# DAYLIGHT PERFORMANCE AND OPTIMIZATION WITH LIGHT PIPE IN THE DESIGN OF MODERN ART MUSEUM ABUJA

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BY

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A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTERS DEGREE IN ARCHITECTURE

DEPARTMENT OF ARCHITECTURE,

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MARCH, 2018

## Declaration

I declare that the work in this dissertation entitled "DAYLIGHT PERFORMANCE AND OPTIMIZATION WITH LIGHT PIPE IN THE DESIGN OF MODERN ART MUSEUM ABUJA" has been performed by me in the department of Architecture. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at this or any other institution.

| | | |
|---|---|---|
| | | 15th May, 2017 |
| Name of Student<br>Samuel Daniel, GANA | Signature | Date |

**Certification**

This dissertation entitled "DAYLIGHT PERFORMANCE AND OPTIMIZATION WITH LIGHT PIPE IN THE DESIGN OF MODERN ART MUSEUM ABUJA**"** by Samuel Daniel GANA meets the regulations governing the award of the Degree of Masters of Science in Architecture of the Ahmadu Bello University, Zaria, and is approved for its' contribution to knowledge and literary presentation.

| | | |
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## Dedication

Dedicated to God the author and the finisher of our faith and to my Parents Mr and Mrs Daniel Gana.

## Abstract

Museums and art galleries collect, preserve, analyse and display historical artefacts and various achievement of the past. Light is basic requirement in museum design for the appreciation of art work. However, achieving daylight in museum spaces particularly in tropical climate is challenging due to its effect on artefacts and this has resulted to over dependence on artificial light. Daylighting has an important role in sustainable architecture as it affects the energy consumption in a building and also promote work efficiency through promoting good human health. In view of this, it is necessary to improve daylighting in museums in order to reduce electricity demand and increase comfort of the users and also as a tool for advance architectural creativity. Hence, the aim of this study is to test daylight performance of light pipe for optimum lighting in museum design in tropical climate.

The study makes use of case study approach and quasi experimental (simulation) to test daylight performance of tubular light pipe. Literature review establishes the level of day light require in museum spaces, while case study find out the types of collections in Nigeria museums and daylight level in the selected museum galleries with light metre readings on sensor points at 900mm above floor level between 1:00pm-3:0pm. To test for the light pipe performance, a standard room of 3mx3mx3.6m was modelled, with light pipe of different aspect ratio (diameter to length) in Ecotect and result visualise in radiance and Daysim.

Findings shows that collections in Nigeria museums range from paper paint work to sculpture and natural history collections, however, visual survey shows that some of the collections are not arranged according to the level of daylight requires for each museum space by IESNA guideline for museum light design. The illuminance readings recorded

in most of the galleries are not up to standard when compared with the requirement for a museum. However appreciably some sensor points in the galleries fall within the range. Case study of museum of colonial history Kogi shows that 47% percent of the building fully depends on artificial light leading to high energy consumption in the galleries. Also, some galleries fully depend on artificial light. In the second case study the average illuminance level decreases from 335lux to 301lux at distance of 2750mm and 897lux to 301lux at distance of 4500mm from window plane respectively.

The test result for the performance of light pipe shows that as the length of light pipe increases with constant diameter, the light level decreases at an average of 15.45% with maximum aspect ratio (D/L) of 1:10 admitting daylight level of between 213.7lux to 195.3lux to 105.2lux at conditions Ac, Ab and Aa respectively on sensor point A, giving optimum performance for most museum spaces. While, the test for effect of increasing diameter of light pipe on daylight performance shows that with increase in diameter of light pipe, there was steady increase in illumination level. For the diameter 300mm the illuminance level is 107.5 lux, while for the diameter 650mm the illuminance level is 177.2 lux at the Sensor B. The average illuminance continues to increase at 24.42% as the diameter increases so that diameter of light pipe has much effect on daylight output.

The research recommended that for optimum performance of light pipe in museum in tropical climate the aspect ratio should not exceed 1/10. The outcome of the research work forms the basis for the application of daylight in museum design and the integrating of innovative daylight devices to diffuse and redirect light in museum spaces. Conclusively major findings suggested a comprehensive way that architects can follow in providing a museum that is less dependent on artificial lighting within the tropical wet and dry climate of Nigeria.

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# 1.0 INTRODUCTION

## 1.1 Background to the Problem

A vital front in the fight against global warming is the reduction of fossil fuel consumption and the resulting fall in Greenhouse Gas Emissions (GHG). One component of realizing this is to use natural lighting rather than electric light to illuminate indoor spaces. According to Oakley, Riffat and Shao (2000), using daylight in buildings can result to 20-30% drop in energy usage, a sizable saving. Similarly, Reinhart and Wienold (2011), sees daylight as an effective means of saving energy and reducing environmental impact. While Chirarattananon, Hien, Chaiwiwatworakul and Chirarattananon (2010), opines that daylighting offers great potential for applications in tropical climates because daylight is voluminous and highly available near equator. Good quality daylight can influence physiological responses and improve health conditions in working environments (Mayhoub and Carter, 2011). It is therefore necessary to improve daylight performance in museums in order to reduce electricity demand and increase comfort of the users and also as a tool for advance architectural creativity.

Museum is a cultural institution, particularly in Nigeria it has to do with collection, preservation, display and interpretation of cultural objects for the advancement of knowledge. It is the treasure house of human race as it stores memories of people, their cultural dreams and hopes (Nnimmo, 2012). There is needs for every society to persevere its culture and historical material or intellectual properties for prosperity, therefore need for museums becomes important. Museums in Nigeria and Africa at large are facing a hard time to survive due to low patronage (Kabir, 2016). Preliminary visual observation indicated that, most museums in Nigeria are ancient and colonial monuments. Which are considered as old, quiet and lonely places. Research by Baewon Koh and Meyer (2015),

shows that most of the daylighting energy saving measures can help save money while enhancing museum aesthetics and staff productivity which in turn attract public interest.

Energy consumption in Nigeria is growing annually at an alarming rate, unfortunately the supply has not been able to meet the demand, this as reach a crises level (Aliyu, Ramli and Saleh, 2013). Study by Community Research & Development Centre (CREDC) (2009), shows that commercial and public building in Nigeria consume 20% of total electricity generated of which museum buildings are not excluded. The energy crises Nigeria is facing coupled with growth stimulated research interest towards finding ways of alleviating or eliminating the unnecessary use of energy in Museum buildings. The use of daylight appears then as a good strategy to offset artificial illumination and to make museum spaces more amenable.

In a museum project, it is important to consider the natural light experience, often referred as more satisfactory than artificial light (Oliveira and Guedes, 2006). However, museum in tropical climates like Nigeria need measures to control abundant natural light into the interiors spaces. Shaw (2013), clearly stated that lighting for museum and art galleries has a unique set of priorities, those of conservation and effective display. Similarly, Ginley (2013), listed the major requirements in museums daylight design as visitor's visual feeling in the course of visit and how to protect photosensitivity exhibits. This implies that, light is on one hand a destructive force which conflicts with the museums role in preserving cultural artefacts on the other it is essential for vision. Therefore, process of lighting design in museum becomes something of balancing act to provide an effective compromise between the conflicting requirements.

There are several approaches of daylighting, however, over the years' side openings have been the common strategies in bringing daylight into space. De Nadal (2005), findings

show that windows side light on the perimeter, will rarely reach the first 5m from the window plane. The result is an uneven illumination, which have effect on museum collections. In such situation, light pipe could become desirable, particularly in wide plant area rooms such as exhibition areas, in which a high-quality light, characterized by low illuminances on the work plane and quite a uniform distribution of luminance of the walls is demanded (Boccia, Chella and Zazzini, 2011). Light pipe is a reflective cylinder between openings which bring control diffuse natural light into interior spaces (Zhang, 2002). Since piped daylight emits off only from light pipe diffuser, the output daylight is easier to control than other innovative daylighting system, which is the major concern of museum lighting designer. However, it application is not pronounced in Nigeria buildings.

## 1.2 Problem Statement

Museum needs light for the appreciation of artefacts on display areas, however light contains rays which has the potentiality of causing deterioration to the collections. This makes achieving daylight into display areas challenging and has resulted in overdependence on artificial light (Onuwe, Goshi and Alonge, 2015). Museum requires controlled, diffused and indirect daylight, but the inherent problems of distributing daylight with traditional windows is non-uniform illumination, introduction of excessive and direct daylight which have effect on artefacts and inability of light to reach interior building core, while light pipes that transport and distribute diffused natural light without heat transfer have been shown to be effective (Boccia, Chella and Zazzini, 2011). Studies by Tukur (2013), also shows the importance of this device to light interior building core. However, research on light pipe performance and application in museums in tropical wet and dry climate of Nigeria have been slow. Its therefore important to determine its daylight performance based on the effect imposed by local climate and its aspect ratio.

## 1.3 Aim and Objectives

### 1.3.1 Aim

The aim of this study is to evaluate daylight performance of light pipe (LP) for optimum lighting in the design of Art Museum in tropical wet and dry climate.

### 1.3.2 Objectives

The above aim will be achieved through the following objectives.

i. To record the daylight level on the existing galleries with light metre.
ii. To identify the light level required for each museum spaces.
iii. To assess daylight performance on varying aspect ratio of light pipe in museum in tropical wet and dry climate using simulation.
iv. To demonstrate the outcomes of the study in the design of Modern Art Museum Abuja.

## 1.4 Research Questions

The research will answer the following questions.

i. What are the types of artefacts in Nigeria museums and the amount of light on existing galleries base on effect imposed by tropical climate and daylight design?
ii. What are the light level required for museum spaces?
iii. How does the aspect ratio affect daylight performance of light pipe in tropical wet and dry climate Abuja?
iv. What are the possible application of light pipe in museum in tropical wet and dry climate Abuja?

## 1.5 Justification

There is no any Government financed Museums in Abuja the Federal Capital Territory the proposed location of the study, however, there is a current call on the Federal

Government by Society of Nigeria Artists (SNA) to establish a Modern Art Museum in Federal Capital Territory (FCT) (New Agency of Nigeria, 2015), which is expected to play a role in promoting national unity. This research is inspired by the desire to avoid instant disappearance of historical relics and the use of natural light to design a vibrant public place rich with artworks.

The relevance of this study cannot be over emphasised especially with the rapid rate of global warming. Architects have responsibility to find solutions to environmental problems in order to ensure man's continued existence and comfort. Nigeria is facing energy crises coupled with population and infrastructural growth and the unrelenting rise of energy prices have stimulated research interest towards finding ways of alleviating or eliminating the unnecessary uses of energy. Also, for the light pipe system to be widely used in Nigeria, it is important to know its daylighting performance with due consideration regarding the effects imposed by the local climate conditions.

### 1.6 Research Scope

This study is on daylight performance and optimization in tropical climate museum by the incorporation of light pipe (LP) of different aspect ratio. The two types of light pipe are vertical and horizontal light pipe. The study evaluates the performance of vertical tubular light pipe by using Autodesk Ecotect, visualize in Radiance and Daysim with the aim to calculate the illuminance distribution in room illuminated by the light pipe in standard local climate. The modern art museum was proposed in Abuja, Nigeria. The climate and geographical area of Nigeria is large, the study purposively sample three case study of Nigeria museums with main focus on wet and dry climate. Reading from light metre was recorded between (1:00pm -3:00pm) from the three cases studied to show the light levels on the existing galleries.

# 2.0 LITERATURE REVIEW

## 2.1 Introduction

The review seeks the method that is suitable for passive lighting in museum. Passive lighting involves admitting natural light from the sun to interior spaces for optimum visual comfort without any undesirable effect, these can be achieved through the use of apertures such as windows, skylights, atriums and light tube located within the building. The art and science of proper daylighting design is not how to provide enough daylight to an occupied space but doing so without any undesirable side effects. Daylighting involves more than just adding windows or skylights to a space, it is the careful balancing of heat gain and loss, glare control, and variations in daylight availability. Successful daylighting designs will invariably pay close attention to the use of daylight devices to reduce glare and excess contrast. In the push towards sustainability and green design, daylighting is becoming important in energy efficient museum design. In most situations daylight, can be easily incorporated into building designs, however museum designs provide a special challenge. Unlike most building situations, where direct sunlight can occasionally grace a surface, museums require that the Ultraviolet exposure from direct sunlight be completely controlled in order to protect the integrity of the artwork and artefacts on display. Therefore, in museum it is important to avoid direct solar radiation in to the display areas.

## 2.2 Light and Daylighting

The word ‘light’ is defined as the energy which produces a sense of brightness that makes seeing possible. light as defined by International Commission on Illumination, is the natural agent that stimulates sight and makes things visible, the primary means of visual communication (Sliney, 2016). Visible light is part of solar ray spectrum, it travelled from

sun to the earth together with other solar rays. Figure:2.1 shows the electromagnetic spectrum and visible light. In the solar energy received on the surface of the earth, 40% is visible light and the rest is ultraviolet (UV) and infrared (IR) wavelengths (Velux Group, 2014). No any electric light source can mimic the qualities of daylight on earth.

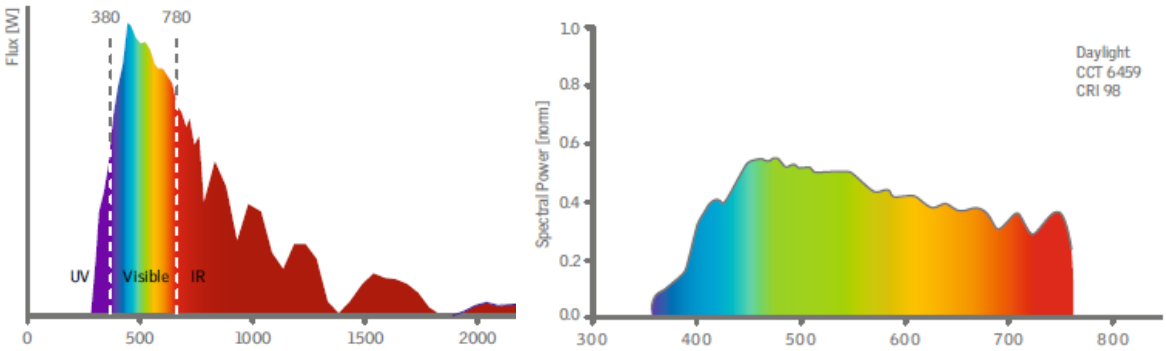



Figure 2.1: Electromagnetic spectrum of visible spectrum
Source: Velux Group (2014)

Aries, Aarts and Van Hoof (2015), defined daylight as the solar radiation visible to the human eye and emitted by the sun and perceived during daytime, while Reinhart (2014), describes daylighting as the controlled use of natural light in and around buildings. Good quality daylight is linked to visual performance and comfort of those who occupy the spaces. Generally, natural light can be introduced by using devices which brings light into space, it is the practice of placing windows, or other transparent media and reflective surfaces so that natural light provides effective internal illumination during the day (Husin and Harith, 2012). Le Corbusier (1989), clearly identified the importance of light in architecture, expressing the point that, “architecture is the masterly, correct and magnificent drama of volumes brought together in light” emphasizing that “history of architecture is the history of struggle for daylight”. It might be added that it is also the history of the struggle for reasonable use of daylight.

Daylight is indeed fundamental in architecture; good daylight design provides opportunity for architectural creativity through creating shapes that produces filtered sunlight while serving as visual stimulating elements of design and can impact human performance through a good design lit interior. While over dependent on artificial light result to much energy consumption in building.

### 2.2.1 Energy Consumption for Lighting Building

Human society has been using fossil fuel as a major form of energy source (Zhang, 2002), this has resulted to climate change. The International Panel for climate change has argued that the world is definitely getting warmer (Cook, et al, 2016). This argument is in agreement with Zhang (2002), that global warming and its affiliated changes in the world's climate would have enormous consequences for people, economies and the environment. The solution to the above challenges consists of two aspects, namely, to save energy and to exploit renewable energy. The use of electricity is not only inefficient but also environmentally detrimental. The combustion of fossil fuels is responsible for the majority of emissions of carbon dioxide $C0_2$, sulphur dioxide $S0_2$ and nitrogen oxides $N0_2$ (Zhang and Muneer, 2000). In the United Kingdom, electrical lighting accounts for an estimated 5% of the total primary energy consumed per annum. Office buildings in the United Kingdom consume up to 60% of their total energy in the form of electric lighting (Muneer, Fairooz and Zhang, 2002)

Study by International Energy Administration (2013), shows that buildings sector is the largest energy consuming sector, accounting for over one-third (1/3rd) of final energy consumption globally. The research by Yohanna, Iortyer and Ierve (2013), on assessment of energy use pattern in residential building (figure: 2.2) shows that energy for lighting take higher percentages. Similarly, study by United State department of energy (figure

2.3), shows that lighting is the leading energy consumer (25%) in United State commercial and Public buildings ahead of space cooling (13%) (U.S DOE, 2009).

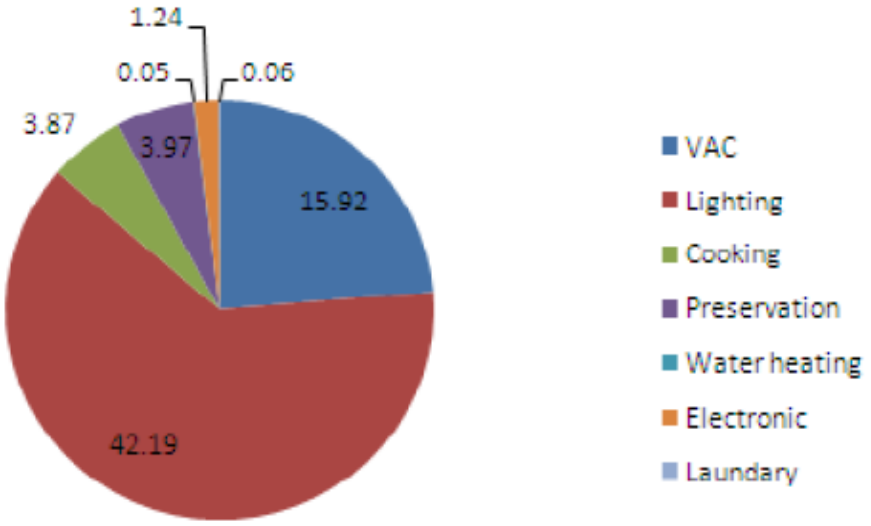



Figure 2.2: Overall energy intensities of convectional and energy efficient buildings

Sources: Yohanna, Iortyer and Ierve (2013)

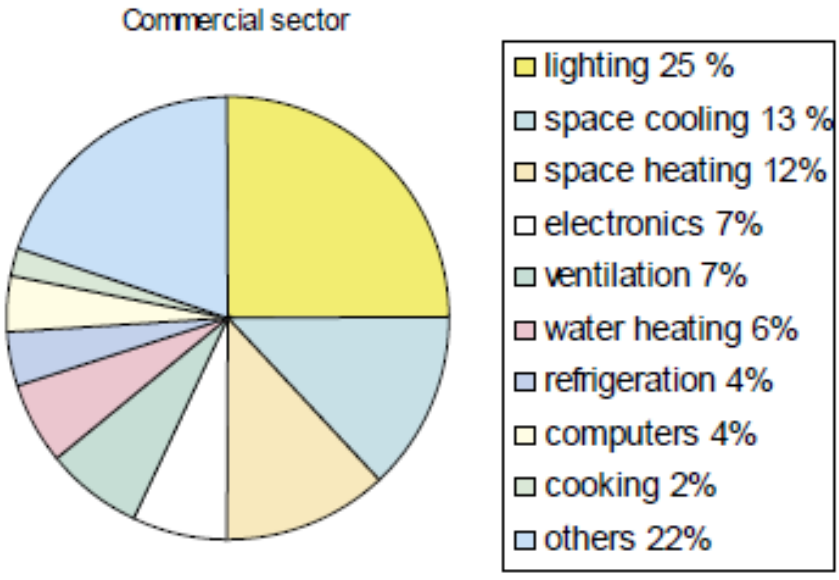



Figure 2.3: Energy consumption in US commercial and residential buildings

Source: U.S DOE (2009)

One component of realizing the challenges of energy consumption in museum is to use natural lighting rather than electric light to illuminate indoor spaces.

### 2.2.2 Museum Energy Usage

Museums serve two separate indoor climatic needs; firstly, to maintaining good conditions for artefacts preservation and secondly to provide a comfortable and healthy environment for visitors and staffs. The main characteristics of museums that uniquely define their energy use according to Energy Information Administration (2003), are; high ceiling gallery spaces, often complex lighting needs, and intermittent occupancy levels. Museum buildings are as varied as their contents and come in a variety of shapes, sizes, and ages. Acting as multiuse cultural centres, museums often include cafeterias, gift shops, kid's zones, educational meeting rooms, and even theatres, in addition to gallery space and staff offices, each of these contribute to increased energy consumption. More than 75 percent of museum energy use is consumed by space heating and cooling, ventilation, and lighting (See Figure 2.4) (Energy Information Administration, 2003). Similarly, research by Mitchell (2014), shows that most Australian museums incur energy costs of between one and a half million dollars a year, climate control systems (Lighting and heating) represents about 60% of those costs.

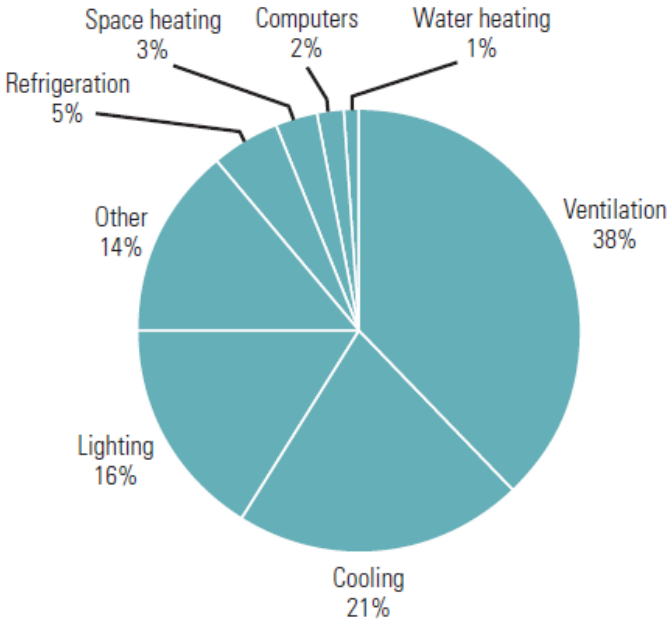



Figure 2.4: Museum energy consumption by end use

Source: Energy Information Administration (2003)

The solution to the problem of energy consumption in the museum is to integrate proper daylighting strategies to reduce energy usage in museum buildings. However, research has been so slow in tropical wet and dry climate on how to incorporated daylight experience in museum design.

## 2.3 Daylight Design Strategies

Daylight is important for it quality, spectral composition and the variability that provides excellent colour discrimination and colour rendering and fulfils two very basic human requirements to be able to see both task and the space well, to experience some environmental stimulation. In terms of natural lighting, openings with different shading designs are introduced as the ways for integrating natural light into the space (Naseri, 2014). Windows, the way they are open, types, sizes, material and shading control, inclusive of the orientation are the major design strategies for daylight in building (WBDG, 2014). Therefore, this section of the research is about opening and fenestration which is directly related to the architecture of bringing nature light into interior spaces.

### 2.3.1 Architecture of Daylighting

Conceptually, daylighting can be distributed to interior space through openings from the side, from the top, or a combination of the two. Building type, height, aspect ratio and massing, dominant climatic conditions, site obstructions and building functions are often drives choice of strategy (Philips, 2004). Daylight can also be optimally implemented with innovative daylight systems. These make use of the physical laws of reflection and refraction to illuminate rooms perfectly and also to avoid excessive warmth (Baewon Koh and Meyer, 2015). The choice of strategies and the devices for optimum daylight therefore, depends on the functions of the buildings and the light requirement on each architectural space.

#### 2.3.1.1 *Side light as means of daylighting*

Side lighting has been a primary way of introducing daylight into buildings. Besides supplying light, side lighting can provide view, create orientation, allow connectivity to outdoors, and allow ventilation during less harsh times of the year (Helmut, 2004). Openings and external controls should vary by compass direction since each facade of a building based on orientation receives different amounts of daylight throughout the day and across seasons. Location of openings in walls can be low, middle, or high depending on desired distribution and structural wall system restrictions (Philips, 2004). Studies have listed sidelight strategies to includes: Single side lighting, Bilateral lighting**,** multilateral lighting**,** Clerestories**,** Light shelves**,** Louvers and blinds**,** Prismatic panels**,** Light guiding shade (Hasen, 2006; WBDG, 2014; & Philips, 2004).

#### 2.3.1.2 *Top light as means of daylighting*

When daylight penetrates a building from above the ceiling plane or is concentrated in the roof, it is referred to as top lighting. Study by Baewon Koh and Meyer (2015), shows that top lighting can provide greater freedom of source placement to achieve more uniform illumination. It takes advantage of high wall surfaces and other architectural elements to distribute light where needed and increases security and privacy. Splayed openings, for example, can spread the horizontal distribution of daylight over a wider area and reduce contrast associated with glare. The major restrictions for top lighting are the structural design, mechanical system, electrical system and fire safety layouts. Top lighting is of limited use in tall buildings because it can only illuminate upper floors, unless combined with other strategies (Philips, 2004). Top lighting strategies include: Skylights, Roof monitor, Sawtooths, Courtyards, Atrium and Light tube (Tukur, 2013). CHPS Best Practice Manual Daylighting (2002), analysed the applicability of different techniques and device of bring daylight into building interior the result in Table:2.1

shows that central and patterned top lighting has high scores for good uniform distribution of light into interior spaces, while tubular skylight as high score of extremely applicable in safe, security concerns and cost effectiveness**.**

Table 2.1:Selection Criteria for Daylighting Strategies

| Design Criteria | View Windows (DL1) | High Sidelight w/ Light Shelf (DL2 & DL3) | Wall Wash Toplighting (DL4) | Central & Patterned Toplighting (DL5 & DL6) | Linear Toplighting (DL7) | Tubular Skylights (DL8) |
|---|---|---|---|---|---|---|
| Uniform Light Distribution | ○○ | ●/○ | ● | ●● | **O** | **O** |
| Low Glare | ○ | ● | ● | ● | ● | ●/○ |
| Reduced Energy Costs | ○ | ● | ● | ●● | ● | ● |
| Cost Effectiveness | ● | ● | ● | ● | ● | ●● |
| Safety/Security Concerns | ○ | ●/○ | ● | ● | ● | ●● |
| Low Maintenance | ○ | ● | ● | ● | ● | ● |

●● Extremely good application ● Good application ○ Poor application ○○ Extremely poor application **O** Depends on space layout and number and distribution of daylight apertures ●/○ Mixed benefits

Source: CHPS Best Practice Manual Daylighting design (2002)

### 2.3.2 Shading Devices Daylighting Strategies

Shading is a strategy to reduce overheating and avoid direct sunlight into buildings. Moreover, problems associated with glare and visual discomfort are inevitable when direct solar radiation is transmitted into the interior spaces. Onuwe, Goshi, and Alonge (2015), clearly stated that to avoid overheating and glare problems, direct sunlight should not be allowed to enter into interior spaces. Shading provision is necessary to prevent thermal and visual discomfort. However, climatic conditions and daylight availability play a major role in the design and control of a shading system. Findings by Naseri (2014), shows that location, properties and control of the shading device have a significant impact on both daylighting and thermal performance in perimeter of spaces. Similarly, studies by Jinia, Trisha, and Mahmood (2015), shows that external shading devices have been

utilized very intensively in the buildings of tropics to control the amounts of daylight and direct sun light flowing into interior spaces. Shading devices can be accomplished through different strategies like self-shading, overhangs on windows, building clustering, planting high trees, laser cut panels and designing shading features and some operable shading devices which give the flexibility of adjusting the shading shutters and blades to increase ventilation and day light into the interior spaces as well as minimizing the admittance of direct heat gain (Prowler, 2014). Shading is considered another significant design strategy that affects thermal comfort. Therefore, carefully design of shading system considering the climatic condition of the region is important.

