

Nature Inspired Interior Design Principles in the Hot Arid Climate of Saudi Arabia

by

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## ABSTRACT

Biomimicry is an approach that entails understanding the natural system and designs and mimicking them to create new non-biological systems that can solve human problems. From bio-based material development to biologically inspired designs, architects and designers excelled in highlighting the fascination of integrating the biomimetic thinking process into the modern design that provide more comfortable space in which to live. This thesis explores how historical sustainable strategies from Islamic traditional architecture incorporated natural design system that could now be appropriately applied to interior architecture. In addition, it explores the current existing problems in this field, and the possibilities of biomimetic sustainable solutions for existing buildings in the hot dry climate regions of Saudi Arabia.

The author concentrates on examining Islamic traditional architecture where the past architects incorporated certain aspects of nature in their construction and through using local resources, built buildings that mitigated heat and provided protection from cold. As a result of completing this research, it was found that there are common characteristics between the traditional Islamic architecture elements and system solutions found in some natural organisms. Characteristics included, for example, evaporative cooling, stack effect, and avoiding heat gain. However, in the natural world, there is always opportunities to further explore more about the impacts of biomimicry and natural strategies applicable to enhance interior environments of buildings.

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# CHAPTER 1

## INTRODUCTION

### **Self-Introduction/ Preface:**

My name is Hawaa Ismail Hawsawi. I was born and raised in the city of Makkah Al-Mukarramah, (Mecca). I obtained my bachelor degree in Housing and Home Management in 2008 from Umm Al-Qura University (the Girls College of Education - Home Economics Department, formerly), in Makkah. I am presenting this research as a final project for obtaining the Master's degree in Science in Interior Design at Arizona State University.

In this introduction, I would like to describe briefly the western cities of Saudi Arabia with particular emphasis on the city of Makkah. This information is to highlight some of the important facts that will illustrate to the reader the significance of this research focus.

The western region of Saudi Arabia is traditionally called “the Hejaz province”. It has five regions along the Red Sea: Tabuk, which is located in the North West, Jizan and Asir in the southwest of Saudi Arabia, and Makkah and Al-Madinah are both located in the Middle West between Tabuk and the southwestern cities. The city of Makkah and Al-Madinah have similar climate except for the northern part of Al-Madinah.

### **Location, weather & population:**

Makkah, which is the capital of Makkah Province in Saudi Arabia, is located at

21.43 latitude and 39.83 longitude and it is situated at elevation of 333 meters above the sea level. It is characterized as having a hot desert climate. Over the course of a year, the temperature typically fluctuates from 19°C to 43°C (66.2°F to 109.4°F) and is rarely below 16°C or above 46°C (60.8°F to 114.8°F). Mecca and other dry cities such as Madinah, and Riyadh have dry periods from May to September, with June being the driest month over the year. The area within 40 km of this station is covered for about 98% by shrublands and the built-up areas of 3%. Currently, Makkah has a population of 1,323,624; making it the third biggest city in Saudi Arabia. Makkah's population is increasing due to immigrants, which makes the housing and the city planning important issues.

**Islamic central:**

The Holy City of Makkah is known to the Muslim believers as Umm al-Qura, the Mother of Cities. It has many features which distinguish it from other cities not only in Saudi Arabia, but also worldwide. Because of the Al-Masjid al-Haram and other sacred sites, Makkah has historically been considered to be the holiest city of Islam.

As a result, every Muslim considers it his/her duty to visit Makkah at some point in his/her life. More than two million Muslims from more than 183 countries (Christopher S. Bowron, 2015), who are not prevented by personal circumstances, come to Mecca every year in the holy month of Ramadan and the month of Dhul-Hijjah to perform the Hajj and Umrah. Most of them return home, however some portion of visitors, who are spiritually elevated, decide to stay in Makkah, thus raising population of the city from year to year.

### **Copiousness of ancient houses:**

In ancient times when urban planning was inexistent, people randomly built their houses around the holy mosque. Each building has been built up using unique way to avoid the heat. During the industrial and the economic growth of the last century, building materials and construction methods have changed with the spread of electricity in towns and villages throughout the Kingdom (Country Analysis Brief, 2014). People began to build modern buildings without considerations to climate, which were constructed lacking thermal insulation and heatproof coatings because of the use of HVAC system. Therefore, today's existing buildings are utilizing these same flawed methods, which is the focus of the current research problem.

### **The architectural systems:**

Architectural systems in Saudi Arabia did not require the household to follow certain architectural pattern or requirements to ensure using thermal insulation materials up until recent years. These kind of materials will not only reduce the heat, but will also decrease consumption of electricity, thus saving income and benefitting the environment. Today, with the construction development campaign in Makkah, a long history of disorderly architecture does not allow Makkah to completely renovate the city according to modern codes. Instead, architects and engineers are looking for ways of solving this problem by enhancing thermal insulation through using heat mitigating materials and techniques.

### **Saudi Arabia's 2030 Vision:**

On April 25, 2016, the Prince Mohammed bin Salman Al Saud revealed a long-term vision, which is an ambitious and achievable plan based on the Kingdom possibilities that aims for the future development of the Kingdom of Saudi Arabia (KSA) in several fields. The Saudi Arabia's Vision 2030 as stated by (Al Arabiya English, 2016) that government would try to increase household income savings from 6% to 10% of-total per household. Additionally, he emphasized the importance of preserving the national identity and cultural heritage in order to consolidate the Arab and Islamic values to enhance the national unity, and to guide the lives of future generations (Saudi Press Agency, 2016).

These goals can be viewed from multiple domains, however, architects and designers can play an important role in reaching these goals and in facilitating this process. by helping household to save money through using alternative resources and by highlighting national identity and cultural heritage through architectural designs. As researchers, engineers, designers and architects should work hard and participate in providing any kind of help to accomplish these goals by 2030.

### **Thesis Statement:**

This thesis explores how historical sustainable strategies from Islamic traditional architecture incorporated natural design system that could now be appropriately applied to interior architecture. Past architects incorporated certain aspects of nature in their design approaches and constructions methods. Using local resources, they built buildings that mitigated heat and provided insulation from cold. This research explores current existing

problems in this field, and the possibilities of biomimetic sustainable solutions for existing buildings in the hot dry climate regions of Saudi Arabia. These solutions can provide comfortable and sustainable structure that reduce demand for mechanically cooled interior environment.

## **Introduction of Study:**

The relationship between humans and nature began and grew since the beginning of human life on earth when our ancestors were surrounded by nature. They observed the surrounding environments and used natural resources, such as stone and wood, in order to ensure protection and survival. Their intellect led them to study the behavior of the living forms around them in which they learned many things from existing examples. This observation of nature allowed them to learn how to secure their lives, protect themselves, and search for the necessities of life.

There are conflicting stories regarding human origin. According to scientists Homo erectus, an extinct hominid species that originated in Africa 1-2 million years ago was the first human species that spread all over the world, and evolved into ancient humans (Science Museum). However, some religions such as Christianity and Islam believed that God has created Adam and Eve as first humans appearing on this earth.

Interestingly, no matter which version of human creation you believe in, there is an example of biomimicry in every one of them. For example, it is worth mentioning one of the well-known stories in religious texts, the story of the first murder, which is accepted by both Christianity and Judaism and mentioned in the Quran the holy book of Islam. This is a story of the sons of Adam, Cain, and Abel, who have both made offerings to God. Abel sacrificed a lamb, while his brother Cain sacrificed some of the green crops; however, God accepted only Abel's sacrifice causing Cain's jealousy, which ultimately leading him to kill his brother. This is where this story gets interesting. According to the Quran, following this murder, God sent forth a raven scratching and digging up the soil trying to bury a dead

raven until it was completely buried. Thus, Caen learned how to bury the body of his dead brother in the soil (The Tafsir).

Burying humans or animals or even dead leaves and plants is an important part in the natural cycle, since microbes recycle organic leftovers and processed nutrients become primary food source for soil. This example shows the genius of nature in the biological sustainability and zero waste process that ensures natural efficiency. Humans learn about these efficient energy conservation processes from nature, plant and animal behavior, thus developing an idea of biomimicry and sustainability in recent times (Kowalski, 2014).

In the modern industrial society, enormous amounts of energy are consumed on regular basis by human activities worldwide (IPCC 2014), which leads to increasing the level of greenhouse gasses available in the atmosphere, thus causing global warming. Moreover, our world today experiences several other challenges that range from energy crises, water and food shortages, to natural disasters and environmental pollution. While most of these challenges appear to be climatic or nature based, some scientists believe that they are the results of our failure to adapt to the Mother Nature.

