ADAPTATION OF BIOMIMICRY ARCHITECTURE PRINCIPLE FOR ENERGY EFFICIENCY IN CIVIC CENTRE LOKOJA, KOGI STATE, NIGERIA

BY

ADINOYI, Haruna

MTech/SET/2017/6771

DEPARTMENT OF ARCHITECTURE
FEDERAL UNIVERSITY OF TECHNOLOGY
MINNA

FEBRUARY, 2020

ADAPTATION OF BIOMIMICRY ARCHITECTURE PRINCIPLE FOR ENERGY EFFICIENCY IN CIVIC CENTRE LOKOJA, KOGI STATE, NIGERIA

BY

ADINOYI, Haruna

MTech/SET/2017/6771

A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL FEDERAL UNIVERSITY OF TECHNOLOGY MINNA, NIGERIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF TECHNOLOGY (MTech) IN ARCHITECTURE

FEBRUARY, 2020

ABSTRACT

Civic centre is a reference point of any city where it is located and has been designed to attract interest, hence symbolic expression is one of the paramount requirements in a civic centre design. Biomimicry is defined as imitation of life. It would go a long way in enhancing the architecture of civic centre design in Nigeria. The capabilities that are abounding in biomimicry architecture could be explored in design of a sustainable civic centre so it could behave like an organism that would respond to its internal and external environmental demands, hence this research seeks to control the building' energy efficiency to create comfort for the occupants. The aim of the research is to adopt the principles of biomimicry architecture as a passive design approach for energy efficiency in civic centre design. The research method used for this study is descriptive survey method. Termite mound architecture principles was adopted in this research as a passive measures for ensuring energy efficiency in the design of civic centre in Nigeria. The research discovered that passive design features for energy efficiency are green roof, breathing skin, roof vent, evaporative effect, and atrium for cooling the building. The research recommended that green building design should be made a criterion to be met by design proposals before approval for construction is given. This is to ensure that new buildings are sustainable.

.

TABLE OF CONTENTS

CHAPTER THREE

CHAPTER FOUR

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

CHAPTER ONE

1.0 INTRODUCTION

1.1 **Background to the Study**

Sustainable buildings are explained as the buildings that make use of environmentally friendly materials that have little or no effects on the environment, utilizing renewable energy that is required for their various functions or tasks carried within the buildings, ensuring energy and water efficiency, as well as making use of the locally availabe materials in the region (Zubairu, 2018). The interest in sustainability grew after the energy shortage that emerged after the first and second energy crises of the sixties; researchers started to search for an alternative way of generating energy such that the total energy consuption in any facility is not heavily dependent on fossil fuels (Wen *et al.,* 2017). Biomimicry is a term that means imitation of life (Pawlyn, 2011). It has the purpose of designing to emulate and integrate with natural systems when planning for a human design with the aim of reducing: energy, material, weight, cost and pollution (El Ghawaby *et al.*, 2010).

Researchers have defined various approachs to answer the problem of energy consumption in buildings thereby moving the idea of sustainability globally towards achieving its utmost aim. Sustainability makes use of nature to solve this immediate problem and questions that the environment demanded from the buildings. Biomimicry architecture is a branch of these different approaches to answer these questions that the environment and it inhabitants demanded.

In addition, the whole concept of sustainable development is an attempt to articulate environmental and human needs in the pursuit of economic growth and development. It is a process of transition in which the exploitation of available resources, investments, application of technology and institutional change are in harmony and enhance both current and future potential to meet human needs and aspirations (Adeyinka, 2005).

1.2 Statement of Research Problem

A civic centre is one of the components of a city that forms and transforms throughout the history of a nation in several periods, but continues to be a reference point or symbol of the city where it is located, and has been designed to attract interest (Cullen, 1998). Hence, expression (placemaking) is one of the paramount requirements in a civic centre design.

Many previous works on civic centres have addressed this issue by the use of Postmodern and Deconstructive architecture which has deliberately minimized architectural coherence and deprives the senses in search for meaningful information and expressions at the heart of the modern urban setting (Salingaros *et al.*, 2004).

An evolutionary-ecological approach to aesthetics suggests that the incorporation of natural shapes and forms, actual or symbolic, into the built environment should have a strong positive impact on people as well as the environment (Joye, 2007). Therefore biomimicry architecture would go a long way in enhancing the architecture of civic centre design in Nigeria. The capabilities that are abounding in biomimicry architecture could be explored in design of a sustainable civic centre so it could behave like an organism that would respond to its internal and external environmental demands. Likewise, this research will adopt this process to control the building" energy efficiency to create comfort for the occupants.

1.3 Aim of the Study

The aim of the research is to adapt the principle of biomimicry architecture as a passive design approach for energy efficiency in civic centre design in Lokoja, Kogi State, Nigeria.

1.4 Objectives of the Study

The objectives of the study are:

i. To determine the principles of biomimicry architecture that are applicable in the area of civic centre design.

ii. To ascertain means of ensuring energy efficiency in civic centre buildings.

iii. To incorporate all the relevant research findings to enhance energy efficiency in the proposed civic centre design.

1.5 Research Questions

This research shall seek to answer the following questions

i. What aspects of biomimicry architecture and to what level can they be applied in Civic centres?

ii. To what extent can energy efficiency be enhanced in civic centres Nigeria?

iii. How can biomimicry architecture be applied to produce an energy efficient civic centre in the study area?

1.6 Justification for the Study

Studies have shown that energy consumption is increasing (Shaikh *et al.*, 2016), with the energy operating costs of commercial and industrial buildings and other building types (Continental Automated Buildings Association, 2008). Civic centres have higher energy consumption as these buildings house many of activities of the community throught the day and night which makes use of heating, lighting, ventilating, and sound. In order to provide leisure and comfort to the occupants and the users, the building services and activities may be running 24 hours throughout the year.

However, the growth in the tourism industry has caused an increase in stress on the environment (Alexander, 2002), hence the need to utilize the environmental potentials for national development and investment not jeopardizing the aim of sustainability. This study seeks to show passive step in which a building can maintain low energy wastage and reduce energy consumption through biomimicry architecture utilizing the maximum tourism potentials on the site, to propose a civic centre design to be located at confluence of River Niger and Benue at Lokoja Kogi State, Nigeria.

1.7 Scope of the Study

This study covers the review of sustainable buildings, how principle of biomimicry architecture can help improve the energy efficiency in civic centre buildings and serve as an icon for attracting tourists from far and near regions around the world. The principles shall be applied to the proposed civic centre design to be located at Lokoja, Kogi State, Nigeria.

1.8 Contribution to Knowledge

This research throws light on the area of Biomimicry Architecture concept that are applicable in the area of civic centre designs in Nigeria. Given that climatic conditions in the world vary from one region to another, the thesis will demonstrate how sustainability design can be achieved by utilizing the potentials on the site to achieve good energy efficiency in buildings in Nigeria.

1.9 Study Area

The study area is located in Lokoja, Lokoja Local Government Area, Kogi State, Nigeria (figure 1.3). Kogi State is located at the central area of Nigeria with Lokoja as its capital (figure 1.1). River Niger and River Benue met at Lokoja which was the first capital of Nigeria. Kogi State consists of three main ethnic groups, which are the Ebira, Igala and the Okun people. Kogi State comprises of 21 local governments of which the proposed site is Lokoja Local Government Area (figure 1.2). The State has many mineral resources such as limestone, iron, petroleum, and coal. It also accommodates the largest steel company in Nigeria and Dangote cement industry at Ajoakuta known as the Ajaokuta Steel Company and Obajana Cement Factory.

Fig 1.1: Nigeria highlighting Kogi State.

Source: Source: Nigeria Zip Codes (2018)

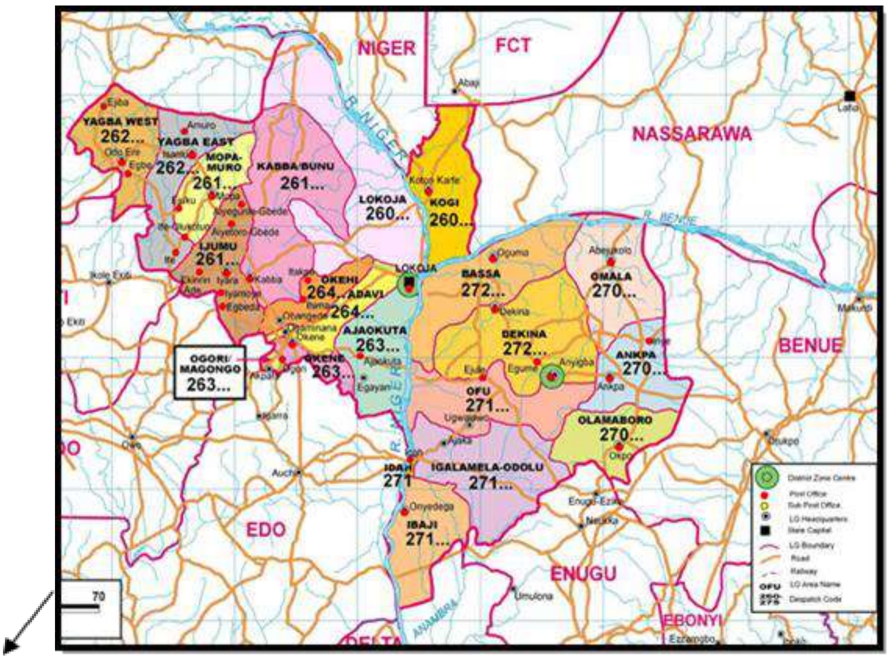


Fig 1.2: The various local government areas in Kogi State.

Source: Source: Nigeria Zip Codes (2018)

Fig 1.3: Selected Site for the Proposed civic centre at confluence River Lokoja, Kogi State,Nigeria

Source: Google Earth Image (2018)

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Civic Centres

Civic centre is an attraction point in any community, housing different structures of the community where various activities of the citizens are performed. The term civic centre has been defined as an entire central business district within a community (Robert, 2009). This study views the appearance and meaning of a civic centre starting with ancient civilization in which civic centres evolved.Trend of the past history will vehemently be discussed not as mere historical discussion, but to stimulate some thoughts for civic centre designs of today. While technical function and socio-economic conditions have changed since the industrial revolution, this should not deter application of lessons from the past to conditions and needs of the present. This approach is useful to specifically define what a civic centre is and how relatively late in history, social conditions and aesthetic urges came to shape this specific spatial form within the urban community.

2.1.1 Greek concept of civic centre

The heart of ancient Athens which is known as the Agora, was the focus of political, commercial, administrative and social activity, the religious and cultural centre, and event centre of Greece.The site was occupied without interruption in all periods of the city's history, Early in the 6th century, in the time of Solon, the Agora became a public area. until a series of renovation and remodelling, it reached its final rectangular form in the 2nd century B.C. Extensive building activity occurred after the serious damage made by the Persians in 480 B.C., by the Romans in 89 B.C. and by the Herulae in A.D. 267 while, after the Slavic invasion in A.D. 580 (Hinkle, 2008).

The Agora as the converging point of the town, was located at the centre. The Agora was primarily the place for political gatherings and legislative assemblies. It changed gradually into a centre for marketing and eventually became solely commercial, whereas the political function of the Agora was taken over by representative meetings in the sacred area of the Acropolis (city). Origin and gradual change in function of the Agora do not suffice to explain the change of it shape.

2.1.2 Roman concept of civic centre (Roman Forum)

The Roman Forum was once the centre of ancient Rome, the place where the Romans used to meet, do business, politics and shop. In 46 BC, Julius Caesar built a new forum because the old one was getting small for the growing population of the city. Today modern Rome is 25 feet higher than the city was when the Forum was built because of the debris that had accumulated over years. As cities grew, however, it became necessary to establish a separate forum (*forum civile*) for legal and administrative affairs, as well as mercantile forums (*fora venalia*), each devoted to the sale of an important commodity. The Fora in the ancient Roman cities which corresponded to the Agoras,, of the Greek cities, were central spaces used for social, commercial, recreational and political purpose.

2.1.3 Medieval concept of civic centres

Some of the late antique cities and towns in Italy, France and central Germany survived the fall of the Western Roman Empire and the Migration Period. In the early Middle Ages cities served as administrative centres, seats of royal or secular authorities, or bishoprics but eventually evolved into trade centres. Apart from the market place, building of public, administrative and religious institutions also needed a certain amount adjacent public space. These public spaces later developed into crowded focal points of social and commercial activities, which made urban spaces a luxury (Hinkle, 2008).

2.1.4 Evolution of civic centre in Nigeria

Before the onset of colonial administration in Nigeria, various communities across the country were involved in communal efforts. It began as a process that was useful for mobilizing community resources in providing physical infrastructure which are functional to both social, political and economic aspects of their lives (Akpomuvie; Onyeazu 2010). The Community was involved in the clearing of farmlands, construction of roads, path ways, bridges and the provision of many social infrastructural facilities that were useful for the wellbeing of its people. Many of the institutions that were found then were the village councils, unions, and various associations. Though some of these institutions have persisted and evolved, it is the self- help activities undertaken by communities in the past that gave rise to what has become known today as civic centres. The differences that exist today from the council meetings that were held then is the level of involvement of organizations and government in civic centre events and information systems used to enable thousands of participants to simultaneously participate in intimate, face-to-face deliberation and contribute to the collective wisdom of a very large group.

By the late 1940"s however, the concept of a modern community began to unveil as rural development was introduced in the form of mass mobilization for self-help activities by the government. This was heralded by the colonial administration of that day. These brought about positive economic and social content to the society by affirming the need for minimum standards of nutrition, health and education. The earlier native authority councils were replaced by the Country Council. This led to the establishment of Community Development division at the local level and it became an important part government policy which is responsible in channelling and coordinating the efforts of the people towards promoting social and economic development (Onwuzuluike, 1987). Thus, the development and welfare that were provided by the Government was to enable development to be taken to the grassroots level.

As population continued to grow exponentially, coupled with a growing sense of belonging to a community more people began to realize the importance of public spaces to the community or society at large in which they live. It became the hub of activities as government engaged people for numerous programmes ranging from poverty alleviation, to health, educational training and politics. The public spaces naturally became busier which increased the possibility of increased in demand of energy consumption.

In recent time, civic centre has become the hub of activities ranging from entertainment, mass rallies and religious events which often attract large public participation. The great urban spaces gain their civic qualities from their multi-functionality, from the desires of citizens to interact for both public and private interest. The civic centres remain a big source of attraction today through use the public put them to, as well as celebration, commemoration and entertainments which now find a proper home there.

One of the important features of civic centre to public space has been that it gives people seeking leisure, training or sense of community an engaging, stimulating and safe place to come together. As more civic centres come with inviting and welcoming spaces to meet for education, enlightenment, conversation, entertainment, and the simple enjoyment of leisure time, there is the challenge of energy efficiency as population of people in civic centre increases.

2.1.5 Spatial components of civic centre :

The components of civic centre include the following:

(a) Seminar Hall section

(b) Multipurpose Hall section

(c) Temporary Gallery Space

(d) Library section

(e) Cafe section

(f) Plaza/ Theatresection

(g) Children"s Room section

(h) Workshops/ Labs section

(i) Administrative section

(j) Service and Facilities section

The listed components of civic centre above will be incorporated in the design to constitute the basic section of the proposed design of civic centre (Cullen,1998).

2.2 Biomimicry

Biomimicry is a term that is derived from two words, Bio means life and mimicry means imitating. Some scientists sometimes prefer to use the term Boinic instead of the term biomimicry which means the same thing (Pawlyn, 2011). The basic idea or concept of biomimicry is the creation of workable designs by imitating various living organisms, plant and animal, which have evolved over time (Aziz *et al*., 2015).

Biomimicry was invented and published by Prof. Benyus Janine in her book (Innovation Inspired by Nature) in 1997. Prof. Benyus Janine proposed biomimicry as a new science that studies the models of nature and imitates their designs for solving human problems. Biomimicry is not a new idea; people have been inspired by nature for long decades. However, Leonardo da Vinci carried out the first scientific study in this knowledge area in 1482. By studying the mechanism of the birds flying, he tried to invent flying machines. Although he was not successful with his flying machine but his idea was an inspiration for the Wright Brothers to invent the first airplane in 1948 that is the best-known biomimicry invention (Goss, 2009).

Biomimcry is a design step that is taken to approach design in any field be it in Engineering , Medicine or Architecture. Its application and process will be narrowed down to the field of Architecture in this research work as it can be applicable and adaptable to civic centre design. Biomimicry looks into nature on how it functions and its workability in the ecosystem within its immediate environment to survive and adapt to the harsh weather.

The word „biomimicry‟ and „biomimetic‟, are not different from their technical meaning, as other terms such as bio-inspired design, biomimesis, bioinspiration, bioanalogous design, biognosis, and bionics are often used interchangeably with both terms (Vincent *et al.*,2006; Shu *et al.*, 2011; Gamage & Hyde., 2012). Wahl (2006), explained that bionic design considers taking control of nature and seeks resolving engineering problems using data related to biological function (Reap and Bras, 2009).

It is important to know that there is no different meaning to the terms in the above paragraph as it has been explained. Moreover, biologists may argue that, the technical meaning is limited here to design scope in architecture.

2.2.1 Biomimicry approaches in architecture

Nature affects everything and it covers everything, it is the iniatiator of all creatures. One of the basic solutions for design, whether in architecture or other fields has been modeling and imitating nature (Antoniades, 1990). Solving several problems in architecture is only through the innovative solutions, the models inspired by nature can cause creativity and innovation in the architect's mind. The transition from nature to architecture is a logical process because the natural models have provided the best type of adaptation under a variety of conditions over the years.

Benyus (1997) has also classified biomimicry into various perspectives: nature as model, nature as measure, and nature as mentor. Some authors agreed that these perspectives form the basis for classifying the different approaches to biomimicry (McGregor, 2013; Reed, 2003). Janine Benyus argues that looking at nature and mimicking its existing models, systems, and process can solve design problems sustainably (Benyus, 1997). Biomimicry is viewed to serve two main aims: innovation and sustainability. Pawlyn (2011) suggests biological organisms can be considered as embodying technologies which offer sustainable solutions. Technological innovations and sustainability criteria could be interrelated aspects of biomimicry as Rao (2014) explains: "biomimicry uses an ecological standard to judge the sustainability of our innovations". In a broader view, there are two distinctive approaches for bio-inspired design: bottom-up (solution-based) and top-down (problem-based) (Lidia Badarnah & Kadri, 2015). The former does not address any application of a scientific systematic method for bio-inspired design due to the fact that specific knowledge on biology leads to solutions which are not necessarily predetermined (Vincent *et al*., 2005). Likewise, in the latter, there is a potential for creating a systematic search process as real-world problems are identified and designers look to nature and use the assistance of biologists to solve the problem. Zari (2007) has also broadly classified biomimicry approaches into two categories, which are design looking biology and biology influence design.

2.2.1.1 Design looking to biology

In this approach, designers identify a human need or design problem and they seek the solutions in nature and organisms. There is a potential for creating a systematic search process as real-world problems are identified and designers look to nature and use the assistance of biologists to solve the problem. This approach is used when designers are confident about the aims of their designs. This approach is also called „„Top down

Approach" (Knippers and Speck, 2012) and „„Problem-Driven Biologically Inspired Design" (Helms *et al*., 2009).

