The Living Facade: Mashrabbia;

A Kinetic Envelope Improves Building Energy Performance

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Abstract

How to make buildings acclimate to the climate has been the challenge of architecture for Thermal comfort. Reducing the outdoor high temperature differences is still the significance of building energy efficiency. In particular, there are many locations with great daily or seasonal variation in climatic temperature. Currently, the common strategies for addressing this wide temperature range of climate are the HVAC (Heating, Ventilating and Air-conditioning) systems. Much energy is needed in these locations for indoor thermal comfort.

There are many studies focusing on the high-tech or high-efficient HVAC system to save energy. However, we believe the fundamental point is orientation, materials and other design strategies rather than external treatment like the HAVC system.

This paper proposes a possible solution for coping with hot- climate architecture utilizing advanced building technologies with vernacular architectural elements. The resulting system will intelligently provide thermal comfort, natural energy and reduce energy usage of HVAC.

This system is a bio-inspired dynamic envelope responding to solar radiation and local climate conditions. In order to explore the envelope system, this paper reviews important literatures related to biomimetic design in architecture and kinetic/interactive building envelope applications. A new Parametric Design method in Building Information Modeling (BIMPD) and computational simulation is used in this paper.

In short, buildings have be inspired place – both culturally and environmentally. The Living Facade isanattempt to preserve the Islamic character and culture with a strong climatic response and energy efficient design.

1.1 Introduction

Recent years have seen an unprecedented growth in the construction of buildings being constructed than at any other time in history. Certainly on an international scale, the past several years have been the most active and dynamic in the history of architecture[1]. However, too many buildings continue to be designed in one of two inadequate ways: either as vertical extrusions of an efficient floor plan, or as iconic pieces of urban 'sculpture'. In both cases the only relationship with the urban setting is a visual one. This has led to the syndrome of buildings as 'isolationist' architecture – stand-alone, non-site specific models that are readily transportable around the cities of the world.

In particular, cities in developing countries seem to ignore the local climate, culture and context and instead simply 'import' the Western model of the air-conditioned, rectilinear glass box. This pattern of gleaming glass buildings springing up in the tropics, deserts and other extreme climates has led many to denounce the new building as inherently anti-environmental. In short, these buildings are contributing to the degradation of both global (climate change) and local (cultural) environments. buildings need to be inspired by place – both culturally and environmentally. This paper seeks to explore a possible design appfoach for building's skin to creat buildins that embrace its location and is inspired by the climatic, cultureal and contextual aspects of place.

1.2Arguable Position

This paper investigates how the use of new materials, technologies, and the digital revolution can express the local culture and make a building harmonizes with its surrounding environment to take the full advantage of the available natural resources and provide an acceptable climate for its occupants, and discusses how solar control and natural ventilation systems can be integrated into kinetic facade systems to minimise the environmental impacts. Sun shading should be considered as an integral part of fenestration system design that is adapted into the facade design.The product of this paper is a kinetic façade, representing the Islamic culture and coping with the region of hot climate.

1.3 Design Objective

The objective of this paper is to design a self-reliant building that appropriately respects and recognizes its surrounding site while subtly reflecting Islamic culture. The main aim of this paper is to create an innovative and next generation sustainable kentic skin designed specifically for hot climate citys by taking advantage of cutting-edge technologies while respecting the traditional way of living that reflects the area's cultural roots.This kinetic façade minimizes undesirable environmental impacts by integrating solar control, daylight and natural ventilation systems, and encompassing a wide range of strategies resulting in an energy efficient building design.

1.4 Design Strategy:

This paper proposes a possible solution by using a great strategy makes buildins offer residents the opportunity to live according to their traditional life style which incorporates an Islamically-acceptable level of privacy and desired access to nature. The design will be generated and moulded by the surrounding environment, and some of the parameters that will be employed in distinguishing the design are natural lighting, shade and stable **c**onditions in the harsh climate through the design of a dynamic skin that has the ability to adapt, mutate and adjust according to the local climate.

The approach of this design is to develop a bio-inspired kinetic envelope system which has the interactive access to the surrounding environment like solar radiation, daylight, etc.

The design of this skin will be inspired by the traditional Islamic architectural element Mashrabbia (a wooden screen with different patterns used to provide privacy and allow air movement), and will almost play the same role of Mashrabbia in providing shade, privacy, and a more comfortable internal environment. It will also incorporate a photovoltaic panel system in the Mashrabbia to provide energy self-sufficiency

1.5 The Expected Outcome

This paper will propose a possible solution for coping with hot- climate architecture utilizing advanced building technologies with vernacular architectural elements. The resulting system will intelligently provide thermal comfort, natural energy and reduce energy usage of HVAC system according to outdoor climate condition, which creates an "Acclimated Building".