### 2.3.3 Building Orientation Daylighting Strategy

Building orientation refers to the way a building is situated at site and the positioning of windows, rooflines, and other features (NJ green building manual, 2011). Building orientation is considered the simplest and sensible design strategy that can be applied and effectively enhance light demand and performance in buildings. US DOE (2014), climatic data revealed that buildings receive the highest amounts of solar gains in the hottest part of the year on eastern and western elevations, while in cold season the highest amount of light is received on the southern elevation. Jinia, Trisha and Mahmood (2015), opines that the designers should also study microclimatic wind patterns of the site because they can help reduce heat gain and increase passive cooling and lighting. Its recommended to orientate buildings on the east-west axis with glazing designed to be located on the north and south sides of the building (figure 2.5), supplemented with suitable shading devices for glare controls.

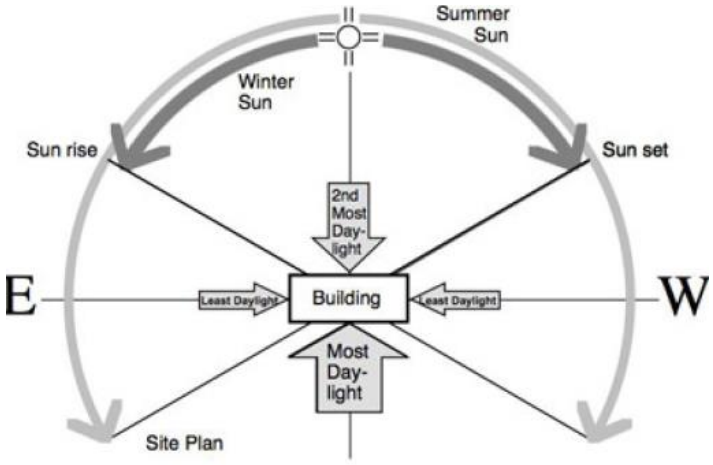



Figure 2.5: Orientation for optimum daylighting

Based on whole building design, http://www.wbdg.org (2014)

### 2.3.4 Building Massing Daylighting Strategies

Another effective daylight design strategy is massing. Massing refers to the structure in three dimensions (form), not just its outline from a single perspective (shape). Massing influences the sense of space which the building encloses and helps to define both the interior space and the exterior shape of the building (Jacoby, 2016). When seen in the urban contexts, like high rise group of buildings which are having similar heights should be avoided because they limit movement of air, minimize ventilation and access to daylight. On the other hand, gathering buildings that have different heights and have longer facades increase movement of air which will help to better ventilate the buildings and reduce heat gains.

## 2.4 Daylighting System in Architecture

Daylighting system consists of systems, technologies, and architecture as shown in figure 2.6, while all of these components listed by (Ander, 2014), Reinhart and Wienold (2011), may not be required for every daylighting system or design, one or more of them are typically present.

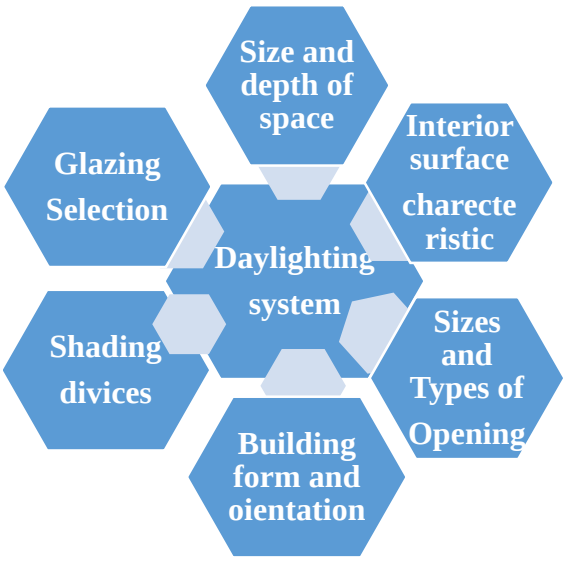



Figure 2.6: Systems of daylighting in architecture

Based on Reinhart and Wienold (2011), WBDG (2014)

### 2.4.1 Core Daylighting Systems

Core daylighting systems can supplement daylight from windows in deep spaces (Nair, Ramamurthy and Ganesan, 2014). Some of the most common examples of core daylighting systems are:

#### 2.4.1.1 *Skylights*

Skylights are fenestration element located at a roof (Plate I). They are the most common top lighting elements but usually entail significant heat gains during the hot season, when the sun is high in the sky and produces glare.



Plate I: Skylight from the roof top

Source:Nair,Ramamurthy and Ganesan (2014)

2.4.1.2 *Light wells*

Light wells are vertical spaces built on top of the roof to provide daylight and ventilation an open area or vertical shaft in the centre of a building, typically roofed with glass, bringing natural light to the lower floors or basement. as shown in Plate II. Their space needs to be heated, which may affect negatively the total energy balance.




Plate II: Diagrammatic representations of light well

Source: Nair, Ramamurthy and Ganesan (2014)

2.4.1.3 *Atrium*

Large open spaces located in the centre of the building as shown in Plate III. Atrium are very space consuming, except if they can be used as inner courtyard where some functions can be achieved.

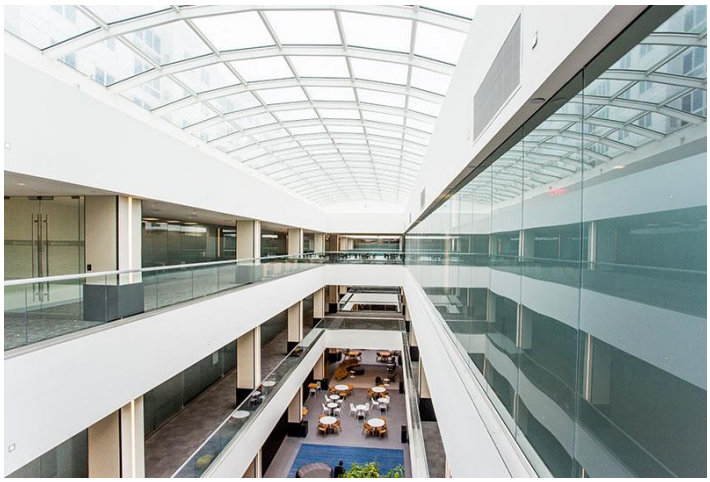


Plate III: Schematic sketch of Atrium

Source: Nair, Ramamurthy and Ganesan (2014)

2.4.1.4 *Hybrid Solar Systems (HSS)*

Daylight is collected by a sun tracking collector (heliostat) Plate IV and then transported by optical fibres to the luminaires. This system can conduct sunlight through many stories with reasonably low losses. However, it only works with direct sunlight.



Plate IV: Heliostat of a Hybrid Solar System
Nair, Ramamurthy and Ganesan (2014)

2.4.1.5 *Light pipes*

Daylight is collected at the rooftop and transported into the building through a mirrored light pipe as shown in Plate V. This system works better with direct sunlight.

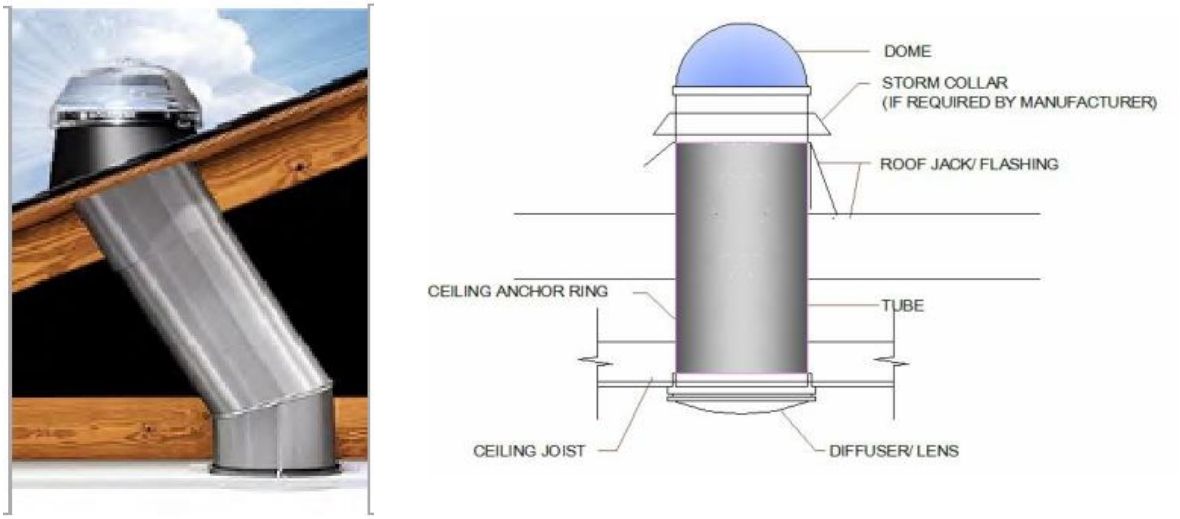



Plate V: Diagrammatic representation of light pipe
Nair, Ramamurthy and Ganesan (2014)

## 2.5 Daylighting Technology, Tools and Devices

### 2.5.1 Heliostats Daylighting Devices

Heliostats are stationary devices that track the sun shown in figure 2.7, usually to focus light towards a receiver of some kind (Allen, Wolfgang, Montgomery, Lee, Murray and Rosenthal, 2008). They are used for a variety of things from focusing more intense light onto photovoltaic, light telescopes and light transporting systems. There are many kinds and functions of heliostats. Some rely on fixed mirrors cut and shaped to increase the focus of the light onto a single area. Others trace the sun across the sky, using timers and clocks that turn the mirrors in accordance to times and seasons, while certain heliostats directly track the sun's position in the sky throughout the day. Though it may not be required for daylighting in tropical equatorial climate like Nigeria as there is abundant availability of natural light during the day.

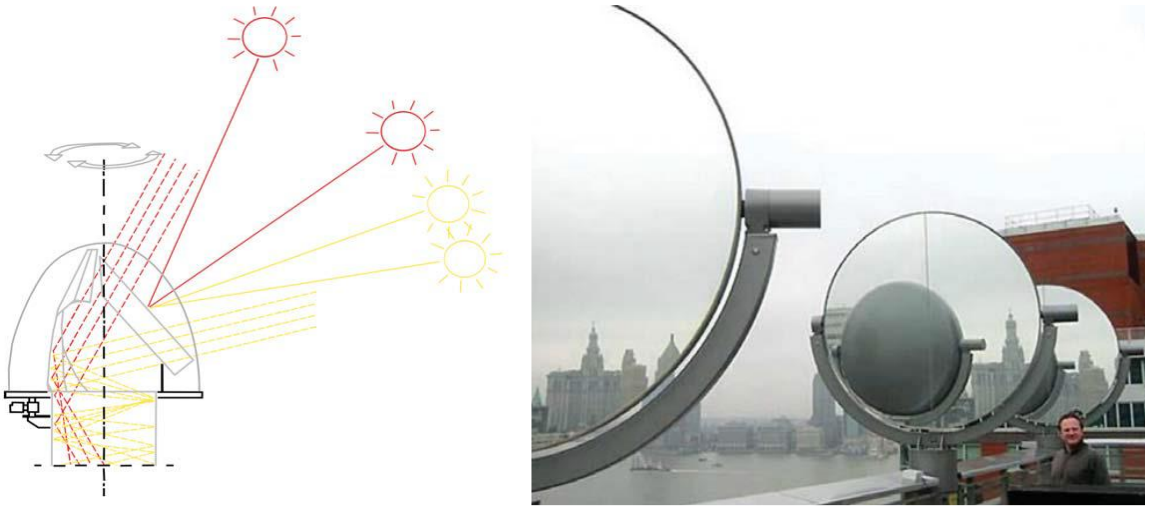


Figure 2.7: Diagrammatical representation of Heliostats
Source: Allen, et al. (2008)

### 2.5.2 Growth Screens Daylighting Devices

Growth green or vegetation screens are a natural way of controlling daylight, taking into account different lighting, heating and cooling requirements associated with changing

seasons. Using deciduous plants allows more daylight and heat to enter the building during the colder half of the year, while blocking unwanted heat gains during the warmest season of the year (Allen, et al., 2008). They can often outperform fixed shading devices because of foliation growth triggered by temperature change. The vegetation responds to seasonal conditions that are warmer or cooler than average, while fixed shading devices are typically designed according to long-term average temperatures. Figure 2.8 shows the growth green daylighting system.

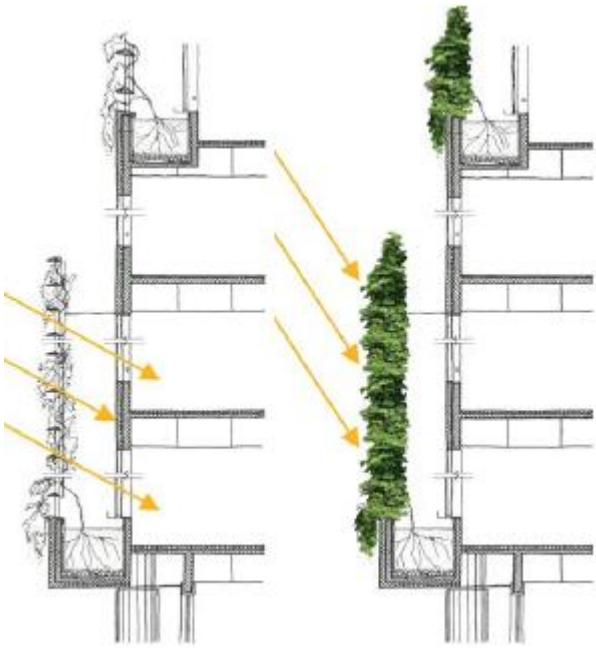


Figure 2.8: Growth green daylighting

Source: Allen, et al. (2008)

### 2.5.3 Fibre Optics Daylighting System

Fibre optic collect using a rooftop collector (comprised of heliostats or lenses) and fed daylight into end of fibre optic cables that can run throughout the building distributing the light as shown in figure 2.9. Egan (2002), findings shows that under full sunning conditions the cable can put out 1,180 lumens (about the output of a 100-watt incandescent bulb). Only the spectrum of light is allowed through the cable; the ultraviolet

light and most of the infrared is filtered out. Some products only loss 4% of light per 10m of cable length. Allen, et al. (2008), pointed out that the high cost of glass cable production makes this current technology impractical, but research is being done on using a less efficient but much cheaper plastic cable. Other research is being done on lowering different costs associated with fibre optic lighting. The current length limit is about 15m.

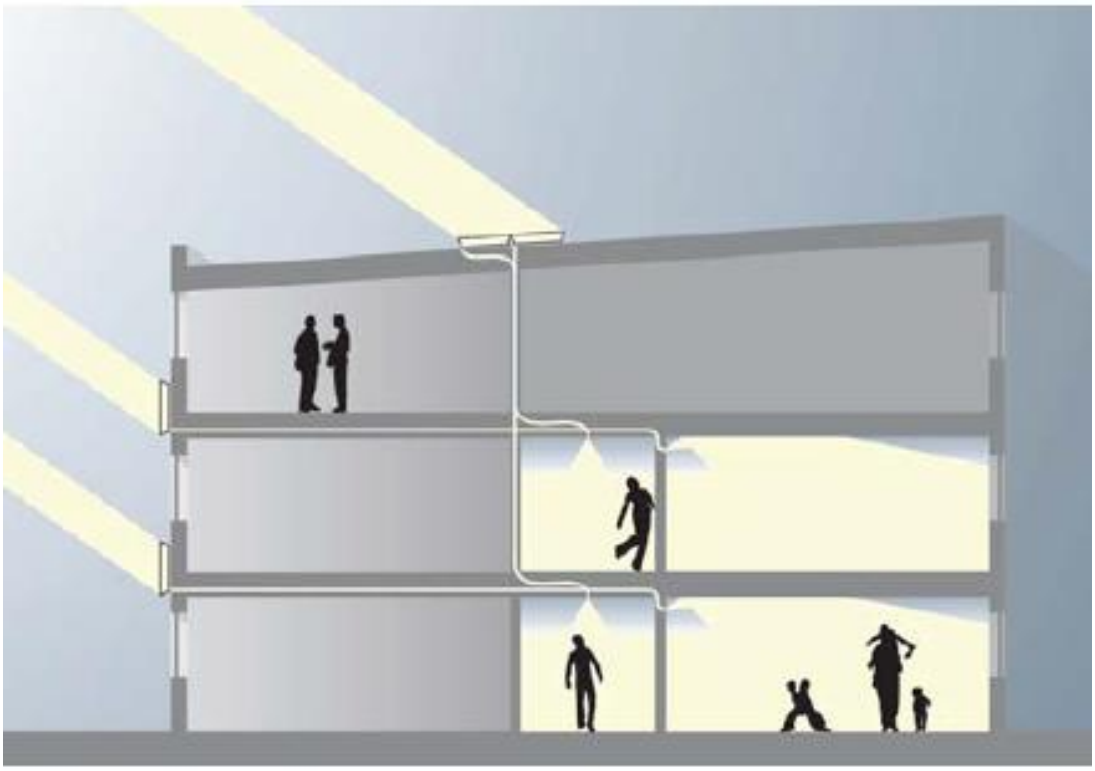


Figure 2.9: Fibre optics lighting technology

Sources: Egan (2002)

### 2.5.4 Light Pipes Daylighting System

Light tubes (also known as sun scoops, tubular skylights, light pipe and solar pipes) are tubes or pipes used to transport natural light into an interior space as shown in figure 2.10. Light tubes allow is possible to get natural light into the dark core of a building or into underground structures. Light tubes are made up of three key components; the collecting head unit, the duct unit, and the diffuser unit (Allen, et al., 2008).

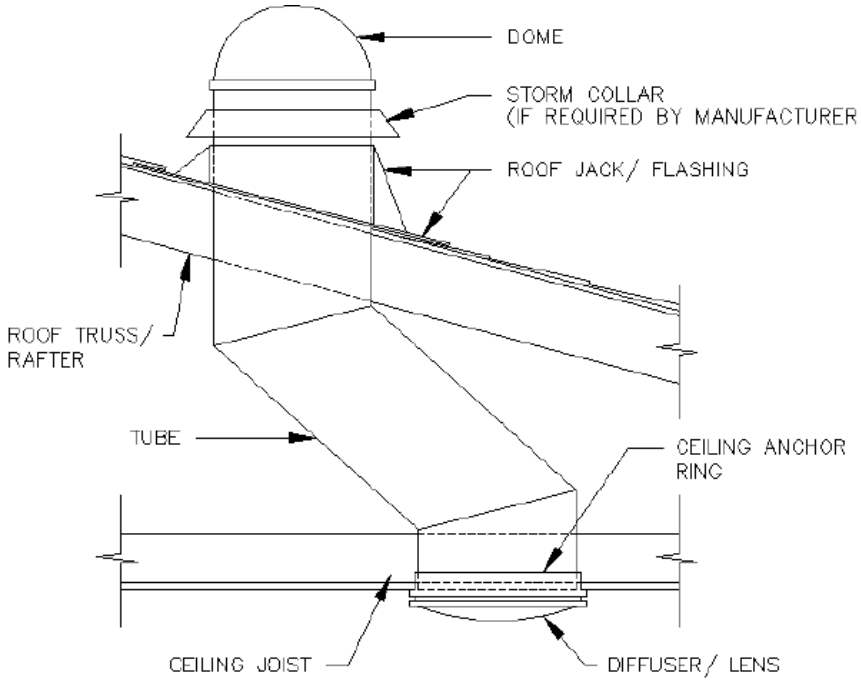



Figure 2.10: Section through a light pipe

Source: www.wascoskylights.com (2011)

The entrance to the tube is usually a dome (Plate VI), which acts to reflect the maximum amount of light into the tube.



Plate VI: A Typical light pipe

Source: Kim & Kim (2009)

Mirrors and heliostats can also be employed to reflect light into the tube for better performance. The interior of the tube is highly reflective to help move light downward into the space with minimal loss. Some light pipe has up to a 90-98 reflection ability inside the tube

## 2.6 Summary on Daylight Strategies and Devices

Table 2.2 is the common and innovative daylighting strategies studied by the researcher, However, this study focusses on the use of Light Pipe (LP). The study focus on the daylight performance of different aspect ratio of the light pipe in tropical wet and dry climate of Nigeria with main focus on passive means of lighting Museum.

Table 2.2:Summary of the literature on daylighting strategies

| Author | (Allen, et al., 2008) | (Hancock, Hinchliff and Hohma, 2009) | (Onuwe, Goshi and Alonge, 2015). | Researcher Remarks |
|---|---|---|---|---|
| Topic | Elements of Daylighting | Daylighting Museums Guide | Assessment of Day Light Design Considerations | Optimizing daylight performance |
| Strategies studied | Side lighting: louvers light shelves<br>Top lighting: Light tubes Heliostats Fibre optic cables Growth green<br>Material: Ultraviolet filters | Side lighting; High level window Clerestories<br>Shading systems: Laser cut panel<br>CBDM: Advances predicting daylight level | Side lighting: view windows light shelves<br>Top lighting: Skylights<br>Shading systems: Interior and exterior | Light pipe of different aspect ratio And CBDM As the simulation frame work. |

Source: Author's study (2016)

## 2.7 Light Pipe and it Components

The use of natural light is very beneficial in building because energy consumption can be reduced, and working condition can be enhanced (Hansen, 2006). However, bringing natural light into museum building is not easy, hence, control measure become important.

Light pipes coupled with prismatic panel as show in Plate VII, are passive and simpler day light transport solutions and are the focus of this MSc thesis. A light pipe is a reflective cylinder between opening at the roof and an opening at the ceiling. Light pipes are, after skylights, the most common roof-mounted daylighting system (Nilsson, 2012). Compared to skylights, light pipes present the advantage of effectively capturing direct beam radiation from the sun while avoiding excessive heat gains and glare patches.



Plate VII: Light pipe illustrations Source: www.solatube.com (2016)

Light pipes are an effective passive way to bring defused daylight into spaces. They can bring daylight to deep spaces without producing glare or increasing the cooling, they are of two types; horizontal and vertical light pipe. Figure 2.11, shows horizontal light pipe; they also contain 3 major components as discuss below in the next heading.

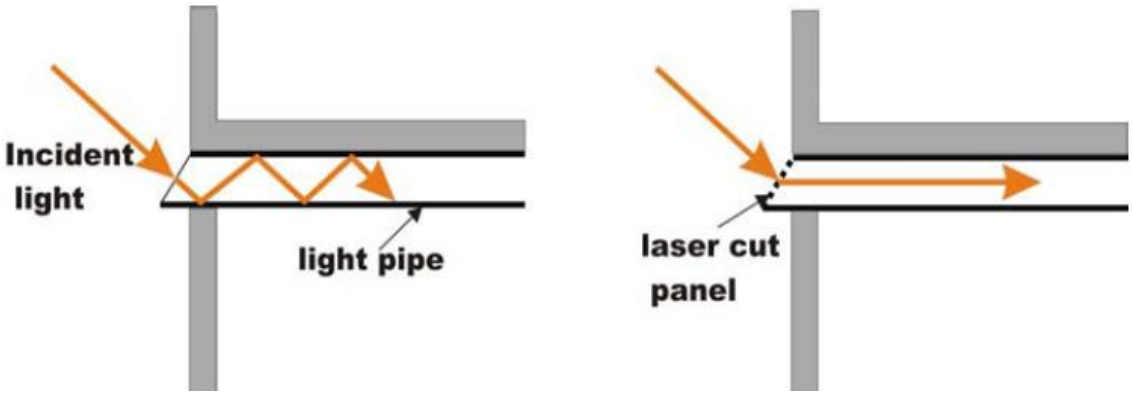



Figure 2.11: Horizontal light pipe (HLP) with laser cut panel (LCP)

Source: Hasen (2006)

### 2.7.1 Components of Light Pipe Devices

The component of light pipe composed of three parts: collector, reflective pipe and diffuser as shown in Plate VIII.

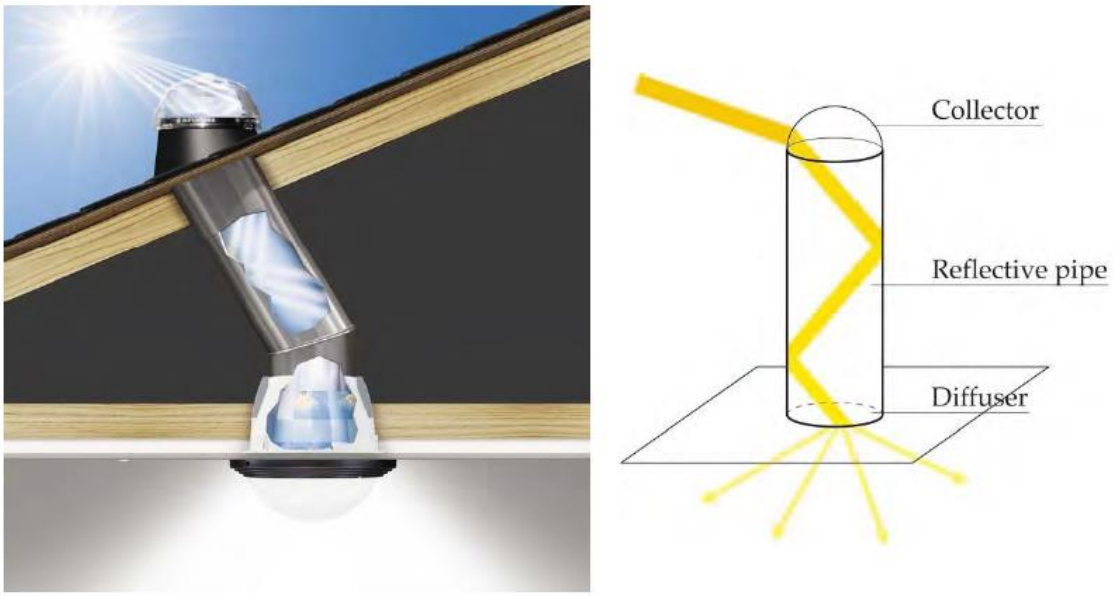



Plate VIII: Diagrammatic representations of a Sola tube light pipe (left) and scheme of a simple light pipe with its main components defined (right)
Source: www.solatube.com (2016)

2.7.1.1 *Light pipe collectors*

The collector is a transparent element located at the external aperture of the pipe as shown on Plate IX. Its main functions are daylight collection and protection of the light pipe from the impact of weather and dirt. It is usually made of a highly transmitting material, which can be flat or dome shaped. Plate IX shows the dome shaped collector of sola tube, which is moulded to a light pipe reflector. Lo Verso, Pellegrino and Serra (2011), agreed that if this component is properly placed it can enhance the light efficiency of the light pipe. Besides optimizing the collection of low sunlight these types of dome usually limit high angle sunlight to avoid visual discomfort from sunlight patches (CHPS Best Practice Manual Daylighting, 2002).




Plate IX: Sola tube dome collector fitted with reflector

Source: www.solatube.com (2016)

The Solar tube dome collector is equipped with a light deflector, which can be classified as an optical redirecting system (ORS). It is a laser-cut panel located within the dome collector and oriented towards the equator. Its purpose according to Lo Verso, Pellegrino and Serra (2011), is to redirect low angle incident beam light into the pipe. Light penetration for low solar altitude angles (below 60º) is thus enhanced further.