2.2.1.2 Biology influencing design

When designers have the knowledge of biological research and it influences human designs rather than first determining human design problems. Biology influencing design approach does not address any application of a scientific systematic method for bio-inspired design due to the fact that specific knowledge on biology leads to solutions which are not necessarily predetermined (Vincent *et al*., 2005). This approach (figure 2.1) is also called „„Bottom-Up Approach" (Knippers and Speck, 2012) and „„Solution-Driven Biologically Inspired Design" (Helms *et al*., 2009).Biomimicry approaches illustrates these two approaches (Knippers and Speck, 2012).

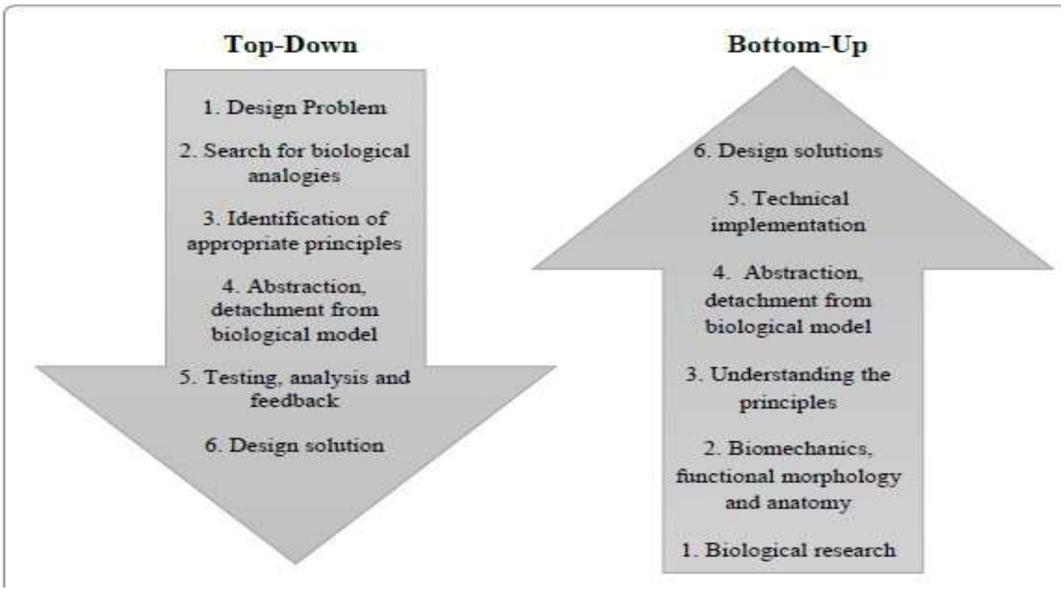


Figure 2.1 : level of biomimicry in architecture

Source: Knippers and Speck (2012)

moreover, biomimicry in architecture is also looks at in level in addition to the two approaches that has been discussed earlier, three levels of biomimicry that are applied individually or collectively in design problems are form, process, and ecosystem Zari

(2007). Through each level, there are five possible dimensions to imitate or mimic, although in these levels some overlap, which deem necessary for complting approaches, these levels are showed in (Table 2.1).

Table 2.1: A framework for the application of biomimicry

Level of Biomimicry	**Example A building that mimics termites**	
Organism level (Mimicry of a specific organism)	Form	the building looks like a termite
	Material	The building is made from the same material as termite; a material that mimics exoskeleton/ skin for example
	Construction	The building is made in the same way as a termite; it goes through various growth cycles for example
	Process	The building works in the same way as an individual termite; it produces hydrogen efficiently through meta genomics for example
	Function	The building function like a termite in a larger context, it recycles cellulose waste and creates soil for example
Behavior level	Form	The building like it was made by a termite; a replica of a termite mound for example
(Mimicry of how an organism behaves or relates to its larger context)	Material	The building is made from the same materials that a termite builds with; using digested fine soil as the primary material for example
	Construction	The building is made in the same way that a termite would build in; pilling earth in certain places at certain times for example
	Process	The building works in the same way as a termite mound would; by careful orientation, shape, materials selection, and natural ventilation for example, or it mimics how termites work together
	Function	The building functions in the same way that it would if made by termites: internal conditions are regulated to be optional and thermally stable for example. It may also function in same way that termite mound does in a larger context
Ecosystem level (Mimicry of an Ecosystem)	Form	The building looks like an ecosystem (a termite would live in)
	Material	The building made from the same kind of materials that (a termite) internal conditions are regulated to be optional and thermally stable for example it may also function in the same way that a termite mound does in a larger context
	Construction	The building is assembled in the same way as a (termite) ecosystem, principles of succession and increasing complexity over time are use for example.
	Process	The building works in the same way as a (termite) ecosystem, it captures and converts energy from the sun, and store water for example

Source: Zari (2007).

2.2.2 Principles of biomimicry architecture

In the book written by Janin M. Benyus, principles guiding the innovation inspired by nature are nine as it were enumerated , which are the foundation principle underpinning the idea of biomimicry (Rozanek & Rombik., 2007). They are the following: nature runs on sunlight; nature uses only the energy it needs, nature fits form to function, nature recycles everything, nature rewards cooperation, nature banks on diversity, nature demands local expertise, nature curbs excesses from within, and nature taps the power of limits. However, the Biomimicry Institute postulated the biomimicry principles that are an expanded and comprehensive version of the principles of nature (Turner, 2000).

They are creative common tools through which biomimetic designs, materials, and applications are evaluated for sustainability (Turner ,2007).They are important checklists to be adhered to in ensuring the application of biomimicry resulting in sustainable outcomes. According to the Biomimicry Group (2014), the six (6) major principles of biomimicry and their constituting twenty-three (23) principles are:

(a) Resource (material and energy) efficient

This is where opportunities and resources are maximized by conservatively taking advantage of the potentials present. There are four (4) principles that this contains, namely using multifunctional design (meet multiple needs with one elegant solution), using low energy processes (minimise energy consumption by reducing requisite temperatures, pressures) recycling all materials (keep all materials in a closed loop) and fitting form to function (select shape or pattern based on need).

(b) Evolve to survive

The continuous incorporation and embodying of information to ensure enduring performance. It consists of three (3) principles, which are replicating strategies that work (repeat successful approaches), integrating the unintensional step (incorporate mistakes in ways that can lead to new forms and functions), and information reshuffling (exchange and alter information to create new options).

(c) Adopt to changing conditions

This responds to different situations and dynamic contexts. It has five (5) principles, namely maintaining integrity through self-renewal (persist by constantly adding energy and matter to heal and improve the system), embodying resilience through variation, redundancy, and decentralisation (maintain function following disturbance by incorporating a variety of duplicate forms, processes, or systems that are not located exclusively together), and incorporating diversity (include multiple forms, processes, or systems to meet a functional need).

(d) Integrate development with growth

This entails optimally investing and engaging in strategies that promote both development and growth. It also contains principles, which include: combining modular and nested components (fit multiple units within each other progressively from simple to complex), building from the bottom up (assemble components one unit at a time), and self-organising (create conditions to allow components to interact in concert to move toward an enriched system).

(e) Been locally attuned and responsive

It looks fitting into and integrating with the surrounding environment. It consists of five principles, namely using readily available materials (build with abundant, accessible materials); harnessing freely available energy (use of solar/renewable energy), cultivating cooperative relationships (find value through win-win interactions), leveraging cyclic processes (take advantage of phenomena that repeat themselves), and using feedback loops (engage in cyclic information flows to modify a reaction appropriately).

(f) Using life-friendly chemistry

This entails the use of chemistry that supports life processes. It also consists of three (3) principles, namely building selectively with a small subset of elements (assemble relatively few elements in elegant ways); breaking down products into benign constituents (use chemistry in which decomposition results in no harmful by-products); and doing chemistry in water (use water as solvent).

Table 2.2: Principles of biomimicry and their constituting principles

S/n	Biomimicry principles	Components of the principle
1.	**Resource (material and energy) efficient**	a. Using multifunctional design b. Using low energy processes c. Recycling all materials d. Fitting form to function
2.	**Evolve to survive**	a. Replcating strategies that work b. Integrating the unexpected c. Information reshuffling
3.	**Adapt to changing conditions**	a. Maintaining integrity through self-renewal b. Embodying resilience through variation c. Redundancy d. Decentralisation e. Incorporating diversity
4.	**Integrate development with growth**	a. Combining modular and nested components b. Building from the bottom up c. Self-organising
5.	**Been locally attuned and responsive**	a. Using readily available materials b. Harnessing freely available energy c. Cultivating cooperative relationships d. Leveraging cyclic processes e. Using feedback loops
6.	**Using life-friendly chemistry**	a. Building selectively with a small subset of elements b. Breaking down products into benign constituents c. Doing chemistry in water

Source: Biomimicry Group (2014).

Thus, there are six (6) major principles of biomimicry and twenty-three (23) constituents principles that made up of the components of the major principles of the biomimicry as it was shown in table 2.2. The nature runs on these principles and they became successful in the environment that they exist in, it is the general principles in which both plants and animals built on by practicing one or more of the highlighted principles. The research will look into a fit and adoptable organism and their guiding principles that they inhibits within their environment to survive and adopt their principles as it is applicable in the area of this study.

2.2.3 Review of related works on biomimicry principle

2.2.3.1 DNA towers, Yangzhou 2014, China

Vincent Callebaut Architectures developed 24 plus-energy towers of housing in October 2013 offices and popularly refeerd to as mixed DNA Towers (Plate I). These "City trees" are swirling shapes that combine the meaning of DNA helix structure in the contemporary urban areas. These towers are eco-designed according to bioclimatic rules (solar cycle, prevailing wind directions.) on the same view, and by the integration of renewable energies (wind turbines, thermal solar energy, photovoltaic solar energy, geothermal energy, biomass (Golenda, 2017).

Plate I: DNA Towers

Source: Vincent (2017).

2.2.3.2 Pearl River tower, Guangzhou 2011, China

Pearl River a 71-story tower Pearl River Tower, Guangzhou designed by Skidmore, Owings and Merrill that was completed in 2011, it is an award-winning building (see Plate II). The design won a competition calling for sustainable design. Designers turned to the sea sponge for inspiration to create Pearl River Tower, Guangzhou. They took the structure of the sponge that is about taking gallons of water and organisms into itself in a day and they used this idea to consume less energy in their designs. Sponge can pump thousands of gallons of water a day, from which they draw and which benefit from the flow of food-bearing water. This porous tower has four holes that house wind turbines. A turbine in one of the four intakes air in the Pearl River Tower to create electricity from the strong winds that blow above the ground sponge like function of Pearl River Tower. The building soaks up energy from the sun as well, thanks to its photovoltaic system integrated to the building"s external solar shading system and glass outer skin (Frechette and Gilchrist, 2008) .With these and other energy-saving measures such as radiant cooling, the building"s energy use will be reduced by 58 to 60 percent (Delgado, 2016).

Plate II: Pearl River Tower, Guangzhou

Source: Vincent (2017).

Plate III: A turbine in one of the four intakes in the Pearl River Tower

Source: Golenda (2017).

2.2.3.3 MMA office building, Qatar

The MMA"s new office in Qatar was built to immitate the shape and adaptation nature of cactus plant. Inspiration from the way these plants deal with the scorching desert climate was immitated into the design and construction of MMA office building, Qatar. Qatar is barren, covered by sand, and receives and average annual rainfall of 3.2 inches (see Plate IV). An excellent example of desert architecture, MMA‟s new building is designed to be very energy efficient and utilizes sunshades on its windows. Depending on the intensity of the sun during the day, the sunshades can open or close to keep out the heat when it is too much. This is similar to how a cactus chooses to perform transpiration at night rather during the day in order to retain water (Meinhold, 2017).

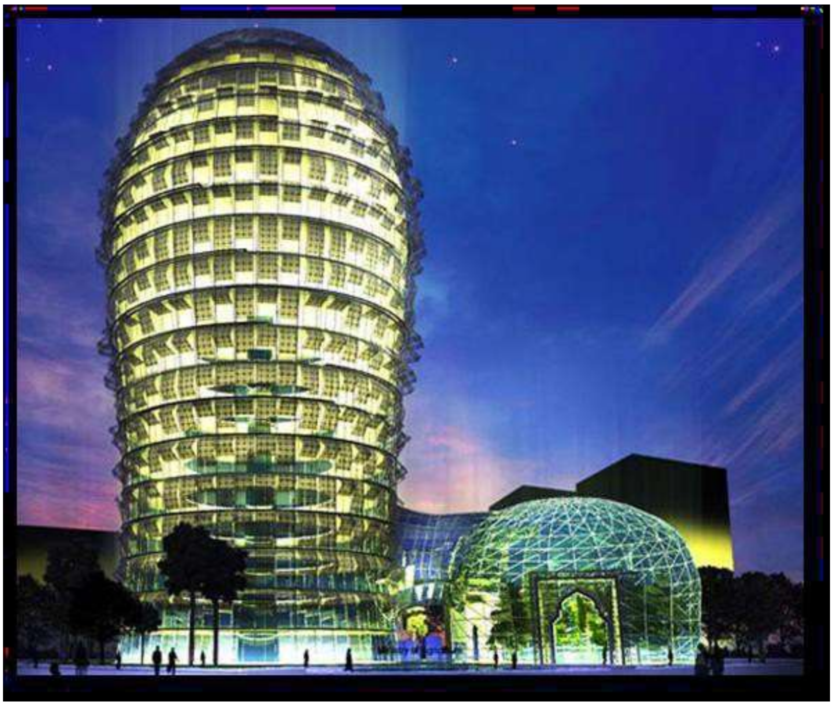


Plate IV: MMA Office Building

Source: Meinhold (2017).

Plate V: Ferocactus cylindraceus. n.d

Source: Meinhold (2016).

2.2.3.4 Deductions

Biomimicry is emulating nature‟s strategies to solve problems that humans face nowadays. One of the major problems of the modern world is to promote sustainability in building sector because of growing number of public buildings and their high energy consumption and negative environmental impact. Buildings become more efficient and sustainable when the biomimicry principles are applied. However, transferring biological principles into human design needs the knowledge of biology and biomimicry principles in order to boost the sustainability level of buildings. These principles should be incorporated into the design in the early design stage (not just added) to have a major impact on architectural sustainability.

2.2.4 Biomimicry principles of termite mound

Maximum utilization of natural ventilation is an effective strategy to achieve energy efficient buildings, but this strategy is difficult to understand and achieve because the air intake and discharge may be more or less than what is actually required in the building at a particular time and in specific spaces (Loonen, 2015). Thus, providing adequate natural ventilation solutions for buildings requires further study on successful examples. Many of such examples can be found in the form of natural phenomena (biomimetic). Looking into nature and picking inpsiration from them is always reliable and inspired, as individual living things have a unique balance with its environment, and continues to multiply and survive by exercising effective activities in response to its needs (repond to stimulus), actions that have been developed and sometimes perfected through recurring tests of survival undergone by countless generations of the living being (Van der Brugge, 2010).

Termite mounds are stable natural structures found in desert areas and have fascinated researchers for more than two centuries (Smeathman, 1781). One source of this fascination is the adaptability of termite mounds with their environment throughout different seasons, which is achieved with minimum energy consumption and only on account of good architectural design of structure. This research frame work seeks to adapt the features of termite mound as a notable example of efficient natural ventilation in the area of civic centre design (Frisch and Frisch, 2014), which in the case of termite mound, is associated with two important needs of the inhabitants, namely thermal regulation and gas exchange in a hot climate (Jacklyn and Korb, 2014; Turner, 2001; Korb, 2003).

With regards to what this review has shown and postulated, termite moulds are successive living things with reference to their methods of internal and external climatic conditions of regulating the thermal and gas exchange in hot climatic conditions. This can also be adopted in the way a building can behave with regards to it environment, both internal and external heat regulation, by tapping the potentials on the site to reduce the energy consumption rate within the building.

However, derivation of inspiration from termite moulds to minimize energy consumption trough effective ventilation has been successfully demonstrated or shown in some previous buildings; research shows a significant difference between the results of these buildings and those of termite mound structure (Turner and Soar, 2008). Hence, Termite mounds can still contribute to understanding the process of ventilation within these mounds through further research and adopting the desirable features in the field of architectural context which will be mainly for the purpose of this study in the specified area of emphasis (civic centre building).

Biomimicry is to take inspiration from natural structures to find new solutions for human problems, including those in regard to architecture (Benyus, 1997). Following this approach could be difficult however, as it requires meticulous study of natural phenomena to deduce their governing principles (Knippers and Speck, 2012). So far, several varieties of termite mound have been identified. In terms of internal structure and mechanism of ventilation, mounds are divided into two categories: capped chimney mounds (operating based on thermosiphon flow) and open chimney mounds (operating based on induced flow) (Badarnah, 2013) In terms of general morphology, termite nests are divided into several categories: epigeal (above surface), subterranean and arboreal (Darlington, 1987). As a general assumption, termite nest need to be able to discharge the air polluted due to physiological and food processing activities of the colony. Likewise, natural ventilation is also necessary for discharging the heat generated due to colony metabolism (Weir, 1973; Camazine, 2003). Studies have shown that outside wind and temperature both have significant impacts on natural ventilation (Korb and Linsenmair, 2000). And studies have also revealed that those with architectural perspectives have generally analysed the mounds" internal ventilation (Gharouni,2015; Mahmoudinejad, 2011), and a detailed description of mechanism of ventilation and the factors affecting the gas exchange process within the mound is yet to be provided. Therefore, examination of termite mound as a natural structure could reveal viable natural ventilation concepts and thereby lead to formation of architectural solutions in the designing of buildings. In other words, this study seeks to examine from a purely architectural perspective and to identify explicit elements influencing the mound ventilation process and incorporate them into passive architectural solutions.

2.2.4.1 Natural ventilation process in termite mound

The nest of a termite species called Macro Termes Bellicosuscan be as high as 3-4 meters and house about two million termites, which would live, work and breathe within this structure. The amount of oxygen to be consumed in such structure is thus significant, and absence of ventilation can lead to suffocation of all inhabitants within 12 hours (Frisch and Frisch, 2014) Thus, how can this nest be ventilated without any visible opening on the exterior? Termites have to build their mounds such that temperature, humidity, and carbon dioxide levels (due to their metabolism) would be controllable (Kleiven, 2003). These goals are achieved in part by active efforts of termites but majorly by passive features of the nest architecture, and most importantly its natural ventilation. Natural ventilation of termite mound has two tasks; firstly to discharge the stale air and draw fresh air into the mound (Turner, 2001) and secondly to exhaust the hot air and draw the cool breeze into the nest (Korb, 2003). As such, natural ventilation is essential for the function of the mound, and itself is shaped by several factors. In general, natural ventilation can be explained in three stages:

2.2.4.2 Elements Influencing the Mound Ventilation Process

1. **Drawing in of fresh air**:

a) **Wind**

Wind is the major facilitator for driving fresh air into termite mound. It has been demonstrated by the Research that the presence of small pores on the mound walls plays the primary role in this respect. One of the obviours differences between the buildings inspired by the mound design and the actual termite mound is the inability of these buildings to exploit the wind, as a primary source of energy, for their own function (Turner and Soar, 2008). But given the uncertain and shifting nature of the wind, relying solely on natural winds to carry fresh air via a certain opening is not a sensible strategy. The mentioned uncertainty means that the likelihood of a wind blowing at desirable times and with desirable speed and from a desirable direction is low and unpredictable. So any work or design counting on directing wind via a certain space will not have much reliability. One way to create air flow in a space is to create a pressure difference between two of its points (also known as Ventury flow).This pressure difference can be due to differences in air flow rate at different places (Klayven, 2010).This is interesting in the sense that natural surface air flow, i.e. wind speed, typically increases with the height. In a termite mound, this effect is used to facilitate airflow, and is strengthened by the increased height difference between wind inlet and outlet points (architecturally known as stack effect). The same effect can also be used more purposefully and much more efficiently in high-rise buildings, because termite mounds using this effect rarely rise above the height of 2-3 meters (Turner, 2009; Jone and Oldroyd, 2006). In a typical termite mound, large vertical chimneys rising above the near ground openings create a negative pressure at the mouth of these shafts (Figure 2.2). As a result, Venturi flow induces the fresh air into the mound, through the nest, and out of the chimney.