According to Blizzard and Klotz 2012, such problems that we encounter are directly related with how we design our environment because everything in nature is innately intertwined. Therefore, the researchers conclude that in order to create safe and healthy environment and successfully model our world for sustainability on the planet, architects and designers need to draw their inspirations from nature itself where all organisms play certain roles that is reflected in their designs. They are very successful at being efficient and sustainable. By looking at nature, designers can create designs, models,

and products that would work harmoniously and in an integrated way with the larger environment surrounding us.

### **Biomimicry Overview:**

The field of Biomimicry can play a harmonizing role in our world when the designs are based on examples from organisms and the natural ecosystem. Although the term “Biomimicry” has gained popularity in recent times, the concept has its roots centuries past (Gust, & Moore, 1985). The first application of biomimicry was the copying of natural figures on the building facades. About 2100 years ago, Vitruvius, a Roman architect, opened a new dimension in biomimicry when he used the dimensions of the human body to make proportions of temples. Since then and until the 18th century, copying natural forms, proportions and figures was mostly the only application of biomimicry in the architectural field. In the 1500’s the great artist and inventor, Leonardo da Vinci studied birds in his attempt to build the machine that would fly. Years later, his nature-inspired vision was fulfilled when the Wright Brothers adopted the same concept and engineered the first plane (Johnson-Laird, 2005). Many experts and researchers considered Leonardo da Vinci as the first biomimetic designer because he changed the phenomena that based on the observations and copying the natural figures to a real man made design application (Mazzoleni & Price, 2013).

By the time of the industrial revolution, a new dimension was created in biomimicry that included copying construction systems found in both animals and plants. According to Elghawaby the crystal palace in London and the Lily house in Strasbourg which were designed by Joseph Paxton, both were inspired by natural constructions. Similarly, in the

mid-20th century, Robert Le Ricolais developed new structural models through copying Haeckel's biological structure models drawn in the 19th century (Elghawaby, 2010).

Additionally, in the middle of the 20th century, architects and engineers such as Frank Lloyd Wright, Frei Otto, and others started to design buildings through copying natural proportions, forms, and structures in their design. The architect Frank Lloyd Wright (FLW), for instance, designed the Price Tower inspired by a tree structure. In addition, in the Johnson & Son building, FLW took the idea of the columns from the shape of mushrooms. The beginning of the 21st century has seen increases in new information and telecommunications, advanced technologies and artificial intelligence, which added new values and ideas to the field of biomimicry. Such new additions include the imitation of natural systems and processes and the creation of new building systems that work like natural organisms (Elghawaby, 2010).

Biomimicry has been adopted through the spread and esteem of the fields of biology and architecture recently. From bio-based material development to biologically inspired designs, the seeds of Biomimicry have brought forth the reality of functionally green designs that continue to shape the social and environmental surroundings.

Janine Benyus defines "Biomimicry" in her book *Biomimicry Innovation Inspired by Nature* (Benyus 1997) as a new science that studies nature as a model, as a measure, and as a mentor. It is a new way to view and value nature and seek to imitate nature's forms and processes for solutions of humans' problems. She argues that biomimicry could be a great emblem for the creation of a sustainable future. However, biomimicry should not only be restricted to mimic 'nature structure' alone, it also aims to promote the adoption of

the learned lessons and then incorporate the knowledge into modern designs. Smart adoption of natural structures will be beneficial for humans and for their environment. Janine Benyus definition is a foundation and inspiration of understanding biomimicry for this research. Nevertheless, the term of Biomimicry in this research refers to learning the strategies of nature through its systems, processes, and adaptation characteristics while emulating or borrowing these functions in order to incorporate them to solve problems of the built environment.

### **Biomimicry as a Technique for Interior Architecture:**

The key to recognizing the role of biomimicry in interior design lies in the philosophy of biological architecture. This philosophy may be viewed in a misinterpreted way. It can be interpreted as the basis of all designs must be traced back to nature. However, biomimicry proposes that all designs must be examples of good designs. Therefore, biomimicry has the potential to support the creation of original and innovative designs in the interior environment, which will result in beneficial advantages either through methods of functionality or sustainability.

To develop and apply Biomimicry in interior design, the designer or architect needs to understand the framework(s) that would be most relevant and efficient for the achievements of his or her goals, firstly. In architecture, buildings should be designed either to solve an existing problem with innovative approach or to use nature inspired methods to tackling a similar problem.

In interior design, two approaches have the potential to change architecture for the better, the direct and indirect methods. The direct problem-based approach suggests that

designers should copy the living world, i.e. organisms, for solutions that, in essence, would solve the issues that they are encountering. By finding plants that solve the same problems, the designer can create solutions that would address the problem that engages them, hence fulfilling the “design looking to biology” approach (Zari, 2007).

Likewise, the indirect solution-based approach promotes the understanding of the biological phenomena or having knowledge on ecological research to influence design. Indirect approach is an abstraction of the natural functions and characteristics to develop design concepts, lessons and principles for solving human design problem hence fulfilling the “biology influencing design” (Gamage & Hyde 2012). These approaches inspire this study, which will explore the problem of heat in the western of Saudi Arabian interior architecture, by drawing from nature; the study hopes to find solutions to the problem or to find a way that may lead or inspire designers to solve the problem.

**Statement of Problem:**

Saudi Arabia has an overall desert climate that is characterized by both extreme heat during the day and cold at night. These climatic conditions have several effects in buildings especially in the western regions of Saudi Arabia. For instance, during summer, the weather temperatures have averaged at maximums of 120 degrees Fahrenheit in some areas of the West Saudi Arabia (Saudi Arabia Travel Guide, 2015). The relative humidity level is varying according to the distance from the sea coast. The humidity average ranges between 30 % in July to 89% which very humid in September in the city of Jeddah, while in Makkah it ranges from 19% in June which is dry, and to 80% in the month of December and over the year (WeatherSpark Beta). While the heat problem is mainly climatic, several

other issues as a lack of understanding regarding quality, and durability of construction materials have unpleasant effects in the interior environments of buildings.

The unfortunate reality is that some of the buildings in Western of Saudi Arabia were designed not taking into consideration the directions of wind and sun movements. Additionally, the necessity to apply thermal insulation for all buildings (commercial, residential and private housing) was only issued in 2009-2010 by the Ministry of Municipal and Rural Affairs in Saudi Arabia. Prior to this time, thermal insulation was required only for commercial and investment buildings in the Kingdom, which indicates that there are many houses that rely on consuming energy and air conditioning to keep the building cool.

In addition, in such a conservative society ruled by Islamic identity, Islamic countries have special requirements for choosing windows' sizes, which in some cases can be an obstacle for many landowners to provide the proper natural ventilation that they wish for their houses. This study, therefore, will focus on the hot-arid regions of Saudi Arabia where biomimetic solutions could have the potential to return nature back to the building interiors where it could reflect its benefit to the residences life.

**Justification/ Significance:**

Over the recent past, with the realization of the importance of biomimicry in architecture, there has been a positive shift towards biologically inspired designs. In several

regions around the world, architects have turned the philosophy of biomimicry to a reality and designers have constructed buildings that have the potential to adapt with the environment. A good example from the Middle East is the Cactus-inspired design building which was designed by Aesthetics Architects Go Group in Qatar (Figure 1). This



*Fig1: The Minister of Municipal Affairs & Agriculture (MMAA) in Qatar (Meinhold)*

building simulates the way that cactus adapts with the harsh environment. This example proves that existing biological designs can be used successfully. While Saudi Arabia cannot just copy the design, of course, the goal is to see such creative design solutions that distinguish the architectural development in the Kingdom.

Likewise, in the western regions of Saudi Arabia, there is the dire need for designs that will improve the aeration, ventilation and heat levels inside buildings. This nature-inspired design, the carbon dioxide (CO<sub>2</sub>) and heat levels can be regulated efficiently.

Just as the organisms in our environment utilize oxygen and exhale carbon dioxide, the use of plants in buildings will have the same effect. Since in reality, human ingest oxygen and reproduce carbon dioxide, there is a need to find ways of transforming the CO<sub>2</sub> back to Oxygen (Building Operation Management, 2013). Plants are able to convert CO<sub>2</sub> and water into oxygen and carbohydrates in the process of photosynthesis. Therefore, the use of plants could be a considerable solution in creating a natural ventilation inside buildings. Plants play a role in providing an environmentally friendly biological solution

for ventilation; buildings therefore can rely on them for the same goal. Likewise, the adoption of more natural designs has the potential to create sustainability in the plans of buildings.