The expected long term achievement of this paper is an innovative design approach integrating BIMPD and biomimicry for thermal comfort and developing building energy efficiency.

1.6 Active Research and Relevant Resources

1.6.1 The Islamic cultural response to modern buildings

The brilliant Egyptian architect, Hassan Fathy had explained very perfectly "Old Islamic houses have filigreed windows and central courts, for example, to admit light without glare, coolness without air conditioning. The same principles could easily be incorporated even into modern buildings" (CNN, 1974).

For generations, Islamic culture has exhibited various fundamental principles of sustainable ways of living. It is the intention of this paper to revive and utilize these fundamental principles into the modern design .

1.6.2 Environmental effect on Islamic culture and its relation to architecture

The heritage of the traditional Arabic architecture has influenced and developed in response to three main factors: the region's hot and humid climate, social and religious aspects, and local availability of building materials. In general, its main features are simplicity, functionality, durability and suitability for climatic environments and social life.[2]

In response to the hot and humid climate, four architectural elements are visible. First, buildings were constructed close to each other. This type of high-density structure created narrow alleys, which were shaded for most of the day. The narrowness of the alleys caused the wind to increase in velocity as it breezed through, creating a comfortable pedestrian zone.

Fig. 1.1: The old city of Tripoli, Libya

The second element is the courtyard house, in which most of the rooms, which may have shaded verandas, face inward toward the courtyard, which was in the center of the house (see Fig 1.2). The existence of the courtyard generates wind movement inside the house by allowing hot air to ascend, while cooler air to replaces it from the surrounding rooms. Such courtyards also reduce cooling loads in the hot climates. At night, cool air comes in lowering the temperature in the thermally massive courtyard walls and floor. These elements hold the coolness throughout the hot day, which represent natural and environmental sustainability (Fig. 1.2).[3]

Fig 1.2: Courtyard House

Wooden screens (mashrabbia), were also widely used in Arab houses. They allow cool breezes to enter through the wooden lattices, thereby enabling the entry of air currents, which reduce the temperature; reflected heat, solar radiation, and the intensity of traffic noise (see Fig 1.3).[4]

Fig 1.3:Islamic Mashrabbia

1.6.2 Case studies:

- Modern adaptation of the traditional Mashrabbia for privacy and solar protection.

Here, some examples of modern building's components design that brings back the concept of Islamic and Middle Eastern mashrabbia presented in the terms of modern technology. Although the modern mashrabbias work in different manner, nevertheless they still plays the same role of the traditional one, providing shade, privacy, and stable conditions in the harsh climate.

1- Tessellate Panels at Simons Center for Geometry & Physics

State University of New York at Stony Brook , Long Island, NY, 2010

Project team: Architect: Perkins Eastman Fabricator: A. Zahner Co.

Adaptive Building Initiative created a dynamic installation for the Stony Brook Foundation's new Center for Geometry and Physics.

The installation serves both as the building's artistic centerpiece and as a functional piece of shading seamlessly integrated within its south-facing glass façade. To achieve the requirements of the building program, ABI installed a floor-to-ceiling composition of Tessellate panels, each with a geometric pattern—mirroring the research focus of the building's resident scientists and mathematicians. As these patterns align and diverge, the visual effect is of sparse geometric patterns—hexagons, circles, squares, and triangles—that blossom into an opaque mesh (see fig 1.4). The result is a kinetic surface that spans 122 square meters and imbues the building with the functional capacity to dynamically change its opacity.[5]