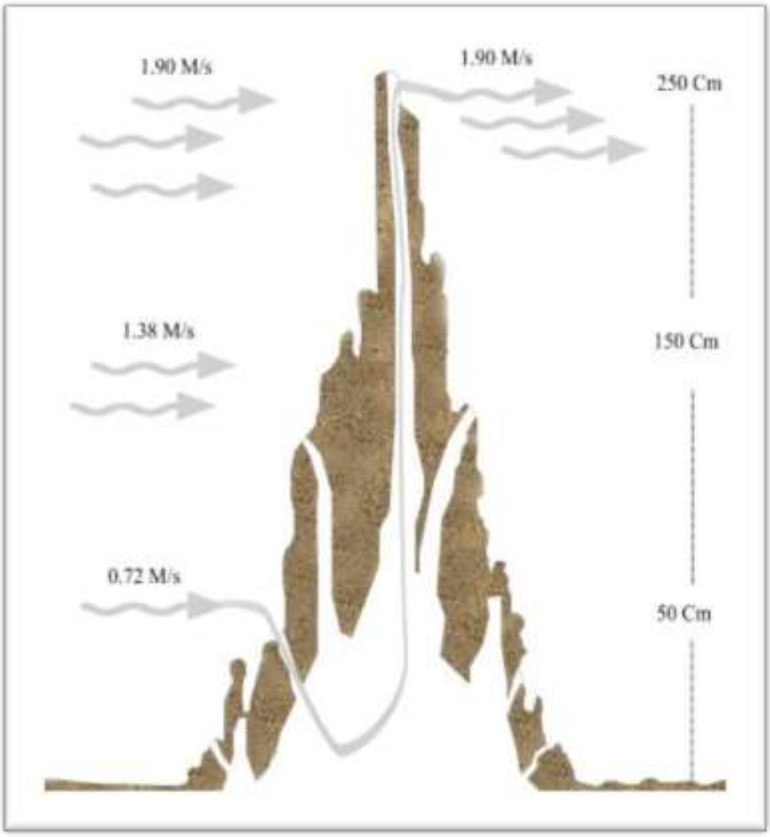


Fig 2.2: pressure difference between air inlet and outlet

As shown in Figure 2.2, wind has a substantial impact on the network of channels within the mound. Wind creates a pressure difference over the mound surfaces, which induces airflow in the channels via the pores on the walls (Turner, 2001). In most cases, wind exerts a suction force at top of the mound and this force induces an upward airflow from the nest toward the chimney (Zari, 2015).

b) **Groundwater**

water is another essential need of termites. The thin and delicate skin of termites means that they need relatively great amounts of water to maintain their metabolism. In a typical termite nest as shown in Figure 2.3, the average moisture content is between 89 to 99 percent. Termites also need some water for drinking and making the mortar required for their nest. In arid and desert terrains, termites may have to dig very deep to reach an underground aquifer. In times of extreme heat, termites move the moist soils (wetted by proximity to groundwater) to the mouth of air inlets to create airflow without upsetting the water vapour or carbon dioxide levels (Frisch and Frisch, 1974), which is why they need to build their mounds in the proximity of underground waters. A study on the nest of an African termite species called Barossa has shown that they dig tunnels as deep as 10 meters to reach the underground water. They then utilize evaporative cooling in a way that temperature fluctuations inside their nest never exceeds 1°C, even in the hottest season (Zari, 2015). Thus, the contact of inflowing air with moisture in the subterranean channels cools and wets the air to be passing across the mound, thereby cooling the entire nest.

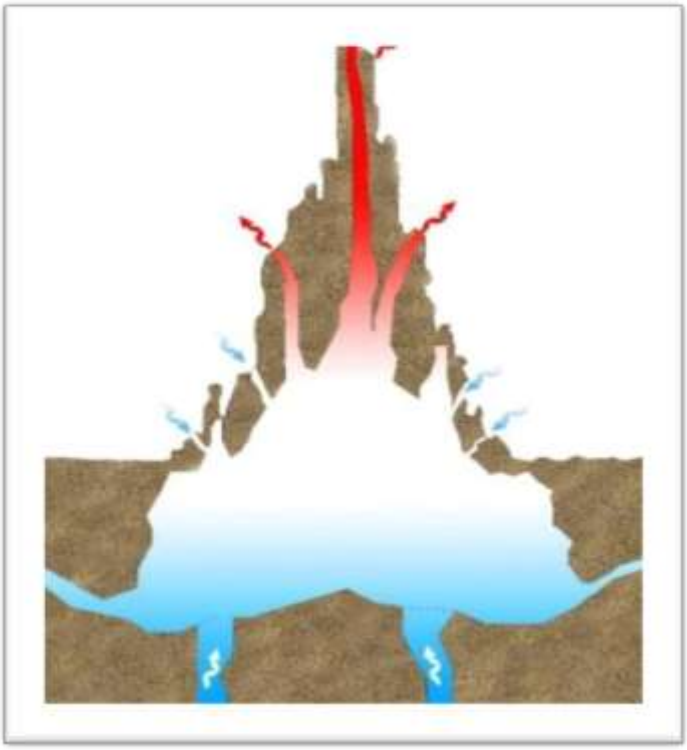


Fig 2.3: Paths of Air Infiltration into the Mound

2. Passage of air throughout the interior spaces:

a) Complex internal structure of the mound

regardless of the source, when air flows into the mound, morphologic features and interconnection of its channels allow the flow to circulate throughout the entire mound. In terms of morphology and size, channels within the termite mound can be generally categorized into three networks:

i) the network of large-diameter underground tunnels spun around the main nest and connected to the nest via a series of sub-channels.

ii) The network of upper tunnels that connect the lower section to the upper chimney.

iii) The network of surface tunnels around the mound, which are connected to both of the mentioned networks via complex structures. This network consists of narrow tunnels of about 2-3 mm in diameter, which is connected to the outside surface. Together, these three networks provide the structure necessary to facilitate airflow throughout the entire mound (Turne, 2006).

3. Exhaust of air:

a) Temperature difference

Temperature is the most important reason behind air density variations in the mound. This can lead to air density differences and increased natural heat transfer within this structure. It is not the heat generated by the metabolism of termites and the inflowing wind but rather the temperature difference that plays the primary role in natural heat transfer within the structure (Turner, 2001). In placed that are extremely heated by intense sunlight during the day, heat flow creates an upward or downward wind flow (Campbell and Norman, 2012). The presence of an opening at the top of the mound creates a suction force from the mound towards the outlet as shown in Figure 2.5. Also, the mound shape allows a part of its surface to be shaded by another part that is intensely heated by sunlight, and the resulting temperature difference induces airflow in the wall interior. The elements influencing the passive cooling of termites mound and the parametres involved to maintain their mound structure where studied and summarised in Table 2.3.

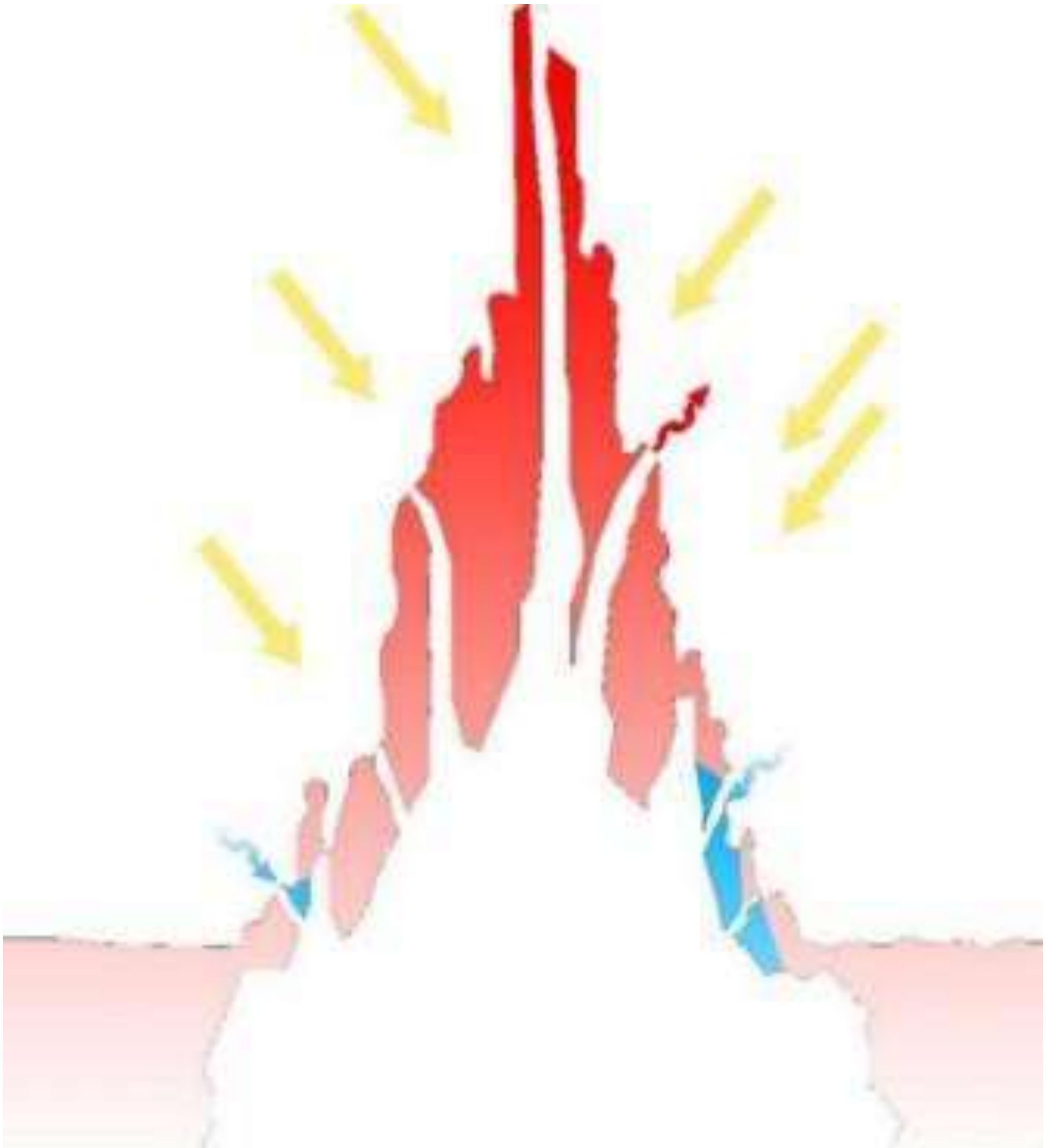


Fig 2.5: Diagram of mound walls on a hot summer say

Table 2.3: elements influencing the passive cooling of termite mound and the parameters involved

Elements influencing the mound ventilation process	Components for passive cooling in termite mould	Architectural features	Architectural parameters (variables)
(a) Draw of fresh air: (i) Wind	Nest and chimney	Stack effects	Wind direction, height of building, openings
(ii) Groudwater	Content of moisture and infilteration of air	Evaporation and cooling	Direction of air flows, water bodies
(b)passage of air throughout the interior spaces:			
(i)distribution of air by channeling	Complex internal structure of the mould	Cooling and air flowing channel	Ice cooling, opening roof
(ii)gas exchange metabolism of organisms	Exhalation of air through the wall surface and duct	Exchanging of fresh air with used air	Plant, porouse wall, screen wall
(c)Exhaust of air : Temperature differences	Due to its shape and shading pattern from the sun	Sun shading	Shading devices

Source: Zari (2015)

2.3 Sustainable architecture

Sustainable buildings are "causing as little environmental interference as possible, such as, the use of friendly environmental materials that do not constitute a health hazard, low energy requirements, renewable energy use, high-quality and longevity as a guideline for construction, and last but not least, an economical operation" (Bauer *et* *al*., 2010). In sustainable architecture, the building interacts with the environment and adapts itself to the climate conditions. The benefit of sustainable construction to the natural environment and human health is undeniable. It has been shown that increasing about 2% in the initial investment cost (in order to support sustainable design) leads to nearly 20% saving in overall building cost (Pooya *et al*., 2016). As stated there are three fundamental levels of sustainability in architecture: reducing resource consumption that deals with reusing and recycling natural resources used in construction, designing based on life cycle which presents a way to analyse construction process and its impact on environment, and finally human design that focuses on the interaction between human and the natural world (Kim *et al*., 1998).

2.3.1 Biomimicry to increase sustainability

Built environment is held responsible for environmental and social problems like excessive waste production, energy, and material use, and greenhouse gas emission attributed to the habitats humans have created for themselves (Zari, 2007). With this rapid development of urban construction, a mechanism should be applied to reduce these harmful effects. Biomimicry suggests innovative and eco-friendly approaches that can provide compatible and flexible solutions (Marshall and Lozeva, 2009). Any organism in nature avoids excesses and overbuilding, attains maximum efficiency with minimum material and energy. Nature recycles everything and finds a use for everything, adapts itself to local conditions, runs on the sun and other natural sources of energy, and uses only the energy and resources that it needs. Biomimicry provides a wide range of solutions for structural efficiency, water efficiency, zero-waste systems, thermal environment, and energy supply, which are essential for any sustainable building design (Singh & Nayyar, 2015) Nature itself is a great mentor for living in harmony with it, for instance, we can learn from plants that how they make use of air pollution and convert carbon dioxide into oxygen. Considering biomimicry levels (organism, behavior and ecosystem), mimicking an organism alone without mimicking how it is able to take part in the larger context of the ecosystem it is in, has the possibility to produce designs without environmental impact (Reap *et al*., 2005) Because mimicking organisms is just a specific feature, for instance, designing a building in the form of cacti (simple shape imitation) may not increase building overall sustainability. In behavior level biomimicry, the behavior of the organism is mimicked. In this level, designers have to figure out if the organism behavior is suitable for human beings to imitate, and which part its behavior will increase building sustainability. For example, mimicking the building behaviour (and outcome of that) of termites might be appropriate for the creation of passively regulated thermally comfortable buildings. Mimicking the social structure of termite colonies would not be suitable however if universal human rights are valued. Ecosystem level biomimicry has the advantage of being used along with other levels of biomimicry (organism and behavior). It can also be used in different temporal and spatial scales. This approach has the potential to be used in two metaphoric and practical level. Designers with little ecological knowledge can apply metaphoric level in their design, but still there is a chance of increasing building sustainability according to (Korhonen, 2001). On the contrary, profound understanding of ecology and biology is required for using ecosystem biomimicry in practical level so this makes it difficult for the architects to use this complex level of biomimicry.

2.3.2 The basic principles of sustainable architecture

i. Locational, functional, and structural solutions need to be selected in harmony with the local conditions, such as topography, microclimate, soil composition, water surfaces, and flora.

ii. Size must be limited, including the footprint, i.e. the reduction of used green areas.

iii. Natural features must be enhanced and it is advisable to use renewable energy resources such as solar energy, wind, and biomass.

iv. The daily use must be carefully planned and organized, otherwise the building cannot be considered ecological.

v. Building structures, sanitary engineering systems, alternative ways of construction are to employ environment-friendly building materials and consider ecological construction theories.

vi. Environment-conscious ventilation, energy, material consumption must be observed in the functioning of the building as well (Lányi, 2007).

vii. Recycling materials, conserving water in different ways such as harvesting rainwater, and recycling grey water.

2.3.3 Measures of energy efficiency in building

Most humans spend most of their time in buildings (Glass for Europe, 2013), requiring more energy to provide comfortable and enhanced indoor environments, and increasing the need for improved energy efficiency (Shaikh *et al.*, 2016). Energy used up by buildings for heating and cooling is approximately 40% of the total energy used up by buildings and constitutes a serious contribution to the looming threat of global warming (Darwish, 2017). Edward (1981) explained that the major reason for energy demand in buildings is not necessarily the building form or envelope, neither is it due to the use of mechanical systems, but it is as a result of users‟ individual requirements for comfort. He pointed out that individual lighting and thermal requirements are controlled to suit needs depending on geographical region, personal life style, culture and age. As a result, energy consumption in buildings is largely dependent on the choices made by the building‟s occupant.

The study will narrow its measures of energy efficiency to the principle of cooling in termite mould house as the nature mimicked in the area of research frame work to achieve the aim of this research work.

2.3.3.1 Theoretical framework of passive cooling

Passive cooling is a viable technique that promote the use of nature (biomimicry) in controlling the temperature (energy efficiency) of a space. This is achievable via some passive cooling strategies, design considerations and environmental factors.

2.3.3.2 Passive cooling design

According to Kamal (2012) passive design involves the follows design features as site planning, building design, building component and material used, site analysis, site inventory to know the local climate condition of the area. This deal with enabling provision of alternate power supply as wind and solar capacity (Taleb, 2014). Passive cooling helps to maintain a comfortable environment within a building in a hot climate by reducing the rate of heat gain into the building and encouraging the removal of excess heat from the building.

2.3.3.3 Passive cooling design of buildings in hot humid climates

Temperature in the indoor of a hot-humid climates can radially be different from the outdoor temperature. But the in cooperation of passive measure can achieve a great difference when appropriate measure are specified to control this indoor temperature. Proper size and position of windows for effective ventilation can change the temperature of the air flow, cooling can be achieved in most cases. Buildings should be designed to prevent the entrance of radiant heat during the day time, store as little heat as possible to prevent unwanted re-radiation of heat at night and promote effective continuous ventilation. Hyde (2008) stated that continuous ventilation is the most important requirement for comfort in hot-humid climates. Maximizing cooling needs in warm and hot climates should include; climate responsive layout of the area and orientation of the building façade‟s windows, adequate size and details of window openings, the use of shading devices for fenestrations, the use of insulation, the inclusion of vegetation in the building‟s surrounding‟s and the use of courtyards.

2.3.3.4 Passive cooling measures

Researches has highlight numerous measure that are to be utilize by building professionals for cooling a space without the aid of active source. These measure control the amount of heat gain from the sun which the building absorb and reduce it effect on the building Ahsan (2009).