2.7.1.2 *Light pipe reflectance*

The reflective pipe or MLP is the pipe that transports daylight from the collector to the diffuser. Its design and optical properties are optimized to minimize the light losses. In this study, the assessed light pipe models are limited to circular cross sections, since this is the most common shape in the market. However, study by Swift (2010), recommend flattened cross section pipes, that enhance the system performance at low solar altitudes. However, in equatorial tropical climate like Nigeria the solar altitude is high. The most important characteristic of MLP is its light reflectance (usually above 98%), and more specifically the high specular reflectance, since they function best with sunlight. Given the large amount of light bounces within the pipes, a small reflectance drop has a large

impact on the performance. This is explained in Sumpner's graph (Figure 2.12). When the reflectance of enclosing surfaces is high, the inter reflected light increases surface illuminance greatly, i.e. the higher the reflectance the more the illumination level.

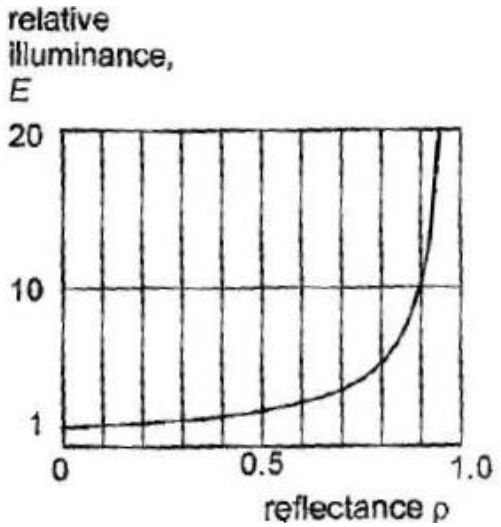



Figure 2.12: Sumpner's graph

Source: Tregenza and Wilson (2011)

2.7.1.3 *Light pipe diffusers*

The light pipe diffuser is installed on the ceiling of the room to be illuminated and usually takes the form of an opal dome or a white flat polycarbonate as shown in plate X. Along with solar altitude, the diffuser choice determines the light output distribution of light pipes (Mohelnikova, 2009). The daylight distribution is affected by the shape and texture or pattern of the diffuser. Zhang, Muneer and Kubie (2002), agreed that flat diffusers (Plate X) produce a narrower light beam while convex shapes allow for wider angles of light diffusion. On the other hand, the total light output from a flat diffuser is approximately 10-12% better than for a curved one (Robertson, Hedges and Rideout, 2010).



Plate X: Interior Pictures of the Tarmac House showing experiment rig set-up. and the diffuser

Source: Tukur (2013)

Two component diffusers are intermediate solutions; they are especially beneficial for clear sky conditions only with modest disadvantages for diffuse incident light. They are equipped with a diffuse central part and clear rim area around it (Kocifaj, 2009). Also, anisotropic diffusers can produce effect of spreading out the light beam and increase the perception of brightness in a space (Akashi, Tanabe, Akashi and Mukai, 2000).

### 2.7.2 Properties of Light Pipe

Light pipes are used in a variety of ways and come in multiple shapes and designs. There is a set of measures for it applications. The following are some major characteristic of light pipe;

2.7.2.1 *Reflectance properties of light pipe*

The interior is usually a mirrored surface for high reflectance (figure 2:13). Study by Dieguez, Gentile, Wanchenfelt and Dubois (2016), found out that a difference of 0.001 for the interior reflectance value of the tube had a significant change on efficiency. The

standard today is a value of 0.98 reflectance index. Other light pipes consist of transparent shafts and prism glass hung in atriums that move light and diffuse it in all directions as it moves downward (Allen, et al., 2008).

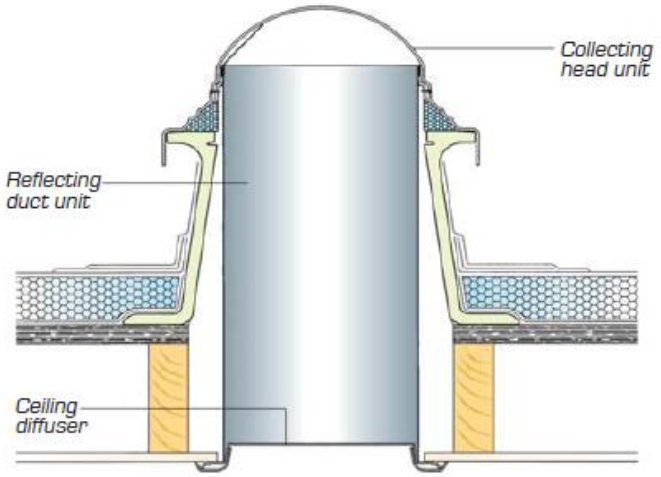



Figure 2.13: Light pipe with reflecting duct
Sources: Allen, et al. (2008)

2.7.2.2 *Diameter of light pipe*

The width of the light tube determines the strength of the light and how far it is able to reach the building interior. The larger the diameter, the more efficient the light tube. Plate XI show the light pipe diameter and reflectance.

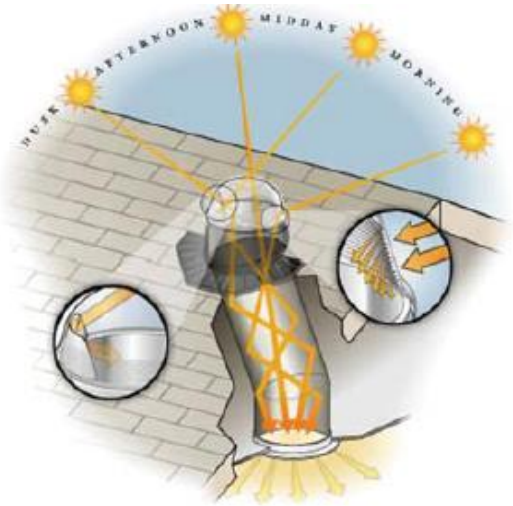


Plate XI: Light pipe diameter
Source: inhabit.com (2016)

2.7.2.3 *Length of light pipe*

A typical length of light pipe goes up to 10m, the longer the pipe, the less effective it is. Although the maximum length typically manufactured length is around 10m, light pipes with enhanced optics and heliostats have been built up to 40m. However, there is abundant daylight in tropic heliostat may not be needed.

2.7.2.4 *Shapes of light pipe*

A linear light tube is the standard for the majority of light pipe. However, there have been studies to explore other designs (figure 2.14). Concentrating pipes such as tapered or coned light pipes has been shown to have higher performance at a lower outside illuminance, but the straight pipe transmits more light during times of higher exterior illuminance. Concentrating tubes are also more sensitive to the sun angle than the linear pipe, which adds to a higher disparity between the seasons

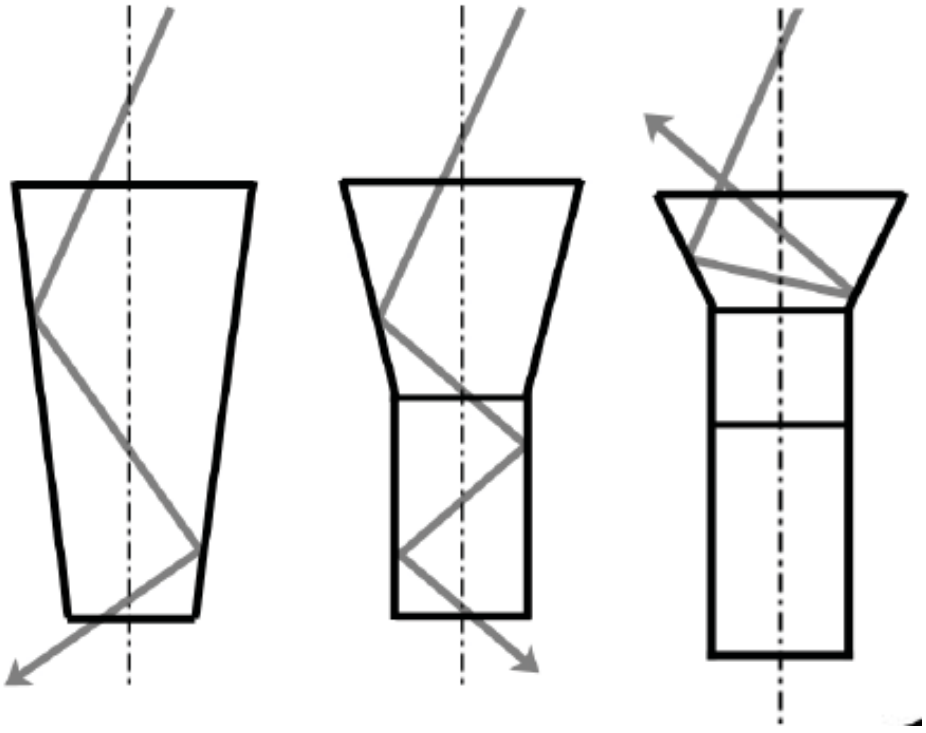


Figure 2.14: Shapes of light pipe; tapered, coned and linear shape light pipe

Source: Allen, et al. (2008)

#### 2.7.2.5 *Properties light pipe dome*

Generally, the light collector glass is mostly domed. Studies showed that the domed collector had higher light transmittance than a planar collector, especially when the sun was at a lower angle. This reduces the difference between the amount of light transferred during various times of the day and the different seasons. The standard material for the dome is an acrylic that has high visible light transmittance and low UV transmittance. Blocking the UV rays extends the life of the interior reflecting surface of the tube due to minimizing sun deterioration and make in more applicable in museum design. A dome with a Low- e glazing would also prolong the life of the reflective surface. Generally light pipe is classified into two; horizontal and vertical light pipe discuss in the next heading.

### 2.7.3 Horizontal Light Pipes (HLP)

The inherent problem of distributing daylight with traditional windows is non-uniform floor illumination over the entire plan depth (Al-Jubouri, 2012). The high brightness near the window may cause discomfort and glare to the occupants at the perimeter zone. Sun shading devices, e.g. vertical blind, to reduce the excessive amount of daylight that penetrate through windows may be required. Smith and Swift (2001), stated that natural daylight illumination available in the far area is further limited. Hence, the illumination of the internal environment unavoidably relies on artificial lighting. The running out of fossil fuels and the recent unusual climate changes globally indicate the need to conserve the environment and reduce the use of energy and global emission (Cook, et al, 2016). All these suggest the need to explore a new distribution method so that daylight can be delivered to a museum spaces optimally. The HLP is a device that brings daylight into the inner parts of buildings without the use of any electrical or other sources of energy. Similarly, Al-Jubouri (2012), stated that HLP help to enhance daylighting performance and improve the uniformity of daylight distribution even when the sun shading device

inside the room is activated since HLP extracts light at the building façade. The extraction and emission of daylight is transmitted horizontally and vertically using internal mirrored surfaced within a box tube structure (pipe) coupled with laser-cut panels at the outer edge of the pipe as collectors (Avers and Cartr, 1995), as shown in the figure 2.15 below.

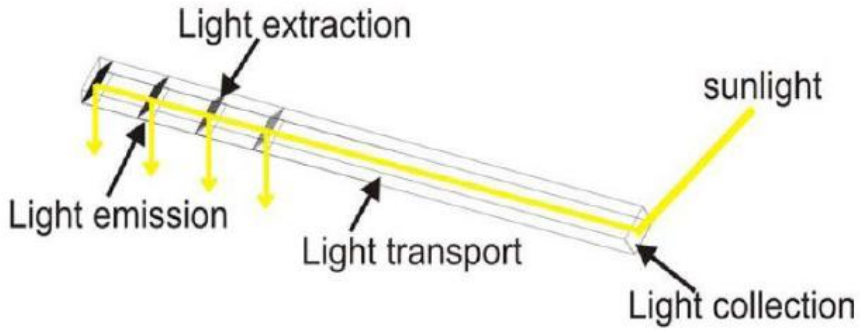



Figure 2.15: Diagram of horizontal Light. Piping System

Sources: Avers and Cartr (1995)

The horizontal light pipe (figure 2.16) comprises of a box i.e. Like a duct, that has highly reflective interior mirrored surfaces and an arrangement of laser cut light deflecting panels (LCP) at the outside edge as sub-light collectors and extractors that redirect light along

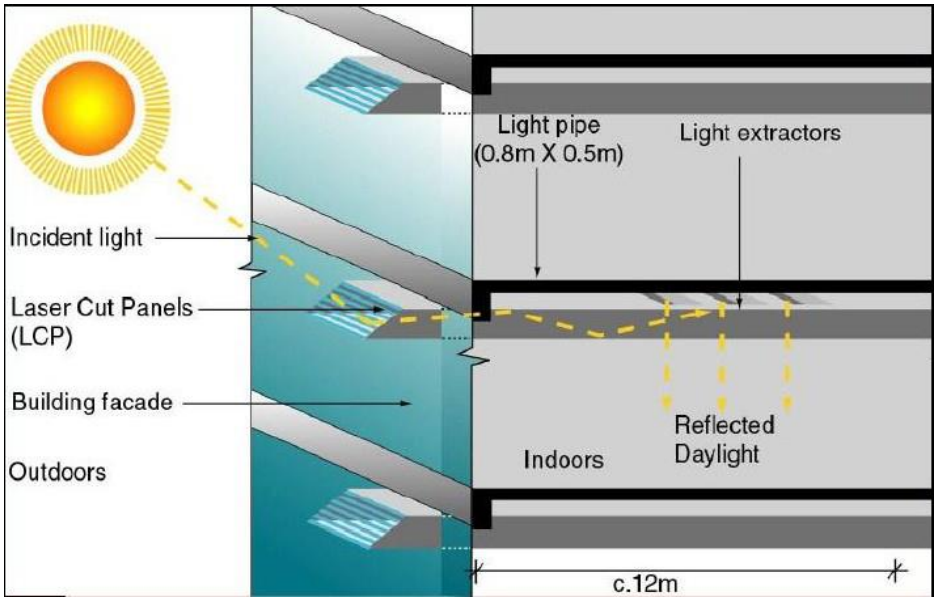



Figure 2.16: Horizontal light pipe

Sources: Al-Jubouri ( 2012)

the pipe to the interior spaces as required and with light emitters to spread the light uniformly around the space.

2.7.3.1 *Application of horizontal light pipe (HLP)*

Hansen & Edmonds (2003), clearly stated that the main reason for deep buildings depending largely on electrical light for illumination is that daylight levels decrease with distance from the window, so that a disproportionate amount of daylight/solar radiation must be introduced into the front of the room to achieve small gains in daylight levels at the back of the room. The application of HLP in building core design is show in figure 2.17. the interior core of the building full depends on artificial light. To introduce daylight into this dark area there is needs for daylight transporting systems.

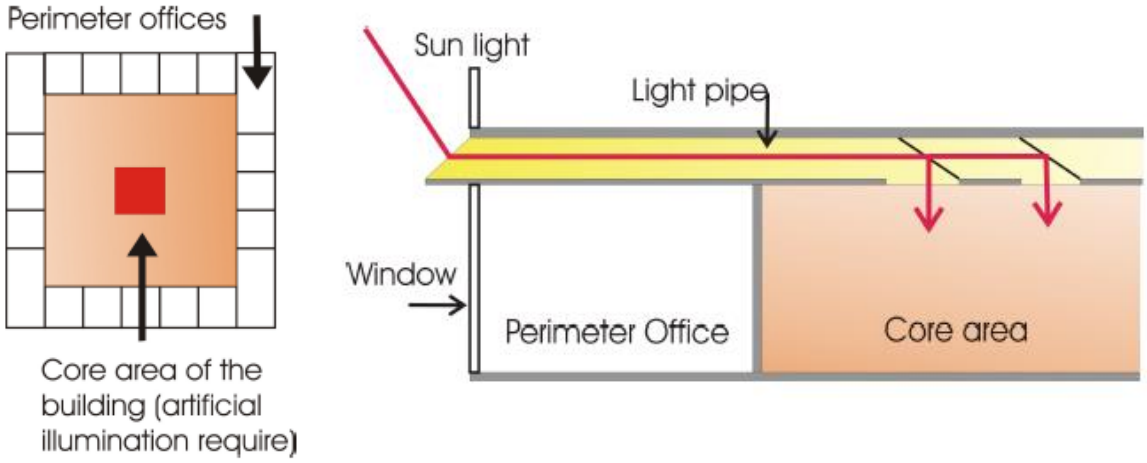



Figure 2.17: (Left) Perimeter offices blocking natural light to the core area of the building, (Right) Possible application of light pipe technology to enhance natural illumination in the core of the building

Sources: Hansen and Edmonds (2003)

### 2.7.4 Vertical Light Pipes (VLP)

Vertical light pipe system as defined by Al-Jubouri (2012), is a simple daylighting device that allows the natural daylight to enter into interior spaces or underground spaces where access to windows or skylights is restricted as shown in Plate XII. Similarly, Baker and Steemers (2000), agreed that the use of a light pipe system can enhance illuminance

without the use of artificial lighting and thus would reduce energy consumption significantly.

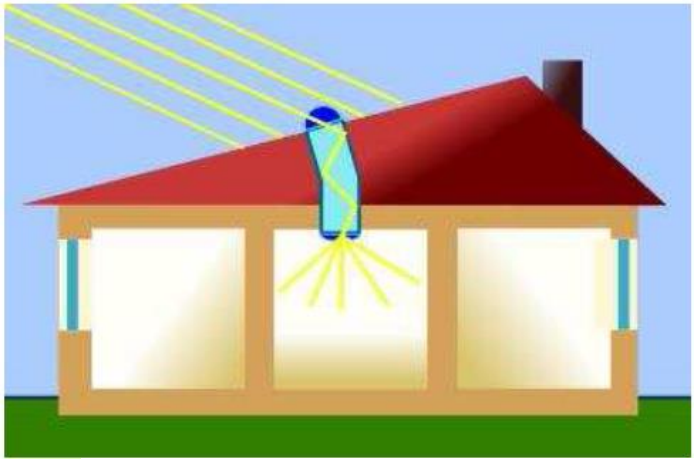


Plate XII: Application of Light Pipe in Buildings

Sources: Green Edmonton (2011)

Study of vertical light pipes as means of natural illumination by the Architect Ken Yeang's and Wilson in Millennium Library in Brisbane, Australia shown that vertical light pipes reach average lux values from 50 to 300 lux for different light collection strategies, under sunny sky conditions, with a good concordance between measured and calculated values. As shown in the figure 2.18 this library has a serious problem in terms of daylight design, the solution to solve this problem was the introduction of vertical light pipe.

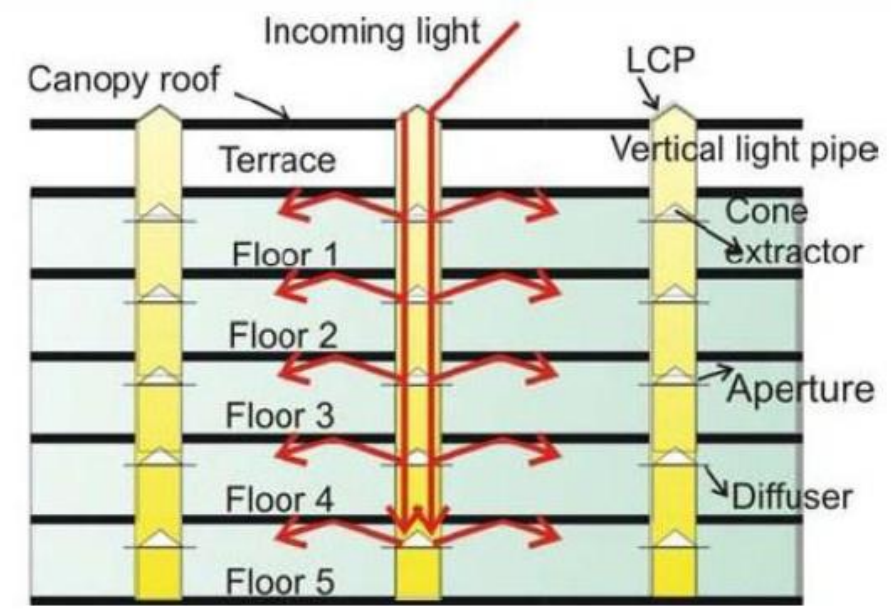



Figure 2.18: Vertical light pipe for Millennium Library in Briban

Sources: Avers and Cartr (1995)

Which help in optimizing daylight in the library. The design of the vertical light pipes in Figure 2.18 comprised of a pyramid form LCP collector to improve the redirection of low and middle-high sun angles more axially into a 2m diameter, 18.4 m long vertical light pipe with Aspect ratio of 1:9.

### 2.7.5 Aspect Ratio of Light Pipe

The ratio of the diameter of the pipe D, to the length of the pipe L, is called the aspect ratio of the light pipe. The aspect ratio (D: L) is an important characteristic for the performance of a light pipe, it also determines the amount of light bounces in the light pipe. Mohelnikova (2009), findings show that it should never exceed 1/20 in order to reach a minimum light output. The impact of light pipe aspect ratio in the light output is significant. However, unlike solar altitude, this parameter can be manipulated by the designer. The innovation of light pipe and its daylighting performance has been reported in a number of studies. Zhang (2002), used modified form of daylight factor, daylight penetration factor (DPF) to build a sophisticated model that takes account of the effect of both internal and external environmental factors, and light pipe configuration. The predicting aimed at daylighting performance of light pipes with various configurations under all weather conditions in the United Kingdom. Similar research by Zazzini, Chella, and Scarduzi (2006), used Ecotect and Energy plus to evaluate light-pipes performances of linear tubular light pipes of two 800 mm long and φ = 250 mm light pipes installed into a 4.24x3.36 m plant area room. The results have been very useful to test the accuracy of predicting numerical methods using Ecotect and Energy plus.

Studies by Hansen (2006), on daylight penetration of mirrored light pipe (MLP) technologies when coupled with laser cut panel (LCP), shows that MLP and LCP were effective in introducing sufficient ambient light levels inside buildings and over distance of >20m from the façade of roof. Average lux level was 150-350 lux for the horizontal

light pipes and 50- 300lux for vertical light pipes. Hasen (2006), stated that pipe aspect ratio is very important for it performance, as pipes with large diameter (e.g. 2m in diameter for 20m long pipes) are required for optimal performance. In Hansen study the area illuminated is the same for all cases, 12x12m, and the incoming light azimuth angles is considered as 0 degree. Previous work has suggested that laser cut panels (LCP) coupled with mirrored pipes could be a simpler, more cost-effective daylight solution for sunny climates. Edmonds, Moore and Smith (1995) and Hansen, Edmonds and Hyde (2001), show that overall performance of a mirrored light pipe coupled with LCP of an aspect ratio of 30 is 20%.

### 2.7.6 Parametric Study

Parametric study that assesses the relative importance of some of the most relevant parameters of light pipes includes; solar elevation, aspect ratio, reflectance and roof tilt orientation. This section justifies the selection of investigated parameters and defines the way they were studied. Case study of Kuala Lumpur project by Hansen (2006), showed good performance, providing average illuminance value varying from 200-300lux over a period from 12pm- 4pm from clear (sunny) sky conditions and efficiency of the system in the order of 25% for light pipe with an aspect ratio of 30 (i.e. where pipe length was 24m and height of 0.8m), this show that light pipe can perform better in clear weather condition. The conclusions of the parametric study by Dieguez (2014), are that aspect ratio limit should be 1/15 in the Scandinavian context, due to the predominance of low solar altitudes. The aspect ratio of the light pipes installed in the pig stables ranged from 1/9 to 1/15 cross sections should never be less than 200 mm in diameter to avoid excessive light losses along the light guide. For this research work, the models have aspect ratio between 1/3-1/10. This is done using daylight model.

## 2.8 Daylight Modelling

Daylight modelling is a software or physical scale model calculation of interior light levels in a space, using specific sky scenarios, such as clear sky or overcast, or real-world weather data files for a specific location (Vangimalla, Olbina and Issa, 2011). For simulation, the building is built within a software and design options can be tested early in design phase. Salisu (2015), opines that for accurate simulation results several factors should be taken into consideration such as the building orientation, location, local climate data, and interior finishes, which all impact the amount of available daylight for a specific project. Results can be displayed through a colour grid and renderings, after an initial analysis, the building model can then be modified to reflect options that may improve the daylight design, such as changing glazing location or light transmittance.

### 2.8.1 Uses of Daylight Modelling

Daylight modelling according Reinhart and Fitz (2007), is use to;

i. Compare different design options.
ii. Verify that a proposed design will provide satisfactory daylight
iii. Predict sources of potential glare, look at contrast ratios or balance of daylight within a space.
iv. Indicate potential energy savings from electric lighting use.
v. Document daylighting code compliance.

### 2.8.2 Measurement of Daylight

Daylight can be measured by hand held measuring instrument and by the use of simulation software to show illuminance and luminance level of a space, looking at light levels at a particular point in time. While for dynamic analysis climate-based daylighting model (CBDM) is use (Salisu, 2015). It is analysis that considers all sky conditions throughout the year at a particular location.

### 2.8.3 Climate Based Daylight Modelling (CBDM)

Climate Based Daylight Modelling (CBDM) is a simulation framework for the analysis of daylight in interiors that uses realistic sky and sun conditions to accurately simulate the amount and distribution of light. This type of modelling is founded on standardized climate files (Mardaljeric, 2006).

It enables the prediction of;

i. Absolute values of illuminance (overall light levels) and luminance (light levels within a specific area)

ii. Time varying and cumulative light levels i.e. dosage

iii. Duration of periods when daylight levels exceed or does not achieve user-determined targets

iv. Field of view luminance, which is related to brightness of surfaces

vi. Prediction of photo sensor response

## 2.9 Daylight and Art Museum

Lighting general circulation and gallery spaces, museums require certain amounts and types of light. In most situations daylight, can be easily incorporated into building designs, however museum designs provide a special challenge. It requires that UV exposure from direct sunlight be controlled in order to protect the integrity of the art work. To attain this in architectural sense there is need to understand lighting requirement for each space and consideration of all aspects of light within the display area.

### 2.9.1 Categories of Museum Object

In respect of the potential of light damage museum objects can be considered in four categories, as shown in Table 2.3. The categories are; most susceptible, susceptible, moderately susceptible and not susceptible (International Association of Lighting Designers, 2000).

#### 2.9.1.1 *Most susceptible*

This are artefacts or collection that requires low uniform illumination levels of not more than 50lux.

#### 2.9.1.2 *Susceptible*

High paper with light stable inks, such as carbon black, modern black and white gelatine, silver photograph, textiles with stable dyes Oil painting; Unpainted Leather; Ivory; Lacquered (Oriental and European) other materials painted or coloured, that required not more than 100lux of daylight falls with the susceptible category of light level in museum.

#### 2.9.1.3 *Moderately susceptible collections*

Oil and tempera paintings, bone, ivory wood finishes, leather, and some plastics that requires illumination level of between 150lux-200lux are categories as moderately susceptible collection

#### 2.9.1.4 *Not susceptible*

This are collections that don't easily deteriorate with adverse light condition they include;

Metal; Stone; Glass; Ceramic; Jewellery, most minerals and inorganic natural history specimens.

Table 2.3:Maximum values of illuminance recommended for museum objects

| Level of susceptibility to light damage and types of the materials | Maximum value recommended illuminance | Lux- hour per year |
|---|---|---|
| Category 1: Most susceptible<br>E.g. Textile; Clothing; Water-colour; Carpet; Stamps; Cotton wool; Drawings; Manuscripts; Tempera painting; Wall paper; Tainted leather; Natural history and ethnology exhibits and some plant material. | 50 lux | 54,000 |
| Category 2: Susceptible<br>E.g. High paper with light stable inks such as carbon black, modern black and white gelatine, silver photograph, textiles with stable dyes Oil painting; Unpainted Leather; Ivory; Lacquered (Oriental and European) other materials painted or coloured. | 100 lux | 108,000 |
| Category 3: Moderately Susceptible<br>E.g. Oil and tempera paintings, bone, ivory wood finishes, leather, and some plastics and works on glass casing | 150-200 lux | 500,000 |
| Category 4: Not susceptible: Metal; Stone; Glass; e.g. Ceramic; Jewellery, most minerals and inorganic natural history specimens. | No limit (or 300 lux) | Depends of exposure condition |

Source: (Illuminating Engineering Society of North America, 1996), (International Association of Lighting Designers, 2000).