### **Objective of Study:**

The main function of the built environment is to provide protection from the stresses that are imposed by the surrounding climate (Koch-Nielsen, 2002). In fact, people currently spend about ninety percent of their time in the interior, and as interior designers, it is important to ensure the well-being and comfortable interior environment for the occupants (Winchip, 2011). This research aims to discuss the issue of interior natural ventilation in the existing buildings in the hot arid regions of Saudi Arabia. It is also seeking for effective sustainable solutions for existing buildings; owners face today, some of the major research questions include:

- What can be learned from nature system's functions that could help to improve the performance of natural ventilation in order to minimize the use of artificial energy in cooling the interior environment?

Studying the history of natural ventilation strategy in the hot regions of Saudi Arabia takes us back to traditional Islamic architecture, which has a long history of dealing with this problem of natural ventilation in such climate. Researchers have reported many examples that show the genius of the historical and vernacular architecture of the Arab world. Aziza Chaouni who is the founder principle of Aziza Chaouni Project (ACP) said during her journey to the Saharan region in Jordan that:

*“The eco-lodges I visited had unique architectural strategies that blend the local language with the new technological system” then she described them as “they were not just beautiful and intelligent buildings: they were made to survive in an environment that has nothing for you.” (Green, 2015, p. 66)*

In another word, these building were able to meet the needs in the most efficient and sustainable way without harming the environment. Li Xiaodong the principle of Li Xiaodong Atelier also mentioned that the “vernacular architecture is about an attitude of how to approach architecture: how can we sustain our culture and lifestyle? How can we live with nature?” (Green, 2015, P170).

From this point of view, this research is seeking to formulate the research focus based on the influences of the traditional Islamic architecture, which could be done by answering the following sub-questions:

- Were the Islamic traditional architectural elements inspired by natural strategies? If yes, what solutions came from these strategies?
- What are the possibilities of integrating the traditional Islamic architecture design elements into current existing buildings and contemporary architecture in hot climate?

Traditional Islamic architecture refers to the Islamic elements that appeared from the foundation of Islam and were ruled by Islamic religion and culture in design. In order to achieve the research objectives, this research will be looking for methods that have been used in constructing of the traditional Islamic architecture in hot arid climate. Some of these buildings were originally inspired by the vernacular architecture that are responding to the local climate, needs, lifestyle and construction materials, and reflecting the local

traditions as well. This aims to improve the natural ventilation, and search for the main design principles that lead to a better sustainable solution for the existing buildings.

## **CHAPTER 2**

### **METHODOLOGY**

This research is using historical qualitative research method, which is a kind of descriptive research that describes and examines issues or facts that happened in the past and set a guidance to the future in order to recreate the past in the present time. Therefore, the methodology formulated in this thesis focuses on the following areas:

- First, is a study of how natural organisms adapt to harsh environments in order to draw nature-based inspirations that could be used in solving the problems in architecture. This will include a literature review that presents some recent studies on the application of biomimetic solutions for improving the interior natural ventilation of buildings in the hot arid regions.
- The second is a study of some of the most common adaptation methods that are used in the Islamic traditional architecture specifically in a hot-dry climate.
- Lastly, the study will include a comparative analysis between organism adoption methods and the Islamic traditional architecture, which aims at highlighting nature-based elements in the traditional architecture.

Studying the historical and vernacular architecture helps us to understand why some of the current buildings often fail to meet the basic human needs. More importantly, studying architecture of places that only had limited resources available for construction offers solutions that create strong connection between the designers, their environment, the materials that they use, and their community (May, 2010).

The old traditional buildings leave an impression of close proximity to nature in terms of their use of building materials and adoption of nature-inspired building strategies. Several studies show that the human relationship with nature positively affects the psychological well-being, fast recovery from illness and increases creativity in the work environment (White, 2004).

Rene Dubos (1980, 68) wrote a very important piece for the architects, designers, and all other relevant specialists to be considered in order to maintain this relationship with nature:

*Wooing of the earth suggests the relationship between humankind and nature [can] be one of respect and love rather than domination. The outcome of this wooing can be rich, satisfying, and lastingly successful if both partners are modified by their association so as to become better adapted to each other.* (Kellert, Heerwagen, Mador, 2008, p.14)

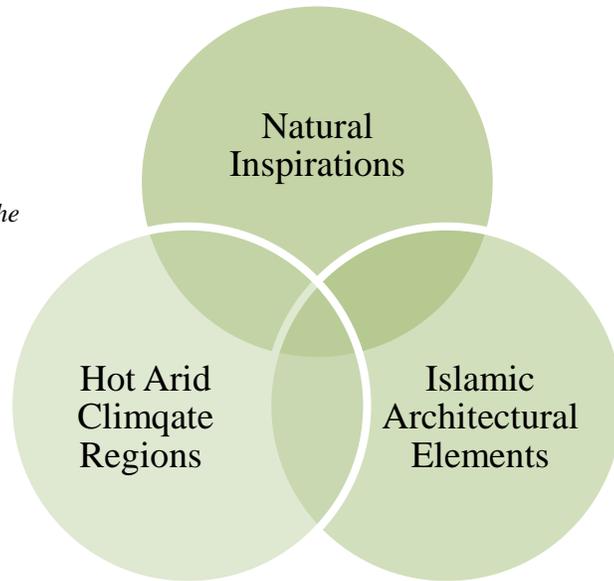
Thinking about environmentally sustainable and responsible solutions has recently become an overarching trend for the future development in architecture. In order to reach this level of satisfaction and successfully adapt with nature, designers and architects should lead the path and face these challenges to achieve a sustainable future. Therefore, in the methodology of this study some of the genius Islamic traditional architecture solutions that had intended to maintain the comfortable interior environment for the occupants has been highlighted.

Islamic traditional architecture has its roots in nature. The aim is to explore ways to engender a good relationship between individuals and nature, by incorporating these Islamic architectural elements and integrating them with the modern architecture. This in

turn would re-engage people back to understanding their Islamic heritage and culture helping to pass it on among the future generations in hopes to apply them to their contemporary architecture.

**Conceptual Framework:**

*Fig:2 The overlapping area is where the designer has a potential to develop a sustainable solution for interior.*



The conceptual framework (Figure 2) was formulated to look at natural strategies as the general topic of the research focuses. Subsequently, exploring the Islamic traditional architectural elements in order to draw a relationship between these traditional architectures and the natural solutions while restricted to be studied and applied in the hot climate region. The overlapping area is where the nature solutions come along with the old traditional architecture strategies thus represents the outcome of the study.

**Limitations:**

The limitations faced by this study include that the study might need a field study in the western region of Saudi Arabia to identify specific examples of the old existing

buildings targeted by the research. This is because not all parts of the western region of Saudi Arabia have hot and dry climate, and the fact that the researcher is out of the country creates an obstacle to the implementation of this study because the researcher cannot access the tangible structures to examine their details and how there are being used by people.

Secondly, the study might face the lack of awareness among landowners and tenants of the importance of rationalization of energy consumption, the benefits of biomimicry and sustainability in architecture as a way of solving problems in buildings as well as the using appropriate interior plants in order to engage nature with our everyday life.

Furthermore, there was a lack of documented information about the original architects and early building construction methods in the western of Saudi Arabia and most of the information obtained were based on analyzing of the existing constructions. In addition, only limited resources were found that addressed the application of biomimetic solutions for hot dry climate.

At last, another obstacle of the study is about how architects and designers would eventually apply these natural strategies into interior architecture and evaluate their efficiency. There are variety of ideas and design solutions, however, it would need further research to expand knowledge, and develop detailed information about the best materials and methods to use and other technical issues.

## CHAPTER 3

### LITERATURE REVIEW

For years, Saudi Arabia and many other hot dry countries in the Middle East have been coming up with skillful and scientific methods to adapt to the hot dry climate. The work of Saudi Arabian and other Islamic cities has always been impressive due to their adaptability to the harsh environmental conditions and integration of religious and cultural values such as family privacy into an architectural form that meets social and physical human needs.

There are different architectural adaptations methods that have been used depending on climate in specific area in the Middle East. Areas within the seacoast cities experience humid and hot conditions; Yemen and Iran are very cold, while areas in North Africa such as Morocco is extremely hot due to the desert and semi-desert (Springuel, Irina, 2006). The ancient builders in all these areas have developed various ways of designing their structures to maintain the temperature during cold night and avoid heat during hot days.