Passive cooling measures are sub-divided into three group as heat reduction and preventive, thermal insulation, and heat dissipation method. Heat reduction and prevention method is achieved by minimizing heat gain from solar radiation into the indoor space by proper integrating building to it local climatic factors and micro environmental element as landscape, nature ventilation, proper orientation, and calculated shading.

Thermal insulation the use of thermal mass material as fabrics for minimizing the heat gain effect in the interior space through night ventilation. Heat dissipation reflect heat back to it sky, double sink (heat sink) or the surrounding through the reflective surface. (Tantsavadi *et.al*., 2011).

Ahsan (2009), classified passive strategies into two categories planning design. This deal with the planning aspect as site analysis, site invention, building form orientation, landscaping element. Design envelop comprises the building external walls, roof, windows size-type, thermal insulation, finishing material, shading device and overhand courtyard and total functionality of the design.

i. Building orientation control

Properly oriented buildings take advantage of solar radiation and prevailing wind. According to Wong and Li (2007), the longer axis of the building should lie along east-west direction for minimum solar heat gain by the building envelope. This is because the orientation of a building controls the heat gain on the exterior walls of the building as it affect the cool capacity in the space as shown in Figure 2.6 below.

In the case of conflict between the building orientation against solar radiation to building and the wind flow, the application of overhangs, wall shades are used and for the wind flow vegetation is advice.

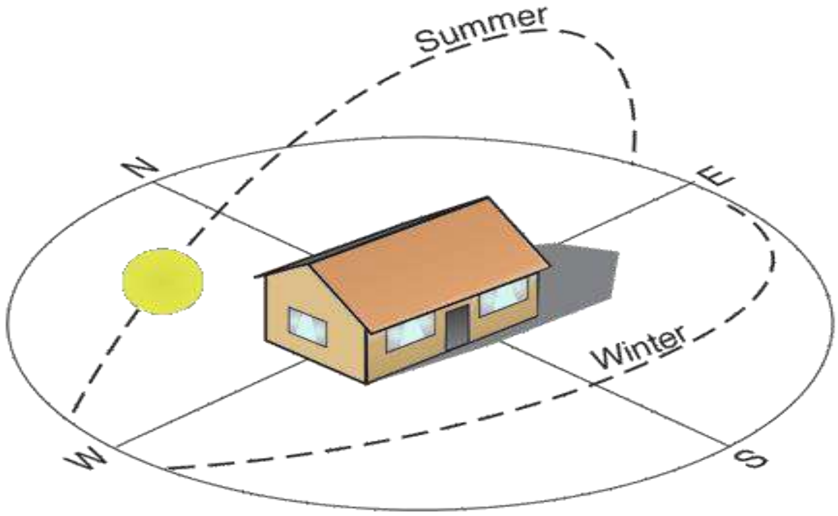


Figure 2.6: building orientation with reference to the sun direction

Source: Divsalar (2010)

ii. Soft landscaping elements in building

Review Study highlight the important of trees and shrub in a built environment, these save energy, reduce and moderate air temperature and reduces air pollution. It increase relative humidity and improve human health. Proper tree planting reduces the heat load on the building to about 40%. Tall tree with large foliage that are positioned well are most preferable for passive system, there canopy prevent solar radiation from the building and easy flow of wind under them (Figure 2.7). They also note that trees can act complementary to window overhangs, as they are better for blocking low morning and afternoon sun, while overhangs are better barriers for high noon sunshine. The study by Simpson and Macpherson (1996) ascertain Raeissi and Taheri discovery right, as both study show that tall tree shades can reduce annual energy for heat gain by 10% -

50%. The style and pattern of plant-covered wall sections affect the cooling behavior of the building dynamics during the dry season. discovery for research study, point the that thermal benefit for tree planting depend mainly on its canopy coverage level and planting density in the built environment, and a little on other species characteristics (Shashuar *et al*., 2012).

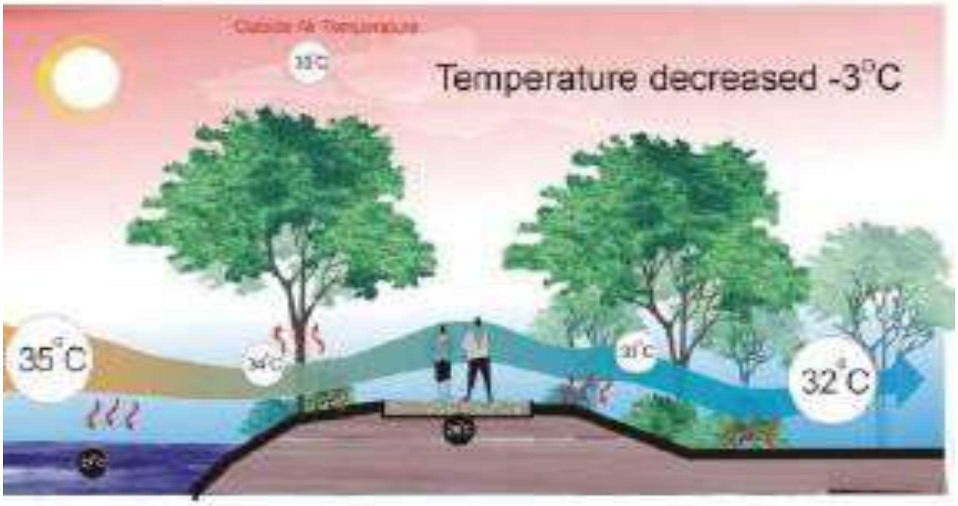


Figure 2.7: Effect of landscape element.

Plate VI: landscape elements use in events center to control and moderate air temperature.

iii. Shading devices use in building

Shading of the building is a permanent or temporary surface cover or an object used to prevent the direct impact of solar radiation on a habitable place as the building, cover for the building envelop or out layer. Shading can be seen in different ways, size, types, and placement depend on the geometric between the sun and the building. Shadow are place in proportional to the angle of the sun ray to the building. shading increase the cool of an environment as it reduce heat load on the building cool the airflow temperature.it should be situated in the direction of sun rise and sun set, this window at such position should be shade to prevent solar load as direct, diffuse and reflect radiation.

The form and shape of building can as well create shade areas to the building. Designers and builders should make use of shading device as horizontal, vertical louvers, overhang and egg-crate shading device (Figure 2.8).

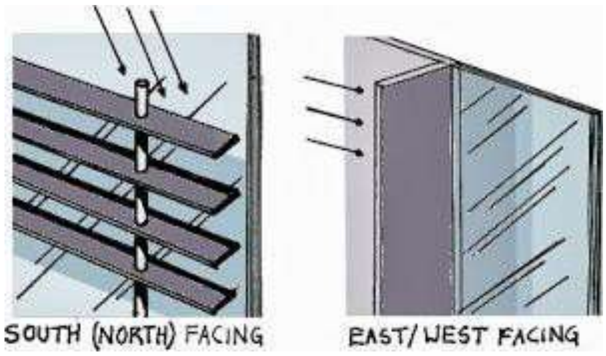


Figure 2.8: Best shading solutions for various sides of a building
Source: architecturerevived.com (2013)

iv. Fenestration in building

This deals with the building opening, window position (orientation), size, and the windows type. The effect of the orientation of windows, the sizes and type of the windows tell how effective it serve.

Orientation of window in hot humid environment should be placed according to the prevailing air flow to achieve natural airflow across the interior space. Akande (2010) emphasized window opening oriented at the south west trade enjoy the benefit of the cool air than east or west facing rooms should be avoided but where this is impractical they should be shaded in all seasons.

Size of the window in the building play an important role in the quantity and quality of air flow for ventilation, admitting of day light, and visual access. Sane size windows are advice to be position in oppose direction for cross and proper ventilation and should be easy to operate.

The casement window is mostly preferable in hot humid climate area due to the free and complete flow of air in and out of the building. It give a wider range of air change in the building space as well easy to fix and maintain.

All these measures have to be designed to give minimal resistance to the airflow. Mosquito-screens, which are essential in these regions, but reduce the airflow considerably, are therefore best installed away from windows, e.g. around the verandah or balcony.

v. Thermal insulation in building

This insulation function as a passive system which reduces the amount of heat gain in hot humid climatic building, and also moderate the rate at which heat is gain or lose for in the building at some period in the day. Thermal insulation can be seen in three type as; capacity, resistive and reflective thermal insulation.

Capacity thermal insulation elongate the time for heat transfer or sink into the indoor space. It mass content slow the movement of heat through it, this might take up to eight to twelve hours (8-12hours). This long hour of heat transfer reduces the effect of the heat gain and later become lower to be ventilated by night ventilation. Thermal massing should be used in places which are exposed to direct solar radiation as under the roofing and the interior of an exposed wall (Figure 2.9).

Resistive thermal massing; this insulation is characterized by air gaps in the fabric material in it bulk nature. Reflective insulation return back what is been absorbed to the sky or the soft landscape surrounding through foils (planed and reflective surface).

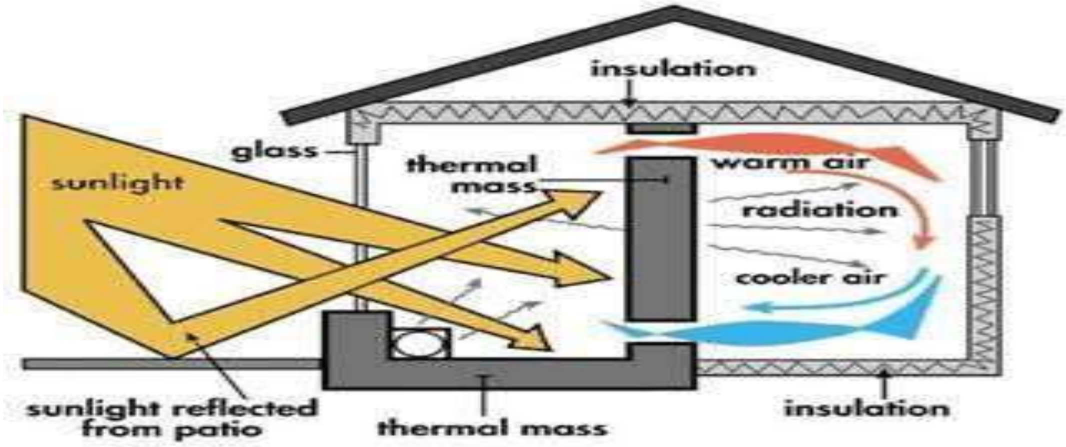


Figure 2.9: Effect of thermal insulation in heat absorption.

Light weight material are essential in heat control, and it helping to achieve high reflective output and lower the capacity insulation material quality. This should be used with light colour painting as it increase efficiency of the reflective capacity material.

The roof and walls should be made of lightweight materials with a low thermal capacity and high reflectivity. Painting the surface in light colors is an economical method to increase reflectivity. Air cavities within walls or an attic space in the roof ceiling Combination reduce the solar heat gain factor, thereby reducing space-conditioning loads. The performance improves if the void is ventilated.

vi. Natural Ventilation

A proper natural ventilation is one of the most important passive cool strategy in a hot humid climate. It is an element which allow the flow of air to increate evaporation and reduce heat from the fabric of the building (szokolay 2004). When natural ventilation is under a shade environment, it is mostly effectively cooling as the flow air changes in evaporation and relative humidity (Figure 2.10).

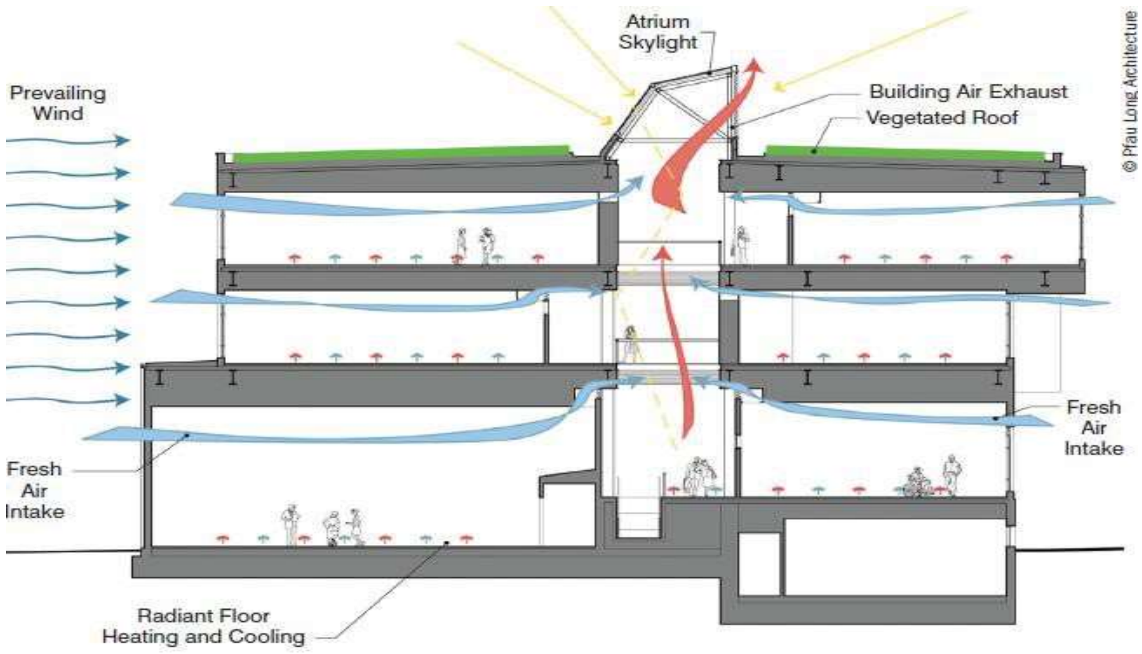


Figure 2.10: Effect of proper cross ventilation to change air flow and its temperature.

vii. Evaporative cooling system in buildings.

Evaporative cooling is cooling that deals with water. Heat from hot air is absorbed by water body, leaving cool air in the atmosphere. The amount of Heat absorbed from the air depends largely on the amount of moisture content in the air. Evaporative cooling can be achieved in the presence of water bodies such as fountains, courtyard pools, and water falls. The presence of these water bodies in an environment cause absorption of heat and flow of cool air. Evaporative cooling can also be achieved through vegetation (plant, shrub and tress) as evapo-transpiration (Figure 2.11).

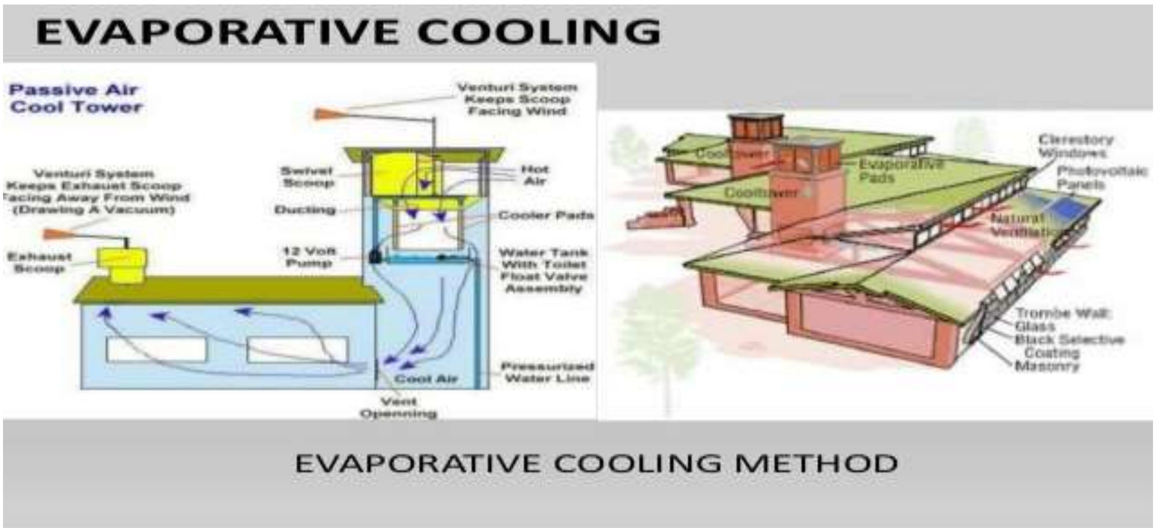


Figure 2.11: Evaporation cooling method.

viii. Radiative cooling in building

Radiative cooling deal with the dissipation of heat through reflecting heat back to the sun or environment to maintain a thermal comfort. The Building envelop used light colour which do not absorb heat but dissipate it to the sky. The roof and external wall are advised to be light colour and reflective as possible for heat to repel back.

ix. Ground cooling system in building

The idea of ground cooling is a way of heat remover from the building to the ground, this passive measure best seen in the rain season when we experience cool temperature in the environment or in an environment with vegetation. This dissipation can be achieve either by direct contact of significant part of the building structure into the ground by injecting. A building exchange heat through conduction to the ground, by convection through evaporative measure (moisture content in the atmosphere) and by radiation building finishes of the external features of the building.

x. Courtyard pool in building

An incident solar radiation in a courtyard get the air warmer and rises cool air from the ground level, then flows through the louvered opening of the room surrounding with a change in air temperature. At night the warm roof surface, get cooled by convection and radiation.

Passive cooling design strategies employs naturally change of air in with heat as hot air for cool air in building give comfort in absent artificial power. The following are variable consider for passive cool building: building orientation, natural ventilation and fenestration, landscaping elements, thermal mass or insulation, Evaporation cooling, radiation cool. These entire variables are measure that will bring about absolute coolness in an indoor space.

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 Research Method

The research method used for this study was the descriptive survey method. The parametres used in this research method were research based factors from reviewed of literature. To carry out this, an observation schedule was specially designed to obtain and assess the types and features of cooling system relevant to the study in the civc centre sampled. Interview guide was also used to collect relevant information from the staff and the customers in the selected centres to throw more light into the energy consumption of the civic centres and sources of energy relied on.This study was carried out in two states in Nigeria, Niger State and Abuja.

3.2 Data Type and Sources

Qualitative and qantitative data were used in this study. At the beginning of the research, secondary data was necessary to have relevant knowledge on the past works concerning civic centres, energy efficiency, biomimicry and passive cooling. While primary source of data collection was most suitable for assessing the civic centres in the research area.

3.2.1 Primary data

A survey was carried out to obtain primary data for this study. Using an observation schedule, the relevant data was obtained and documented.Other sources of primary data used include questionaire for the management staff and taking of photographs. Table 3.1 shows the data obtained and their instruments utilised.

Table 3.1: Sources of data

Data	Instrument
Passive cooling features	Observation schedule
Energy perception	Structured questionnaire

Source: Author‶s fieldwork, 2018

3.2.2 Other source of primary data

Journals, books, conference papers and webpages were other sources of primary data for this research. Previous works of scholars and researchers were studied to obtain useful information concerning the types and charateristics of termite mould cooling strategy that can be adopted in civic centre design.