### 2.9.2 Applications of Daylighting in Museum

Daylighting in museums have evolve over time from placing of side windows to a more complex device to bring daylight into interior of the buildings. Some of the examples of the applications of this device in museums includes; The Broad Museum, Morgan Lewis international headquarters, high museum etc.

2.9.2.1 *The Broad Museum.*

The Broad Museum (Plate XIII) designed by Architects Diller Scofidio and Renfro Located at 221 South Grand Avenue, Los Angeles, CA 90012, United States. The art museum which have Area of 11148.37m² Was Opened 2015. The museum is named after philanthropist Eli Broad, who financed the 44.21 billion building that houses the Broad art collections (Cotter, 2015).



Plate XIII: The Broad museum 221 South Grand Avenue, Los Angeles
Source: Cotter (2015)

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2.9.2.2 *Architecture and daylight of the broad museum*

The building design is based on a concept entitled “the veil and the vault”. “The veil” is a porous envelope that wraps the whole building, filtering and transmitting daylight to the indoor space. This skin is made of 2,500 rhomboidal panels made in fiberglass reinforced concrete supported by a 650000kg steel substructure. “The vault” is a concrete body which forms the core of the building, dedicated to artworks storage, laboratories,

curatorial spaces and offices (Cotter, 2015). The three-story museum features 4,600 square metres of exhibition space on two floors, with 3,300 square metres of column-free gallery space on the third floor and 1,400 square metres more on the first. The roof has 318 skylight monitors that let in diffused sunlight from the north. In the non-Euclidean lobby, there is no front desk; instead, visitor-services associates greet guests with mobile devices. Lobby and exhibitions spaces are connected by a 32 metre escalator and a glass-enclosed elevator as shown in figure 2.19 and figure 2.20




Figure 2.19: Floor plan of broad museum

Source: Cotter (2015)

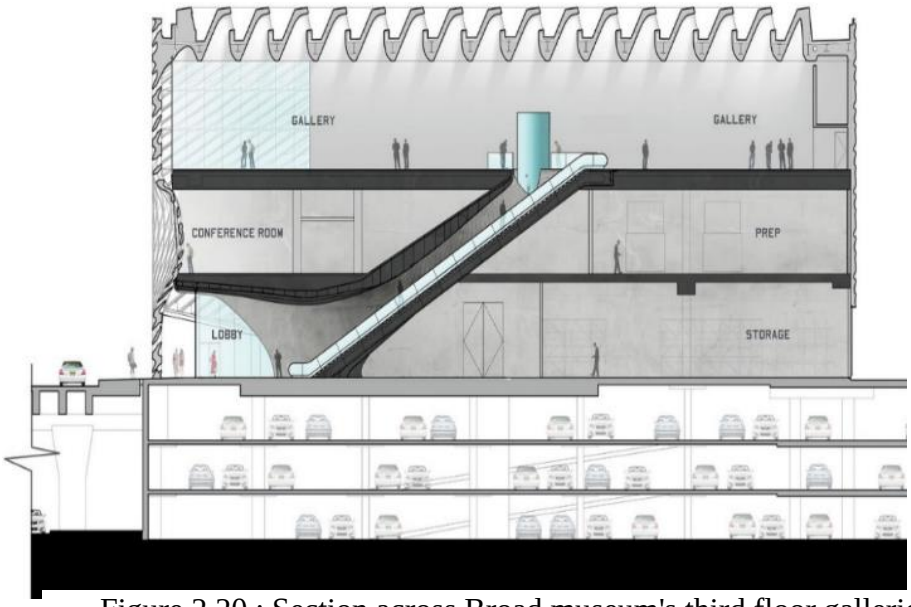



Figure 2.20 : Section across Broad museum's third floor galleries with skylights and interior veil

Source: Cotter (2015)

2.9.2.3 *High museum addition*

Another example of applications of light devices is in High museum design (Plate XIV) Designed by Architect Renzo Piano, Area; 16443.84 sq. metre. The museums were opened in 2005. Daylighting device used in the facility is light pipes



Plate XIV: Approach view of Renzo piano high museum

Source: Shaw (2012)

2.9.2.4 *Daylighting consideration in high museum*

Renzo Piano's High Museum addition takes advantage of the sun to naturally illuminate its permanent gallery space. The top level receives overhead sunlight from a matrix of 1,000 light tubes (Plate XV). Here Piano was hoping to create a gallery that was not simply a white box while avoiding anything that would be so distracting as to take away from the art. He was able to achieve this by employing the changing effects of natural light. Each of the 1,000 light tubes has aluminium sun scoop shaped to catch the diffused, northern light and prevent damaging by direct light entering the gallery. Piano called the aluminium sun shades (plate XVI) "velas", meaning sails in Italian, to communicate the idea being that they catch sunlight just as sails catch the wind. The sun scoops along the parapet of the roof also fold down to form part of the façade. The light scoops of the High Museum add to the aesthetic design of the building while performing the function of filtering sunlight into galleries.



Plate XV: Exterior view of the light tube
Source: Shaw (2012)



Plate XVI: Exterior view of light tubes at high museum
Source: Shaw (2012)

2.9.2.5 *Morgan Lewis international headquarters*

Morgan Lewis international headquarters also Employed light tube and heliostat (Plate XVII) as Daylighting elements to lit deep inside the building. The light tube designer was Norris carpenter.



Plate XVII: Interior view of Morgan Lewis international headquarter
Source: Allen, et al. (2008)

2.9.2.6 *Architectural consideration of Morgan Lewis headquarters*

The 36.5m long “solar light pipe” at the Morgan Lewis law office brings daylight from the rooftop into its unusually narrow 14-story atrium (Plate XVII). Due to the atrium’s proportions, the space’s previous skylight allowed daylight to reach only the uppermost floors. The lighting designers devised a variation of a light tube with a double-skin system to bring the daylight illumination down into the space. A rooftop heliostat follows the sun’s course and reflects sunlight onto a secondary mirror, which is composed of 24 sub-mirrors and redirects light into the cone-shaped, prismatic glass core as seen in figure 21. As sunlight transverses, the core, it hits angled pieces of serrated glass, refracting outwards and bouncing off and through the translucent Lycra fabric skin that forms an outer cylinder



Plate XVIII: Interior view of light tube at Morgan Lewis International Headquarters
Allen, et al. (2008)

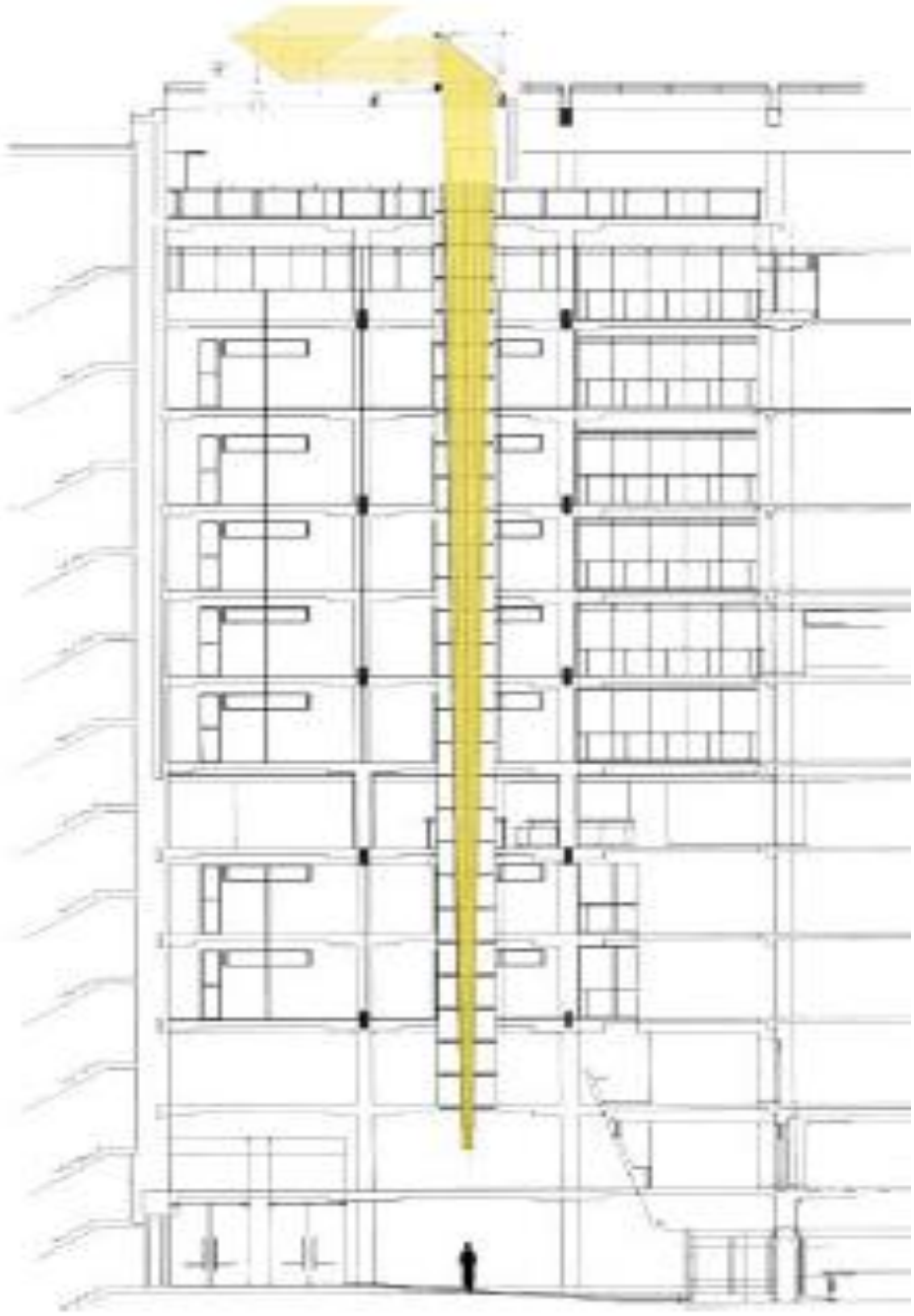


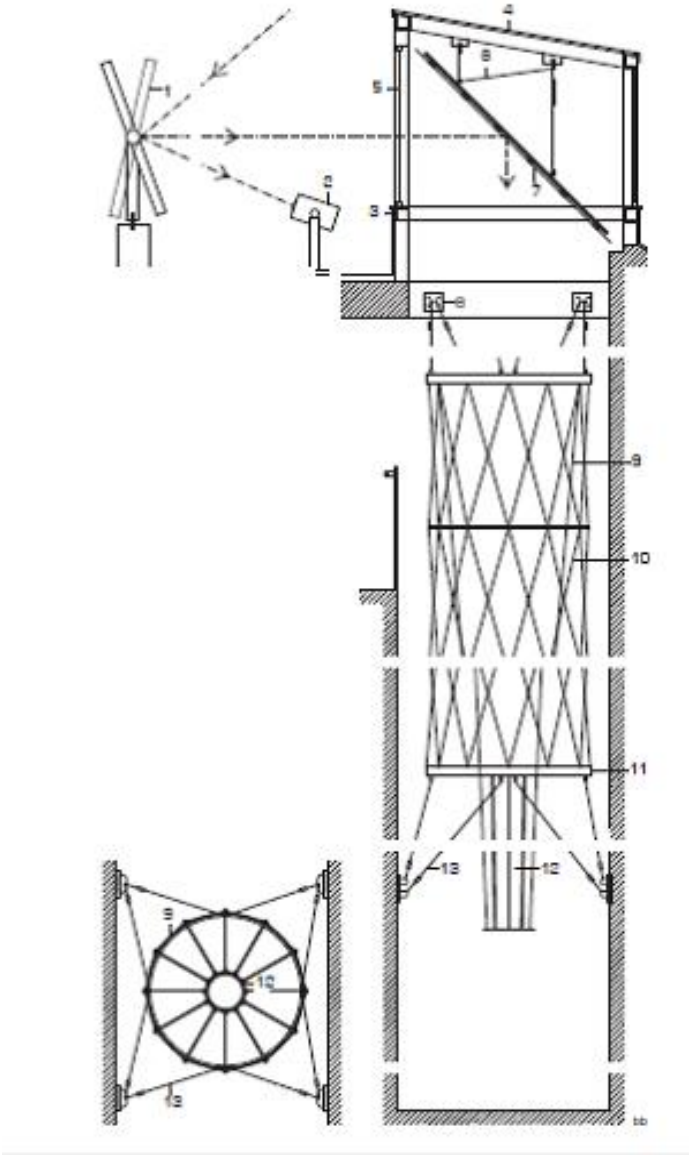
Figure 2.21: Section through light pipe at Lewis Morgan Headquarter

Source: Allen, et al. (2008)

The core is held in place by a steel and aluminium support system, and the tensioned fabric is stretched over compression rings held to the core by radiating steel arms

2.9.2.7 *Details of light tube at Morgan Lewis headquarter*

Figure 2.22 is the illustration and diagram of light pipe installed in Morgan Lewis headquarters, were daylight is distributed to the building interior from the windows in the duct.



1. heliostat
2. Searchlight
3. 125/125 mm steel SHS
4. Sheet-metal covering
5. 12mm toughened glass
6. Suspensions for light deflecting mirror at 45° angle
7. 24 mirror elements 500/500 mm fixed to 1,900/3,100/10 mm steel plate, manually adjustable by spherical caps
8. Anchor fixing in concrete tie beam
9. Ø 1,830 mm light-diffusing tube: translucent, reflecting Lycra fabric
10. Ø 6.5 mm diagonal cables
11. Cone consisting of 1,600/15 mm prismatic glass panels with optical film adhesive fixed on inside face
12. (Ø 1,754 mm at top; Ø 500 mm at bottom)

13 Ø 6.5 mm

Figure 2.22: Detail section of light tube at Morgan Lewis headquarter
Source: Allen, et al. (2008)

### 2.9.3 Conclusion

For the study to be places within an existing body of knowledge. This chapter covered the literature research carried out on existing daylight devices available as well as their applications. Especially with main focus on passive means of lighting museum. Daylighting was also defined and the strategies studied elaborately discuss. The choice of light pipes as the strategies of bring daylight into the museum was also justify from the review of literature. The review also goes further to analyse the different methodology applied by different researchers in their studies. This was to get the author used to different accurate method that can be used to collect and analysis data in the related cases. Since museum needs diffuses and indirect daylight, this study focuses on light pipe as a means of bringing light to interior space and other means such as growth green, prismatic panel, laser cut panel and high-level windows.

# 3.0 METHODOLOGY

## 3.1 Introduction

Methodology is the general research strategy that outlines the way in which research is to be undertaken and identifies the methods to be used in it (Howell, 2013). This study was on the optimization of daylight performance by incorporating light pipe for the achievement of optimum lighting in museum in tropical wet and dry climate of Nigeria. The research approach adopted is qualitative and quantitative research, the use of case study and quasi experimental (simulation) research method will help in achieving the aim and objective of the study by answering the research questions. Veal (2006), clearly state that the evaluative case study type is mostly relevant, as its application establishes facts that are for testing effectiveness of programs in order to suggest modification and alternatives in a context

This study used climate-based daylight modelling as framework for the simulation as it allows the prediction of various radiant or luminous quantities (Irradiance, illuminance, radiance and luminance) by using sun and sky conditions that are derived from standard meteorological datasets of a particular location (Mardaljeric, 2006). Mardaljevic (2008), agreed that in museum environment (Galleries), it serves as performance indicator (light exposure design) for a long period of time. It will also provide data founded on absolute values for the valuation of building designs and the calibration of daylighting schemes (Mardaljeric, 2006).

## 3.2 Research Design

Burns and Grove (2003), define a research design as a blueprint for conducting a study with maximum control over factors that may interfere with the validity of the findings. Parahoo as cited by Draper (2004), describes research design as a plan that describes how,

when, where data are to be collected and analysed. Research design of the study includes; multiple case studies and quasi experimental (simulation). Visual survey to the selected case studies were data was collected and analyses using Ecotect-Radiance and DAYSIM.

### 3.2.1 Case Studies Research Design

In architectural research, the case study has become a dominant methodology (Alizadeh, 2006). Case studies are a means of getting practical information about similar buildings that have been designed and learning from the mistakes others have made as well as their success. In this case, it involves the study of existing facilities to form a basis of identifying existing problems and different methods of applying day lighting in the design of Art Museum and identify the various ways natural light is incorporated to the design as well as the types of collection in the museum. Oluigbo (2010), clearly state that for the cases to be identified, they have to possess some intrinsic virtues which are in relation with the phenomenon under consideration. Therefore, the Museums for the research were selected based on the following criteria:

#### 3.2.1.1 *Case studies selection criteria*

i. Access to the facilities
ii. Presences of daylight architectural elements in the building
iii. Climatic zone of the proposed site for the research

### 3.2.2 Population of the Study

This involve buildings related to the research with respect to case study. Presently there are only eleven (11) registered Museums in Nigeria located within its boundaries, with only three (3) specialized once to address the preservation of national history and modern arts.

### 3.2.3 Sampling

Case study is normally selected based on the purpose it's meant to serve; cases are selected because they can provide information regarding the research problem (veal, 2006). Due to the nature of this research, purposive sampling was used for the case studies selection base on the following criteria; access to the facilities, present of daylight architectural elements and climatic zone. The country has three distinct climate types according to the Koppen system as modified by Trewartha and Horn, 1980 cited by (Salisu, 2015). The study areas are located within Nigeria. Nigeria is located along the West African coast in between latitudes 3°-15°E and longitudes 4°-14°N with a distinctly tropical climate that varies from the damp and very humid in the south to the hot and semi-arid climate in the north as shown in figure 3.1.

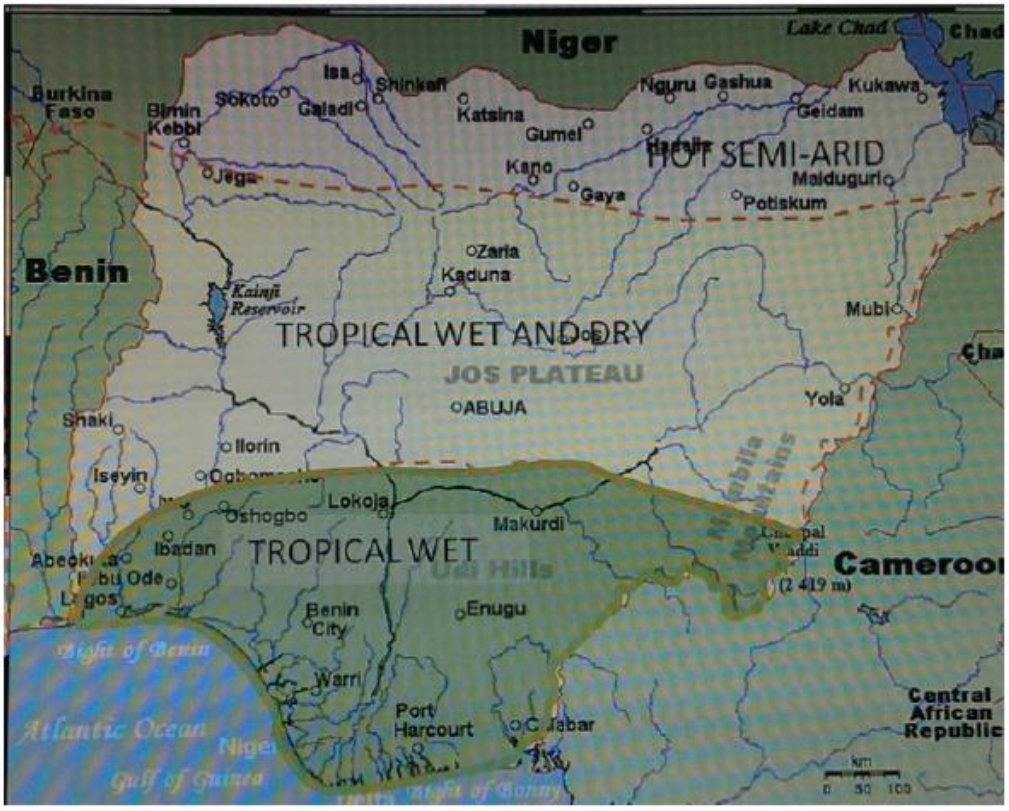



Figure 3.1 Map of Nigeria showing the three Climate Region
Koppen-Trewartha-Horn classification scheme (1980) cited by Salisu (2015)

The study purposive sample one case study from each climate region classified according to the Koppen system as modified by Trewartha and Horn (1980), which is noticeable as one moves from the southern region through the middle belt and up to the northern states of Nigeria

Table 3.1: The selected case studies

| **Location** | **Climate** |
|---|---|
| Gidan Makama Museum, Kano. Kano state | The Hot-Semiarid Climate |
| National Museum of colonial history, Lokoja. Kogi State | Tropical Wet and Dry Climate |
| Kaduna Museum, Kaduna. Kaduna states | Tropical Wet Climate |

Source: Author's study (2016)

### 3.2.4 Method of Data Collection.

Theoretical research in architecture may require the use of general methods for data collection (Oluigbo, 2010). However, this data collection method depends on condition under investigation, hinging on this Gambari (2011), clearly state that writing a research report is incomplete without describing the method and instruments used for data collection and how they were validated. Being an evaluative in nature, this study employed, case study visual survey as the method of data collection.

3.2.4.1 *Visual survey*

This is a method of data collection in which the eyes are used to study and observe. Case studies were assessed based on the visual appearance of the buildings and the daylight elements and guided by critical literature review guidelines. The result was documented in tabulation, sketches, pictures, written reports etc.

3.2.4.2 *Case study approach*

Visit to three (3) selected case studies where data was collected. The data that was collected includes, the floor plans, window sizes, types of collection in the museum. Readings from illuminance metre was also recorded for both exterior and interior lighting for different hours of the day.

### 3.2.5 Instruments for Data Collection.

Writing a research report is incomplete without describing the instruments used for data collection and how they were validated (Gambari, 2011). To effectively investigate the cases, the instruments used to for the collection and documentation of data are check list, camera, notebook, sketchpad, light metre reading and computer software.

3.2.5.1 *Light metre or illuminance metre*

An instrument that measures the intensity of light in a certain place (Collins English dictionary, 2014). Light metres are also used in the fields of cinematography and scenic design, in order to determine the optimum light level for a scene. For the study the light metre uses for the collections of the readings on existing museums is HS 1010A shown in plate XIX.




Plate XIX: Light metre HS 1010A

Source: amazon.com (2016)

Features of light metre HS1010A

i. HS1010A: Measuring range between 1lux-200,000 lux
ii. Max and Min reading hold function supported and lux/fc unit selection
iii. Lux/Light metre has unit selection function and automatic data recording
iv. High accuracy wide measuring range of ± 4% ± 10dgts (<10000lux) and ± 5% ± 10dgts (>10000lux)
v. It has low battery indication feature
vi. More precise than most other light meters: Accuracy ±4% Repeatability: ±2%

Architects and lighting consultants use this to test light levels in buildings, offices, workshops and production areas. Light metre HS1010A as shown in Plate XIX was used to measure the actual amount of daylight on the existing museum spaces to be analysed, and average of 3-4 readings were taken at the respective work plane during the sunny hour of the day (2:00-3:00pm).

### 3.2.6 Variable of the Study

The two types of variables are dependent and independent variable (McLeod, 2008). Independent variable (IV); are variables the experimenter manipulates (i.e. changes) assumed to have a direct effect on the dependent variable while, dependent variable (DV) are variables the experimenter measures, after making changes to the IV that are assumed to affect the DV. The variables considered in this research are design dependent variables (see figure 3.2) which are required in the integration of natural light in the building of the selected cases and design considerations required for optimum performance of day light design.

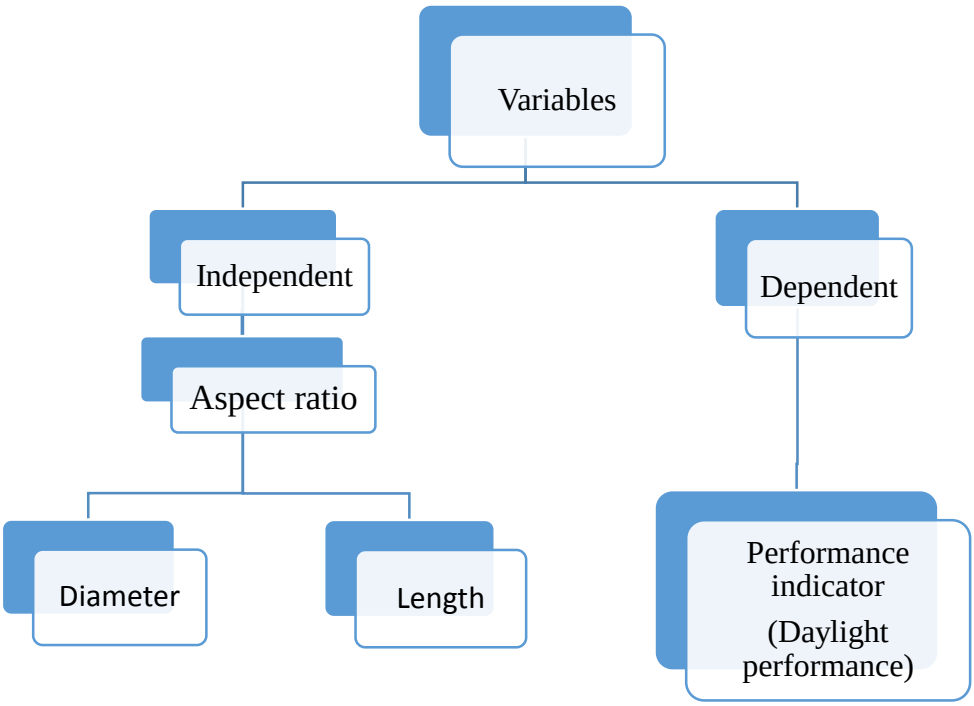



Figure 3.2:Dependents and independent variables for simulation
Source: Author's study (2016)

The dependents variables and independent variables to be considered in this research are shown in figure 3.1. These variables are examined as part of the process of climate-based daylight models using climate datasets for simulation to determine quantity of daylight admitted into each space (Mardaljeric, 2006) through light pipe. The light pipe with aspect ratio that give satisfied result will be identifies and selected for the design of modern art museum Abuja.