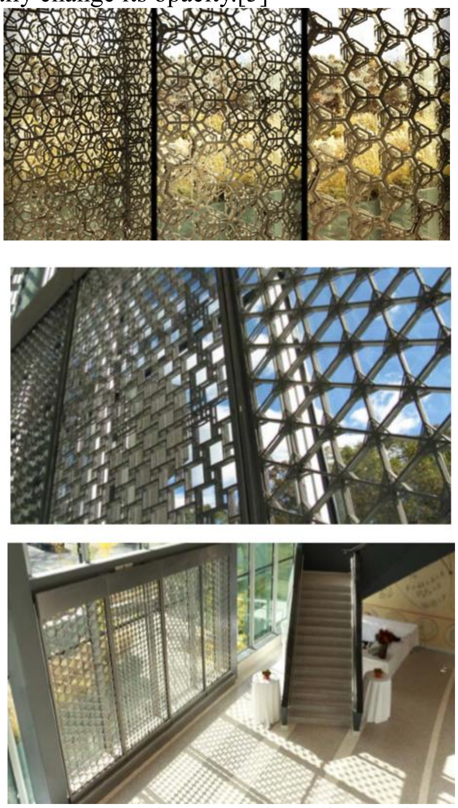


Fig 1.4: Geometric Patterns of Tessellate Panels

Tessellate is controlled using location-based sensory data to respond to light and weather conditions and fully integrates into the building management system. For instance, when high levels of direct light are detected, the metal panels diverge, and their patterns completely overlap, blocking the sun's rays. The sensors are programmed in a variety of ways to maximize energy efficiency and savings.[6]

Façade:

Adaptive Shading Coverage: 124 sq. m.
Materials: Waterjet-cut steinless steel, glass
Dimensions: 5.6m Wide x 6.7m Tall

2- Strata System at City of Justice (AP + TSJ)

Architect: Foster + Partners

Ciudad de Justicia, Madrid, Spain, 2006-2011, Strata

The new Campus of Justice in Madrid is the largest single site dedicated to law courts in Europe. Following the master plan, Foster + Partners has designed two distinctly circular buildings, Tribunal Superior de Justicia (High Court) see fig 1.5, and Audiencia Provincial (Appeals Court).

Fig 1.5: Interior rendering of the Court yeard by Foster+ Partners

Both buildings were designed to minimize unwanted solar gain, while allowing natural daylight inside. ABI systems were used to develop a customized shading scheme. Each building will use ABI's Strata system; when extended, the system will cover the triangulated roof grid. When retracted, their profile will 'disappear' into the structural profile of the roof (see figs 1.6, 1.7). During the day, the primary function of the system will be sun shading. A custom algorithm combining historic solar gain data with real-time light-level sensing will control the shading units.[7]

Fig 1.6: ABI's Strata System

AP:
- 20,000 sq. feet of shading area
- System Geometry: Hexagonal
- Number of operable units: 257

TSJ:
- 7,000 sq. feet of shading area
- System Geometry: Parallelogram
- Number of operable units: 115
- Materials: Aluminum, Steel

- Control System: Each unit driven by a servo motor with custom array control

Fig 1.7: Detail of ABI's Strata System

3-Abu Dhabi Investment Council Headquarters Towers

Architects: Aedas+Arup architects
Height: 476 ft (145m), Client: Abu Dhabi Investment Council
Location: Abu Dhabi, United Arab Emirates (UAE)
Site area: 11,500sq m
Number of floors: 29 floors
Total ground floor area: Over 32,000sq m
Area of Curtain Wall: 67,500m2
Curtain Wall System: Unitized and Stick Curtain Wall

Fig 1.8: Abu Dhabi Investment Council Headquarters Towers

CONCEPT:

The design of the towers considers both traditional Islamic architecture as well as sustainability. It includes and utilises sustainable techniques, including a state-of-the-art computer operated shading system. The designers have also striven to fuse Islamic architecture with the modern design, basing the entire structure of the building on a mixture of two-dimensional circles and three dimensional spheres. The entire structure is designed to reflect a single geometric theme. "Our concept for the Abu Dhabi Investment Council headquarters was generated from a mathematically pre-rationalised form which was in turn derived from Islamic principles," said Aedas deputy chairman Peter Oborn. "It's a thoroughly modern building rooted in tradition."[8](see Fig. 1.9-1.10)

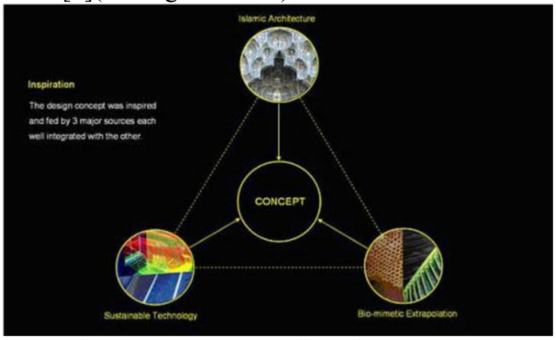


Fig 1.9, Investment-Council-Headquarters-Towers-Concept-Design

Use: Commercial office use, as well as facilities for a full-service restaurant, café, a fully configured auditorium for up to 150 people, a multi-use conference space, and prayer rooms for the building's estimated 2,000 office workers.[9]