3.3 Population of the Study, Sampling Techniques & Sample Size

A total of six conference centres within the Municipal Areas of the F.C.T and renowned centres in Minna, Niger State, Nigeria were assessed. Conference centres were selected in place of the civic centre due to the fact that there is no single building in these states that has been named civic centre rather conference centre or youth centre and this depends on the use and the scale of the design. The seletion of these two states were based on geopolitical zone and common features in respect to the site location of this reseach work. Total number of six hundred questionnaires were administered to both staff and customers of the six selected centres which were distributed evenly among the conference centres. This structured questionnaire aimed to obtain information on the energy efficiency in public buildings in order to proffer a sustainable solution to reduce the energy consumption in the building. Structured observation schedule was used to assess the natural cooling features that were integrated in the design of each centre.

Table 3.3 List of conference centres that were assessed in Abuja and Minna, Nigeria

S/No	**Names of conference centres visited**
1	Abdulsalam Youth Centre, Minna (A.Y.C)
2	Legbo Kutigi International Conference Centre, Minna (L.K.I.C.C)
3	Hmedix City Centre, Abuja (H.C.C)
4	Abuja International Conference Centre, Abuja (A.I.C.C)
5	Yar Adua Youth Centre, Abuja (Y.Y.C)
6	Naf Conference Centre, Abuja (N.C.C)

Source: Author‟s fieldwork, (2018)

3.4 Method of Data Analysis

Data were obtained from the field by means of physical observation with an observation schedule as guide. The data obtained from the field survey was analysed with measures of central tendency such as mode and percentages, otherwise known as descriptive statistical tools. Results are derived using Microsoft Office Excel, and represented in tables and pictures. The data obtained from the questionaire was analysed using SPSS and the results were represented using charts.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Data Analysis

This chapter is a discussion on how data collected from the field was analysed, and the tools employed. These discussions are arranged in the order in which the objectives discussed in Chapter One were stated.

4.2 Principles of biomimicry architecture that are applicable in the area of civic centre design.

From the discussion in Chapter 2.0, the research focused it study deeply into the biomimicry architecture principle that can be adopted in cooling system of the building. The biomimicry architecture principle for civic centre that was adopted in this research as the passive means of ensuring energy efficiency in the design of civic centre in Nigeria was the termite mound architecture. Nigeria as a nation does not suffer harsh winter conditions, therefore the passive design features assessed were those necessary for the control of heat gain and heat loss in the building. These design features are integrated within the building‟s envelope from the roof to the walls and the surrounding environment. These passive design features were the features adopted from the biomimicry architecture of termite mound. They are classified into general principles of biomimcry and adopted principle of termite mound architecture and their passive features for energy efficiency are summarised in Table 4.1 and Table 4.2 respectively.

Table 4.1: Principles of biomimicry and their constituting principles

S/n	Biomimicry principles	Components of the principle
1.	**Resource (material and energy) efficient**	Using multifunctional design Using low energy processes Recycling all materials Fitting form to function
2.	**Evolve to survive**	Replcating strategies that work Integrating the unexpected Information reshuffling
3.	**Adapt to changing conditions**	Maintaining integrity through self-renewal Embodying resilience through variation Redundancy Decentralisation Incorporating diversity
4.	**Integrate development with growth**	Combining modular and nested components Building from the bottom up Self-organising
5.	**Been locally attuned and responsive**	Using readily available materials Harnessing freely available energy Cultivating cooperative relationships Leveraging cyclic processes Using feedback loops
6.	**Using life-friendly chemistry**	Building selectively with a small subset of elements Breaking down products into benign constituents Doing chemistry in water

Source: Biomimicry Group (2014)

Table 4.2 : elements influencing the passive cooling of termite mound and the parameters involved

Elements influencing the mound ventilation process	Components for passive cooling in termite mould	Architectural features	Architectural parameters (variables)
(b) Draw of fresh air: (iii) Wind	Nest and chimney	Stack effects	Wind direction, height of building, openings
(iv) Groudwater	Content of moisture and infilteration of air	Evaporation and cooling	Direction of air flows, water bodies
(b)passage of air throughout the interior spaces:			
(i)distribution of air by channeling	Complex internal structure of the mould	Cooling and air flowing channel	Ice cooling, opening roof
(ii)gas exchange metabolism of organisms	Exhalation of air through the wall surface and duct	Exchanging of fresh air with used air	Plant, porouse wall, screen wall
(c)Exhaust of air : Temperature differences	Due to its shape and shading pattern from the sun	Sun shading	Shading devices

Source: Zari (2015)

4.3 Means of ensuring energy efficiency in civic centre buildings.

Before assessing the relevant design features, it was a necessary to get some background information on the civic centres studied. This information is represented in Table 4.3.

Table 4.3: Basic Information on the civic centres Studied

Name of Civic Centres	Location (LGA)	Type of buildings in centre
Abdulsalam Youth Centre,	Minna	Bungalows
Legbo Kutigi International Conference Centre,	Minna	Mixed (double volume)
Hmedix City Centre,	Abuja	Mixed
Abuja International Conference Centre,	Abuja	Bungalows
Yar Adua Youth Centre,	Abuja	Mixed
Naf Conference Centre,	Abuja	Mixed

Source: Author‟s fieldwork (2019)

The analysis of feedback of the questionnaire distributed is shown in table 4.4 and the result from the valid data collected were analyzed below using SPSS software which were represented using descriptive charts and tables .

Table 4.4: Information on the data collected

Total no. of distributed questionnaires	Total no. of returned questionnaires	Total no. of invalid questionnaires	Total no. of valid questionnaires
600	520	40	480

Source: Author"s fieldwork (2019)

The respondents of this instruments were mainly of people have visited and used the centre for more than once, this shows reliability of the data collected. The respondents to the information gathered were more of male than the female identified that both genders make use of the centres. However, The centres are frequently being used by the youth who are single with age bracket of 31-40 years . Therefore more exercises and youthful activities are encouraged to be present in the centres. Majority of the users of the centres were single and employable skill labour.

The educational qualification of the majority of the users in the centre were Diploma holders which is 46% from the result in Figure 4.1 followed by the 23% of O"level holders. This reveals that the data collected were mainly from educated individuals which emphasis the credibility and also the reliability of the research.

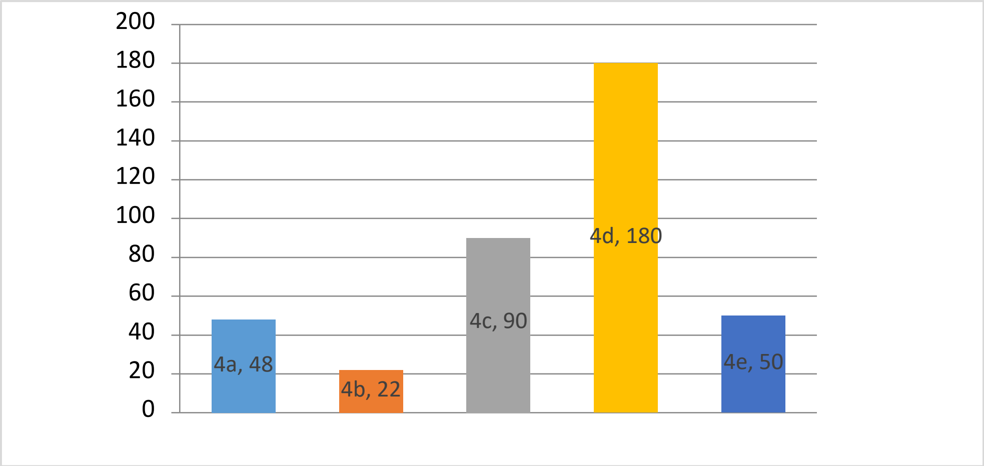


FIGURE 4.1: Educational qualification of the respondents

Source: Author (2019)

The staff working experience were evaluated and it revealed that the majority of staff that data were collected from have being working in the for 3-4 years as was shown in the figure 4.2 below that 32% were from 3-4 years working experience.

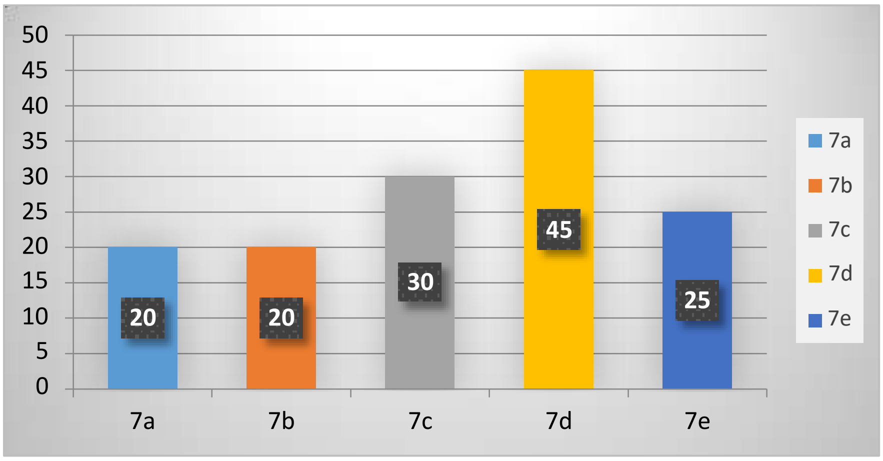


FIGURE 4.2: Length of working experience of the respondents in the centre

Source: Author (2019)

From Figure 4.3 it indicated that the operational hours of the centres were mainly from 8am-6pm which has the percentage of 36% from the result. This result revealed the operation hour of the centres , it shows that land and sea breeze principle can be achieved to cool the building during the day time.

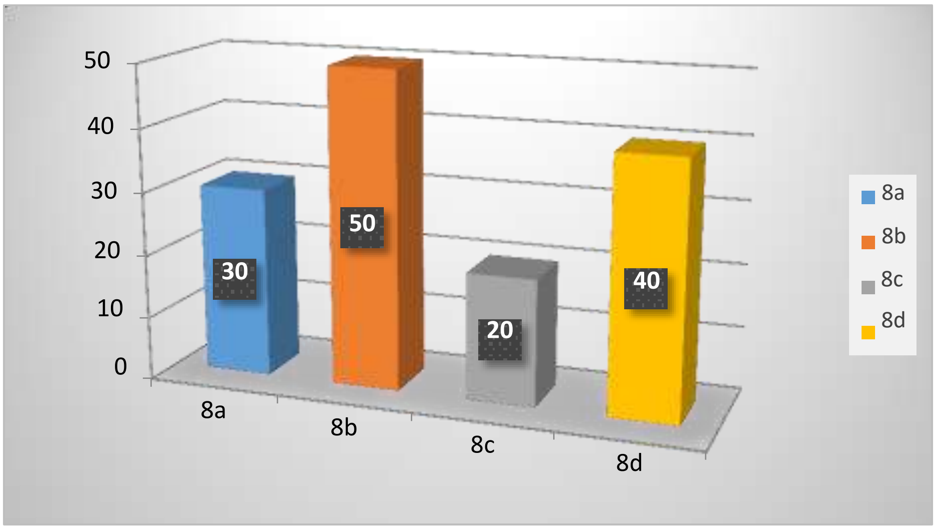


FIGURE 4.3: Working hours of the respondents in the Centre

Source: Author (2019)

39% of the result from Figure 4.4 below showed that AC/ Fan were usually switch on between 12pm-7pm to cool the building. This implied that the building became warmer within this period.

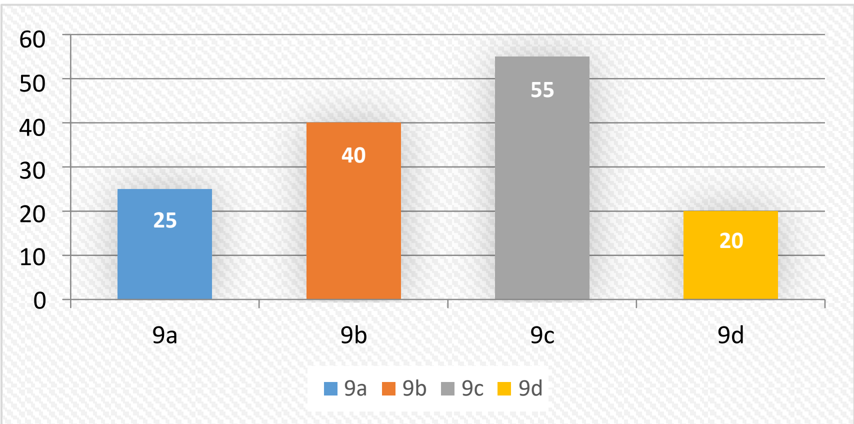


FIGURE 4.4: Period for putting on the AC/Fan

Source: Author (2019)

The result indicated that the users have good knowledge on cooling system as it depicted in Figure 4.5 about 40% of the result showed that . this indicate how well the users have ideas about the research area of this work.

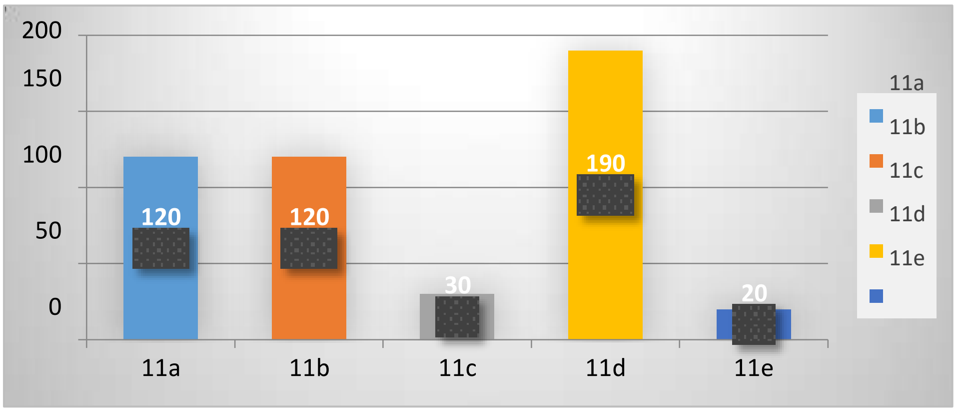


FIGURE 4.5:Respondents‟ knowledge on cooling system

Source: Author (2019)

44% of the result showed that the majority are a little concerned about the energy conservation in the centres from Figure 4.6. This implied that the users are not really concerned about energy conservation in the centres.

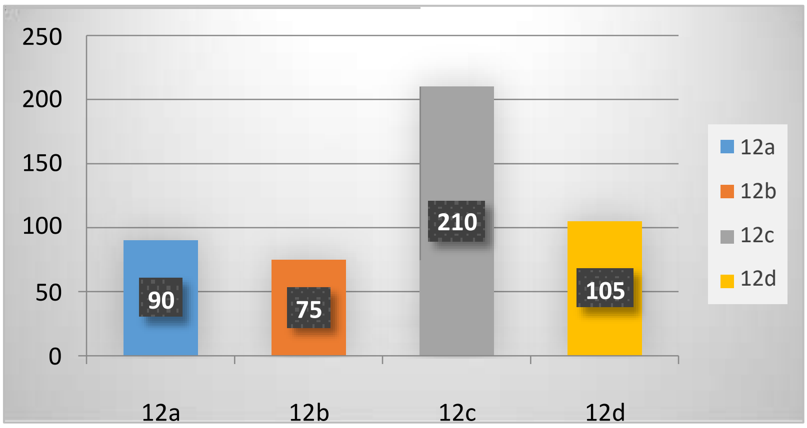


FIGURE 4.6: Respondents‟ perception on energy conservation in the building

Source: Author (2019)

In the course of this research, it was discovered that the passive design features for energy efficiency in civic centre buildings could be addressed through energy conservation and passive cooling features adopted in the buildings. Therefore, this objective was divided into two parts, thus:

i. Design features for energy conservation in civic centre buildings.
ii. passive cooling features adopted in the buildings.

Table 4.5: Design Features for Energy Conservation

S/N	Design features	Variables
1.	Windows	Types of Windows Sizes of windows
3.	Glazing	Type of Glazing Use of double-skin façade
4.	Shading Devices	Type of shading device Orientation of shading device
5.	Roof	Type of Roof Size of Roof overhang
6.	Landscaping	Type of planting used Orientation of trees

Source: Author"s fieldwork (2019)

Table 4.6: Adopted Biomimicry Architecture Design Features for passive cooling in building.

S/N	Passive Design features	Variables
1.	Roof	- Green roof - Roof vent - Roof material (Breathing skin)
2.	Building Envelope	- Breathing Wall material - Floor vent - Basement floor - Photovoltaic cell/glass/curtain walls
3.	Evaporative Cooling System	- Atrium - Fountains for evaporative cooling

Source: Author"s fieldwork (2019)

4.3.1. To assess the design features for energy conservation in civic centre buildings

Table 4.7 shows the types of windows found in the centres sample. From the Table, it is observed that none of the centres used automated louvers; these would have helped reduce heat gain by automatically opening up to aid natural ventilation when the indoor temperature is high and vice versa. 80% of the selected civic centres have sliding windows installed. This implies that these centres have their openings for air inlet and outlet reduced by 50%, 60% of the centres have casement windows which admits more air compared to sliding windows of the same size. Finally, 40% of the centres have a combination of sliding and casement window.

Table 4.7: Types of Windows Found in the Selected Civic Centres

S/N	Name Of Sample	Sliding Windows	Casement Windows	Projected Windows	Louvres
1	**Abdulsalam Youth Centre**	X			

2	**Legbo Kutigi International Conference Centre**	X	X	X	
3	**Hmedix City Centre**	X	X		
4	**Abuja International Conference Centre**	X			
5	**Yar Adua Youth Centre**		X	X	
	Naf Conference Centre,				
		4	**3**	**2**	**0**

Source: Author‟s fieldwork (2019)

Key

X=YES

Plate VII. Sliding windows at Abdulsalam Youth Centre

Source: Author‟s fieldwork (2018)

Plate VIII. Casement Windows at Legbo Kutigi International Conference Centre

Source: Author‟s fieldwork (2018)

Table 4.8 reports the shading devices in the centres studied. From this Table, it can be derived that 40% of the centres studied were made up of horizontal shading devices on east facing wall, combination of both on southwest wall and combination of both on southeast wall. that shading devices were not considered in majority of the centres studied, as only some of the centres studied is seen to possess short balconies and veranda walls as shading devices.

Table 4.8: Type and Orientation of Shading Devices in Selected Civic Centres

S/N	Name of sample	Horizontal shading devices on east facing wall	Horizontal shading devices on west facing wall	Vertical shading devices on south facing wall	Combination of both on southwest wall	Combination of both on southeast wall
1	**Abdulsalam Youth Centre**	X				X
2	**Legbo Kutigi**				X	

	International Conference Centre					
3	**Hmedix City Centre**				X	
4	**Abuja International Conference Centre**	X				
5	**Yar Adua Youth Centre**					X
6	**Naf Conference Centre**					
		2	**0**	**0**	**2**	**2**

Source: Author"s fieldwork, 2019.

Key

X=YES

Plate IX. Shading devices at Legbo Kutigi International Conference Centre
Source: Author"s fieldwork (2018)

Plate X. Shading devices at Hmedix City Centre
Source: Author‟s fieldwork (2018)

Table 4.9 shows that none of the centrs studied incorporated green roof into its design. This implies that the building envelope is not protected from solar radiation and direct sunlight. 80% of the civic centres were found to use roof overhang with eave projection of 600mm; this size of eave projection is largely insufficient to provide shading for the building envelope and 20% of the buildings studied use roof overhang above 600mm. A deep roof overhang of above 1200mm would have been sufficient to provide shading for the building envelope.