### 3.2.7 Parametric analysis

The aim of the parametric analysis is to observe the response following the modification in the variables. Parametric analyses are conducted for reasons of determine the extent of change of variable (Hamby,1994). The parametric analysis is used to examine the consequence of changing a given independent variable (aspect ratio), have on daylight

penetration of light pipe using computers simulation. Figure 3.3 describes the process of parametric analysis based on Batagarawa (2013)

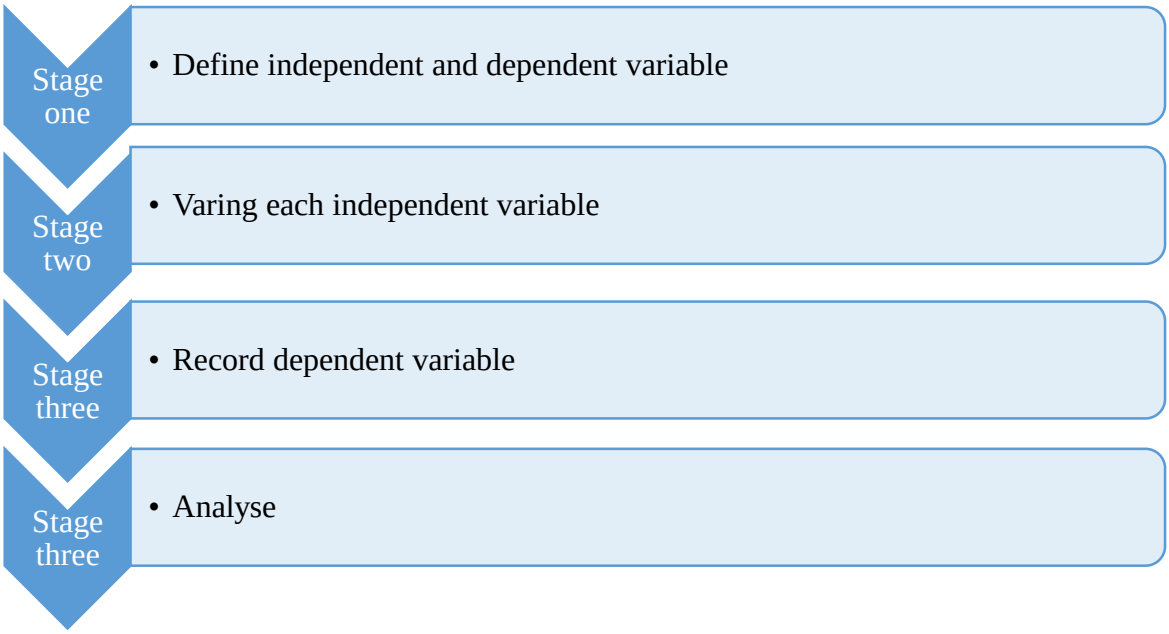



Figure 3.3: Parametric analysis procedure

Based on Batagarawa (2013)

Stages are to

i. Define the model independent and dependents variable. This includes defining the climatic data set of the location as the simulation is climate-based daylight modelling.
ii. Vary the values of each independent variable once at a time, in rational and incremental manner using the aspect ratio i.e. ratio of the diameter of the light tube to the length of the light tube.
iii. Record the corresponding values of the dependent variable in lux (performance metric).

iv. Assess and compare the influences of the input and output relationship though statistical analysis.

### 3.2.8 Procedure for Data Collection

The procedure for data collection included visits to three local museums and taking a case study visual survey of architectural features and sketching out the floor plans, taking note of the daylighting design strategies in the building, measuring window opening and types of the materials and types of opening as well as the list of collections in the museum. Not every information seen on site was evaluated but those related to daylight provision in the museums. Also, foreign case studies were obtained through the internet and their features discuss as well. Readings from light metre on amount of light admitted into existing museum spaces were taken at sunny time of the day (2-3pm), three to four reading were taken to ensure valid results.

### 3.2.9 Data Analysis and Presentation

This research used descriptive and parametric analysis. Data from case study was describe and quasi experimental (simulation) was performed. Visual survey and observation is based on the descriptive account as observed, the illustrative qualitative method was used because it is descriptive and add detail examples to the study. Simulation was performed using Ecotect, Radiance and Daysim. Data collected on each case study was analysed and represent in different forms which include:

*Photographs*: Pictures of the existing art museum were taken and documented showing the museum and how the concept of daylight design has been reflected; as well as the degree of its application.

*Tables:* Data collected on this research from case studies were documented and presented in table, which shows the findings and readings taken from field survey.

*Figures:* Data collected on the case studies was also documented in form of drawings, such as the Museum plans. sketches and details of daylighting elements

*Diagrammatic representation:* Proper representation of data was made by the uses of sketches

*Computer simulation:* Computer simulation is a simulation, run on a single computer or a network of computers, to reproduce behaviour of a system or situation in real life. It can be used to explore and gain new insights into new technology and to estimate the performance of systems too complex for analytical solutions. In daylight simulation, it involves predicting, planning and proper design for the impact of daylighting in a space (Vangimalla, Olbina and Issa, 2011). For this study, it's the test for light pipe performance

*Description of simulation:* To evaluate the performance of light pipe of various aspect ratio for optimum lighting in museum in tropical wet and dry climate of Nigeria, simulation was conducted. This was used to assess the effect of the different aspect ratio of light pipe on daylight penetration. The result of the simulation was then used to compared with the maximum level of light requirements in museum gotten from the literature review and case study. Aspect ratio was the variable checked, while the other variables were kept constant throughout the analysis, this is because aspect ratio has high effect on daylight performance of light pipe. The material reflection index of the light tube is 0.98 and the properties of all the other variable were according to standard specification required for a museum optimum lighting. The comparison between the result obtained from the case study, the literature review and simulation will form bases for the design. Finally, the proposed design was simulated against daylight performance of each spaces and light requirement for the spaces. Real sky conditions a data set was used for the simulation.

*Simulation software:* The model was first built in Autodesk® Revit architecture then exported to Autodesk® Ecotect® for the analysis using Daysim, the exported back to Ecotect to visualised the result. An accurate Daylighting Simulation Software, is a physically accurate and comprehensive lighting analysis tool that can be accessed via Autodesk® Ecotect®. It can help to accurately calculate daylight factor, illuminance, luminance, daylight autonomy and daylight sensitivity factors. Most of daylight model's software are built in Autodesk® Ecotect®, then the model is exported to Radiance or Daysim for analysis. Radiance and Daysim are both validated software packages and the software can be used to generate several forms of daylight analysis. Radiance is a backward ray tracer developed by the Lawrence Berkeley National Laboratory.

*Procedure for simulation*: The computer simulation will make use of four packages, Revit, Ecotect, radiance, and Daysim. The stages of the simulation are show in the figure 3.4.

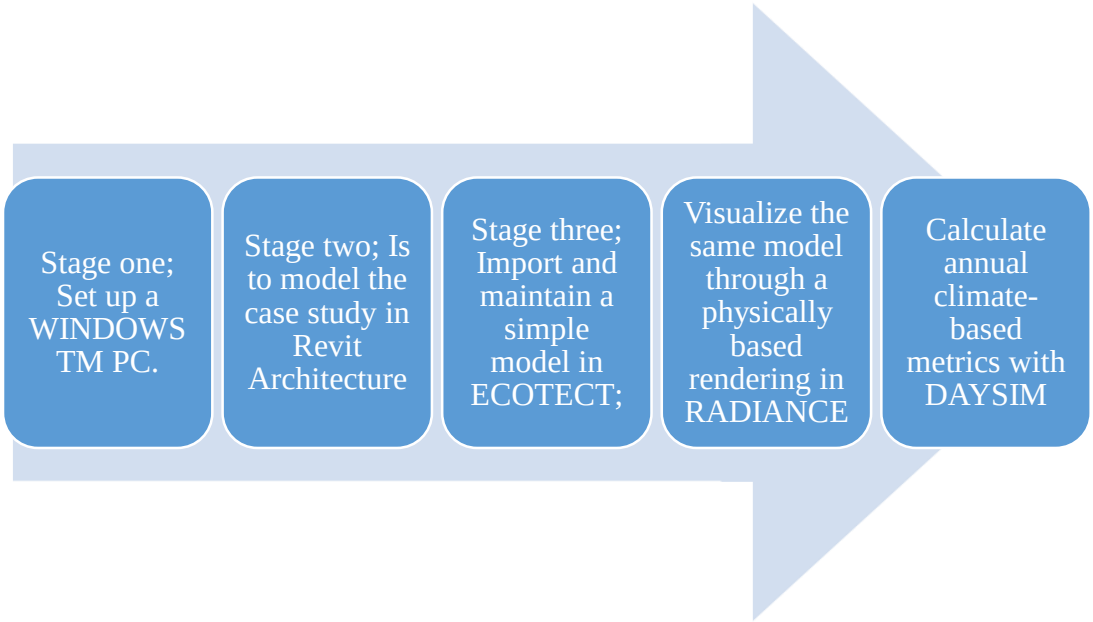



Figure 3.4: Stages for simulation

Source: Author's study (2016)

*Radiance and User Validation Studies:* Even though the Radiance software has been repeatedly validated across the world, it is important to validate it in context the research and researcher competence. This validation study should be able to test the capability of both the user and the software in predicting daylight performance of light pipe in the tropics and to test for the reliability of the results. The relationship between the measured and simulated illuminances, if any, will be assessed using statistical tests to test for associations and levels of significance. Detailed procedures and tools for this stage are listed in Figure 3.5

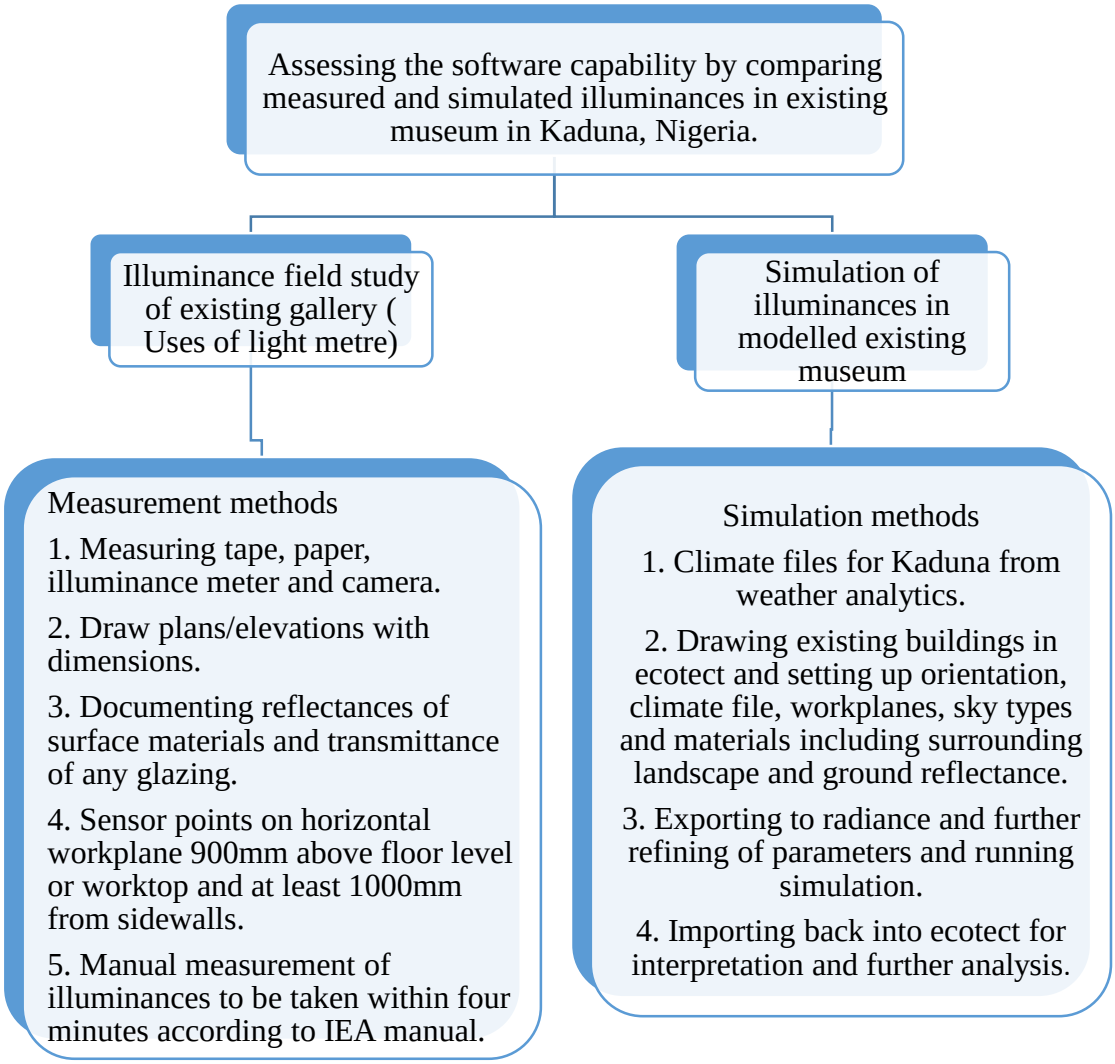



Figure 3.5: Details of Validation Study Procedures

Source: Author's study (2016)

The case study conducted in Kaduna museum (located within the tropical wet and dry climatic zone) is very relevant to the area of study. The museum was made up of three galleries. To test the predictive accuracy of *Radiance*, measures of actual and simulated values of horizontal illuminances were undertaken for the museum based on the procedures for daylighting performance assessment as laid out by IEA. Therefore, the measurements were divided into two:

i. Assessment of daylighting in existing museum

ii. Simulation of daylighting in virtual model

### 3.3 Summary of Research Methodology

| | |
|---|---|
| Research Context | • Over dependence on artificial lighting<br>• Need to reduce energy for lighting |
| Research type | • Qualitative and quantitative |
| Research design | • Multiple case studies, quasi experimental (Simulation). |
| Sampling | • Purposive sampling |
| Method of data collection | • Case study , Visual survey. |
| Instrument of data collection | • Check list, Camera,note book, Skectch pad, light metre and computer software. |
| Data analysis | • Descriptive for case study and paramatric analysis using computer software. |
| Data presentation | • Figures, Graph, Tables and Plates |

Figure 3.6: Overall research methodology

Source: Author's study (2016)

# 4.0 FINDINGS AND DISCUSSION

## 4.1 Findings

Findings from the study answers research question one "what the types of artefacts in the selected Nigeria museums and the amount of daylight on existing galleries are based on effect imposed by tropical wet and dry climate and daylight design?".

Findings from case studies survey reveal the amount of daylight in existing museum gallery by the use of measuring instrument, while simulation answered research question three "How does the aspect ratio affect daylight performance of light pipe in tropical wet and dry climate Abuja".

Finally, the technological approach to the application of light pipe in the proposed design answer research question four; What are the possible application of light pipe in museum in tropical wet and dry climate Abuja?

### 4.1.1 Findings from Case Study 1 (Gidan Makama museum Kano)

Gidan Makama museum shown in Plate XX, located in the city of Kano Nigeria is an art museum within the hot-semiarid climate of Nigeria, officially opened in 1975. The Gidan Makama was constructed in 1750 for the then emir of Kano Muhammed Rumfa as his palace before the construction of the present-day Emir's palace. After the construction of the new palace (present day palace), the Emir Muhammed Rumfa left the old palace then Makama Kano, one of the highest dignitaries of the emirate after whom the house was named.

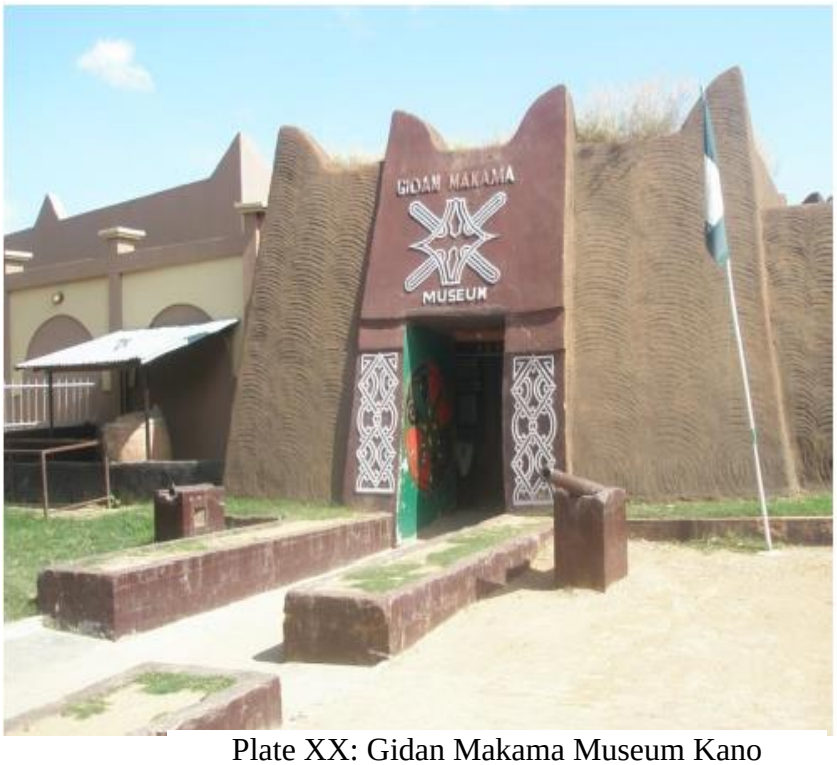



Plate XX: Gidan Makama Museum Kano

Source: Author's field study (2016)

4.1.1.1 *Site planning and landscaping*

Gidan of Makama is situated in the south-east corner of the large square in front of the Emir's palace (figure 4.1). The facility landscape is generally hard concrete walkways




Figure 4.1: Satellite image of Gidan Makama Kano

Source: Google Earth pro 7.0 (2016)

and exposed earth flooring within the compound with scant vegetation cover, mainly consisting of shrubs at the entrance to the facility. A few trees found on the site do not show a pattern or visual logic by which they were planted.

4.1.1.2 *Spatial organisation*

The structure is divided into three parts, the Gidan Makama primary school, the central area which is the home of Makama and the main suite of the rooms which is the museum. The museum is divided into 11 galleries (figure 4.2) with different kind of display with courtyard as centre of focus. Galleries include the Zaure in the main entrance with

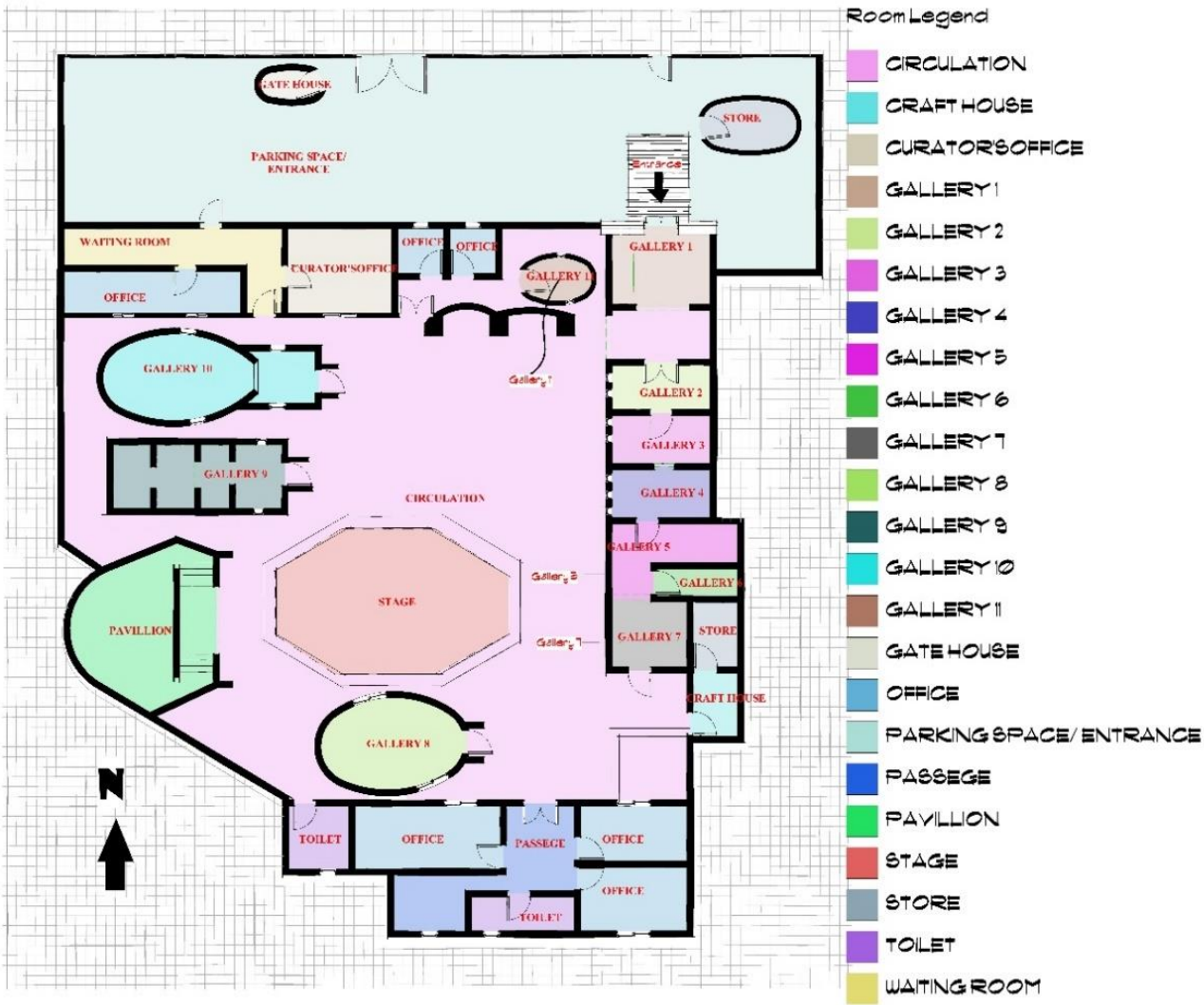



Figure 4.2: Floor plan of the existing Gidan Makama Museum

Source: Author's field study (2016)

displays of traditional materials, city walls and maps of Kano, the history of statehood, Kano in the 19th century, the Civil War, economy, industry and music. The main courtyard is where craftsmen exhibit their traditional skills, a hair dressing saloon, and the remaining galleries also includes 8, 9 and 10

*Building form:* The building complex consists of different traditional building forms ranging from cubic, cuboidal, cylindrical and also curvy-linear building forms. The building form exhibit Hausa style of architecture as seen in the (Plate XXI)



Plate XXI: Dominant building form of Gidan Makama gallery

Source: Author's field study (2016)

*Auxiliary facilities:* The building also consists of the following facilities; open air theatre (Plate XXII), Parking for both staffs and guest and Craft room (Plate XXII) and Administrative section.




Plate XXII: Craft shop Gidan Makama, Kano State

Source: Author's field study (2016)




Plate XXIII: Open Air Theatre Gidan Makama, Kano state

Source: Author's field study (2016)

4.1.1.3 *Materials and reflectance*

The walls were erected using *Tubali* locally moulded bricks, made of red clay and *makuba* a type of dry grass, formed and heated to solidify. The interior view of the art galleries finished with red clay material, which resulted low reflectance of the galleries Plate XXIV. This give non- uniform distribution of daylight in the interior. The low reflectance of the room makes the interior dark during the day and affect visitor's visual comfort.



Plate XXIV: The walls finished with clay plaster both interior and
Source: Author's field study (2016)

The floors in all the separate structures of the facility is of cement-stone finish. The scholar believed that this finish was used in rescue of the decrepit clay or sand floor which was the early floor finish material

4.1.1.4 *Building orientation*

The building has no proper consideration for orientation in order to have greater access to daylight as well as reducing solar heating. However, due to the sizes of the opening the effect is minimal. The longer side is oriented slightly along the NS direction, i.e. the shorter sides are facing the North and South direction respectively (figure 4.2). This has

been a greater potential for glare within the building as orientation happens to be a key determinant for daylight control.

4.1.1.5 *Size and depth of the space*

The rectangular and circular spaces within the structure are light with side windows. The windows along the perimeter wall has been of vital help in providing daylight into the building (Plate XXV). The building is very high tapered gradual toward the headroom build with red clay.



Plate XXV: Clay plaster and side windows that light the gallery

Source: Author's field study (2016)

The front gate is circa 4.3 metres high and roughly square in plan with sides measuring approximately 9 metres with strongly tapering earthen work walls vary in thickness.

4.1.1.6 *Ceiling geometry and window sizes*

The ceiling is the combination of flat and dome shaped geometry (Plate XXVI), plastered with red clay, while high level windows is the major source of daylight into the building interior, the windows are of timber and a later introduced gallery building has glass

windows with aluminium frames which the dimension of 300x750mm. The main doors are made of smelted black stones, while some other structures do not have any doors, just openings.



Plate XXVI: The dome like ceiling at the gallery

Source: Author's field study (2016)

4.1.1.7 *Daylight situation of Gidan Makama*

The building was originally a palace converted into museum, the art gallery with a central courtyard was design to take advantage of natural light. However, gallery 5, 6 and 9 has no window or any sources of daylight. The gallery that have access to daylight where having problem associated with side window design, which is continue depreciation in the light level as one move from window level. Evidently the building interior finishes also affect the daylight distribution of this building. The average light level recorded in all the galleries range from 5-514 lux. Appreciably they are some galleries with good daylight design when compared with ISENA standard requirement for a museum spaces. Though, some gallery has either too much or no enough daylight which resulted to visual

discomfort. Below in figure 4.3 is the plan of light level recorded in existing galleries at Gidan Makama museum.

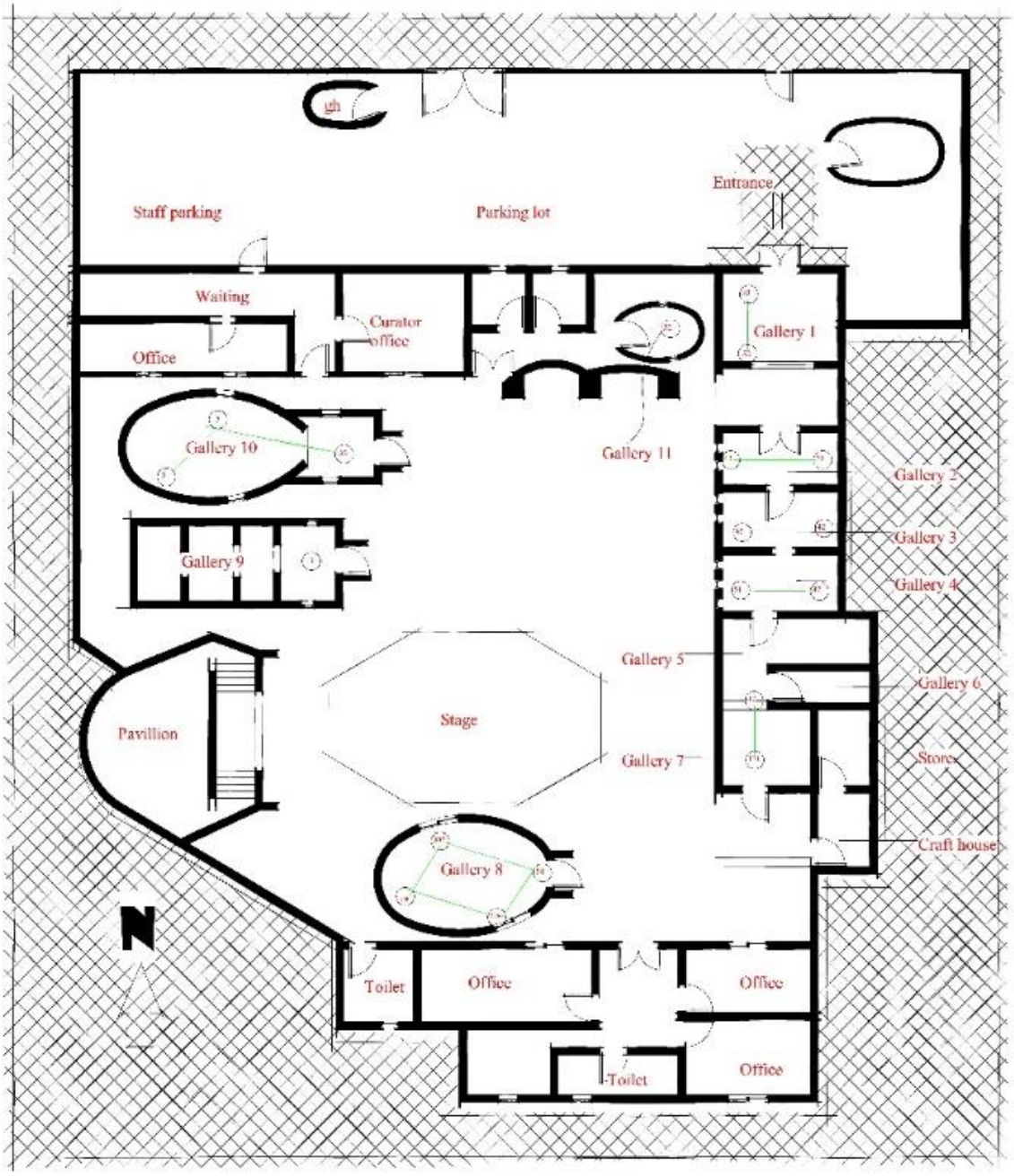



Figure 4.3: The illuminance level of Gidan Makama museum at the sensor
Source: Author's field study (2016)

#### 4.1.1.8 *Measured illuminance level at Gidan Makama museum*

The daylight level at Gidan Makama museum was measured with illuminance metre at 900mm working plane to shows the daylight distribution over the entire building spaces and compare with the IESNA standard as shown in table 4.1. Nevertheless, visual survey shows that most of the collections are not classified based on the amount of light to be admitted to the space Meaning the artefacts were haphazardly arranged which make it difficult to categorise. The change in the interior illuminations of the galleries are as a results of daylight design and architectures of the spaces. The interior finishes, reflectance properties of the materials and the opening design are the major factor that affect daylight distributions within this gallery. Gallery10, history of Kano and Nigeria history admit light level range of between 19-514 because of the large side opening on the perimeter of the circular form Building. This excess light level for art collections resulted to faint and deteriorated collections over time by the curator. Gallery 5 and 6 fully depends on artificial light as the there is no access to daylight.