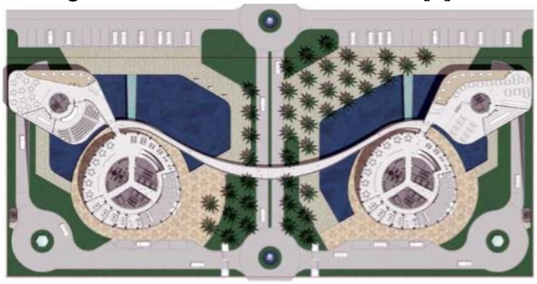


Fig 1.10: Investment-Council-Headquarters-Towers-Ground-Design

Details:

Fig 1.11: Façade Layers

Both towers are covered from top to bottom with a dynamic 'mashrabbia' screen, which opens and closes in response to the position of the sun (see Fig. 1.9). The mashrabbia comprises over 1,000 translucent moving elements on each tower and is controlled by specially designed computer software. It will reduce solar gain by an estimated 20%, and provide 80% to 90% of the shading on the building.

The mashrabiya is made of a translucent fabric mesh (PFTE), providing occupants closed. The honeycomb design is not only practical in terms of shading, but is also very resilient and difficult to damage.

These sustainable initiatives will lead to an estimated 20% reduction in electricity consumption, due to a reduced in the need for air conditioning and lighting, a 20% reduction in CO2 emissions and a 15% in cooling plant capital cost.[10]

2. Schematic Design:

2.1 Islamic Geometric Patterns:

Geometric patterns occur in rich profusion throughout Islamic cultures, displayed as they are on a diversity of materials include tiles, bricks, wood, brass, paper, plaster, glass and on many types of objects, such as, windows,doors, screens, railings, carpets , furniture, ceramic and metal decorative and bowls, furniture-specially pulpits in mosques, and on other surfaces. Islamic art demonstrates great achievements in geometry, calligraphy and arabesque For more than thirteen centuries Islamic designs have acted as unifying factors, linking architectural expression throughout the Muslim world, extending across Europe, Africa and Asia.[11] The four fundamental concepts in Islamic patterns: beauty, harmony, symmetry and unity are all intrinsic to the contemplative side of Islamic Art.[12]

2.2 Types of Islamic Patterns

1-Geometric patterns based on the Square Repeat Unit and the Root Two proportion system.

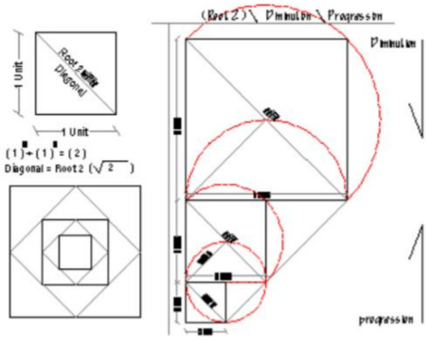


Fig. 2.1: The Root Two proportion system

2- Geometric patterns based on the Hexagonal

Repeat Unit and the Root Three proportion system.

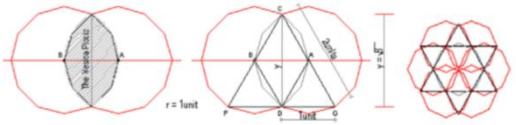


Fig. 2.2: Root Three proportion system

3. Geometric patterns based on the pentagon Repeat Unit and the Golden Ratio proportion system.

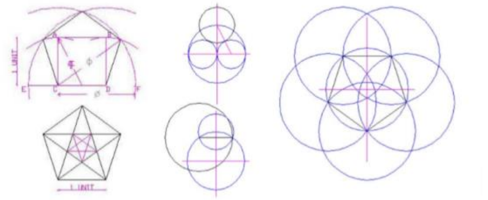


Fig. 2.3: The Golden Ratio proportion system

Even though geometric patterns are generated from simple forms; they have been combined, duplicated, interlaced and arranged in the fascinating combinations that became one of the most distinguishing features of Islamic art.[13]

2.3 The Proposed Masharabbia Patterns

After identifying Islamic patterns, the next step for this paper will be to experiment and generate some dynamic mashrabbias in order to understand how these systems would operate, with response to the sun's movement as the main parameter. Fig. 2.4 shows some screen shots of dynamic masharbbia case studies that were inspired by Islamic patterns and generated using *Maya software*.