Table 4.9: Roof in Selected civic centres

Percentage of Hotels with Green Roof	Percentage with Roof Overhang 0-600mm	Percentage with Roof Overhang above 600mm	Percentage without Roof Overhang
0%	80%	20%	0

Source: Author‟s fieldwork (2019)

Plate XI. Roof Overhang at Abdulsalam Youth Centre
Source: Author‟s fieldwork (2018)

Table 4.10 is a report on how landscaping has been used as a tool for reducing heat gain in the studied centres. It was found that the centres paid attention to the use of shrubs for landscaping more than lawn and trees. The surroundings of the centres were found to be covered mostly by hard landscaping as a result of the need for parking spaces for guests. This significantly reduces the rate of evaporative cooling as hot air is met mostly by hard surfaces than the leaves of plants.

Table 4.10: Landscaping for Energy Conservation

S/N	Name of sample	Shrubs around building	Tall shading trees on south face of buildings	Shading trees on east face of buildings	Shading trees on west face of buildings
1	**Abdulsalam Youth Centre**	X			
2	**Legbo Kutigi International Conference Centre**				
3	**Hmedix City Centre**	X		X	
4	**Abuja International Conference Centre**	X	X		
5	**Yar Adua Youth Centre**	X		X	
6	**Naf Conference Centre**				
		4	1	2	0

Source: Author‟s fieldwork (2019)

Key

X=YES

Plate XII. Shrubs at Abdulsalam Youth Centre
Source: Author‟s fieldwork (2018)

4.3.2 Adopted biomimicry architecture design features for passive cooling in civic centre buildings, Nigeria.

In assessing passive design features for energy efficiency in civic centre buildings, the necessary design features were checked to ascertain how well they were adapted for energy efficiency.

Table 4.11 reveals that 40% the centres have roof vent for hot air outlet from the building however, they did not take advantage of their roof material or green roof as passive cooling features in the civic centre buildings. This implies that solar heat, which is abundant in the studied location, is being absorbed by the roof surface through radiation effect into the building and thereby increasing and generating much heat gain within the building. This raised the amount of energy consumption in the civic centres studied in cooling the building for the occupant"s comfort.

Table 4.11: Integration of Roof Passive Design Features for Cooling in the Buildings Studied

S/N	Name of sample	Green roof	Roof vent	Breathing roof material
1	**Abdulsalam Youth Centre**			
2	**Legbo Kutigi International Conference Centre**			
3	**Hmedix City Centre**		X	
4	**Abuja International Conference Centre**			
5	**Yar Adua Youth Centre**		X	
6	**Naf Conference Centre**			
		0	**2**	**0**

Source: Author"s fieldwork (2019)

Key

X=YES

Plate XIII. Roof vent at Hmedix City Centre
Source: Author‟s fieldwork (2018)

Table 4.12 shows that floor vent and basement floor have not been incorporated into the centres studied in any way. In table 4.12 the result shows that 40% of breathing wall material (perforated bricks wall) and 40% of curtain walls were also incorporated in the building. This implied that most of the buildings studied do not applied passive design features in the building envelope for energy efficiency.

Table 4.12: Integration of Building Envelope (Passive Design Features) for Cooling in the Buildings Studied

S/N	Name of sample	Breathing Wall material	Floor vent	Basement floor	Photovoltaic cell/curtain walls	
1	**Abdulsalam Youth Centre**	X				
2	**Legbo Kutigi International Conference Centre**					
3	**Hmedix City Centre**	X			X	
4	**Abuja International Conference Centre**					
		2	**0**	**0**	**2**	**0**

Source: Author‟s fieldwork (2019)

X=YES

Table 4.13 shows that evaporative cooling design features were rarely applied in the studied civic centres, 20% of atrium and fountains were applied in the buildings studied as demonstrated in table 4.13 below. This implied that evaporative cooling features were not adopted in the civic centres studied thereby increasing the cooling cost of the building and increases the energy efficiency of the building.

Table 4.13: Integration of Evaporative Cooling Design Features in the Buildings

S/N	Name of sample	Atrium	Fountains for evaporative cooling
1	**Abdulsalam Youth Centre**		
2	**Legbo Kutigi International Conference Centre**		
3	**Hmedix City Centre**		
4	**Abuja International Conference Centre**		
5	**Yar Adua Youth Centre**	X	X
6	**Naf Conference Centre**		
		1	**1**

Source: Author"s fieldwork (2019)

Key

X=YES

Plate XIV. Roof vent at Hmedix City Centre
Source: Author‟s fieldwork (2018)

4.4 Incorporating all the research findings to enhance energy efficiency in the proposed civic centre design

The civic centre building proposed is 5 suspended floors and one basement floor. It is designed with every floor having a different floor area and gentle ramp running from the basement floor to the top roof of the proposed civic centre.

In order to encourage passive cooling within the building‟s interiors, it has been designed with a central atrium, which has openings at different levels of the building. These openings provide inlet and outlet to aid air circulation in the building. These openings are provided on the ground floor (floor vent), the roof vent, breathing roof materials and the breathing wall materials which enhance more fenestration and air movement by the presence of basement floor in the building as illustrated in Figure 4.7.

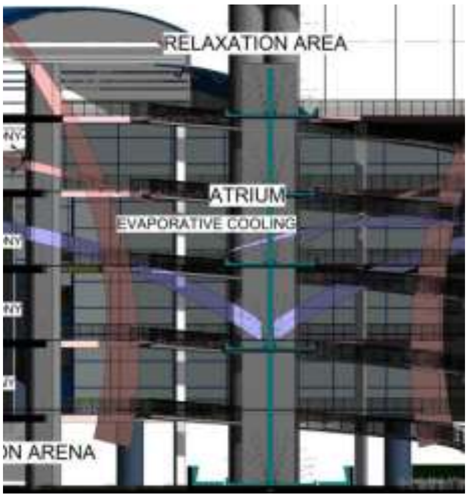


Figure 4.7: 2-Dimensional Section of the Proposed Civic centre Showing the Atrium and Air Inlets

Source: Author‟s work (2019)

Fountains as shown in Figure 4.8 were integrated the proposed civic centre design at each floors it cools the hot air from the building as it comes in contact with the cool water vapour from the fountains in the atrium that brings about the evaporative cooling of the hot air and building in general thereby cooling the structure and increases the energy efficiency, as demonstrated in Figure 4.9.

Figure 4.8: 3-Dimensional Section of the Proposed Civic centre Showing the Fountains

Source: Author‟s work (2019)

Figure 4.9: 2-Dimensional Section of the Proposed Civic centre showing the Evaporative Cooling

Source: Author"s work (2019)

From Figure 4.10 , it shows relaxation area within the basement floor and in figure 4.17 demonstrated the flowing and possibilities of air movement into the building atrium . thereby increasing the outlet of air and inlet of air. This basement floor allowed the free movement around and within the building and increases the cooling rare of the proposed civic centre. This reduces the use accumulated heat within the building and increases the air fenestration. This take site advantages like the trade-winds and the land - sea breeze.

Figure 4.10: 3-Dimensional Section of the Proposed Civic centre Showing the Basement Floor and Relaxation Centre

Source: Author"s work (2019)

Figure 4.11: 3-Dimensional Section of the Proposed Civic centre Showing the Basement Floor

Source: Author"s work (2019)

Figure 4.12 shows the application of louvers and breathing walls in the proposed civic centre design it increases the cooling ability of the building and also allowed the free flow of inlet and outlet of air. The louvers are adjustable and can be control to suit the demand air flows. The breathing wall materials applied is ETFE materials which have pores on it surface and have the capability of fenestration of air in and out thereby increasing the cooling level of the proposed as there will not be any much or little hot air within the building thus increases the energy efficiency.

Figure 4.12: 3-Dimensional Section of the Proposed Civic centre Showing the breathing walls and louvers

Source: Author‟s work (2019)

From Figure 4.13 it is demonstrated that the proposed civic centre design applied the ETFE material as the major roof material in the design due to it ability to breath in and out of the air within and around the building coupled with the roof vent made the design a total sustainable building that behave like the adopted biomimicry concept in this research. These are the passive features of the termite mound for cooling and was also adopted in this proposed design for cooling the civic centre.

Figure 4.13: 3-Dimensional Section of the Proposed Civic centre Showing the Roof Vent and ETFE Materials

Source: Author‟s work (2019)

Figure 4.13 shows the application of floor vent in the proposed civic centre design , the floor vent applied aid the air flow in the auditorium and also in the other spaces where it was applied in this design.it allows the flow of air inlet and outlet from the spaces and thereby brings about cooling in the space. The floor vent taked the advantage of the basement floor to cool the space within the building as it increases the ventilation of the spaces therefore increases cooling efficiency in the civic centre.

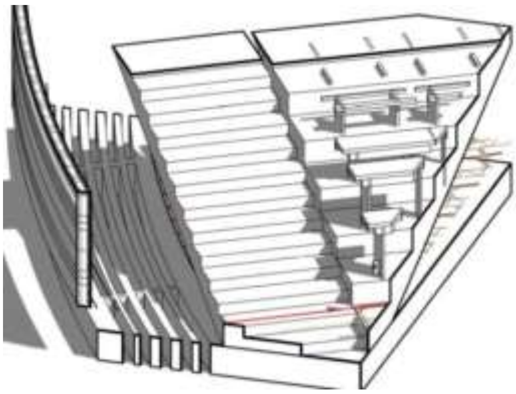


Figure 4.14: 3-Dimensional Section of the Proposed Civic centre Showing the Application of Floor Vent

Source: Author"s work (2019)

These ramp greens and gardens provide shading for the floors below them. The plants on the green ramp and garden also provide evaporative cooling by absorbing heat from sun above. The ramp also serve as an emergency and evacuation exit in the building it is demonstrated in Figure 4.14 below.

Figure 4.15: 3-Dimensional Image of the Proposed Roof Gardens for the Building.

Source: Author"s work (2019)

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Biomimicry architecture principles are essential for energy efficiency. However, they cannot run without adequate passive design features and energy conservation thereby putting energy at the core of sustainable development.

This research showed that although some of the passive design features necessary for the adoption of biomimicry architecture principles are not present in the civic centre buildings sampled, they have not been consciously adopted as a passive measure in the civic centre designs for energy efficiency. Although the conservatory design features are fairly integrated in some of the centres sampled, most of the passive design features are rarely adopted for energy efficiency in the buildings sampled.

Passive design strategies for energy efficiency were not considered in the design stages of the civic centres. However, it is still possible, that some of these passive means can still be integrated in the centres studied to improve their sustainability and the energy efficiency of the building.

5.2 Recommendations

From the research conducted, it is recommended that:

i. Nigerian commercial industry and indeed the whole country should look to renewable sources of energy due to the fact that energy plays a vital role in technology and sustainability advancement in any nation.

ii. As a preventive measure, green building design should be made a criterion to be met by design proposals before approval for construction is given. This is to ensure that an energy crisis is averted, and there is preservation of the natural environment.

iii. Nigeria, should adopt the tradition of celebrating green and smart buildings as a way of encouraging sustainable building design.

REFERENCES

Adeyinka, S.A. (2005). The challenges of global planning legislation for sustainable urban development in Nigeria: *Proceedings from the conference on Globalisation Culture and the Nigeria built environment,* Ile-Ife: O.A.U. 2, 386– 394.

Ahsan, Y. H., Pearce, A. R. & Kun, K. (2009). Paradigm Shift of Green Buildings in the Construction Industry: *International Journal of Sustainable Building Technology and Urban Development*, 2(1), 52-62.

Alexander, S., & Kennedy, C. (2002). Green hotels: Opportunities and resources for success. *Zero Waste Alliance, 5*(7), 1-9.

Akpomuvie, S., Onyeazu, G. (2010). *High performance façades for commercial buildings*. Texas: Centre for Sustainable Development.

Antoniades, A.C. (1990). *Poetics of architecture theory of design*. New York,U.S.A: Van Nostrand Reinhold.

Aziz, M.S. (2015). Biomimicry as an approach for bio-inspired structure with the aid of computation. *Alexandria Engineering Journal*, 55 (1), 707-714.

Badarnah, L., & Kadri, U. (2015). A methodology for the generation of biomimetic design concepts: *Architectural Science Review*, 58(2), 120-133.

Bauer, M., Mosle, P., & Schwarz, M. (2010). Green building: guidebook for sustainable architecture. Springer, Berlin.

Benyus, J. (1997). *Biomimicry Innovation Inspired by Nature*. New York, U.S.A: William Morrow.

Camazine, S. (2003*). Self –organization in biological systems.* New Jersey, U.S.A: Princeton University Press.

Cullen, J.B. (1998). The effect of ethical climates on organization commitment: A two study analysis. *Journal of Business Ethics*, 46: 127-141.

Darlington, J.P., & Dransfield, R.D. (1987). Size relationships in nest populations and mound parameters. *Termite Macrotermes michaelseni Insectes Sociaux*, 34(3), 165-180.

Darwish, A. S. (2017). Green smart sustainable building aspects and innovations: *Mediterranean Green Buildings & Renewable Energy*, 5, 717-727.

Delgado, L. (2016). Imitation of life. Retrieved on 20th March, 2018, from: https://archpaper.com/2007/09/ imitation-of-life/.

Disalar, H. (2010). Future structure and reuse of recycled materials: Clean Energy Technologies, 3(3), 140–143.

Edward, B. (2007). Rough guide to sustainability. London: RIBA Enterprises

Elghawaby, M. (2010). The future of smart architecture in Egypt: *A Way to Design Environmental Building*, 34(4), 280-298.

Frechette, R. & Gilchrist, R. (2008). Towards Zero Energy- A Case Study: Pearl River Tower, Guangzhou, China: Proceedings of the Council on Tall Buildings and Urban Habitat‟s 8th World Congress. 7–16.

Frisch. K. V., & Frisch, O. V. (1974). *Animal architecture*. Tehran, Iran: Center for Intellectual Development of Children and Adolescents.

Gamage, A., & Hyde, R., (2012). A model based on Biomimicry to enhance ecologically sustainable development. *Architectural Science Review*, 55 (3), 224-235.

Glass for Europe. (2013). *The smart use of glass in sustainable buildings.* Retrieved on 29th April, 2018, from: https://www.glassforeurope.com/images/cont/165_90167_file.pdf

Ghanouni,M.K. (2015). The relation between perceived sensory dimensions of urban green space and stress restoration. *Landscape and Urban Planning*, *94*,264-275.

Golenda, G. (2017). Architecture inspired by nature: Biomimicry from Art Nouveau to Neo- Futurism. Retrieved on 20th March, 2018, from: http://arhitizer.com/blog/biomimicry-binet-som.

Goss, K.H. (2009). Designing space to support knowledge work. *Environment and Behaviour*, *39*(6), 815-840.

Helms, M. Vattam, S.S. & Goel. A.K. (2009). Biologically inspired design: Process and products. *Design studies*, 30 (5), 606-622

Hinkle, M. (2008). Key Factors in Guest‟s Perception of Hotel Atmosphere: *Cornell Hospitality Quarterly*, 50, (1), 29-43

Hyde, P. (2008). Green libraries national and international initiatives fostering environmental sustainable libraries and library services: *BOBCATSSS*, 24, 1–7.

Jacklyn, P.M. & Korb, T.A. (2014). *Termite mound surface are oriented to suit wind and shade conditions*. New york, U.S.A: Harvard University Press.

Jones. J., & Oldroyd, B. P., Nest thermoregulation in social insects: *Advances in Insect Physiology*, 33, 131-191.

Joye, Y. (2007). Architectural Lessons From Environmental Psychology: The Case of Biophilic Architecture. *Review of General Psychology*, *11*(4), 305-328.

Kamal, G. O. (2012). Achieving the millennium development goals: Issues and options for the Nigeria's tourism industry. *Tourism Review*, *61*(1), 26-30.

Knippers. J., & Speck, T. (2012). Design and construction principles in nature and Architecture. *Bioinspiration & biomimetics*, 7 (1), 15-20.

Korb, J., & Linsenmair, K. E., (2000). Ventilation of termite mounds: New results require a new model. *Behavioral Ecology*, 486-494.

Korhonen, J. (2003). Four ecosystem principles for an industrial ecosystem: *Clea Production* ,9(3), 253–259.

Lányi, E. (2007). The basic principles of sustainable architecture: *Periodica Polytechnica Architecture*, 38, 79-81.

Mahmoudinejad, H. (2011). *Design base on nature*, Tehran, Iran: Tahan Publisher.

Marshall, A. & Lozeva, S. (2009). Questioning the theory and practice of biomimicry: *Biomimicry*, 4(1)1–10.

McGregor, S. L. (2013). Transdisciplinarity and biomimicry: *Transdisciplinary Journal of Engineering & Science*, 4: 57-65.

Meinhold, F. (2017). Genetic optimization of external shading devices. In *Proceedings: Building Simulation*, 29-37.

Onwuzuluike A. W. (1989). *Landscaping to Conserve Energy*. New York, U.S.A: William Morrow.

Pawlyn, M. (2011). *Biomimicry in architecture*, London, England: RIBA Publishing.

Pooya, W. J., Van, H. C., & Maziarz, A. (2016). Modelling the double skin façade with plants. *Energy and Buildings*, *37*(5), 419-427.

Rao, R. (2014). Biomimicry in Architecture: International Journal of Advanced research. *Civil, Structural, Environmental and Infrastucture Engineering and Developing*, 1(3), 10-17.

Reap, J., Baumeister, D., & Bras, B., (2005). Biomimicry and sustainable engineering. *In ASME 2005 International Mechanical Engineering Congress and Exposition*, 423-431.

Reed, P. A. (2003). A paradigm shift: Biomimicry is a new way of linking the human-made world to the natural world. *The Technology Teacher*, 63(4), 23-29.

Robert, D. H. (2009). Smart Buildings- not only Green but also Intelligent. *Envirocities eMagazine* , 33-37.

Rozanek, M. & Roubik, K. (2007). Mathematical model of the respiratory system:comparison of the total lung impedance in the adult and neonatal lung.

Proceedings of the World Academy of Science, Engineering and Technology, 24, 293-296.

Salingaros, M. J., Shrestha, M. L., Ailikun, Dong, W., McGregor, J. L., & Wang, S. (2004). Climate in Asia and the Pacific: *Security, Society and Sustainability*, 2(4), 17-57.

Shaikh, P. H., Nor, N. B., Nallagownden, P., & Elamvazuthi, I. (2016). Intelligent Multi- objective Optimization for Building Energy and Comfort Management. *Journal of Engineering Sciences*, 65, 232-240.

Shaushuar, R. M. (2012). Integrating intelligent building technologies: a means for fostering sustainability. *Conference on Technology & Sustainability in the Built Environment,* King Saud University- College of Architecture and Planning, 459-478.

Shu, L., Ueda, K., Chiu, I. & Cheong, H. (2011). Biologically inspired design: *CIRP Annals - Manufacturing Technology*, 60(2), 673-693.