**Table 4.1: Collection and light situation of existing gallery of Gidan Makama**

| Spaces | Collections | Range of light level R. (lux) | MVIR IESNA (lux) |
|---|---|---|---|
| Gallery 1 | History and Map of Kano and important history (painting) | 52-93 | 100 |
| Gallery 2 | Illustration of building technique and important monuments (painting and sculpture) | 21-43 | 100<br>300 and above |
| Gallery 3 | Skin and iron works and history of Kano (kansar) (natural history and iron work) | 9-51 | 50<br>300 and above |
| Gallery 4 | Devoted to the Jihad of Usman Dan-Fodio, the establishment of the emirate, government and the events of the 19th century (Painting). | 37-51 | 100 |
| Gallery 5 | Displays materials, illustrates aspects of Kano civil war, the reign of Emir Aliyu, the British invasion and the over-throw of the Sokoto caliphate. (Natural and painting) | 0 | 50<br>100 |
| Gallery 6 | Shows Kano under the colonial rule | 0 | 100 |
| Gallery 8 | Islamic paintings | 19-514 | 100 |
| Gallery 9 | Mostly sculpture | 0-13 | 150- 200<br>300 and above |
| Gallery 10 | History of Kano and Nigeria (painting) | 5-33 | 100 |
| Gallery 11 | Natural history; skin and painting Arts and crafts of Kano, the works of weavers, embroiders and leather works | 52 | 50<br>100 |

Source: Author's field study (2016)

The light level in some gallery shows optimum light level for museum. However, some museum space either has excess or insufficient daylight for visuals task and daylight requirement for artefacts.

### 4.1.2 Finding from Case Study 2 (National Museum of Art Kaduna)

The National Museum of Art Kaduna (Plate XXVII) is located within tropical wet/dry climate of Nigeria. The structure which was constructed with concrete and stones was originally the house for Northern People's Congress (NPC) and official became museum in 1975. This magnificent edifice is where artefacts from all part of the country are kept depicting Nigeria's artistry. The museum has collections of both Archaeological and Ethnographic materials ranging from terracotta figurines of human and animals from the famous Nok culture dated to about 2,500 years ago.



Plate XXVII: Approach Facade, National museum Kaduna

Source: Author's field study (2016)

#### 4.1.2.1 *Site planning and landscaping*

The site that houses the rectangular plan form building has been utilized to accommodate staff parking as well as those for visitors see figure 4.4. Though the parking space is small

and narrow which is the major problem to staff and the visitors to the facilities. in general, the site consists of few tress, hedges and disperse grasses.




Figure 4.4: Satellite image of National Museum of Art Kaduna

Source: Google Earth pro 7.0 (2016)

The trees on the site act as ground cover and also provides shades to the vehicles. Located on the site is the administrative section to the left of the museum and the education department. Behind the museum building is the sculpture garden, open seat out for outdoor activities, new library under construction, new museum kitchen and craft village. The site has one major entrance which is accessed from the busy traffic road of Angwan Sariki, it is bounded to the left by investment house and to the right by shops.

4.1.2.2 *Spatial organisation*

The functional spaces are divided into three categories which are; Archaeological section, Ethicon logical section and Modern section as shown in figure 4.5. Archaeological section shows artefacts of the; Early Stone Age, Middle Stone Age, and Late stone age, Ethicon logical section display artefacts of the; Juju, Money seat e.g. currency change, gods e.g.

god of the worm, god of peace, weapon, Musical instrument and Modern section basically encompasses brass, cast work display. The upper floor of the building is the staff and management offices as shown in figure 4.6.

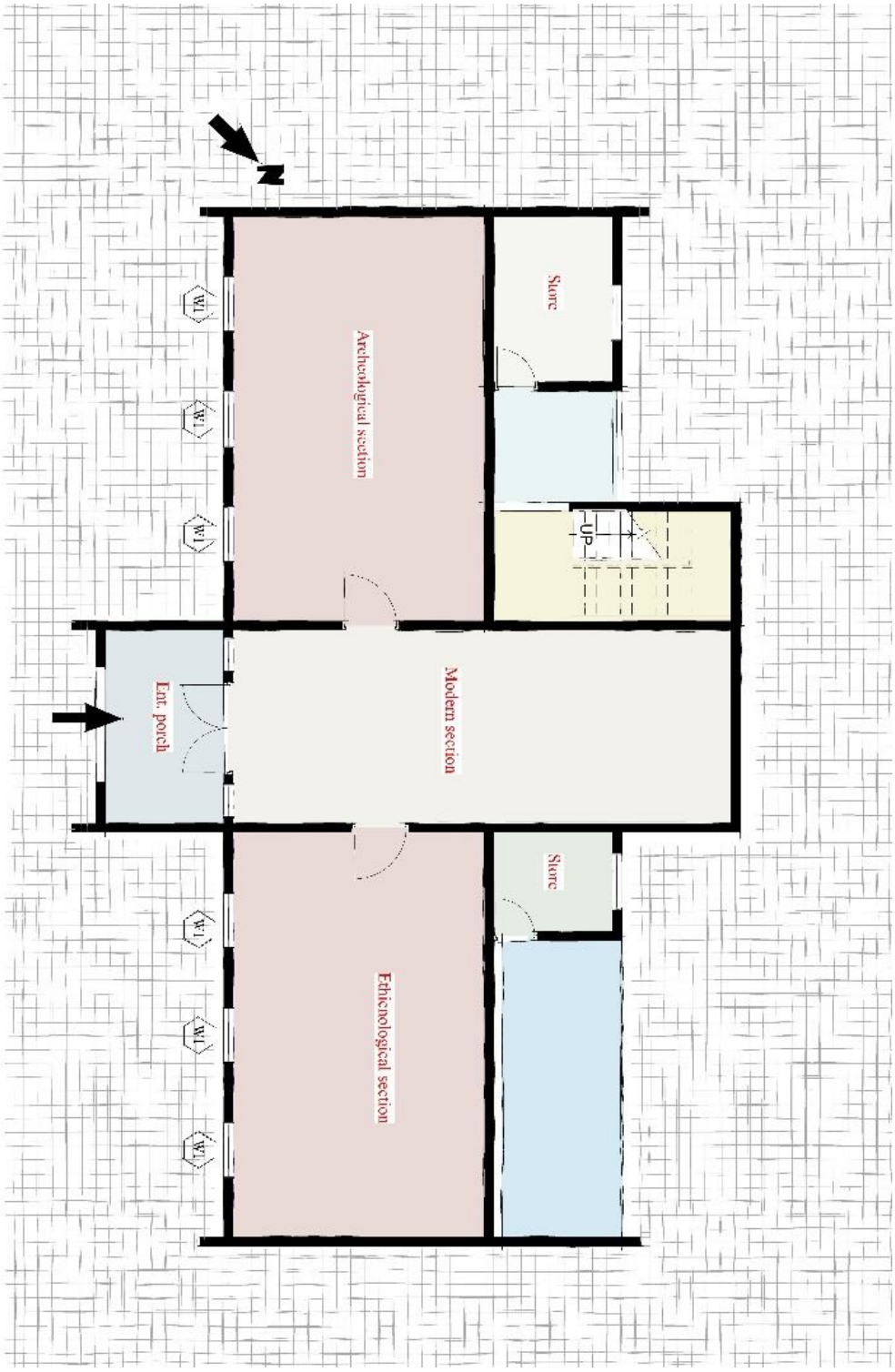



Figure 4.5: Ground floor plan of National Museum Kaduna

Source: Author's field study (2016)




Figure 4.6: First floor plan of National Museum Kaduna

Source: Author's field study (2016)

*Auxiliary facilities:* The auxiliary facilities include outdoor (craft village) (Plate XXVIII) hair weaving area with wooden chair, Cloth weaving, Painting and Dying area, Potter area, Restaurant, Bronze and silver smith and Exhibition area. The other facilities include administrative block, Education department, Museum kitchen (shown in Plate XXIX),

green spaces with concrete and steel sculpture as shown in plate XXX, this facility are located within the same site layout with the museum building.



Plate XXVIII: Craft Village, National Museum Kaduna
Source: Author's field study (2016)



Plate XXIX: Museum Kitchen, National Museum Kaduna
Source: Author's field study (2016)



Plate XXX: Sculpture Garden, National Museum Kaduna
Source: Author's field study (2016)

4.1.2.3 *Materials and reflectance*

The interior wall of the building is plastered with cement/sand mortar and painted white for high reflectance of light in the galleries. Although findings from field survey shows that the louvre side windows give no optimum performance for a museum building when compared to standard museum lighting requirement. This is due to the window sizes and the major problems of distribution daylight with side windows.

4.1.2.4 *Building orientation*

The museum is orientated with longer axis 45-degree NE see figure 4.5. Most structures located on the sites are designed with no proper consideration for orientation. Which have effect on daylight performance of the building.

#### 4.1.2.5 *Size and depth of spaces*

Sizes and depth of spaces doesn't only determine the size of furniture to be used within a space but also helps in determining the path through which daylight can travel within space. This case has spaces with depth of 3.3m which has given enough room for daylight to occupy the spaces. Which give a comfortable working environment (visual). In gallery, the light level reduces from window plane toward the end of room deep inside

#### 4.1.2.6 *Ceiling geometry and window sizes*

The ceiling is a normal screed floor slab in the ground floor and the first floors. The design is plain which help in reflecting daylight further within the space. The ceiling is painted white; however, the paint is fading which resulted to low room reflectance. The source of daylight into this space is louvre side window of dimension of 1.2x1.5m which is only from one side of the perimeter wall. The light keeps reducing from window side light to the end of the room, this is in accordance with De Nadal (2005), findings that windows side light on the perimeter, will rarely reach the first 5m from the window plane.

#### 4.1.2.7 *Daylight situation of Kaduna museum*

The measured light level at Kaduna museum is shown on figure 4.7 below, the readings taken with illuminance metre on sunny day between 2-3p.m on 13$^{th}$ October. At the work plane of 900mm from the floor level and the sensor point located and the readings was recorded. The reading show that here is excess daylighting in the three galleries this is has a result of side opening of 1200mmx1500mm

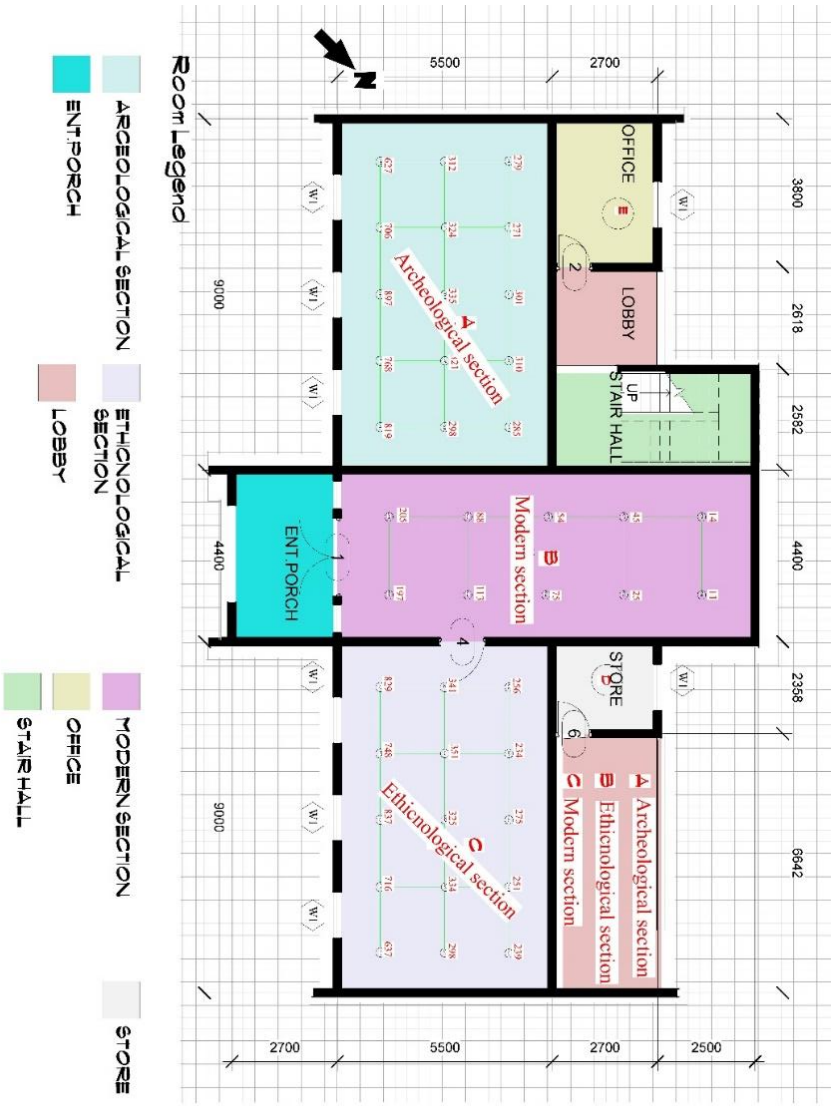



Figure 4.7: The illuminance level of Kaduna museum at the sensor points.

Source: Author's field study (2016)

4.1.2.8 *Measured illuminance level at Kaduna museum*

Table 4.2 below shows the measured light level and compared with the standard specification by IESNA standard for museum building. This is shown on floor plan in figure 4.8. However, the arrangement of the art works and the collections is not well classified making it difficult when comparing. The result from table 4.2 shows that the amount of the light in all the three separate galleries is more than what is require. This is as a result of large opening on side wall.

Table 4.2: Collection and light situation of existing gallery of Kaduna museum

| Spaces | Collections | Range of light Recorded (lux) | MVIR IESNA (lux) |
|---|---|---|---|
| Archaeological section | Early Stone Age, Middle Stone Age, and Late stone age. | 310-950 | 50<br>100<br>300 and above |
| Ethnological section | Juju, Money seat e.g. currency change, gods e.g. god of the worm, god of peace, weapon and Musical instrument collections | 313-952 | 100<br>300 and above |
| Modern section | Modern section basically encompasses brass, cast work display | 11-207 | 300 above |

Source: Author's field study (2016)

### 4.1.3 Findings from Case Study 3 (National Museum of Colonial Kogi)

Kogi State is the most centrally located of all the states of the federation. Lokoja, the state capital town was originally established in 1945, as the provincial headquarters of Kabba. The area has contributed in no small measure to the political growth of the Nigeria before, during and after the colonial period in 1904. Located within coordinates 7049N, 6045E, with an average temperature of 28 ºC, the study area experiences an average mean day light of 12 hours, which could be harnessed for the benefit of the museum for display. Kogi state museum of colonial history (see Plate XXXI) is a structure build with wood, steel and concrete materials, located within tropical wet climate of Nigeria (Koppen-Trewartha-Horn classification scheme, 1980). The museum was formally Lugard house before it conversion. The exhibition gallery of museum of colonial history was formally

commissioned by Alhaji Idris the then executive governor of Kogi state on Friday 30th June 2006.




Plate XXXI: Approach view of Kogi Museum of colonial history
Source: Author's field study (2016)

4.1.3.1 *Site planning and landscaping*

The 2.5m suspend structure is supported by other facilities. They include the entrance gate house and the parking space provided just a few metres from the entrance to the building for the staff and visitor. The kitchen, restaurant and the toilet are at the rear of the museum. the Planting of hedges around the building help beautify the place as well as serve as ground cover. The few trees were also observed in the surrounding which help shade against solar radiation as show in figure 4.8. The restaurant and the bar located toward the north of the museum open to visitors and the passer-by




Figure 4.8: Satellite image of Kogi Museum of colonial history
Source: Google Earth pro 7.0 (2016)

4.1.3.2 *Spatial organisation*

The galleries are access from the southern stair case which lead directly to the reception hall were visitor are first introduce (figure 4.9), to the left side is the galleries of precolonial history of Nigeria. Showcase the painting of leaders before colonial master and the date they ruled. Labelled B shows the gallery of colonial ruling of Nigeria with series of the picture and painting of the colonial leader and the period they ruled. The gallery with legend C as shown in the figure 4.10 is the paintings of history of Nigeria and history of Kogi was elaborated on the gallery D. The administrative facilities surrounded the main galleries denied the galleries directed access to daylight.

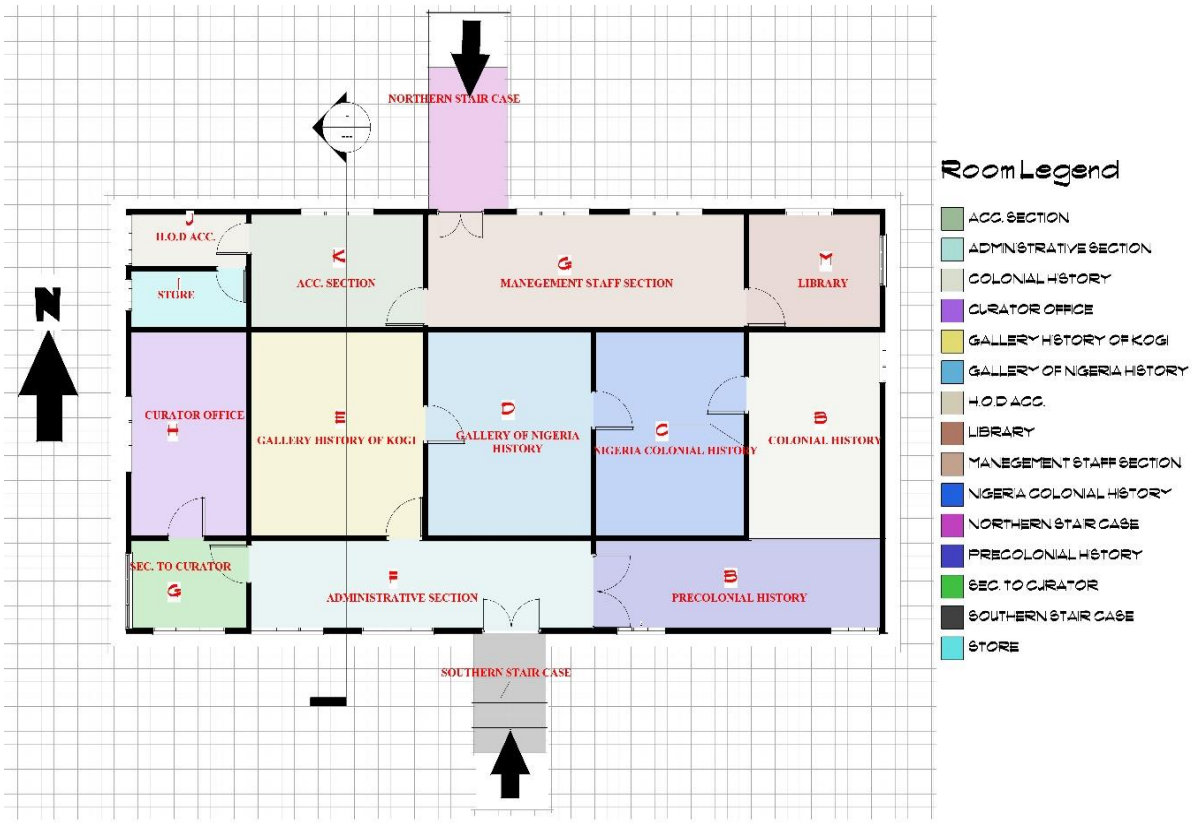



Figure 4.9: Floor plan and daylight level at Kogi state museum

Source: Author's field study (2016)

4.1.3.3 *Materials and reflectance*

The building used white finishes for both the walls and the ceilings. However, wooden material used for the construction of the walls, has resulted to low reflectance of light within the spaces for the required visual task (Plate XXXII) and uneven light distribution. Appreciably some of the sensor point fall within the illuminance requirement for a museum building.



Plate XXXII: Checking for light level at 900mm above floor

Source: Author's field study (2016)

4.1.3.4 *Building orientation*

The longer axis of the building was oriented to face the North-South direction (see figure 4.8); this feature has given the building the advantage of capturing more daylight while reducing the thermal impact of sunlight. Few Trees along the East-West direction has helped in shading the museums and offices along this side.

4.1.3.5 *Size and depth of spaces*

They building mostly rectangular spaces of different sizes and headroom of 3.6m from the floor level. The depth is not much and have helped the spaces achieved a considerable level of daylight for task performance (figure 4.10), though the optimum performance was not achieved as the like light level is in excess for the museum collections.

4.1.3.6 *Ceiling geometry and window sizes*

The ceiling is made of wood painted with white colour, designed curved as shown in figure 4.10, which give visitor feeling of spaces. The windows were top hung (see plate xxix) large enough to admit daylight in to the building, hence there was abundant light at the places the windows were position.



Plate XXXIII: Top hung window at Kogi state museum

Source: Author's field study (2016)

4.1.3.7 *Daylight design strategy*

The building which was originally Lugard house is a suspended wooden structure painted with white in the interior. The openings significantly allow much light into the space for museum design where much emphasis is place in daylight control. Evidently the window design which is intend to serve as shading device is poorly constructed and not suitable

to bring in the desired light level (Plate xxx) thus causing dark areas on the displayed artefacts while leaving some part with excessive daylight.



Plate XXXIV: Effects of window design on the daylight performance

Source: Author's field study (2016)

The core interior of the building which include gallery C, D and E has no access daylight as they are bounded by administrative block and management offices as shown in figure 4.11. This leaving space with high percentages of about 47 percentage of the building fully depending on the artificial light. This was in line with (Onuwe, Goshi , & Alonge, 2015), findings that museum in Nigeria over dependent on artificial light due to inability of designer to make optimal use of the available daylight.

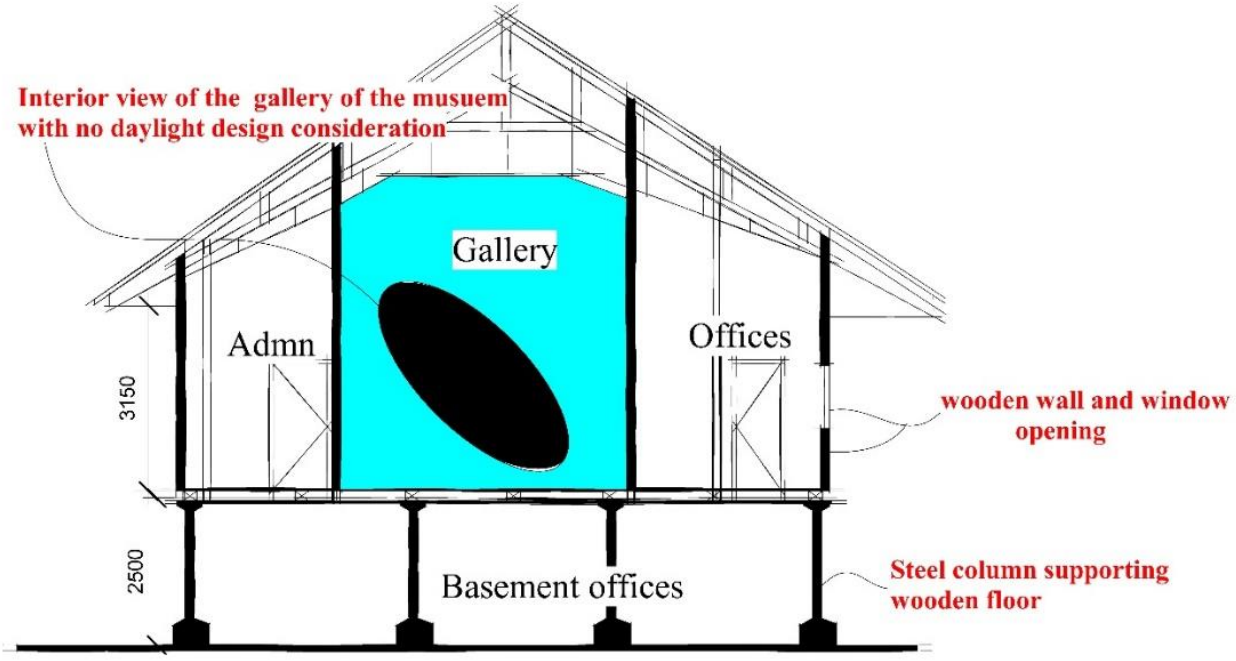



Figure 4.10: The core interior of the museum depending full on artificial light

Source: Author's field study (2016)

4.1.3.8 *Measured illuminance level at Kogi museum*

For the study to answer research question one, light metre reading was recorded at 900mm work plane with many sensors point at existing Kogi museum on a sunny day (1-3pm). This is represented on the plan below in figure 4.12. Furthermore, table 4.3 was developed to show the collection in each gallery and compared the measure result with the standard by ISNEA 9$^{TH}$ edition

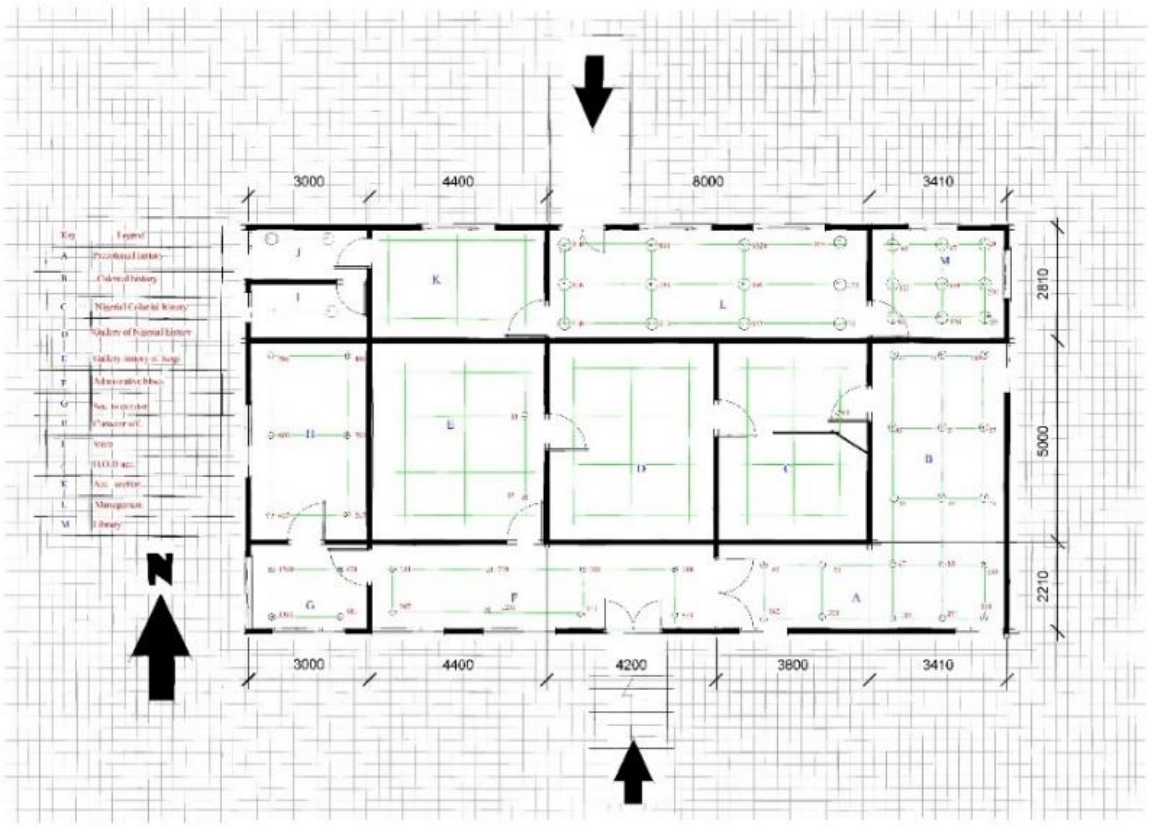



Figure 4.11: The illuminance level of Kogi museum at the sensor points.