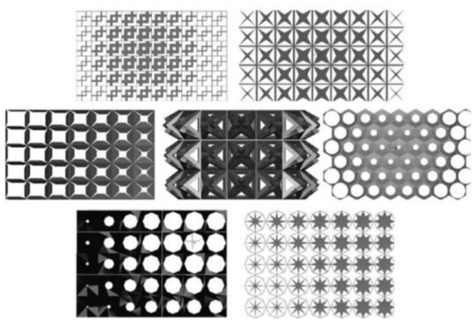


Fig 2.4: Islamic mashrabbias pattern case studies

Each interface consists of repeated units whose apertures have the ability to open and close throughout the day in response to the sun's position. The gills close when facing the sun directly in order to provide shade and minimize the amount of solar radiation in the interior spaces, then the gills gradually open as the sun becomes far in the sky in order to maximize daylight.

2.5 Dynamic Mashrabbia Environment Simulations

Three of these case studies were chosen for expanded research through real time environment simulation to gain more in-depth understanding of how these systems could affect the interior space and building performance.

These simulations include shadow study, solar radiation analysis and daylight study using *Ecotect software* as a conceptual design tool that provides an accurate and easy way to simulate the environment.

This study aims to investigate the level of shade, solar radiation and daylight at the time when the mashrabbia is semi-closed, i.e., when the sun is facing its apertures directly.

The south façade was studied in winter at 1:00 pm and the west façade in the summer at 6:00 pm. The same study was done in two different depth spaces, 6-meter depth interior space, and 9-meter depth exploration space for determining the depth that would allow an acceptable level of daylight to enter.

2.5.1 Pattern I

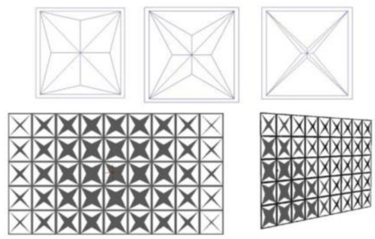
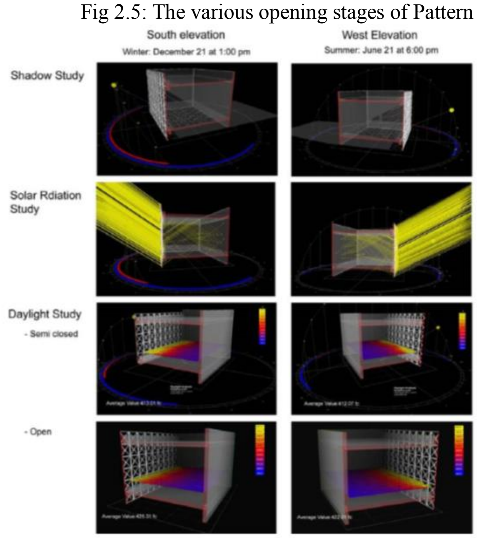