Simopson, J. & Mac, p. (2008). How do smart buildings make a building green: *Energy Engineering*, *105*(6), 17-22

Singh, A. & Nayyar, N. (2015). Biomimicry-an alternative solution to sustainable buildings: *Journal of Civil and Environmental Technology*, 2 (14), 96-101

Smeathman, H. (1781). *Some of the termites which are in Africa and other hot climat*. New york, U.S.A: Harvard University Press.

Taleb, C. (2014). Role of renewable energy sources in environmental protection: *Renewable and Sustainable Energy Reviews*, *15*(3), 1513-1524.

Tantsavadi, H., Hygge, S., Halin, N., Green, A.M., & Dimberg, K. (2011). Open-plan office noise: Cognitive performance and restoration. *Journal of Environmental Psychology, 31,* 373-382.

Turner J.S. (2009). *The physiology of animal built structures.* New york, U.S.A: Harvard University Press.

Turner, J.S. (2007). *The Tinkerer's Accomplice: How design emerges from life itself.* Cambridge, U.K: Harvard University Press.

Van den Berg, A. E. (2010). Environmental preference and restoration: *Journal of Environmental Psychology*, *23*, 135–146.

Vincent, J.F., Bogatyreva, O.A., Bogatyrev, N.R., Bowyer, A. & Pahl, A.K.(2006).Biomimetics practice and theory. *Journal of the Royal Society*, 3(9), 471- 482.

Vincent, J. F. V., Bogatyreva, O., Pahl, A. k., Bogatyrev, N. and Bowyer, A. (2005). Putting Biology into TRIZ. A Database of Biological Effects. *Creativity and Innovation Management*, 14(1), 66-72.

Wahl, D.C. (2006). Bionics vs. biomimicry: From control of nature to sustainable participation in nature. *comparing design in nature with science and engineering*, 87, 289-298.

Wen, S. L., Hsiao, C. P., & Chen, C. T. (2017). Intelligent Buildings. Retrieved on 25th June, 2017 from: https://www.eolss.net/Sample-Chapters/C15/E1-32-03-03.pdf

Weir, J.S. (1973). Air flow,evaporation and mineral accumulation in mounds of Macrotermes subhyalinus: Animal Ecology Journal. (42) 509-520.

Wong, J. (2007). Development of a conceptual model for the selection of intelligent building systems: Building and Environment; 41(8), 11–23.

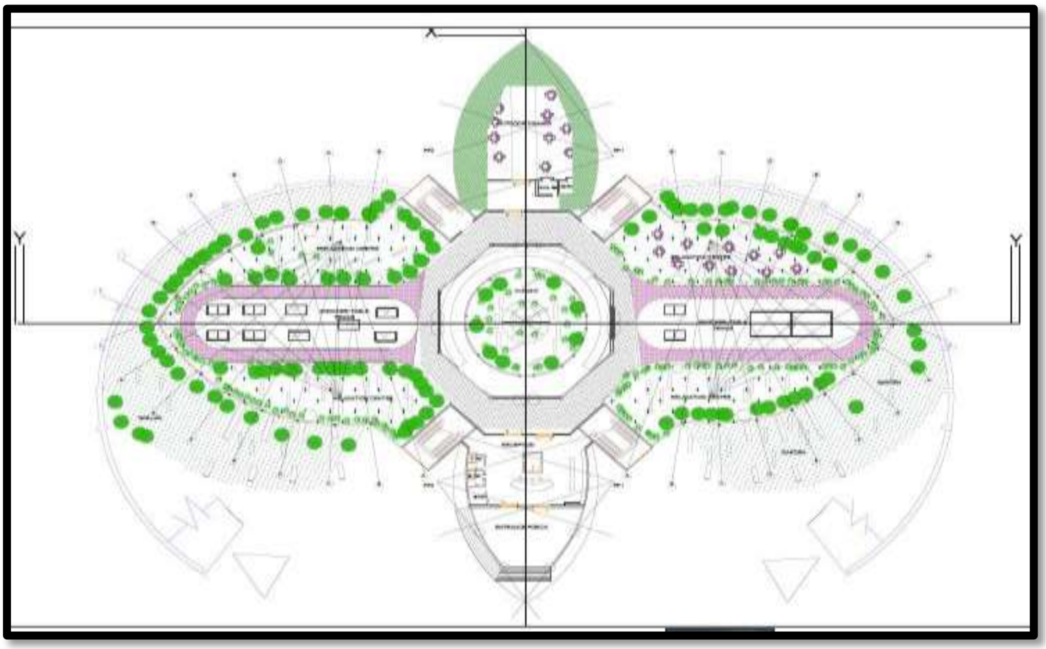
Zari MP (2007*). Biomimetic approaches to architectural design for increased sustainability*. Willington, New Zealand, Victoria University.

Zubairu, S. N. (2018). Intelligent Buildings and Green Buildings- Which Way for Nigeria? *Proceedings from the School of Environmental Technology International Conference, Minna.* 4-25.