Source: Author's field study (2016)

Table 4.3: Collection and light situation of existing gallery of Kogi museum

| Spaces | Collections | Range of light Recorded (Lux) | MVIR IESNA (Lux) |
|---|---|---|---|
| Precolonial history | Precolonial paintings | 67-562 | 100 |
| Colonial history | Colonial Paintings | 35-310 | 100 |
| Nig. colonial history | Paper Paintings | 0.00 | 100 |
| History of Nigeria | History of Nig. Painting | 0.00 | 100 |
| Gallery history of Kogi | Paintings | 0.00 | 100 |

Source: Author's field study (2016)

The result in table 4.3 shows that 47% of the building area depends on artificial light which is the assumption of (Onuwe, Goshi , & Alonge, 2015), that museum building fully depends on artificial light.

## 4.2 Validation Studies

The measured result from the field study of existing daylight situation of Kaduna museum and simulated illuminances from validation studies were analysed. The simulated results were obtained using Autodesk Ecotect Analysis and Daysim Lighting software. The data were analysis using descriptive statistics; visually, the data were analysed using a two-line graph for comparison, while statistical tests for mean bias error, root mean square and percentage error were used to analyse the data. In Table 4.4 are listed, the characteristics of the museum to be simulated and the state of the museum at the time the research was carried out.

Table 4.4: Information on measured and simulated museum

| Name | Details |
|---|---|
| Location | Kaduna, Kaduna state. |
| Electric Lighting | off |
| Time and date of Measurement | 1-3pm<br>13/10/2016 |
| Latitude and Longitude | 10˚32’55.69’’N<br>07˚26’33.22’’E |
| Elevation from sea level | 210M |
| Orientation of test rooms | 45˚NE |
| Internal length, width and height | 9.0 m, 5.5m and 3.3m |
| Were the rooms occupied during measurements | yes |
| Type of window and glazing | 1.2 x 1.5m louvre windows, 3mm glass |

Source: Author’s field study (2016)

While table 4.5 describes the variable to be measured, position of sensor and the measuring tools to be used. The illuminance level was recorded at fifteen sensor points with a height of 900mm from floor level in clear sky condition between 1-3pm.

Table 4.5: Measured variables, position of sensor and measuring tools used

| Variable to measured | Illuminance |
|---|---|
| Measuring Tool | Light metre HS 1010A |
| Number of sensors | 15 |
| Height of sensor | 900mm from floor level |
| Type of Sky | Clear sky |

Source: Author's field study (2016)

### 4.2.1 Simulation and Measured Results

Table 4.6 Shows results of the measured and simulated result from field survey the error and Error². The result is also represented on plan in figure 4.12 (Measured Illuminance Level) and figure 4.13 (Simulated Illuminance Level). The sensors point for the simulation were position using the grid system as in the measured results.

With the sensors points on the same position the result shows average illuminance level of 456.87 lux for the actual measurement while the simulated results recorded during testing was 448.15 lux. This difference can be attributed to the changing irradiance of the sun as well as shading from surrounding buildings. Which is beyond researchers control. However, Reinhart (2009), opines that for a validation simulation data to be acceptable as reliable, the values of mean bias error (*MBE*) have to fall within a range of -15% to 15%, while for root means square error (*RMSE*) the values have to be less than 35%. Below in table 4.6 is the measured and simulated results.

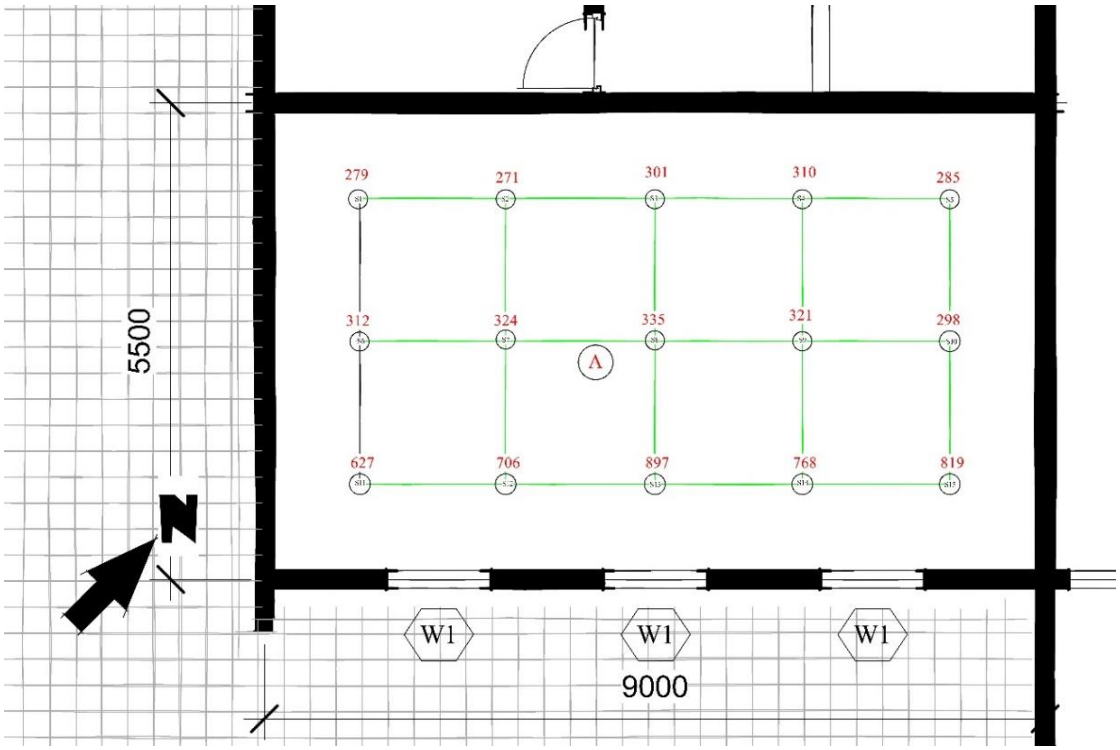



Figure 4.12:The measured Illuminances of Kaduna museum, Kaduna state

Source: Author's field study (2016)

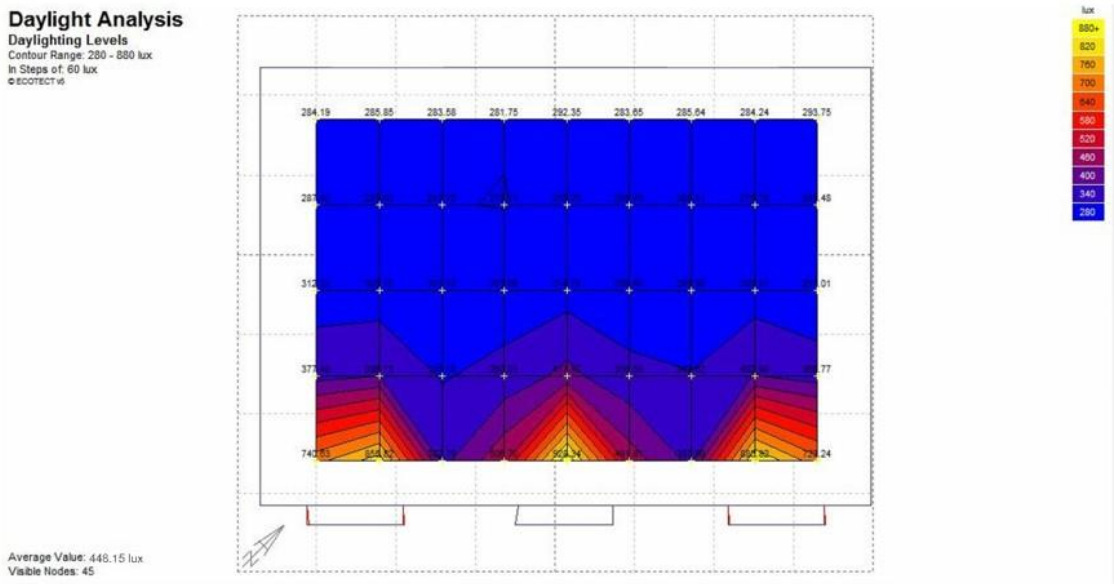



Figure 4.13:The Simulated Illuminances of Kaduna museum, Kaduna state

Source: Author's field study (2016)

Table 4.6 Measured and simulated illuminances in museum at Kaduna

| Work plane sensors | Measured (lux) | Simulated (lux) | Error (Sim-Mea) | Error² $(Sim-Mea)^2$ |
|---|---|---|---|---|
| S1 | 279 | 284.19 | 5.19 | 26.94 |
| S2 | 271 | 283.58 | 12.58 | 158.26 |
| S3 | 301 | 292.35 | -8.65 | 74.82 |
| S4 | 310 | 285.64 | -24.36 | 593.41 |
| S5 | 285 | 293.75 | 8.75 | 76.56 |
| S6 | 312 | 312.00 | 0.00 | 0.00 |
| S7 | 324 | 301.00 | -23.00 | 529.00 |
| S8 | 335 | 314.78 | -20.22 | 408.85 |
| S9 | 321 | 299.98 | -21.02 | 441.84 |
| S10 | 298 | 297.01 | -0.99 | 0.98 |
| S11 | 627 | 740.63 | 113.63 | 12911.78 |
| S12 | 706 | 682.79 | -23.21 | 538.70 |
| S13 | 897 | 928.34 | 31.34 | 982.20 |
| S14 | 768 | 683.89 | -84.11 | 7074.49 |
| S15 | 819 | 722.24 | -96.76 | 9362.50 |
| Average | 456.87 | 448.15 | | |
| Sum | | | -130.83 | 33180.33 |

Source: Author's field study (2016)

From the results of the tests above, it can be deduced that there is an indication of a strong relationship, which is also significant between the measured and simulated values of illuminances in the model.

### 4.2.2 Visual Analysis

Looking at the table 4.6 in page 87, it is difficult to trace a relationship due to numeric values. The data's is plotted on a graph below (figure 4.14) to show the inter-relationship between the measured and simulated illuminances in Kaduna museum. Looking at the preceding figures, the results are not easily indicative of any relationships. Upon comparing the descriptive graphs visually, it can be seen that the simulated illuminances followed the measured illuminances closely (Figures 4.14). A good qualitative agreement can be seen with the peaks and troughs of the simulated illuminances following that of the measured. However, there are some deviation which is statistically calculated to show it level of significance and relationship.

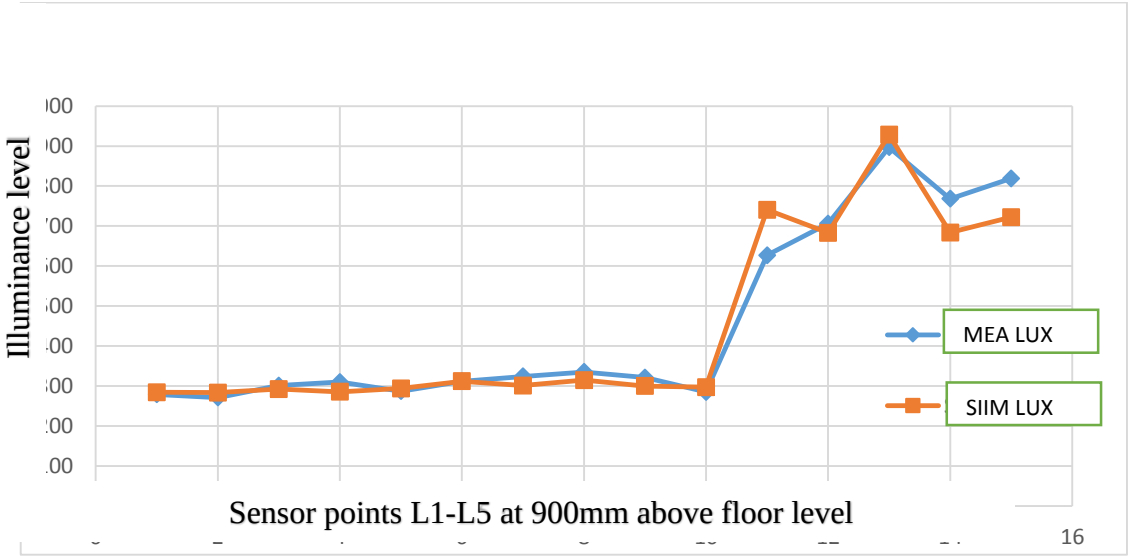



Figure 4.14:Measured and simulated illuminances, Kaduna museum, Kaduna

Source: Author's field study (2016)

### 4.2.3 Tests for Relationships

In order to ensure the computational reliability of the proposed daylight performance of light pipe, validation methods have to be applied to assess the model's validity. Therefore, rather than to rely on a single statistical procedure, model evaluation is to be carried out using two statistical procedures the mean bias error percentage (*MBE*) and the root mean

square error percentage (*RMSE*) (Efim & Kudish, 2009; Katiyar, Kumar, Pandey, & Das, 2010). A summary of the statistical tools used throughout this work is presented below.

4.2.3.1 *Mean bias error (MBE)*

Mean bias error percentage (*MBE*) percentages are an indication of the average deviation of the predicted values from the measured values and provide information on the long-term performance of the models. Positive values demonstrate that the predicted values overestimate the measured values while negative values demonstrate an underestimation of the measured values ( Falayi, Rabiu, & Teliat, 2011).

The %MBE for this study is; $\%MBE = \frac{100}{Xmea(av)} \sum \frac{(Xsim - Xmea)}{N}$

Where $X_{sim}$ is the simulated illumination value, $X_{mea}$ is the measured value of illumination and $X_{mea(av)}$ is the average value of measured illuminance and N is the frequency of measured illumination value (No of sensor points).

Data;

$X_{mea(av)=}$ 456.87

$\sum(X_{sim}-X_{mea})$ =-130.83

N=15

Therefore %MBE= -1.91% which can also be called Percentage average deviation (PAD) according (Zhang, 2002)

4.2.3.2 *Root mean square error percentage (RMSE)*

The *RMSE* percentage is a measure of variation of predicted values around the measured values and is always a positive percentile and it provides information on the short-term performance of the models and the lower its value, the more accurate the prediction.

$\%RMSE = \frac{100}{Xmea(av)} \sqrt{\frac{1}{N}} \sum (Xsim - Xmea)^2$

Where $X_{sim}$ is the simulated illumination value, $X_{mea}$ is the measured value of illumination and $X_{mea(av)}$ is the average value of measured illuminance and N is the frequency of measured illumination values (No of sensor points).

Data;

$X_{mea(av)=}$ 456.87

$\sum(X_{sim}-X_{mea})^2$=33180.33

N=15

Therefore % *RMSE* = 10.30%

The above results of %MBE= -1.91% and % *RMSE* = 10.30% show that the instrument for test of daylight performance of the variable is reliable. According to Reinhart (2009), for a validation simulation data to be acceptable as reliable, the values of mean bias error (%*MBE*) have to fall within a range of -15% to 15%, while for *RMSE*, the values have to be less than 35%. From the results of the tests above, it can be deduced that there is an indication of a strong relationship, which is also significant between the measured and simulated values of illuminances in the model.

### 4.3 Evaluation Studies

In the test for the performance of light pipe, the independent variables; sky condition are fixed while the dependent variables; light pipe aspect ratio is adjusted to test for it daylight performance. The results are recorded to score the extent to which aspect ratio of light pipe affect it daylight performance. In table 4.7 is the list of the variable to be tested for, while table 4.8 represent sensor position on the room

Table 4.7: The conditions of simulation

| Condition | Light pipe diameter | Light pipe height | Aspect ratio | Area lit |
|---|---|---|---|---|
| Aa | 600 | 1800 | 1:3 | 3x3 |
| Ab | 600 | 3000 | 1:5 | 3x3 |
| Ac | 600 | 6000 | 1:10 | 3x3 |
| Ba | 300 | 3000 | 1:10 | 3x3 |
| Bb | 650 | 3000 | 1:5 | 3x3 |
| Bc | 750 | 3000 | 1:4 | 3x3 |

Source: Author's field study (2016)

Table 4.8: Sensor positions in the test room

| Point | Position in the test room |
|---|---|
| Sensor A | 600mm from floor level |
| Sensor B | Suspended in the mid Centre of the test room |
| Sensor C | Top entry of the test room |

Source: Author's field study (2016)

### 4.3.1 Room Reflectance

In architecture, Light Reflectance Value (LRV) is a measure of visible and usable light that is reflected from a surface when illuminated by a light source (Jefferies, 2010). Light distribution is highly dependent on room reflectance. In general, the ceiling is the most important light-reflecting surface (Queen, 2008). The IESNA guideline of 70/50/20 (ceiling/walls/floor) for minimum reflectance follows this principle (Mankova, Hraska, & Janak, 2009). Therefore, for the study the reflectance's index of the material used are listed on table 4.9

Table 4.9: Material reflectance for the simulation

| Material | Reflectance index |
|---|---|
| Mirrored light pipe | 0.98 |
| Wall | 0.50 |
| Floor | 0.30 |
| Ceiling | 0.70 |

Source: IESNA guideline (1996)

### 4.3.2 Software Application and Computer Model Processes

The parameters were input into the Ecotect®, Radiance and Daysim® software so as to compare and validate results. The room was modelled in Revit® architecture Design software as seen in Figure 4.15.

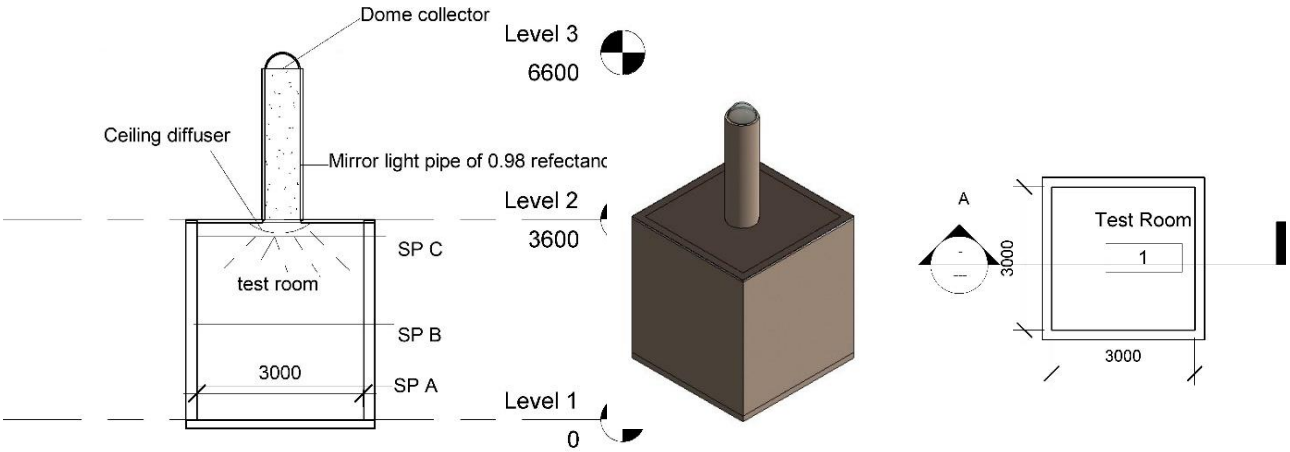



Figure 4.15:The Model

Source: Author's field study (2016)

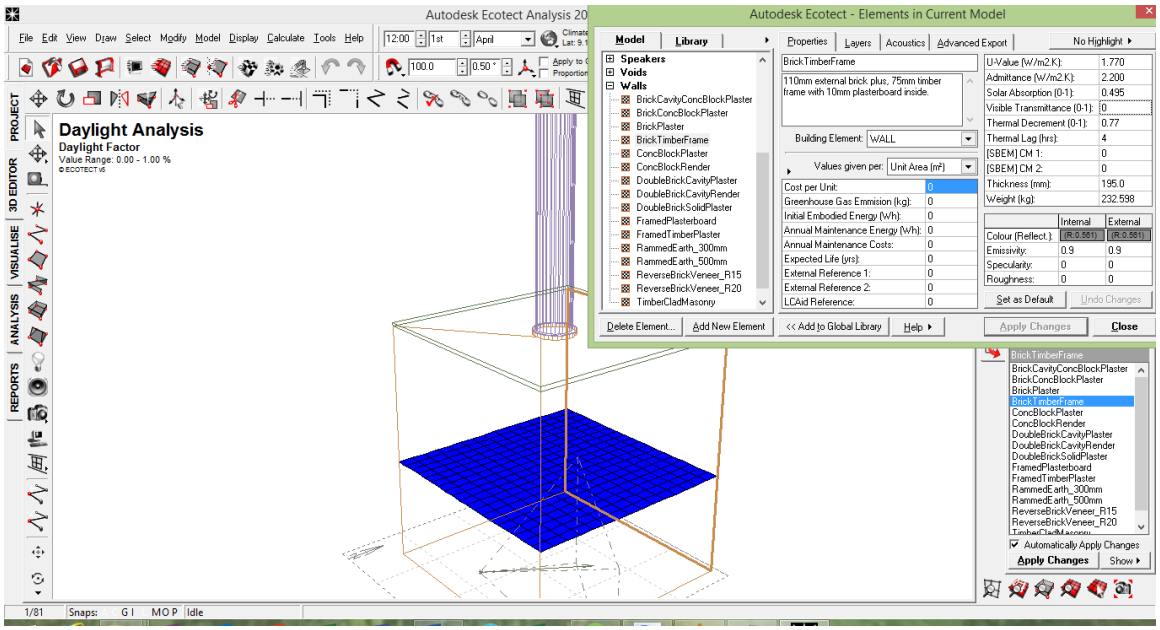



Figure 4.16:Appling material

Source: Author's field study (2016)

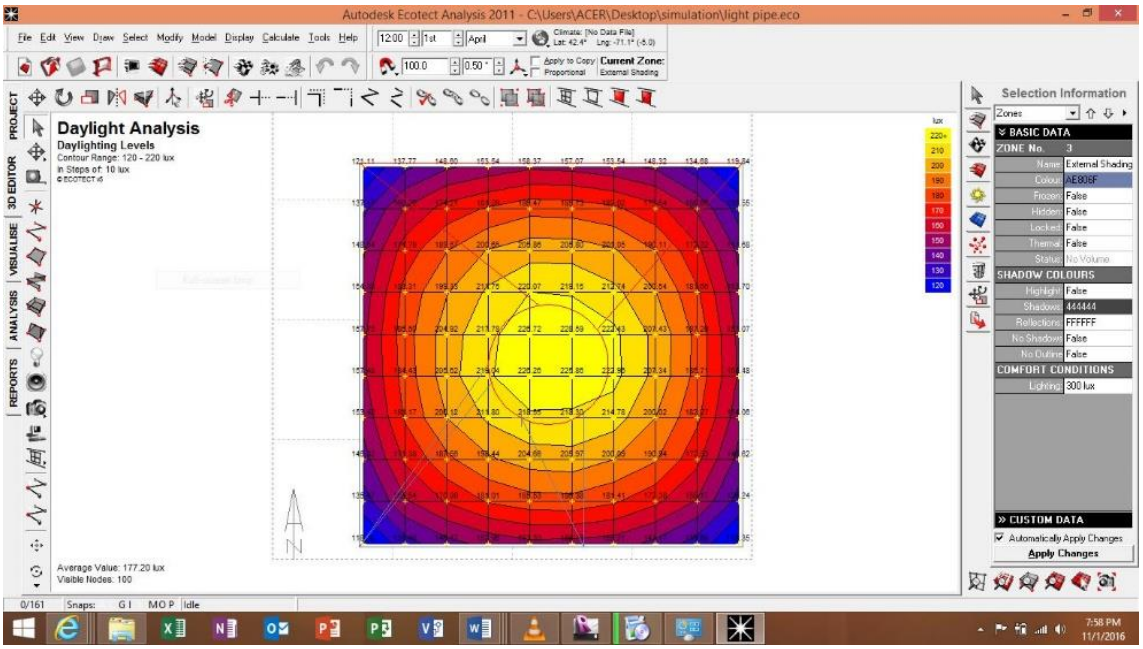



Figure 4.17:Visualizing the result

Source: Author's field study (2016)

Further modelling was carried out through the employment of the same process under a given number of conditions as seen in Table 4.7. The sensors were kept as listed in Table

4.8 for all the simulations carried out under conditions Aa, Ab, Ac, Ba, Bb and Bc. The result is shown below in table 4.10

Table 4.10: Test result and Generation of design frame work for light pipe design

| Condition of simulation | Sensor A light level | Sensor B Light level | Sensor C light level |
|---|---|---|---|
| Aa | 213.7 | 228.4 | 232.1 |
| Ab | 195.3 | 198.7 | 201.5 |
| Ac | 105.2 | 153.5 | 165.7 |
| Ba | 87.5 | 107.5 | 114.1 |
| Bb | 169.7 | 177.2 | 189.2 |
| Bc | 187.1 | 195.8 | 209.4 |

Source: Author's field study (2016)

The above simulation results show that with the increase in height of light pipe in condition Aa, Ba and Ca, there is steady decrease in average light level from 232.1-201.5 lux and 201.5-165.7 lux at the test room sensor point C. The level of illumination began to decrease gradually at an average of 15.45%, with aspect ratio 1:10 give optimum performance for daylight requirement in museum galleries. At the entrance of the pipe to the test room the illuminance level is high recorded as 232.1 lux.