Fig 2.5: The various opening stages of Pattern I



Fig, 2.6: Pattern I Environment Simulation Result, 6-meter depth space

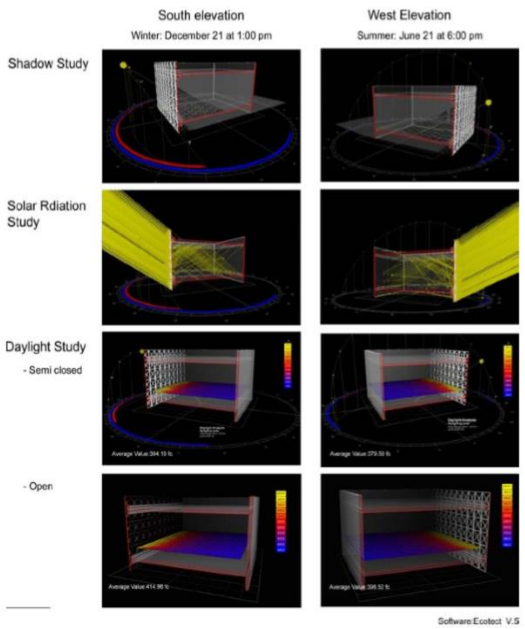


Fig 2.7: Pattern I Environment Simulation Result, 9-meters depth space

2.5.2 Pattern II

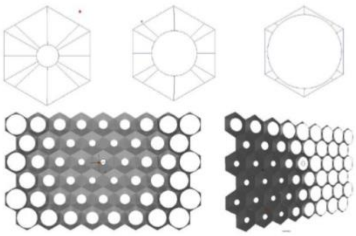


Fig 2.8: The various opening stages of Pattern II

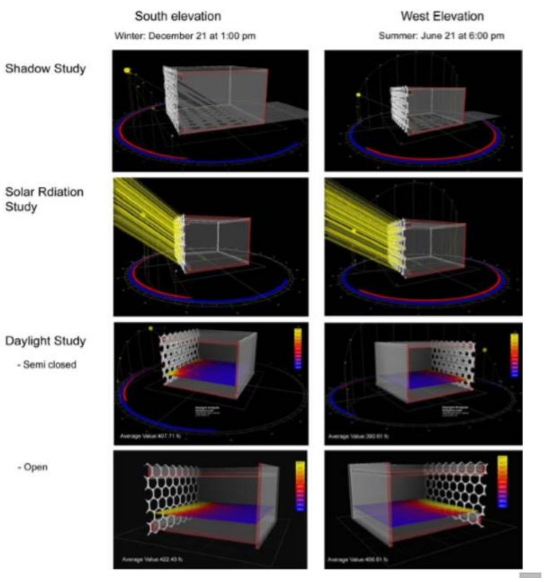


Fig. 5.9: Pattern II Environment Simulation Result,6-meters depth space

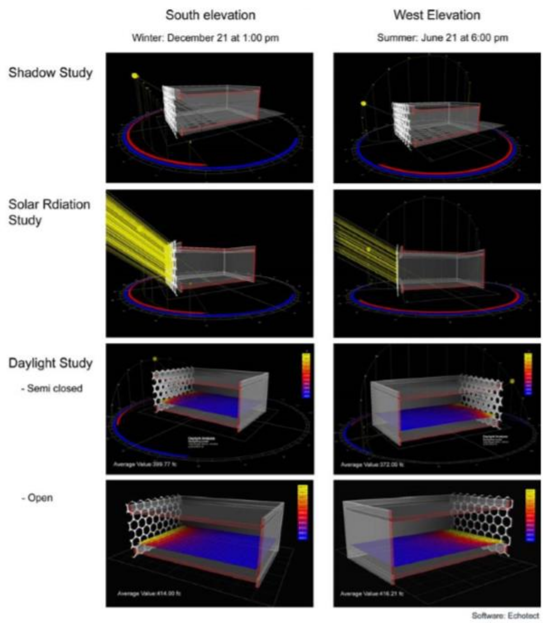


Fig. 5.10: Pattern III Environment Simulation Result, 9-meters depth spac

2.5.3 Pattern III

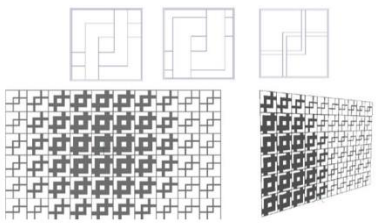


Fig 2.11: The various opening stages of Pattern III

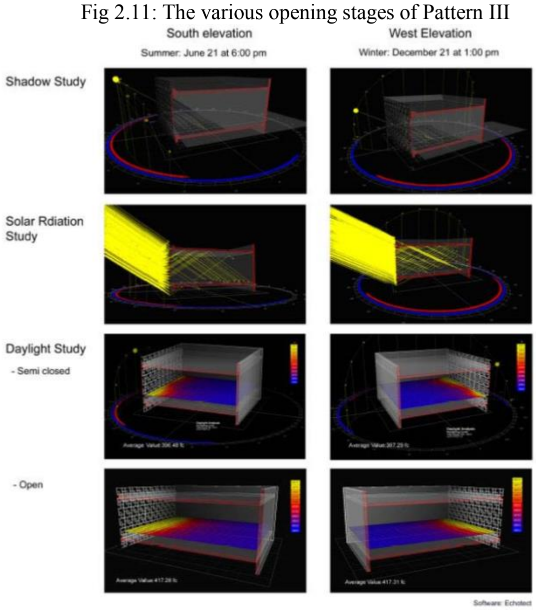


Fig. 2.12: Pattern III Environment Simulation Result, 6-meters depth space

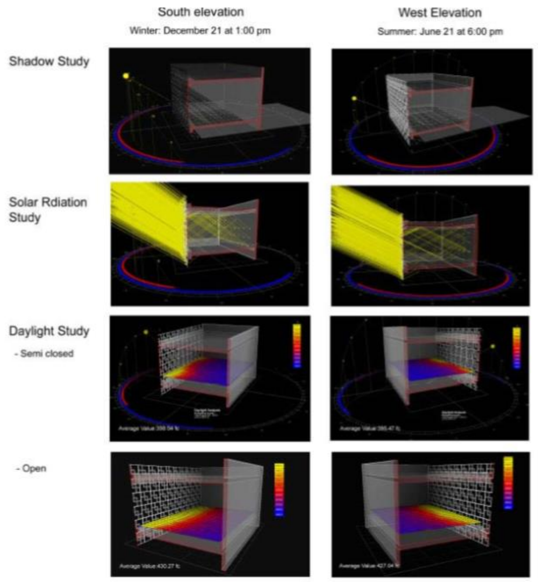


Fig. 2.13: Pattern I Environment Simulation Result, 9-meters depth space

2.6 Simulation Result:

Shadow Study: The result of the shadow study shows that the three dynamic mashrabbias worked as perfect solar shading devices, providing the interior space with a good level of shade, thereby reducing the building's inside temperature.