In ancient times, Saudi Arabian people used thick roofs and walls to counter the day's heat as well as the chilling of the night. They also used earth-based materials to limit storage heat from transferring into the interior environment of the building. They built alleyways and narrow streets that would moderate the sun's glare, solar radiation, and the often-hot dusty winds.

In this part of the literature, the focus will be towards representing examples of the concept of biomimicry and the nature based strategies that can be emulated on design and

architecture. It will discuss the early application of biomimicry in the traditional buildings in a hot climate, and final section will include recent researches on the application of biomimicry in today's modern design.

### **Nature Organism Solutions and Strategies:**

It is very important for organisms to maintain a stable temperature to do their physiological and biochemical function. Animals and plants that live in either hot or cold climate have creative ways of adapting to the surroundings temperature. Some organisms often store heat to keep cool and buffer from extreme heat fluctuation of the surrounding temperature. However, in general, there are four main mechanisms for heat gain and loss, which include evaporation, conduction, convection, and radiation (Mazzoleni & Price, 2013). Evaporation happens when the organism loses its heat while the ambient temperature is warmer than the body. For organisms, evaporation is considered a cooling system that occurs through losing the heat due to the process of changing the water from liquid to vapor (USGS Science for changing world, 2016).

Conduction and convection are similar: conduction happens when two objects with different temperature are connected to each other, (like animals when they stick on a cold surface such rocks and vice versa), therefore, gaining or losing heat. While the convection occurs via transferring the heat through water or air to cool down.

Lastly, radiation happens when heat transfers without a physical contact. Animals for example lose heat when the surrounding temperature is cooler than their body temperature (Mazzoleni & Price, 2013).

There are also many other strategies that animals and plants use to prevent overheating, which range from physical characteristics, behavioral changes, and physiological adaptation. Some animals for instance have long limbs that keep their body far from the hot ground, thus reducing radiation. The light color that characterize animals in the hot climate helps to reflect heat (Mazzoleni & Price, 2013). Likewise, plants also have several mechanisms to adapt with the climate. Some plants in the desert grow only in shaded areas while other grow only in winter. Meanwhile some species have the ability to change their color depending on the climate. In addition, most of the desert plants have small leaves to minimize the surface area exposed to the sun and very long roots to access the water (Kelly & Schnadelbach, 1976).

There are various examples representing solutions and strategies adapted in the natural world. This thesis addresses some examples of organisms living in a desert climate, which can be used to derive inspiration to solve the challenges facing design of structures in such a Saudi Arabia.

**Dromedary camels** (Figure 3) possess distinctive characteristics that help them to endure living in such a harsh environment. A camel is a big creature that in addition to producing body heat, it is exposed to inescapable time under solar radiation during the day. However, camels gain and lose heat slowly, and that slowness allows them to warm up slowly during day, and lose heat slowly during the night. Consequently, they manage to control both body heat and water



*Fig3: Dromedary camels (Camel Fact Sheet.)*

evaporation effectively. Besides that, the large desert mammals are coated mostly with short and smooth hair, which reflects solar energy, while the long dense hair of the dorsal ridge provides an insulation, and shading for the skin from both solar heat and overnight cold (The Open University, 2016).

Camels have three layers of eyelids (Figure 4) two of them have long thick eyelashes to protect their eyes from sand and dust, and the third layer works as a windshield wiper to wash the remaining dust out of the eyes (British Lama Society, 2011). They also have slit-like nostrils that are able to open and close in the times of sandstorms. Their nostrils



*Fig4: Camels eyelids (Barrow)*

have the ability to extract moisture from the air and to conserve the moisture going out of their body during exhalation. Sweating in camels plays an important role in thermoregulation for the camel's skin. Although camels do not sweat much, they start sweating when their body temperature reaches 41-42°C (105.8-107.6°F) to eliminate the loss of water (Camel Fact Sheet).

Examples of such local species that adapted to hot dry climate is very important in finding solutions in architecture. This gives architects and designers a natural example of adaptation with environment that can be copied in buildings in hot regions such middle east.

**Tree barks and leaves** (Figure 5) in the other hand provide another mechanism of staying cool even during the hottest days in hottest regions. They maintain temperature

very efficiently. Tree bark never becomes as hot as to be untouchable by hand. This means that it can maintain temperature in more than fifty degrees Celsius. Researchers found that tree barks have the ability to absorb radiation through tannin and

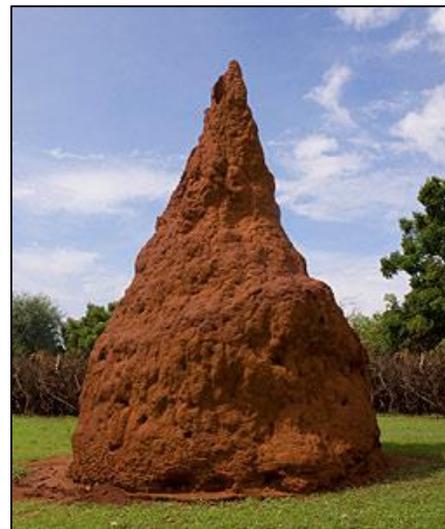


*Fig5: Tree barks (AskNature.org)*

cellulose, and reflect the incoming sunlight, which keeps surfaces cool (Henrion & Tributsch, 2009).

**The giant mounds of African termites** (Figure 6) that were discovered in *Macrotermes Natalensis* provide one of the best examples of the thermal buoyancy by the ecosystem. The mound is occupied by a thousand of termites which are breathing oxygen and producing carbon dioxide, thus generating a lot of heat at the same time. Researchers found that the mound built out of a soil that does not conduct heat well. It has many ventilation tunnels within the wall, which are controlled by the termites to keep the steady temperature inside the mound.

These tunnels can be open when the inside temperature gets too high, so the hot air moves upward the mound by the stack effect. Since the raised air still stays inside, it is drawn by another tunnel that extends all the way down to the ground level where it saturates with water (Pawlyn, 2011). This, in turn,



*Fig6: Termites Mounds (termite web, © 2009 - 2015)*

cools the air once more to stay at the lower level of the mound where it maintains the optimal temperature condition for the eggs of the queen termites (Allen, 2010).

**Living stone plant**, which is also known as “Lithops” (Figure 7) is a kind of plant that can survive in an extremely harsh environment. It grows only a few millimeters above the ground while taking advantage of the underground stable



*Fig7: Lithops. (Ultimate Christoph)*

temperature to protect itself from the heat and cold temperature in the desert climate. It also has a small window, transparent surface that allows sunlight entry to the inner of the plant in order to do its photosynthesis process (Fearn, 1981). The interior designers could simulate such strategies by ensuring the way to control solar light absorption and thermal emission in wall painting or surfaces.

## Nature Inspired Early Islamic Architecture:

**Thermal mass:** It was observed that the extreme heating during the day and the cooling during the night were brought about by the physical process of solar radiation. To minimize the cooling effect during the nights, builders applied thermal mass in the design of the building. In thermal mass, they would use heavy, dense materials that are capable of absorbing substantial heat during the day, as mentioned in using the thick walls and roofs. The best materials they choose for that which do not conduct heat such as were stone, concrete, and sun-dried earth brick (Figure 8). Through this method, the interior spaces would stay warm during the night despite the outside cooling. By morning, the thermal mass of the thick walls and roofs had cooled off leaving the interior cool during the day (Gut, & Ackerknecht, 1993).



*Fig8: Traditional sun-dried earth brick materials and thick walls (the homes of Najran, Saudi Arabia (Roffy)*

**Underground housing:** According to Benyus, other methods that were used by the nomads were the underground housing or dwellings. The surrounding earth in these dwellings would act as a thermal mass that would keep steady temperature throughout the day and night. Temperature stayed somewhat constant, similarly to living in caves. Matamata village (Figure 9) that is located in southern Tunisia is one of the most remarkable examples of the



*Fig9: Matamata village in Tunisia. (Carvin, 2005)*

underground courtyard houses that recently have been transformed into hotels for tourists and guests (Talib, 1984).

**Wind catchers:** (Figure 10) As a way of cooling the interior of the house and keeping it as comfortable as possible during the hot days, people in the hot arid regions have devised various designs of wind catchers depending on the different climate conditions, culture, and material availability. They have designed multi-directional, bi-directional and unidirectional wind catchers, which are still present in traditional architectural structures in many countries.

There is the Malqaf, which is a kind of wind catcher known in the traditional Egyptian architecture, The Badgir or Barjeel was developed in Iran, and Wind Scoops that were used in multi-story buildings. The Barjeel appeared in a high-density population of the city of Pakistan, where the scoops were placed over the top of the buildings to draw the air down into the building interior (Al-Shaali, 2002).