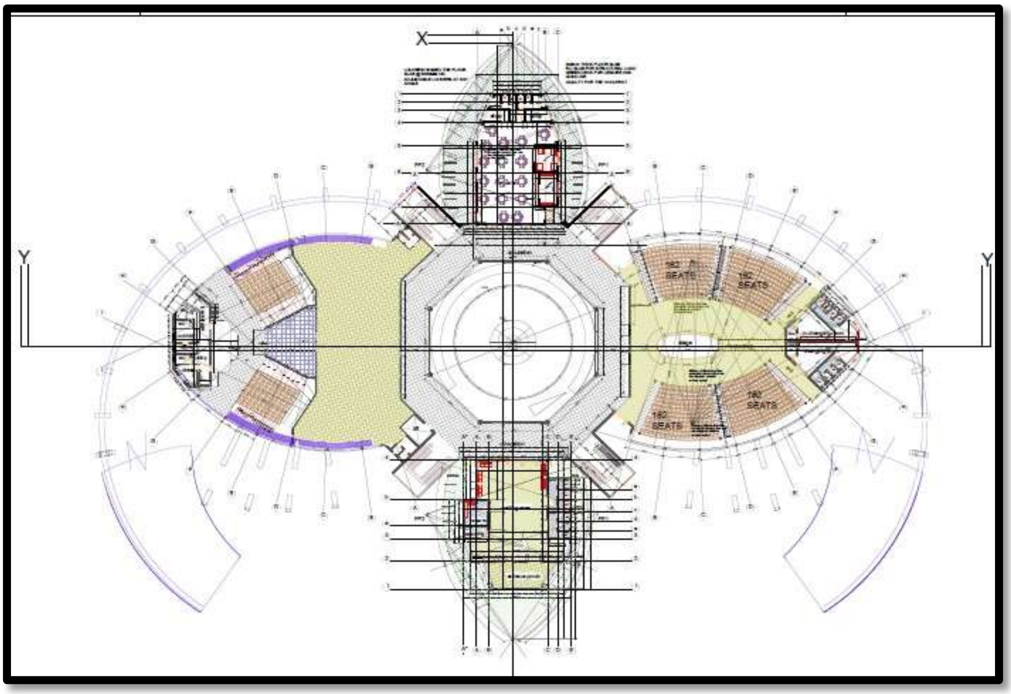
APPENDICES A

DESIGN PROPOSAL

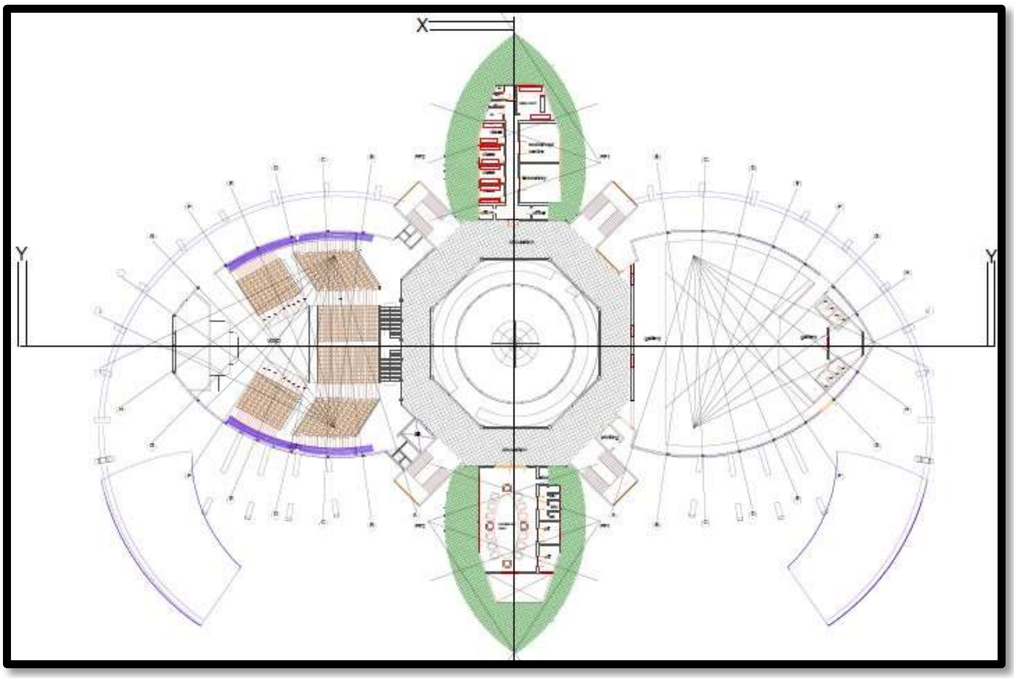
Appendix 1.0: Site plan



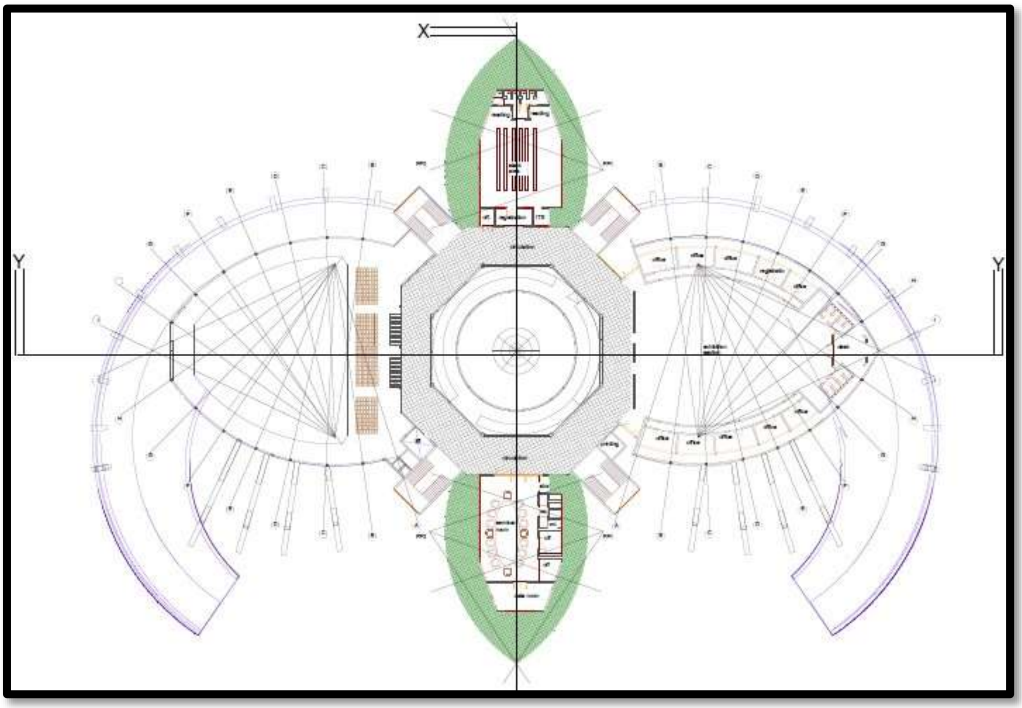
Appendix 2.0: Ground floor



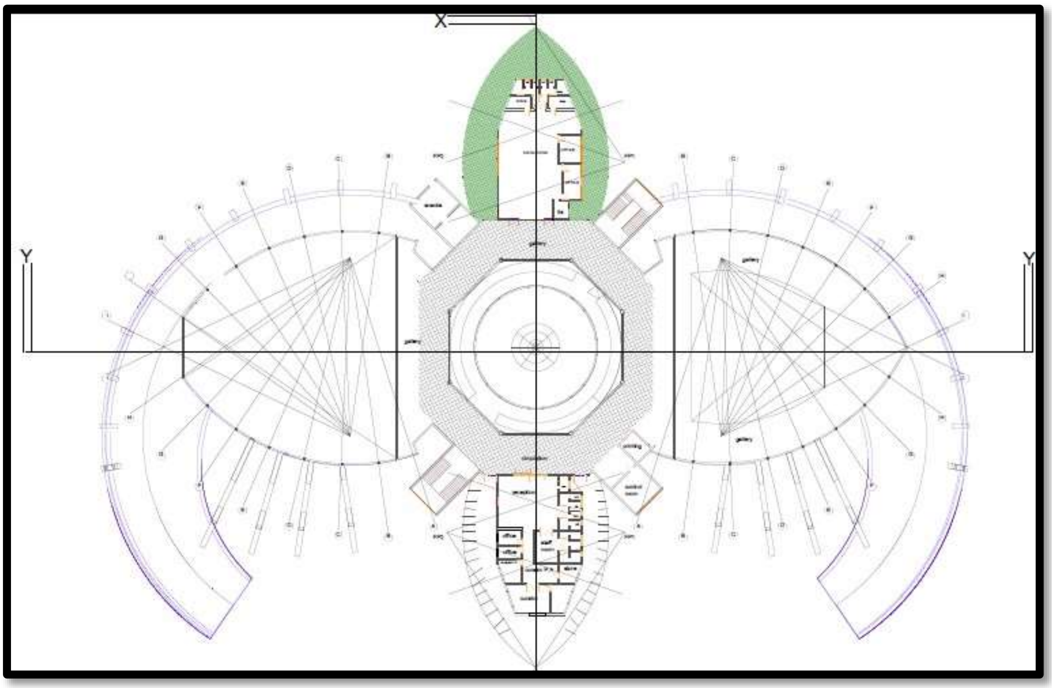
Appendix 3.0: First floor



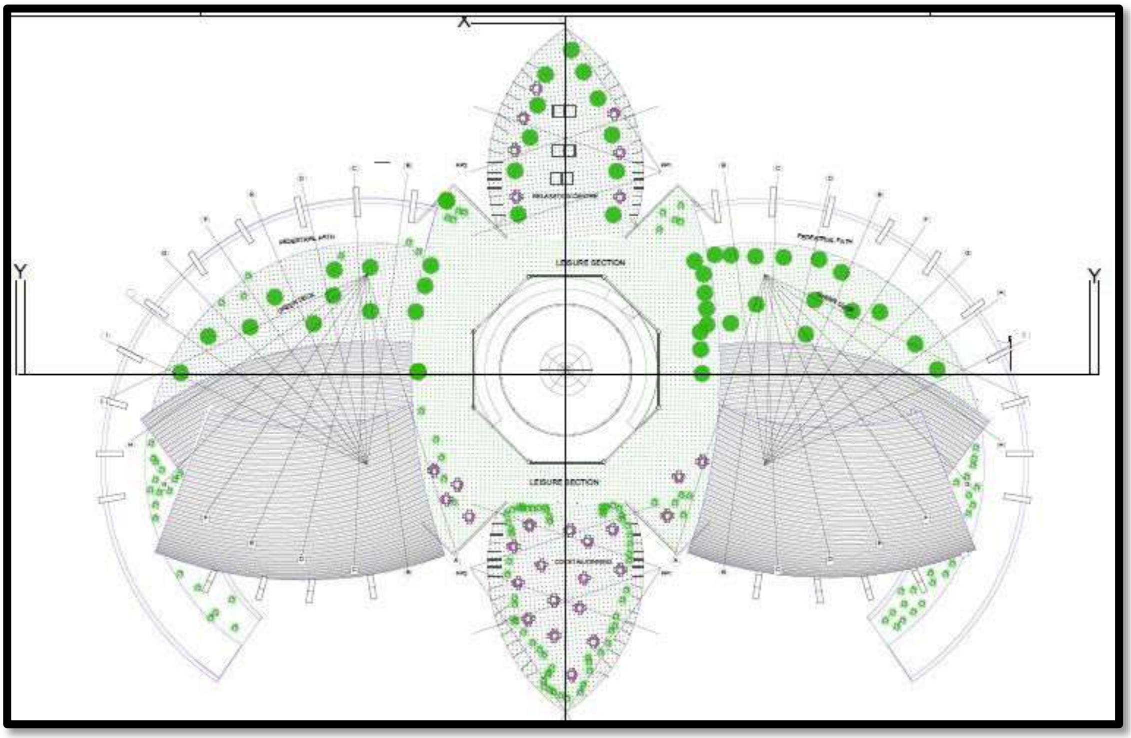
Appendix 4.0: Second floor



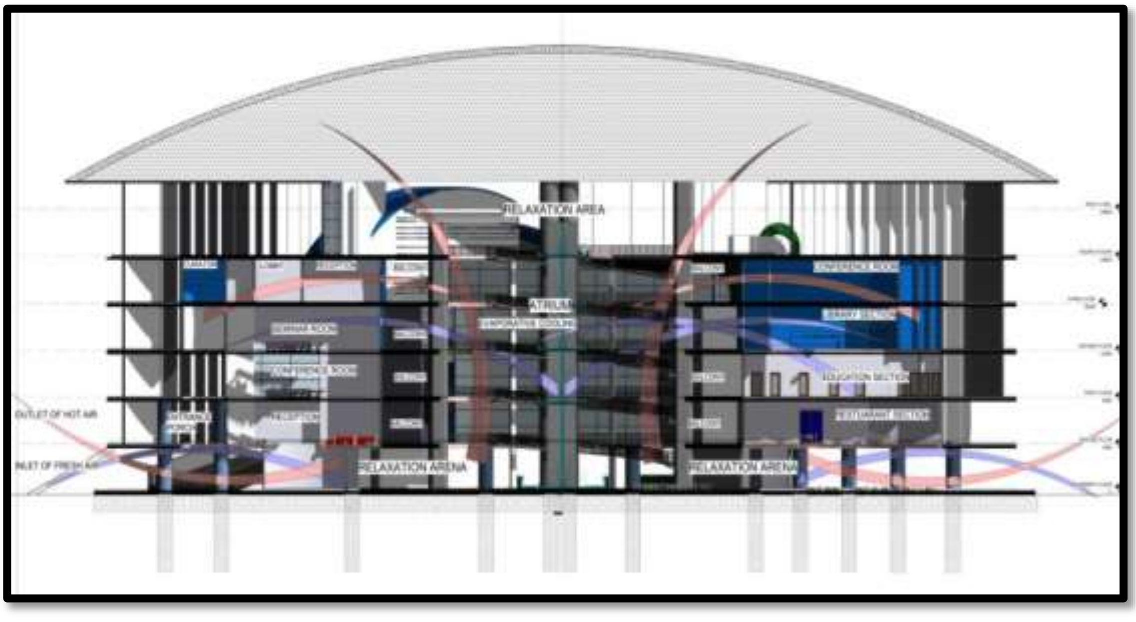
Appendix 5.0: Third floor



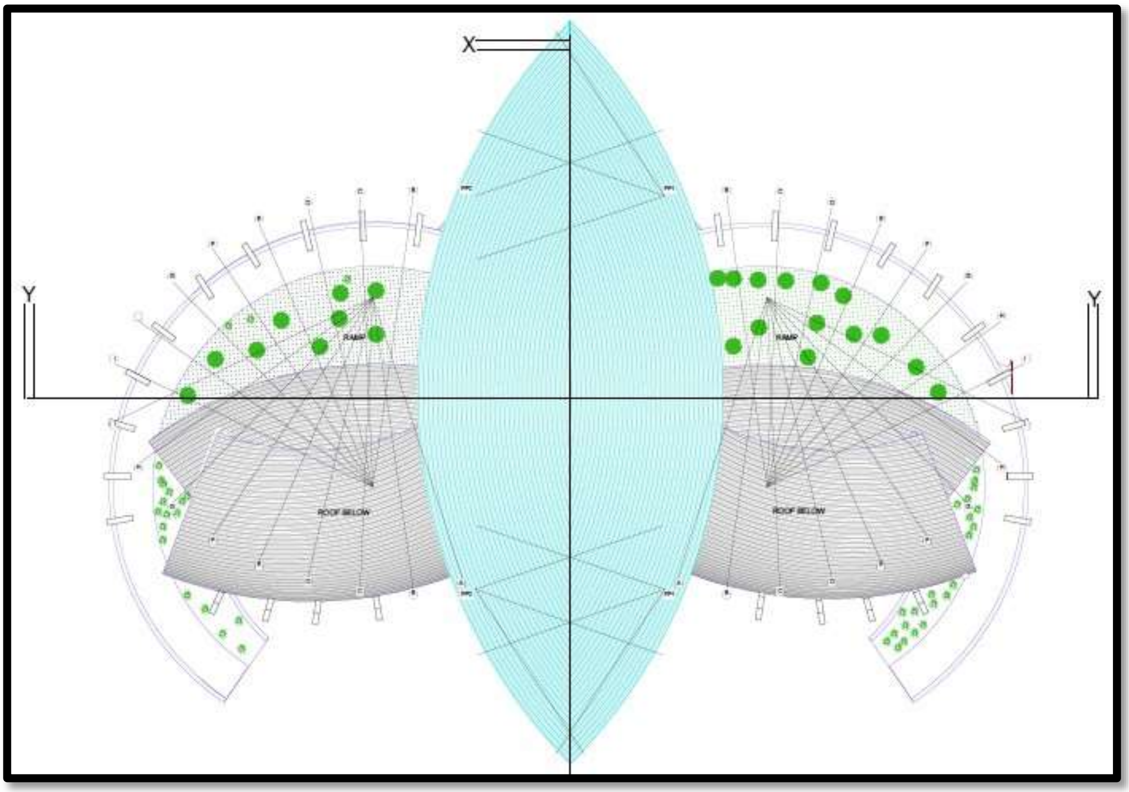
Appendix 6.0: Fourth floor



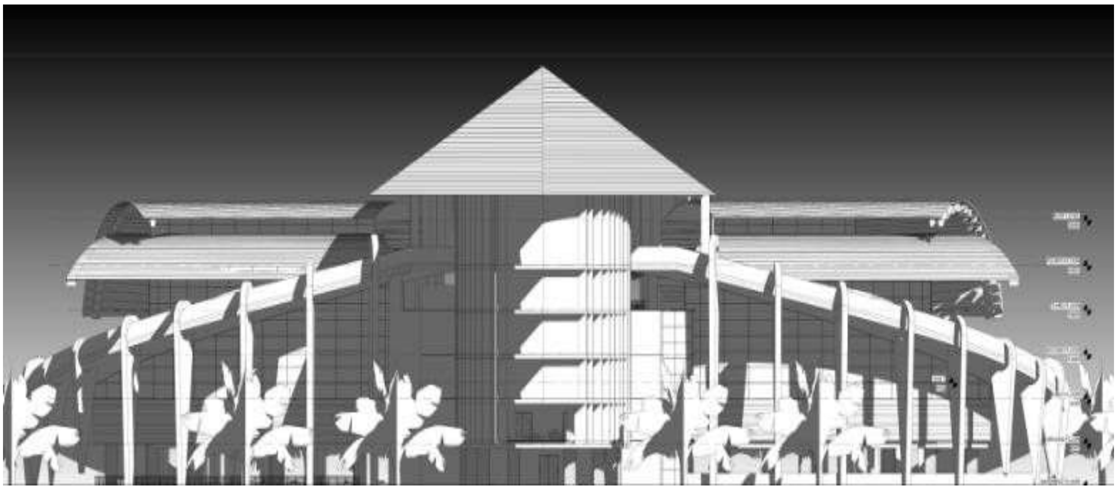
Appendix 7.0: Fifth floor



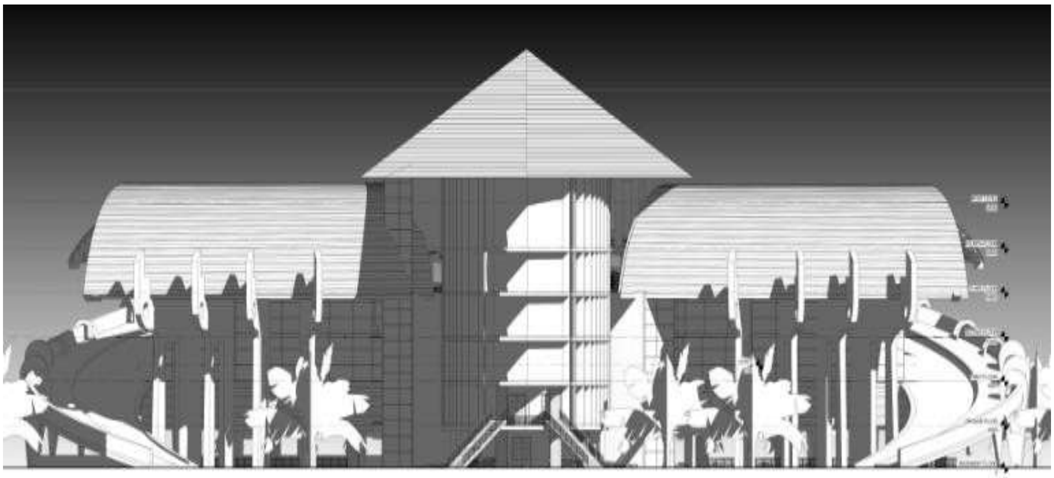
Appendix 8.0: Section X-X



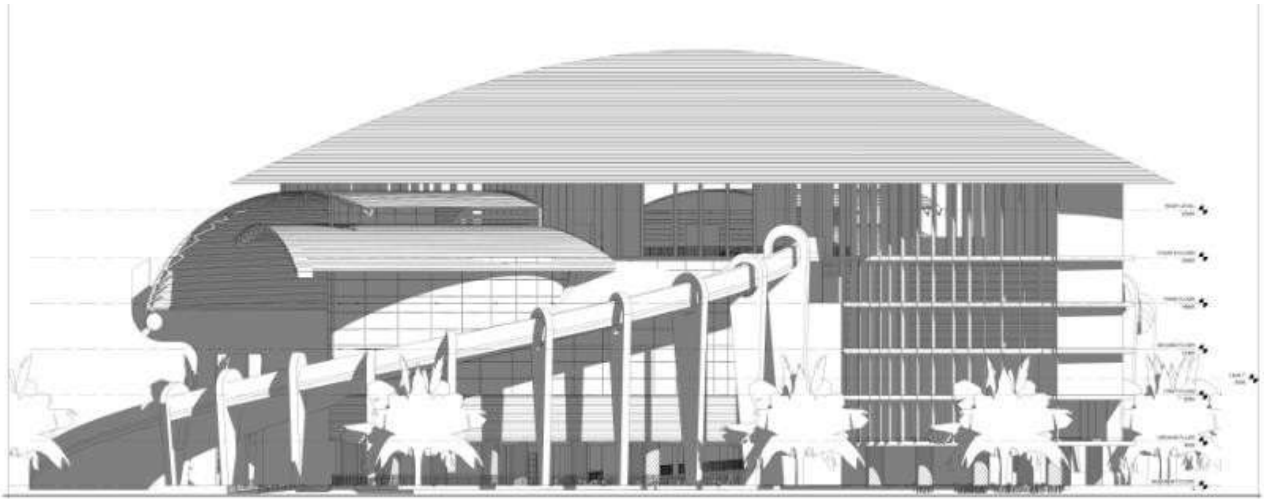
Appendix 9.0: Roof plan



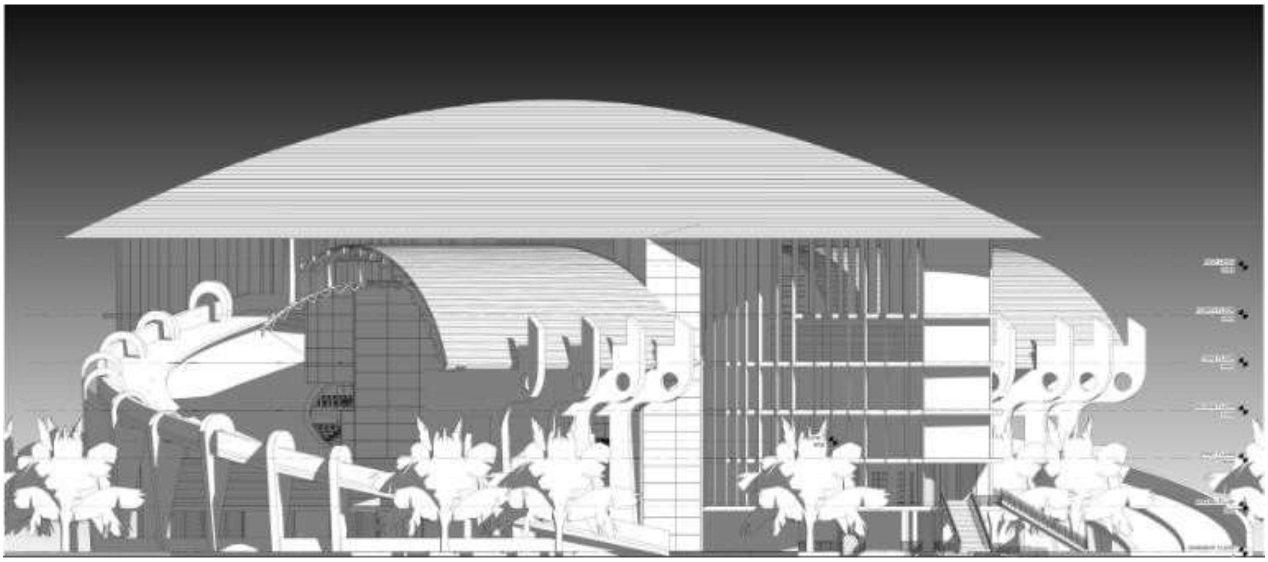
Appendix 10.0: Rear View



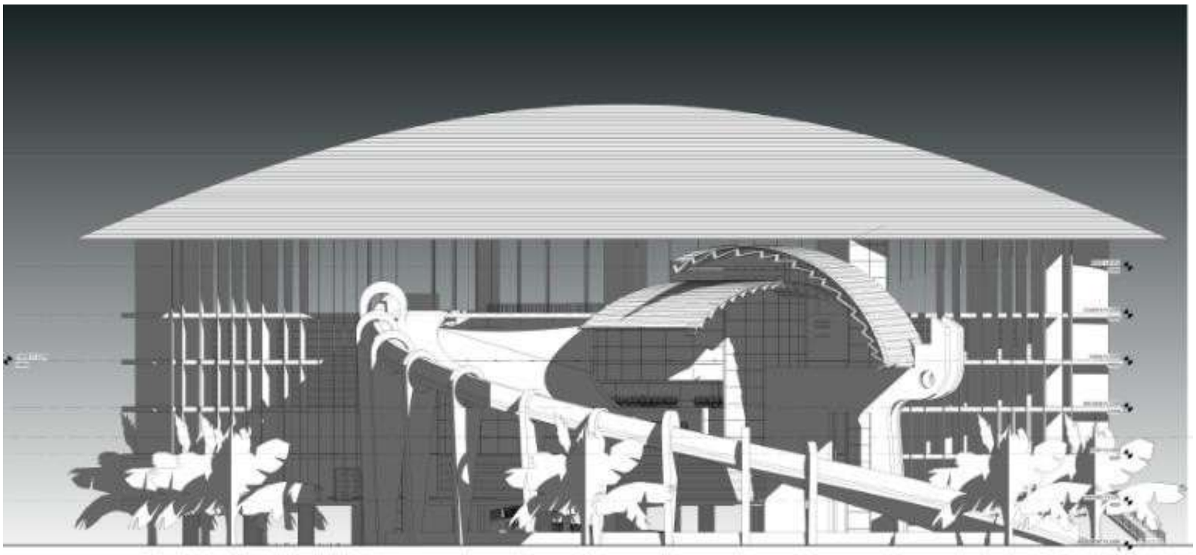
Appendix 11.0: Approach View



Appendix 12.0:East View



Appendix 13.0: North East View



Appendix 14.0: West View

Appendix 15.0: Dimensional View

Appendix 16.0: Dimensional View

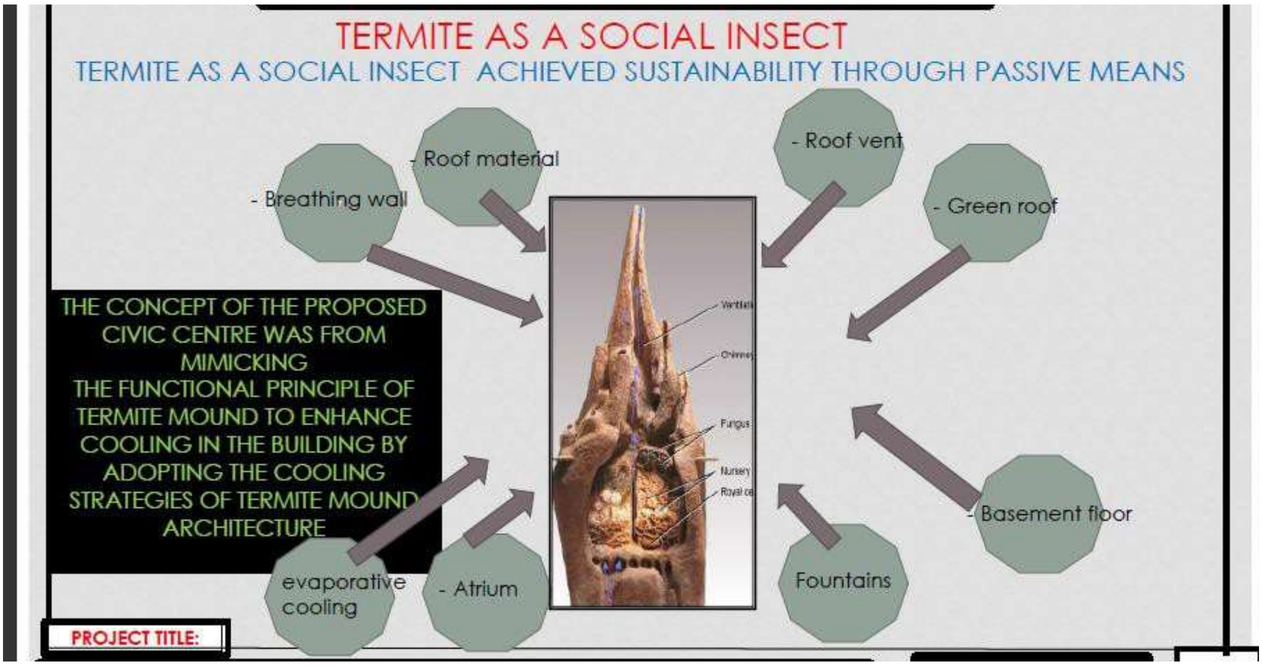
Appendix 17.0: Dimensional View

Appendix 18.0: Dimensional View

Appendix 19.0: Dimensional View

Appendix 20.0: Dimensional View

Appendix XXI: Concept Analysis



Appendix 21.0: Concept Analysis

APPENDIX B
(PLEASE TICK AS APPROPRIATE)

Name of conference centre: ____

SECTION A: Demographic information.

1. Are you a customer in this complex or a staff indicate below please

   a) ☐ Customer   b) ☐ Staff

2. Please indicate your gender:

   a) ☐ Male   **b)** ☐ Female

3. Kindly indicate your age bracket **:**

   a) ☐ 0-17   **b)** ☐ 18-30   **c)** ☐ 31-40   **d)** ☐ 41-50   **e)** ☐ 51 and above

4. What is your highest educational qualification?

   a) ☐ No formal qualifications **b)** ☐ Primary Education **c)** ☐ GCSE/ O-Level

   d) Diploma (ND/HND) **e)** ☐ Degree **f)** ☐ Post Graduate Qualification

5. Marital status (tick the most appropriate)

   a) ☐ Single   **b)** ☐ Married   **c)** ☐ Divorced   **d)** ☐ Widowed

6. What is the nature of your occupation?

   a) ☐ Unemployed **b)** ☐ Unskilled Labour **c)** ☐ Skilled Labour **d)** ☐ Employed

   e) ☐ Others(specify)……………

7. How long have you been working with the centre (**STAFF ONLY**)?

   a) ☐ 0 - 1 **b)** ☐ 1-2 years **c)** ☐ 2 - 3year **d)** ☐ 3-4 years **e)** ☐ Above 4 years

8. Please indicate your operation hours (staff only)

   a) ☐ 8am- 4pm **b)** ☐ 8am- 6pm **c)** ☐ 8am- 8pm **d)** ☐ 8am- 10pm

9. when do you normally switch on the Ac/Fan (staff only)

   a) ☐ 8am- 4pm **b)** ☐ 11am- 6pm **c)** ☐ 12pm- 7pm **d)** ☐ 9am- 10pm

10. How often have you visited the centre ?

    a) ☐ 1-2yrs **b)** ☐ 3-5yrs **c)** ☐ 6-7yrs **d)** ☐ 7 yrs and above

APPENDIX C
OBSERVATION SCHEDULE

NAME OF SAMPLE: ____

LOCATION: ____

SECTION 2: ASSESSMENT OF ENERGY-EFFICIENT FEATURES IN CIVIC CENTRE BUILDINGS.

S/N	DESIGN FEATURES	ENERGY-EFFICIENT REQUIREMENTS	YES	NO	N/A
1.	Windows	Automated blinds/ shutters			
		Sliding windows			
		Casement windows			
2.	Glazing	Single glazing			
		Double-skin facade			
3.	Shading devices	Horizontal shading devices on south-facing wall			
		Vertical shading devices on west-facing wall			
		Vertical shading devices on east-facing wall			
4.	Roof	Green roof			
		Photovoltaic panels			
		Oriented for solar application			
5.	Landscaping	Shrubs and trees around building			
		Indoor planting			
		Shading trees on the west face of building			
6.	Building orientation	Longer side on northeast-southwest axis.			
		Longer side on southeast-northwest axis.			