Solar Radiation Study: The result shows that the three mashrabbia patterns have the potential of reducing the solar radiation gain, thereby reduce the interior temperature which in turn reduces the energy used for the cooling system.

Daylight study: The daylight simulation study indicates an adequate range of daylight, especially with the first pattern, which shows the highest range, both in winter and summer. The study also shows that 6 meters is a good range of space depth, allowing an appropriate level of daylight relative to the 9-meter depth.

2.7 Appling the Mashrabbia on a building

In this experiment the dynamic mashrabbia is carefully distributed on towers which proposed to be built in Tropli-Libya in order to be more focused on both the western and eastern elevations to protect the building from solar radiation.

Some of the mashrabbia units are established around the first ten floors of the towers to provide the occupants of these floors with an acceptable level of privacy (see Fig. 2.14).

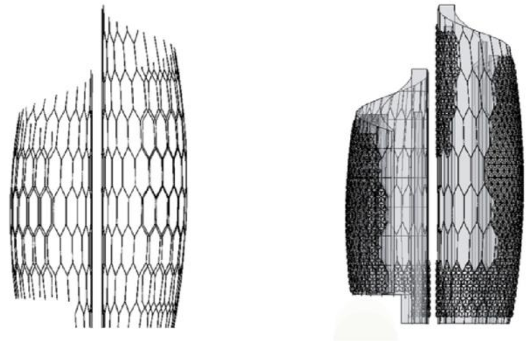


Fig. 2.14: Distributing the dynamic mashrabbia on the towers(*Revit software*)

2.8 Dynamic Mashrabbia Evaluation:

After applying the responsive mashrabbia on the building, and since the main goals of this dynamic mashrabbia, besides representing Islamic culture, are first, to provide the buildings' occupants with stable conditions in the hot climate of Tripoli and second, to improve building energy performance, it is time to evaluate the impact of the kinetic mashrabbia on the building through applying solar radiation analysis and building energy analysis on the building with and without the dynamic mashrabbia using Vasari software.

2.8.1 Solar Radiation Analysis

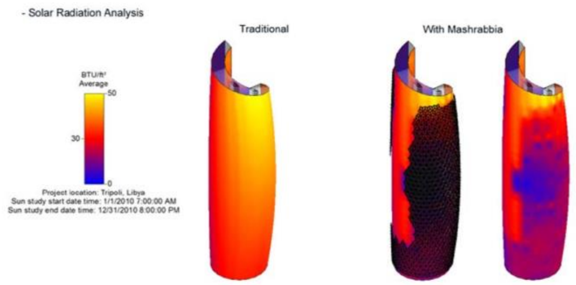


Fig. 2.15: Solar radiation study result (*Vasari software*)

2.8.2 Building Energy performance Analysis:

Fig. 2.16: Building energy analysis result (*Vasari software*)

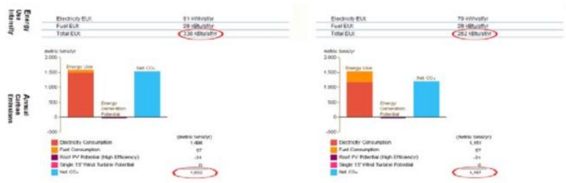


Fig. 2.17: Building energy analysis result (*Vasari software*)

2.8.3 Dynamic Mashrabbia Benefits:

1- Lighting and views:

- Improved daylight
- Acceptable level of shading
- Acceptable level of privacy
- Improved views for building occupants
- Represents Islamic culture

2- Energy Consumption:

- Effective reduction in solar gain, about 50%
- Approx. 23% reduction in CO2 emission
- Approx. 23% reduction in energy use intensity

2.9 Dynamic Mashrabbia Details

2.9.1 Dynamic Mashrabbia Behaviour during Daytime

The shading device, whose translucent components open and close as the sun moves around the building, gives buildings a sense of breathing during its smooth movement. Fig. 7.1 shows the behavior of the dynamic mashrabbia during daytime, starting from 7:00 am when almost all the mashrabbia's units are open to 7:00 pm when the western units of the mashrabbia are almost closed and ready to open after sunset.