*Fig10: Wind tower in Dubai. (The Foto Genius, 2014)*

All wind catcher types serve similar function: their towers usually are built higher than the roof level to reach higher wind velocity; as a result, it catches the airflow and passes it downward to the interior; as for the hot air, it goes upwards out of the building. When the building gets cool during the night, the warmer air rises due to its lower density.

**Courtyard houses:** Literature indicates that courtyard houses have been known as far back as 3,000 B.C. in most of the Middle Eastern countries (The History of Courtyards, 2011). They were intended not only for providing the family privacy, but also, they provided an excellent solution for natural daylighting and air movement to the surrounding rooms. In courtyard houses, several architectural techniques have been developed to reduce the temperature difference between interior and exterior of the building. It succeeded to keep the temperature difference as 10 to 20 degrees Celsius between inside and outside of the building in the summer months. It is well known that the location, size and the treatment of openings will have an effect on the quantity and the quality of light entering buildings, and the amount of heat gained and heat excluded from a building. For instance, thick walls in the courtyard houses work as an isolating device from solar heat and maintains the cold temperature during the night.

For ventilation, most of the traditional houses rely on the air-exchange (airflow) from the courtyard instead of cross-ventilation. Most of the interior doors and windows are shaded and protected from the dust and the hot dry winds by interior arch or colonnades. The cold air at night cool down the courtyard, floors, walls, and columns. By noon, the sun hits directly the courtyard, which warms up the floor and interior house by the late afternoon.

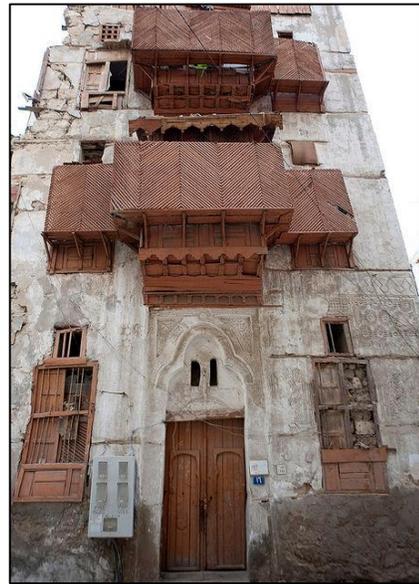


*Fig11: The fountain in the courtyard of Achik Bash House in Aleppo. (The islamic-arts.org Team.)*

During this period, the cool air stayed inside the rooms keeping the interior cool, thus this cycle continued over and over again by the night arrived (Talib, 1984). Furthermore, in some regions, architects incorporated water fountains in the center of the courtyard, (Figure 11) which helped to create a cool microclimate that humidified the hot and dry air (Attia, 2006).

**Mashrabiyya or Rowshan:** The mashrabiyya (Figure 12) is one of the most famous elements of the Arab architecture. It was utilized in the medieval times up to the mid-twentieth century. It was created as an exterior cantilevered wooden space with openings “it usually built in the second story of the building or higher” to catch the cross ventilation and to keep the occupant privacy. The name of mashrabiyya originated from the Arabic word “Shurb or Sharabh” means “drink”. It is originally meant "a drinking place" (Gallo, 1996), thus people used to place a clay jar of water which cool the surrounding environment through air movement, the convection, and the leaking water.

er. Mohammad Arif Kamal has summarized five functions of mashrabiyya, which are controlling the light entry, and airflow, reducing the current temperature of the air, increasing the humidity and maintaining privacy (Kamal, 2014).



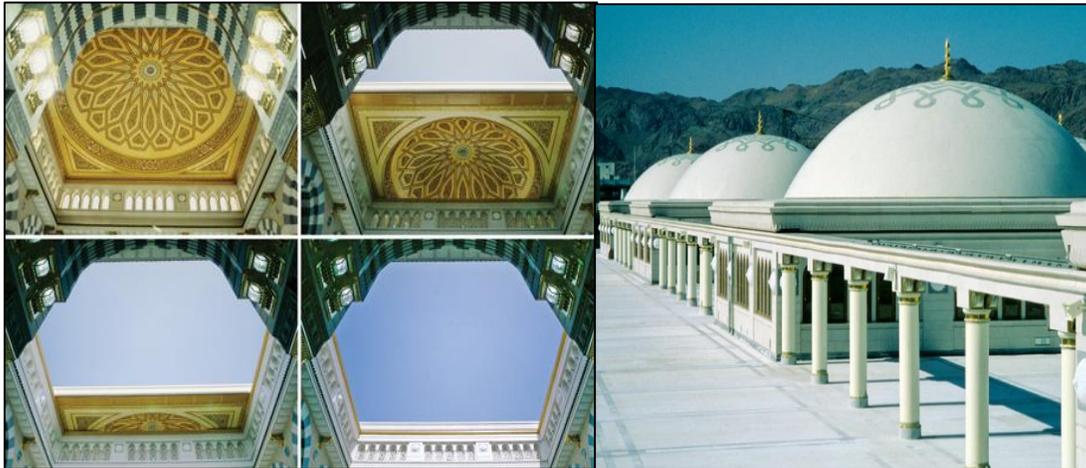
*Fig12: Mashrabiyya from old Jeddah. (Lafforgue, 2010)*

**Domes:** Domes in Islamic architecture started as an architectural element in Jerusalem since the Umayyad period in 691 AD. They were usually used in religious

buildings where they added both functional and aesthetic aspects to space. Functionally, they used to cover huge spaces without using columns and in addition to their important role in enhancing the stability of the building. Its spherical form decreases heat absorption due to the small surface area that exposed to heat and radiation. In addition, it is providing a passive cooling effect in the hottest days of the summer to the building (Mahdavinejad, Badri, Fakhari, Haqshenas, 2013).

The sliding domes that were developed by Premier Composite Technologies (PCT) in the Prophet's Holy Mosque in Al Medina is an extraordinary example of the domes' design. It was designed to provide a movable roof to the internal courtyard that allowed natural light to enter the courtyard and exchange the air to in and out.

The knowledge of the early Muslim scientists of science and engineering have played such important role in designing most of these distinguished architectural elements and structures known in Islamic countries.

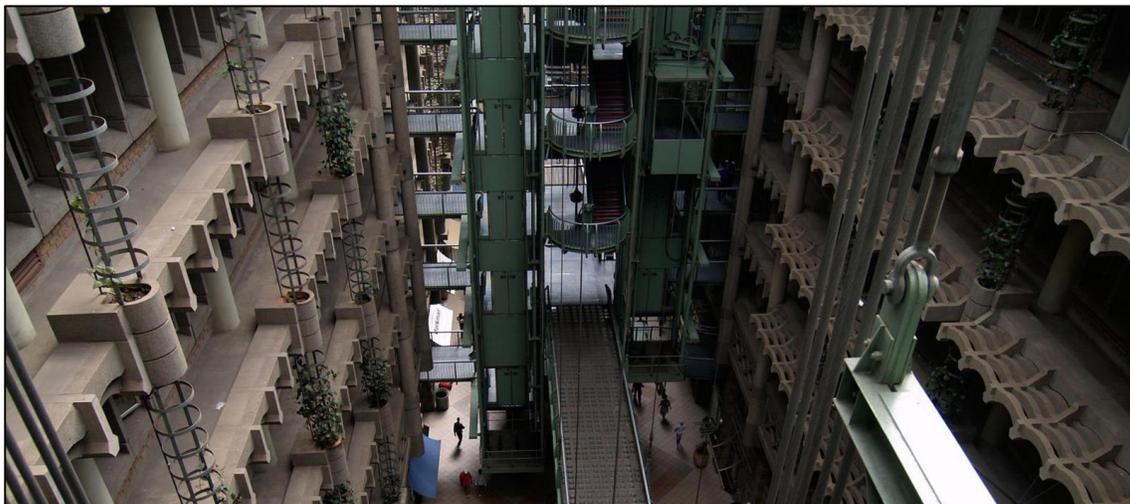


*Fig13, 14: Interior and exterior view of the sliding domes in the Prophet's Holy Mosque in AL Medina (PCT)*

### **Recent Application of Biomimetic Solutions for Interior Environment:**

Nowadays, the desire of integrating natural solutions in the design principles and targeting challenges of solving the interior design problems using biomimicry is obvious among researchers, architects, and design specialists. As an example, the self-cleaning paint and fabric was developed by a German company that adopt the lotus flower as a design inspiration. Lotus flower has a bumpy surface; a hydrophobic and hydrophilic surface structure, and covered by a thin waxy layer, which makes it water-repellent, able to repels water, dust, fungi, and keep the surface shiny and clean (Anous, 2015). Applying such genius solution helps to reduce the use of water and detergents, in addition it improves the lifespan of the hard wall materials.

