylighting in residential desert buildings: Identification of minimum perforation percentages. *Journal of Solar Energy*, 86(12), 1929-1940.

Sidawi, B. (2012). A conceptual analytical model of the vocabulary of architecture. *Emirates Journal for Engineering Research*, 17(1) 47–56.

Smith, P. (2005). Architecture in a Climate of Change. Oxford, England: Oxford Architectural Press.

Spencer, J. (1990). Mashrabiya an architectural language (pp. 49-52). *Journal of Art & The Islamic World*, 18(1), 49-52.

Sprogoe Ch., and Maher Ch. (2014). The photographers of Hamersley Road Residence in Australia. Retrieved September 15, 2015 from http://onekindesign.com/2014/08/09/modern-conversion-old- australian-workers-cottage/

Steele, J. (2005). The Architecture for People, *The Complete Works of Hassan Fathy* (pp 16-38). Cairo, Egypt: The American University in Cairo Press.

Sretenova, G. (2013). An old Mashrabiya at Farhi House in Damascus, Syria. Retrieved March 15, 2015 from http://enchantingnagchampa.tumblr.com/post/119189837791/mideast-nrthafrica-cntrlasia-house-of-farhi-in

Strong, S. and Hugo, I. (2003). Solar Electric Building: Photovoltaic. Retrieved December 20, 2015 from http://www.solardesign.com/about/technology-photovoltaics.php

Swalwell, D. (2013). The photographer of Blairgowrie House. Retrieved November 29, 2013 from http://www.archdaily.com/448533/blairgowrie-back-beach-wolveridge-architects/52843532e8e44e8e720000fd_blairgowrie-back-beach-wolveridge-architects_wolveridge_blgw_012-jpg/

Sweeney, S. (2015). A blue Mashrabiya in Morocco. Retrieved December 9, 2015 from http://t-a-h-i-t-i.tumblr.com/post/27407781045

The skyscraper Center. (2012). Skyscraper center: Doha Tower. Retrieved October 10, 2015 from https://skyscrapercenter.com/building/doha-tower/1083

Tolba, Y. (2011). An interior view of Mashrabiya at al-Suhaymi House in Cairo, Egypt . Retrieved June 6, 2014 from https://tr.pinterest.com/pin/555350197780387612/

Tzempelikos, A., and Athienitis AK. (2007). The impact of shading design and control on building cooling and lighting demand. *Journal of Solar Energy* 81(3) 369-382.

Usher, A. (1929). A history of mechanical inventions (pp. 18-19). New York, NY: Courier Corporation Press.

Waterson, R. (1990). The Living House, *Anthropology of Architecture in South-East Asia*, Oxford University Press. Indiana University, Oxford University Press.

Welch, A. (2013). Al Bahar Towers Abu Dhabi. Retrieved November 29, 2013 from http://www.e-architect.co.uk/dubai/al-bahar-towers-abu-dhabi

Wise, Z. (1998). Capital Dilemma, *Germany's Search for New Architecture of Democracy*. New York, NY: Princeton Architecture Press.

Winstanley, T. (2011). Architecture Studio of The Arab World Institute. Retrieved October 10, 2012 from http://www.archdaily.com/162101/ad-classics-institut-du-monde-arabe-jean-nouvel

Wood Turnery. SIS Publications. (2014). Retrieved August 17, 2016 from http://www.sis.gov.eg/section/531/533?lang=en-us

Wittbrodt, T., Glover, G., Laureto, J., Anzalone, C., Oppliger, D., Irwin, L., and Pearce, M. (2013). Life-cycle economic analysis of distributed manufacturing with open source 3-D printers. *Journal of Mechatronics*, 23(6) 713–723.

Young, N. (2014). The photographer of Abu Dhabi Central Market. Retrieved September 22, 2015 from http://www.archdaily.com/558920/abu-dhabi-central-market-foster-partners/54447279c07a801fe7000584-abu-dhabi-central-market-foster-partners-photo