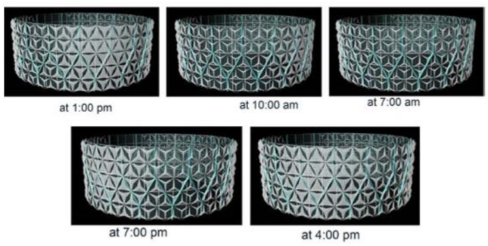


Fig. 2.17: Dynamic mashrabbia behaviour during daytime

2.9.2 Detailed Mashrabbia Design:

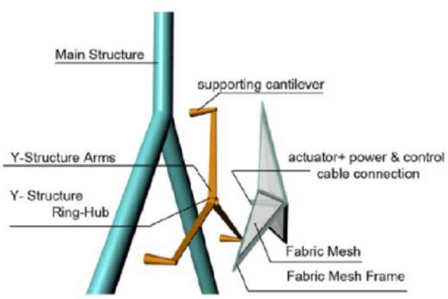


Fig. 2.18: Dynamic mashrabbia detailed design

Each mashrabbia comprises an umbrella-like unit which opens and closes throughout the day in response to the sun's movements. Each mashrabbia is made up of a series of PTFE fabric mesh panels that are driven by a linear actuator.

PTFE Fabric Mesh:

PTFE fiberglass fabric is made of high intensity fiberglass yarn by plain weaving, satin weaving or cross grain, coated with fine quality PTFE Teflon latex and then dried.95

Features of PTFE high temperature fiberglass fabric:

1. Outstanding electrical insulation and dielectric properties.
2. High temperature resistance; continuous operating temperature is -70-260, can resist up to 320 in a short time
3. High release from sticky materials ("non-stick")
4. Chemical, corrosion, and moisture resistance
5. Easy cleaning
6. Mildew and fungus resistance

2.9.3 Dynamic Mashrabbia Effect on Interior Spaces:

Below, some still images show the effect of the kinetic mashrabbia on the interior spaces of the building.The dynamic mashrabbia reduces solar gain by reflecting almost all sun rays. Moreover, it provides the occupants with a desirable leve of shading while allowing daylight to enter even when the mashrabbia is almost closed.

Fig. 2.19: Dynamic mashrabbia effact on interior spaces at different opening stages

7.2 Building Skin Layers and Ventilation system

By using the dynamic skin(Mashrabbia) the building will consist of three layers.

Immediately next to the dynamic mashrabbia comes a double-glass façade.

The Double-Skin Façade is essentially a pair of glass "skins" separated by an air corridor. The main layer of glass is usually insulating. The air space between the layers of glass acts as insulation against temperature extremes, wind and sound.

During wintertime and at night, the Living facade can rely on natural ventilation through the controlled windows in the inner skin, while in summer and during the hot season, the building's skin layers work as an insulation system that keeps the building cool (see Fig. 2.20).

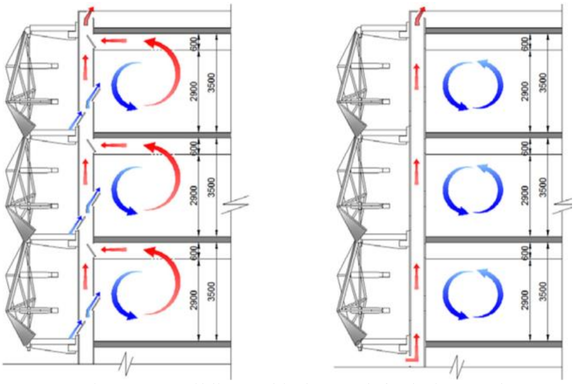


Fig. 2.20: Building's skin layers, left: during moderate climate and at nights, right: during hot climate

4-CONCLUSION

Designing a building for a specific location needs great understanding of the people, culture and the available building technologies while engaging them in a meaningful way. The building could represents the translation of Islamic architecture to contemporary architecture, it attempting to preserve the Islamic character and culture with a strong climatic response and energy efficient design.

Creating buildings that meet the needs of society today and in the future is not an easy task. However, the use of a range of advanced computer-aided design techniques can greatly help produce such buildings more quickly, easily, and at less cost.

At the same time and as outlined in this paper, culture and architectural vernacular has much to offer the modern world. Sustainable design is not only a way of viewing and valuing good design but a way of linking the past with the present to protect our natural world and ecosystems, as well as to preserve historical and cultural artifact.

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- Softwares used in design and anylisis:

-Maya
-Vasari
-Revit
-Ecotect

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