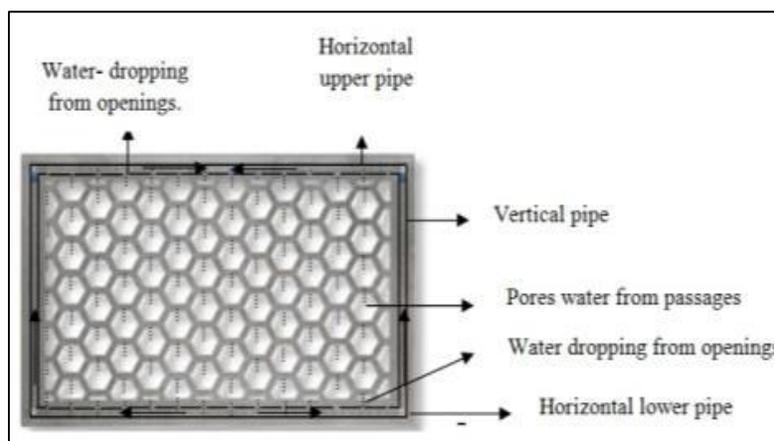
The Eastgate Centre in Harare, Zimbabwe (Figure 15) is also a remarkable example that was inspired by the termite mound. The architect Mick Pearce aimed to mimic the ventilation system that cools the entire mound and tried to maintain stable temperature in internal environment. The main design principle includes using limited resources and less energy, which is done by creating holes all over the surface and building's skin to allow



*Fig15: Interior view from the Eastgate Centre (Douglass, 2015)*

air movement. Eastgate as Dr. Rupert Soar says is “probably the best example of the word 'biomimicry' that's out there at the moment” (Douglass, 2015).

Similarly, several researchers endeavor to solve the problem of over-usage of energy in hot climate regions by offering natural ventilation solutions inspired by natural organisms such as the previously mentioned Eastgate Centre in Zimbabwe. A recent biomimetic study by Doaa' Attia proposed a technological biomimetic solution that formulates a 'breathing window' (Figure 16) which also aims to enhance the natural ventilation in buildings. The breathing window would apply the concept of the 'design looking to biology' where it would study the structures, forms and functions of the bee's honeycomb, human nose, and the cacti cooling plant. The human nose is able to regulate the temperature using the mucous membrane that moisturizes the air passing through from the outside to the body while filtering the airflow using tiny hairs (cilia) and blood capillaries. Whereas the cacti plant is able to absorb CO<sub>2</sub>, reflect direct sunlight, and prevent from dust and foreign particles. Finally, she was inspired by the Hexagonal structure of the honeycomb and its stability when facing the exterior wind force.



*Fig16: In summer, a frontal sector to show how the water drops directed from the hexagonal horizontal passages to horizontal lower pipe, to vertical pipes then dropping once again from the horizontal upper pipe (Attia, 2015)*

According to Attia, the breathing window can use several natural phenomena such as shading, evaporative cooling and changing the light to heat (fiber optic) just like how the natural organisms adapt themselves to the harsh climate. During the summer time, the window reflects the direct sun rays to reduce heat gain, uses evaporative cooling strategy to cool down the interior environment and filters the inflowing, in addition to its ability to regulate the shade. While in the winter, the window allows sun rays into the interior, thus spreading heat and light and filters the incoming airflow (Figure 17). Functionally, the breathing window has an outstanding aesthetic design appearance in addition; it is “easy to clean”, manages to filter air from dust and micro particles and is notable for the simplicity of used materials (Attia, 2015).

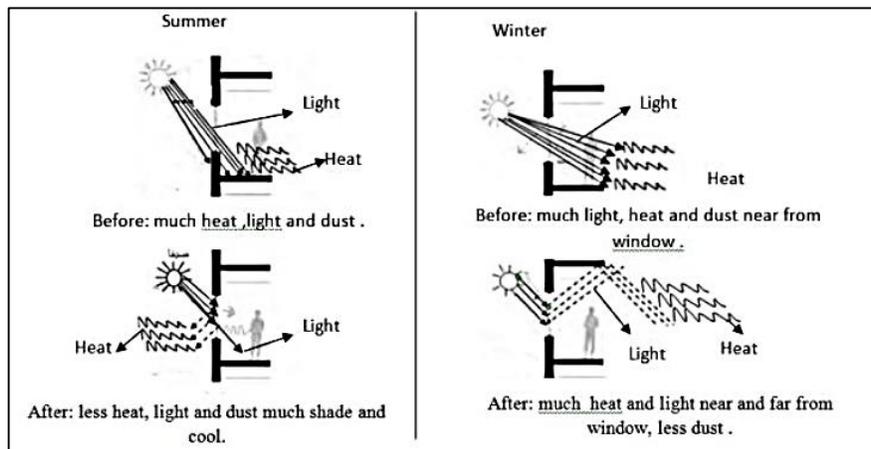


Fig17: The intensity of light and heat before and after using “Breathing Window” (Attia, 2015)

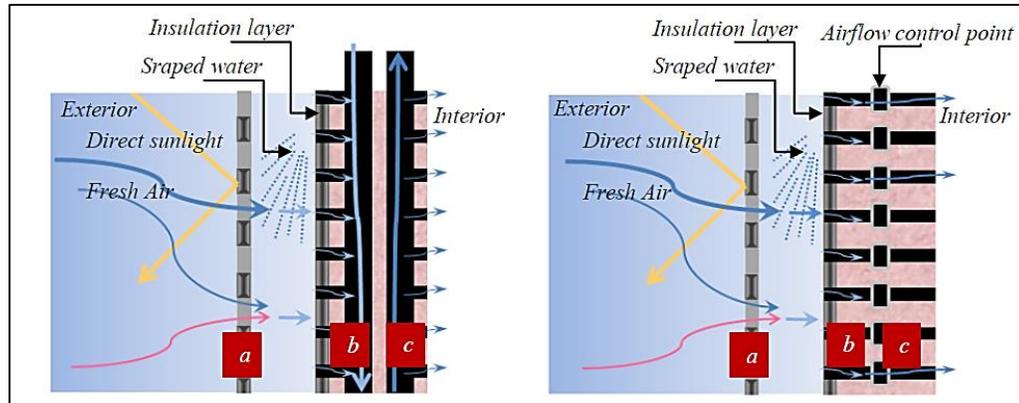
Another study by Mahmoud Elghawaby 2010, discussed ways of improving the ventilations system in architectural structures through mimicking natural adaption methods of flora and fauna in the hot and arid climate of Sinai. Elghawaby believes that the research on biomimicry aims at finding principles that can be adapted in architectural structures. He

proposed the ‘breathing facades’ as one of the adoption principles that would lead to the creation of architectural buildings that can breathe. The research study that served as the basis of this suggestion was based on ability of plants and animals to adapt to the hot and arid climate. These methods seek to provide thermal insulation for the exterior skin, dissipating overheating in addition to avoiding the direct sunlight. Mangroves plant, for example, rotates its leaves away to avoid the direct sunlight, while some animals, such as lizards, move fast and raise their bodies up to stay away from the hot ground. They also turn to their burrows and shaded areas as a way to avoid the heat. The author believes that many of these adaptation methods of flora and fauna could be imitated in buildings and is considered as a conceptual basis for architectural solutions in such climate. Elghawaby suggested that:

*“Buildings could rotate, use movable shading devices, windows, and controlled wind catch. It could be also transformed into constant features like constructing underground buildings or raise them above the heated ground with high columns”* (Elghawaby, 2010).

Elghawaby’s study proposed adding some features to the building skin to improve the natural ventilation system and turn it into a dynamic interactive cooling system. He studied the human skin system and the sweating process as a design inspiration in order to apply the knowledge to building façade. His research presented a conceptual model of “breathing wall” that is able to control the airflow and cooling can cool it through the entire surface. The model (Figure 18) includes three layers; each one has specific tasks: one is for blocking out the direct sun rays; the middle layer has water sprayed system to cool the

airflow by evaporation. The third, which is the internal layer, it is controlling the ventilation outlet by extracting the water vapor from the exhaust air.



*Fig18: Conceptual model of breathing wall; (a) exterior layer capable of preventing or filtering direct sunlight while allowing airflow to pass, (b) Middle layer acts as thermal insulation layer, then it cools air temperature by evaporative cooling and receives air flow, (c) Internal layer aims at controlling airflow. (Elghawaby, 2010)*

All of the three layers combined are aiming at enhancing the natural ventilation in hot arid climate in the areas such as Sinai climate. According to Elghawaby, applying such approach will help to control and cool down the airflow, and minimize heat gain that is coming from the direct sunlight (Elghawaby, 2010).

## CHAPTER 4

### FINDINGS AND DISCUSSION

#### **Findings:**

Studying the strategies of living organisms as well as nature-inspired traditional Islamic architecture in hot and dry regions can help tackle a lot of problems of modern architecture. As mentioned in a previous chapter of this study, existing buildings lack many sustainable specifications in their design, and one of the aims of this study is to provide possible alternative solutions for householders to reduce energy consumption.

The study highlighted several adaptation strategies of the early traditional Islamic architecture which summarized by:

- Tradition architecture using building materials that are capable of absorbing solar heat, light and radiation.
- Utilizing building materials that did not conduct heat.
- Utilizing external shading device to distribute heat and protect from the direct sun rays.
- Taking advantages of the winds and cross ventilations in many ways:
  - a) By building a higher structure tower to draw the air down to the interior spaces.
  - b) By taking advantages of air-exchange in the courtyard houses and cool down the space by building a water fountain to moisturize the air current.

c) By taking advantages of the cross ventilation by building oriel windows covered with a wooden latticework.

- Taking advantages of the stack effect by building a high roofing structure with small openings to allow the hot air to escape from the top.

Although, it is difficult to assert if those early architects were certainly inspired by or learned from the biological nature strategy in their design principles because there is no clear evidence found and only the minority of those architects were actually documented. However, their design seems to be inspired by the plants and animals that were living in the same environment. This similarity is not surprising, because both of them are experiencing the same weather conditions and both are trying to adapt with the same harsh environment.

Reading through different literature that studied nature as a design solution shows that there are several common and similar characteristics between the traditional architecture and some nature organisms from different aspects:

**Similar function:**

- Absorbing heat and radiation, reflecting sunlight.

Traditional architecture has a common feature with the barks of the trees. The chosen building materials are capable of absorbing heat during the day in addition to not conducting it, and they are mostly having a light color to reflect the sunlight.

- Avoiding heat gain.

The living stone plant and underground housing are able to avoid heat gain by living underground and taking the benefits of the surrounding mass that absorbs heat and blocks from the sunlight in the scorching desert climate.

- Evaporative cooling:

Sweating in animals helps to cool down their body while in traditional architecture the clay jar placed in mashrabiyya, the water inside leaks out when absorbing the heat in the process of evaporation, thus causes to cool the passing breeze to the interior.

- Stack effect:

Domes, wind capture, and placing the traditional mashrabiyya in the upper floor of the buildings all designed with the same stack effect as the giant termite mounds of Africa. Both are aimed at increasing the interior ventilation by having high small openings that allowing the hot air to rise to alter by the cold.

- Air exchange:

Courtyard houses rely on exchanging air from the inside air and outside air without using energy. This occurred by the wind effects while the existing of the openings and windows is important to cool the air. The air density (because of the temperature difference) between the inside and the outside, the hot air (the less dense) arise to replace with cold air (Al-Bakri, 1997).

On the another hand, both projects of Doaa' Attia the “berthing window” and the “breathing wall” for Mahmoud Elghawaby have concentrated on almost same design principles which are ensuring external shading device to avoid direct sun rays, evaporative

cooling to cool incoming airflow and filtering the air entering the building from dust and foreign particles. Common feature is that the existence of water is the key element to survive in the desert climate. In order to bring building to live and sustain, it is a beneficial to have sort of water source or evaporative system that is able to moisturize the surrounding environment.

## Discussion:

Building close relationships with nature and learning from natural strategies to solve today's design problem has uncountable benefits for all human kind, and the most importantly for the environment. It is not limited to architects and designers; there are broad opportunities in almost all fields of science to draw inspiration from nature in order to develop and improve the quality of life for the future. The purpose of this thesis is an attempt to provide a solution for a problem that could be considered a source of threatening for the whole creatures in this world. Consuming energy and producing enormous amount of waste reflecting negative impact for the environment.

Saudi Arabia has been recorded as one of the countries that consumes a lot of electricity on regular basis. A study done back in 1998 by Alajlan, Smiai, & Elani, 1998, reported that studies on electricity growth and energy demand in Saudi Arabia showed a

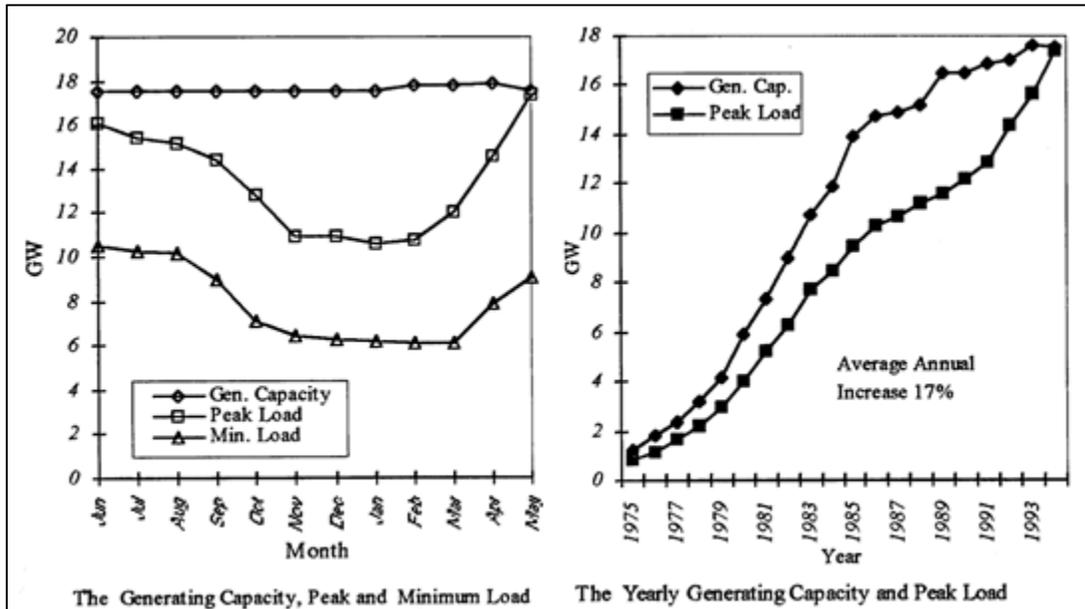


Fig19: Electricity growth and development in the Kingdom of Saudi Arabia up to the year 1994. (Alajlan, Smiai, & Elani, 1998).

sharp increase in electrical capacity consumption with the rate increase of 17% a year. Which means that an average capacity per householder at rate of 5% a year, while the peak load has risen to a yearly growth of an average 16%, as shown above in the graph. (Figure 19) The electricity growth in KSA over the five years' development plan around 1970-1995. However, it indicates that the generating capacities were distributed depending on the regions. They have reached 17,484 megawatt (MW) by 1995 in terms of quantity, which equals 15 times that of the year 1975. In addition, by 1995 the peak load has reached 16,907 MW, which shows the annual development of the peak load, and generating capacity in Saudi Arabia. It is likewise normal; the energy capacities are expected to continue increasing in the following 5 years because of the national improvements in failed.

Besides, later in the study there is a comparable examination by Saudi United Electric Organization (SCECO), indicates that 65% of the electricity in KSA is consumed due to heating ventilation and air conditioning system (HVAC) which contrasted by 22% in the UK, 21% in the US and 21% in Australia. As stated by SCECO (eastern area), the average of energy consumption if an apartment on Dammam will be 20,000 kWh/yr., same time the average of consumption in a similar environmental conditions in the US (e. G. Arizona) is 8000-10,000 kWh/yr. (Alajlan, Smiai, & Elani,1998). This information leads to the need of reconsidering the issue of overusing energy in order to find solutions that help the community to reach the KSA 2030 vision in the near future.

This study proposes developing a window application that could use in existing buildings which would function by using the airflow entering the building to capture natural ventilation and meet the requirements of the modern design. It suggests enhancing the design of mashrabiyya by improving the performance of evaporative cooling feature and replacing the use of the clay jar by a water system build up within the design of the window. For example, integrating a such misting system or using materials that are able to absorb water from the atmosphere such as ceramic or clay.

As a matter of fact, the contemporary mashrabiyya has been succeeded and proved its efficiency in several applications in different types of buildings around the world. There are many remarkable examples that have Islamic influences in their designs such as the Masdar Institute of Science and Technology in Dubai. (Figure 22) The project designed by the architectural firm Foster + Partners. It has an oriel window, a contemporary sustainably developed mashrabiyya that represents the influences of the Islamic architecture in the residential buildings. It is enhanced with reinforced glass, concrete, and colored with local



*Fig22: Masdar Institute of Science and Technology in Dubai. (Foster + Partners, 2010)*

sand to harmonize with its desert context in addition to minimizing the maintenance (Masdar Institute, 2010).

The Arab World Institute “Institut Du Monde Arabe “IMA” by Jean Nouvel in Paris (Figure 23) is another distinguished example of mashrabiyya inspiration. It won the Aga Khan Award for Architecture in 1989, and the Equirre d’Argent for French architecture in 1987 for its design quality (Winstanley, 2011). The main feature of IMA was the south metallic façade that called “Brise Soleil”. It is a French word, refers to an architectural projection or screen that deflect and block off undesired sunlight (Merriam-Webster). These metallic diaphragms are light sensitive, which can be opened and closed by hydraulic engines (Winstanley, 2011). Therefore, this Institute quickly became the focus of attention of many tourists and visitors from all around the world.



*Fig23: The Arab World Institute in Paris (Winstanley, 2011)*

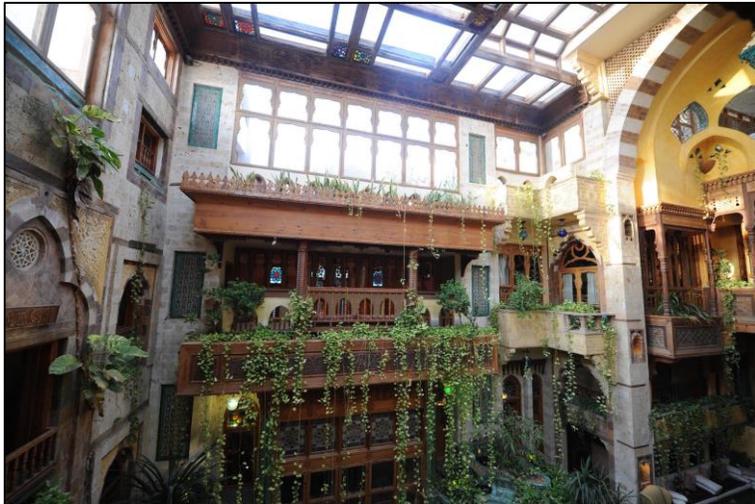
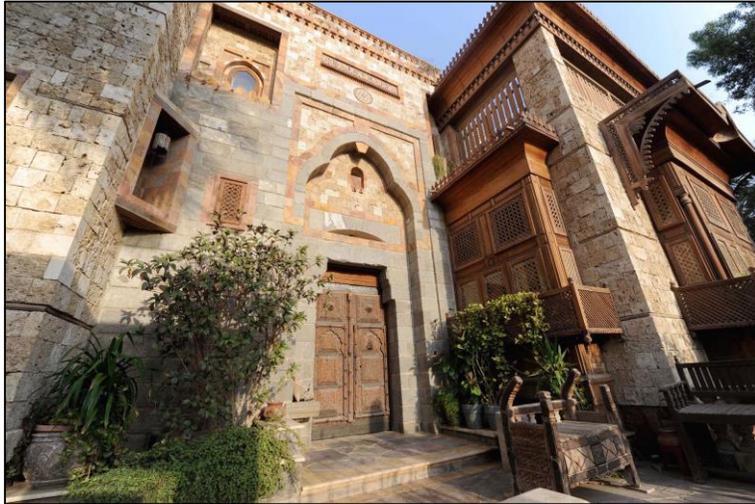
King Abdullah University of Science and Technology (KAUST) in Thuwal Saudi Arabia (Figure 24) which was designed by the global architectural firm HOK, has earned the “Top Ten Green Projects” award by the American Institute of Architects (AIA) in 2010 (Welch, 2011). The project also applied a wooden latticework as an external shading device inspired by mashrabiyya in the Islamic architecture to cover the southwestern façade of the

campus. It adds a beautiful shading pattern in addition to its main function of reducing the heat load and blocking the direct sunlight (Kamal, 2014).



*Fig24: King Abdullah University of Science and Technology (KAUST) shaded exterior areas (Elgendy, 2010)*

Finally, the unique house of Dr. Sami Angawi in Jeddah Saudi Arabia, which called “Al Makkiyah” (Fig25,26&27). This house is such amazing example of combining the modern construction techniques with the Islamic traditional influences in its design. The architect aesthetically applies natural ventilation techniques that succeeded in reducing the need for air-conditioning. Its construction includes internal courtyard with pool and it has intelligent water-recycling system that feed the roof garden. It has also high ceiling, wooden mashrabiyya for windows which participates in regulating the interior temperature. Most of the exterior and some interior materials are natural and local. This house has successfully attracted many researchers and international media worldwide (Al-Makkiyah Residential Villa, 2007).



*Fig25,26&27: Interior views of Al-Makkiyah Residential Villa (2007)*

Several advantages can be achieved when applying such contemporary mashrabiyya in the regular residential houses in many aspects:

- Sustainability:

Mashrabiyya as a nature inspired, sustainable and environmentally solution is a suitable solution for desert climates. It is borrowing several functions from nature models to architecture. It allows air exchange from in and out of the building in addition to losing the air by the stack effect. Materials used in mashrabiyya have potential to be recyclable and less pollution emissions and toxic gases.

- Functionally:

Mashrabiyya works as an external shading device that controls the sunlight accessing the building, reducing the bright glare of the sun, reducing the heat gain and maintaining the privacy. In addition, the small openings allow the airflow that come from the cross ventilation to entering the building and ensure occupants privacy. With adding evaporative cooling feature, the mashrabiyya will be able to cool the entering airflow to the interior.

- Traditionally:

Using mashrabiyya limits the need of using the curtains, (as it was traditionally used) which therefore gives the feeling of widening the space in the room, and allows utilizing the interior space by either a plant pots or other decoration. Moreover, using a contemporary mashrabiyya in residential buildings, in addition, of being considered as an

elegant decorative shading solution, it would maintain the Islamic heritage and appreciate the historical traditional building elements to be recognized and respected for the next generations. Nowadays, there are broad opportunities for creative to design such a residential mashrabiyya in many different patterns, forms, sizes and styles, which can be integrated into the modern architecture requirements.

## CHAPTER 5

### CONCLUSION AND FUTURE IMPLICATION

#### **Conclusion:**

Studying natural organism adoption strategies as solutions for design problems has opened broad scopes of creative thinking and innovation in architecture and many other disciplines. One of the main goals of this research was maintaining the traditional Islamic architectural elements, so that developing a contemporary mashrabiyya design will respond to the aspect of the research while borrowing the nature-inspired strategies that functions and fits within modern interior structures. It looks to harmonizing our valuable historical influences and the Mother Nature inspiration with our modern architecture requirements. This helps to preserve the identity of Islamic traditional architecture and its historical values to the next generations.

Devolving mashrabiyya for residential buildings contributes in combining feeling of the sense of nature and the historical value simultaneously in either interior or the exterior of the building. Design today can appreciate the natural genius to enhance the present architecture and achieve both living and inspiring from nature. The first part of the study was presenting examples of natural organism strategies that would be a source of natural inspirations for buildings to the architects and designers. The second was analyzing the similarities and differences between the natural strategies solutions and the Islamic architectural elements. The last part dealt with the researchers analyzes of the issue of the interior natural ventilation in the hot region environment.

**Future implications:**

The implications of the future research include continuing to explore through the biomimetic lens and learn from natural strategies for interior environments. There is a great variety of the local desert plants and animals in hot climates which deliver sources of natural inspiration to solve design problems. It may also continue to engage cultural Islamic designs and heritage in order to be seen and used more often in public not only in commercial buildings but regular residential houses. Also, existing buildings need alternative sustainable solutions to deal with heat problems that help to reduce households from consuming and relying on artificial energy. Meanwhile, there is a need to increase the awareness of the importance of rationalizing the consumption of electricity and establishing a close relationship with nature. This could be done by increasing the awareness of using indoor plants to provide a visual connection with nature and by increasing the people's knowledge about how intelligently nature solves problems and what the environmental benefits would be obtained from that.

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