While the test for effect of increasing diameter of light pipe on daylight performance shows that with increase in diameter of light pipe, there was steady increase in illumination level. For the diameter 300mm the illuminance level is 107.5 lux, while for the diameter 650mm the illuminance level is 177.2 lux at the midpoint (sensor B). The average illuminance continues to increase so that diameter has much effect on daylight output of light pipe. The result at different sensor points are shown in figure 4.18

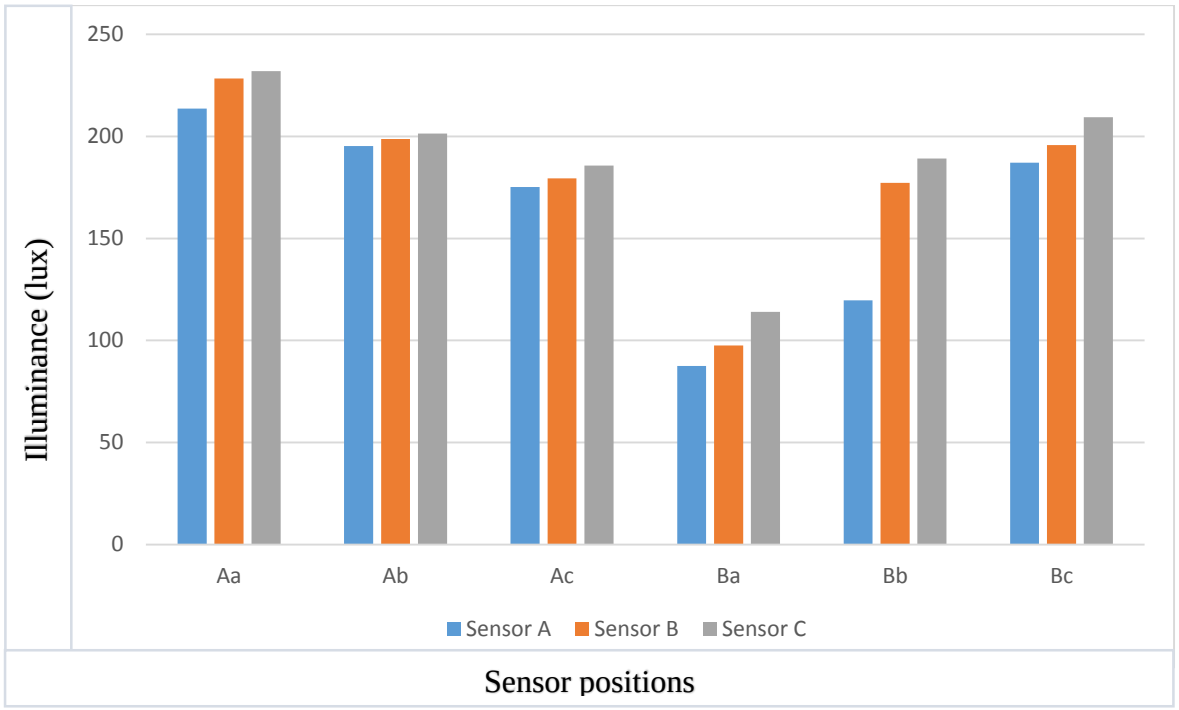



Figure 4.18:Illumination Quality for all Conditions at all Sensor Positions

Source: Author's field study (2016)

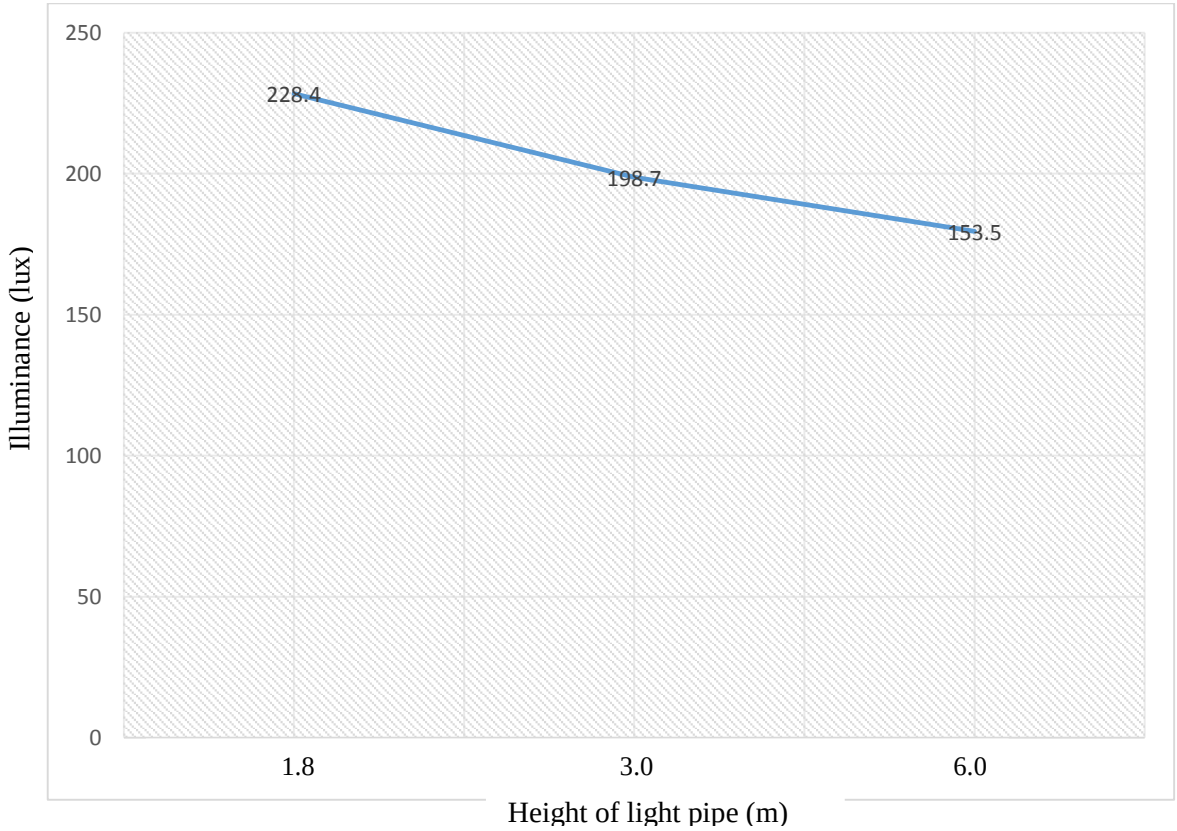



Figure 4.19:Daylight performance of light pipe with increase in height

Source: Author's field study (2016)

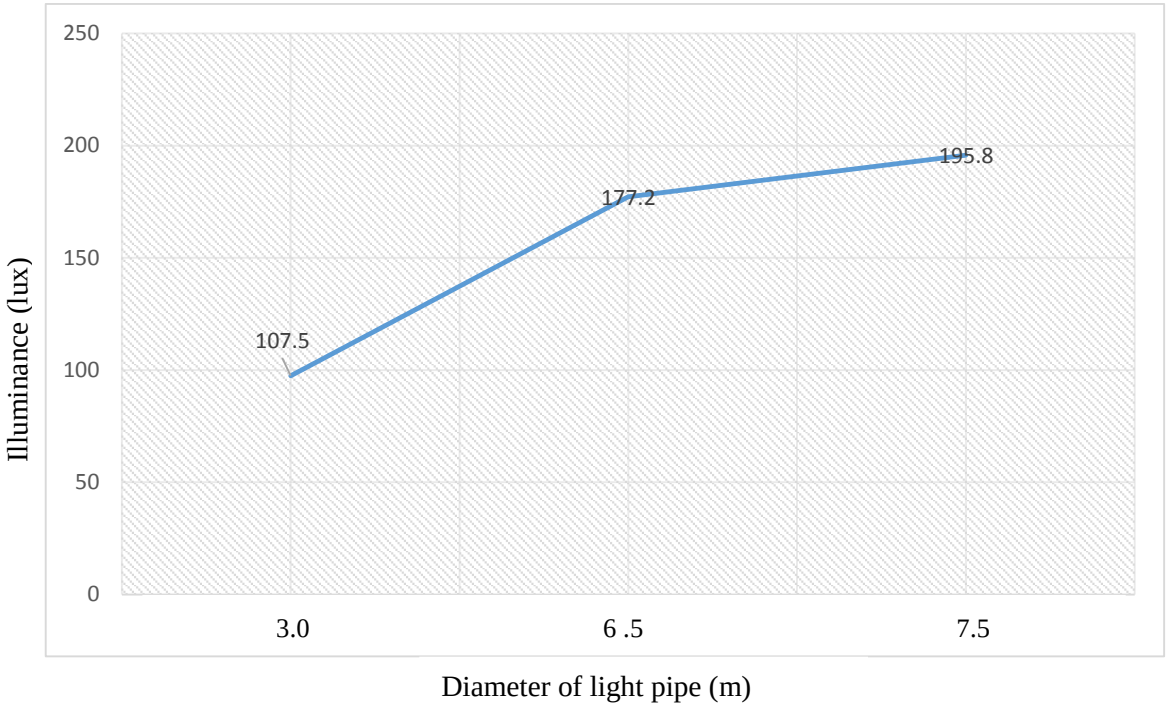



Figure 4.20:Daylight performance of light pipe with increase in diameter

Source: Author's field study (2016)

### 4.4 Analysis Summary

The test for light pipes performance, a box (3m x 3m x 3.6m) was modelled and exported to Ecotect® Radiance® Daysim® and the illumination received in the box was recorded. Varying the lengths of light pipe while keeping the diameters of the pipe constant to test for how far the illumination within the Light pipes can travel while meeting the minimum illumination requirement for museum space. The results show that the illumination decreases for condition Aa to Ab and Ac at sensor C is 232.1 lux to 201.5 and 165.7 lux respectively. The illuminance reduces at an average of 15.45%, However, light level can further be increase by introducing light redirection device.

The simulation test for effect of both diameter and length of light pipe, shows that light pipe with aspect ratio of 1/10 give optimum performance for daylight requirement in museum design in tropical climate.

## 4.5 Summary of Findings

Collections in Nigeria museums range from paper paint work to sculpture and natural history collections; however, the case study visual survey show that some of the collections are not arrange according to the amount of daylight required for each space as specified by IESNA guideline for museum daylight design.

**Research question two;** The illuminance readings recorded in most of the galleries are not adequate when compare with standard requirement for a museum, however appreciably some sensor point in the galleries fall within the range. In the second case study the average illuminance level decreases from 335lux to 301lux at distance of 2750mm and 897lux to 301lux at distance of 4500mm from window plane respectively. This is in line with the argument of De Nadal (2005), that light continues to reduce from window plane. De Nadal argument is that light rarely reach 5m from window level.

The case study of Kogi museum of colonial history shows that 47% percent of the building fully depends on artificial light leading to high energy consumption, this research confirms an assumption by Onuwe, Goshi , & Alonge (2015), that museum in Nigeria fully depend on artificial light.

**Research question three**

For a test room of 3x3x3.6m and increase in height of light pipe in series with other variable keep constant there was steady average decreases in illuminance output of 15.45% with aspect ratio of between 1/3-1/10

For the diameter 300mm the illuminance level is 107.5 lux, while for the diameter 650mm the illuminance level is 177.2 lux. The average illuminance continues to increase at 24.42% so that the diameter of light pipe has much effect on it daylight output.

## 5.0 DESIGN REPORT

### 5.1 Site Location

Nigeria is located in Western Africa, bordering the Gulf of Guinea, between Benin and Cameroon, 10°N 8°E and has a total area of 923,768km$^2$, with varying climate from equatorial in the south, tropical in the centre to arid in the north. Nigeria has 36 states and a Federal Capital Territory at the centre (figure5.1), which serves as the seat of government. Abuja is both a Federal Capital Territory within the nation of Nigeria and a city within that territory which serves as the nation's capital. Both were created in 1976, while the city was built throughout the 1980s. It officially became Nigeria's capital on December 12, 1991, replacing the role of the previous capital, Lagos. When Nigeria's independence from the United Kingdom necessitated a new capital city, it created not only a city, but a new Federal Capital Territory as well.. This territory was formed with the express purpose of supporting Abuja city, encircling it within a womb of nature. It is, therefore, virtually impossible to speak of one as separate from the other.




Figure 5.1: Map of Nigeria showing Abuja

Source: www.abuja-ng.com(2016)

It lies between latitude 9.02°N - 9.25°N and Longitude 6.045°E-7039°E. It has access to all major cities in the country and indeed the continent. Abuja (figure 5.2) was as an entirely purpose-built, planned city, The Abuja master plan is similar to Lucio Costa's airplane plan for Brasilia. Besides being the administrative seat of government, Abuja is a beautiful city in a scenic valley of rolling grasslands in a relatively undeveloped ethnically neutral area, surrounded by hills such as the Gwagwa Hills near Suleja, the Chukuku Hills, the Agwai Hills and the famous Zuma rock, just to mention a few.

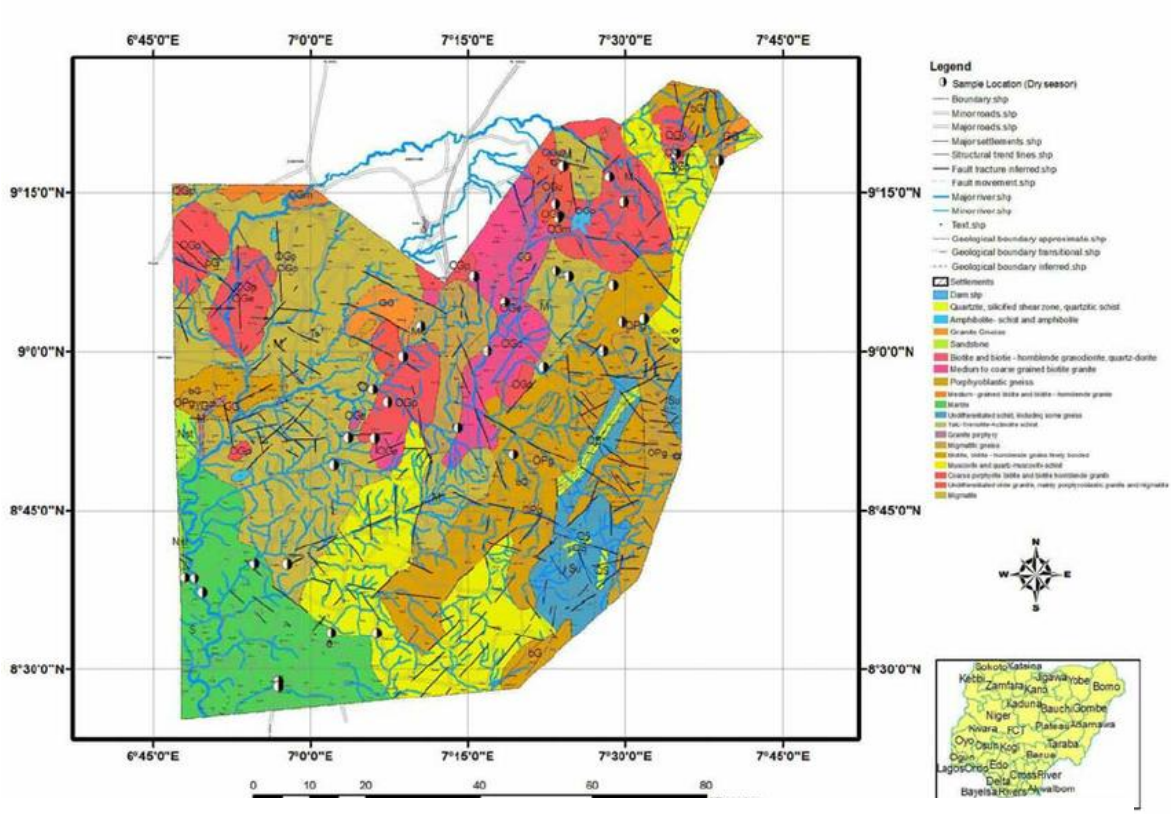



Figure 5.2: Map of Abuja

Source: www.abuja-ng.com(2016)

The indigenous inhabitants of Abuja are the Gbagyi (Gwari) as the major language, Bassa, Gwandara, Gade, Ganagana, Koro etc. In light of the ethnic and religious divisions of Nigeria.

## 5.2 Climate of Abuja

Abuja under Köppen climate classification features a tropical wet and dry climate. The FCT experiences three weather conditions annually. This includes a warm, humid rainy season and a blistering dry season. In between the two, there is a brief interlude of harmattan occasioned by the northeast trade wind, with the main feature of dust haze and dryness. The rainy season begins from April and ends in October, when daytime temperatures reach 28 °C (82.4 °F) to 30 °C (86.0 °F) and night-time lows hover around 22 °C (71.6 °F) to 23 °C (73.4 °F). In the dry season, daytime temperatures can soar as high as 40 °C (104.0 °F) and night-time temperatures can dip to 12 °C (53.6 °F). Even the chilliest nights can be followed by daytime temperatures well above 30 °C (86.0 °F). The high altitudes and undulating terrain of the FCT act as a moderating influence on the weather of the territory. Rainfall in the FCT reflects the territory's location on the windward side of the Jos Plateau as shown in table 5.1 and the zone of rising air masses with the city receiving frequent rainfall during the rainy season from April to October every year.

Table 5.1: Climate data for Abuja

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average high °C (°F) | 34.7 (94.5) | 36.8 (98.2) | 36.9 (98.4) | 35.6 (96.1) | 32.7 (90.9) | 30.6 (87.1) | 29.1 (84.4) | 28.9 (84) | 30.0 (86) | 32.0 (89.6) | 34.4 (93.9) | 34.6 (94.3) | 33.03 (91.45) |
| Average low °C (°F) | 20.4 (68.7) | 25.5 (77.9) | 24.3 (75.7) | 24.7 (76.5) | 19.5 (67.1) | 18.3 (64.9) | 21.9 (71.4) | 17.7 (63.9) | 17.5 (63.5) | 21.4 (70.5) | 15.7 (60.3) | 15.5 (59.9) | 20.2 (68.36) |
| Average rainfall mm (inches) | 1.7 (0.067) | 5.4 (0.213) | 11.3 (0.445) | 62.8 (2.472) | 134.1 (5.28) | 164.2 (6.465) | 217.5 (8.563) | 262.7 (10.343) | 253.4 (9.976) | 103.2 (4.063) | 3.7 (0.146) | 1.2 (0.047) | 1,221.2 (48.08) |
| Average rainy days | 0.1 | 0.2 | 1.3 | 4.2 | 9.4 | 12.3 | 14.0 | 16.2 | 15.9 | 8.0 | 0.3 | 0.1 | 82 |

Source: World Meteorological Organization (2012)

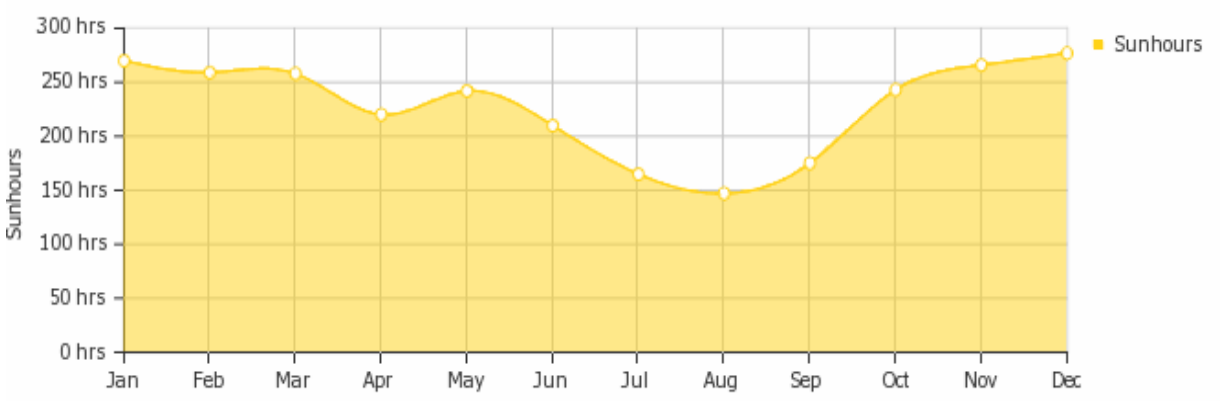



Figure 5.3: The monthly total of sun hours over the year in Abuja, Nigeria
Source: World Meteorological Organization (2012)

### 5.3 Site Selection Criteria

The rapid development in Abuja make choosing a viable site challenging. Three sites have been selected. The first is located in Jabi district of Abuja Close to Jabi lake. The second is near to Silver Bird and third is at Central Business District, within in phase 1 and 2 of Abuja. the following under listed criteria shall be used to weigh the suitability of each of the site and thus the most appropriate site shall be selected (table 5.3). They are:

i. Location/ accessibility
ii. Proximity to recreational facilities
iii. Land use compliance
iv. Utility and services
v. Proximity to national landmarks
vi. Size of site, possibility for expansion, suitability and availability
vii. Traffic consideration
viii. Proximity to residential facilities
ix. Security and safety

Table 5.2: Site selection Criteria

| **Criteria** | **Site 1 (Jabi lake)** | **Site 2 (Art and craft Centre)** | **Site 3 (CBD)** | **Remarks** |
|---|---|---|---|---|
| Location/ accessibility | 3 | 4 | 4 | Site 2 and 3 are easily accessible. |
| Proximity to recreational facilities | 3 | 4 | 2 | Site I surrounded by recreational activities |
| Land use compliance | 2 | 5 | 3 | Site 2 complies more with Abuja land use and zoning regulation |
| Utility and services | 3 | 4 | 4 | Site 1 as less utility and services |
| Proximity to national landmarks | 2 | 4 | 3 | Site 2 is near to National mosque |
| Size of the land, possibility for expansion | 3 | 3 | 4 | Site 3 is large in size than the other two |
| Traffic consideration | 4 | 3 | 3 | Site 1 have an alternative route when there is traffic on site |
| | 4 | 4 | 2 | |

| | | | | |
|---|---|---|---|---|
| Proximity to residential facilities | | | | Site 1 and 2 are more centralise and closer to residential facilities |
| Security and safety | 3 | 4 | 4 | Site 3 and 4 have high security. |
| Total | 27 | 35 | 29 | Site 2 is selected |

Weighing scale: Excellent 5, Very good 4, Strong 3, Weak 2 and very weak 1.

Sources: Author's study (2016)

### 5.3.1 Site Location

The selected site for the Museum is a public reserved space and therefore, the cultural building, which is also a public building could be established on the site in view. The site is located behind Abuja art and craft village, closer to silver bird from the east and Sheraton hotel from the western part of the site. As shown below in plate.




Figure 5.4: Goggle image of the selected site

Source: Google Earth pro 7.0 (2016)

## 5.4 Site Analysis

The site selected was analysis critically based on the design consideration and the need to understand the site and it feature for the building of museum and the incorporation of delight devices in it design.

### 5.4.1 Site Location

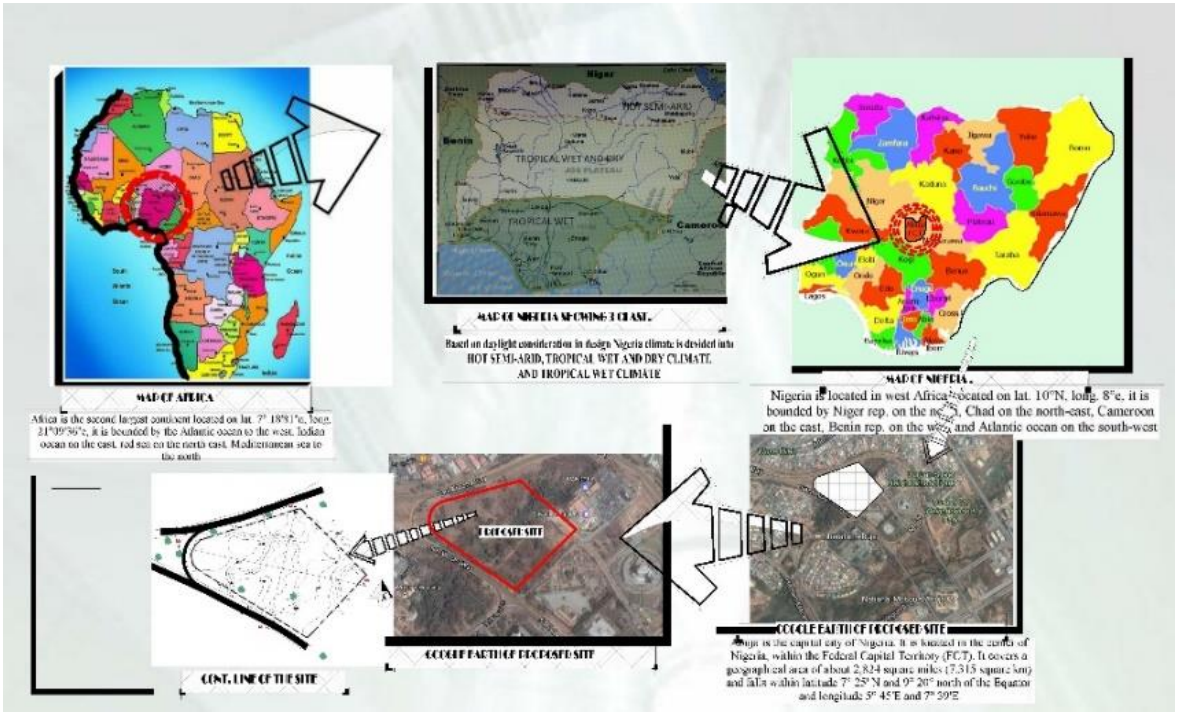



Figure 5.5: Site location map

Source: Author's field study (2016)

### 5.4.2 Site Analysis

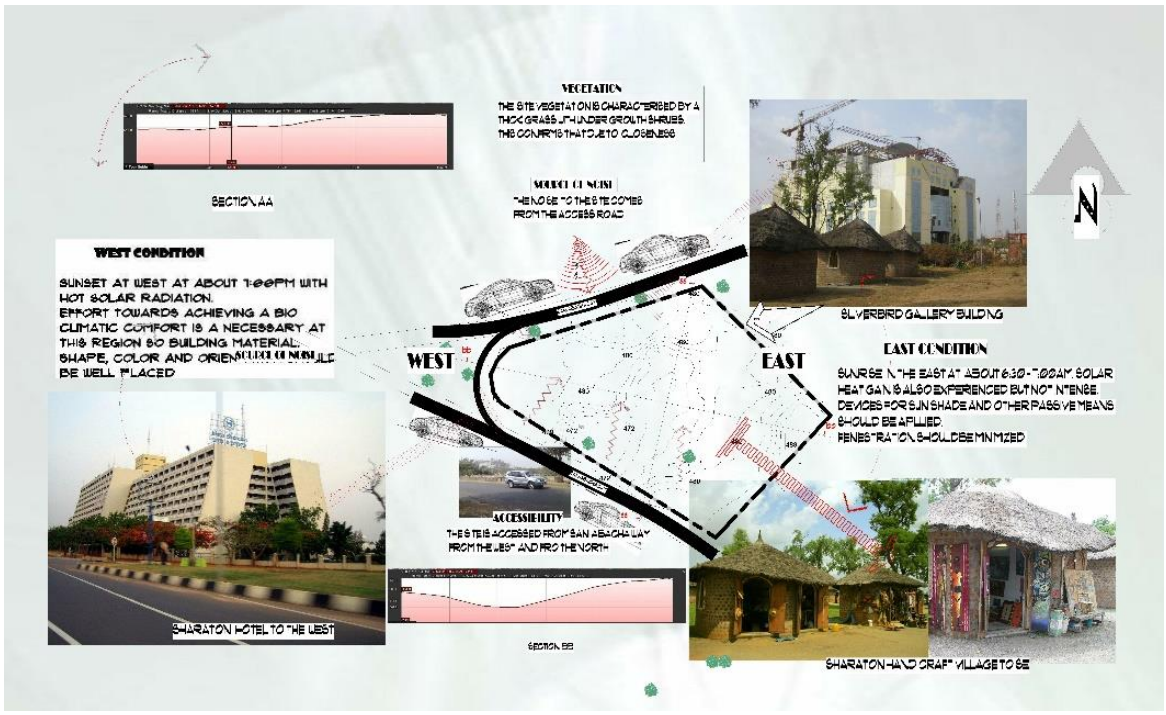



Figure 5.6: Site analysis showing the site features

Source: Author's field study (2016)

### 5.4.3 Site Climate Analysis

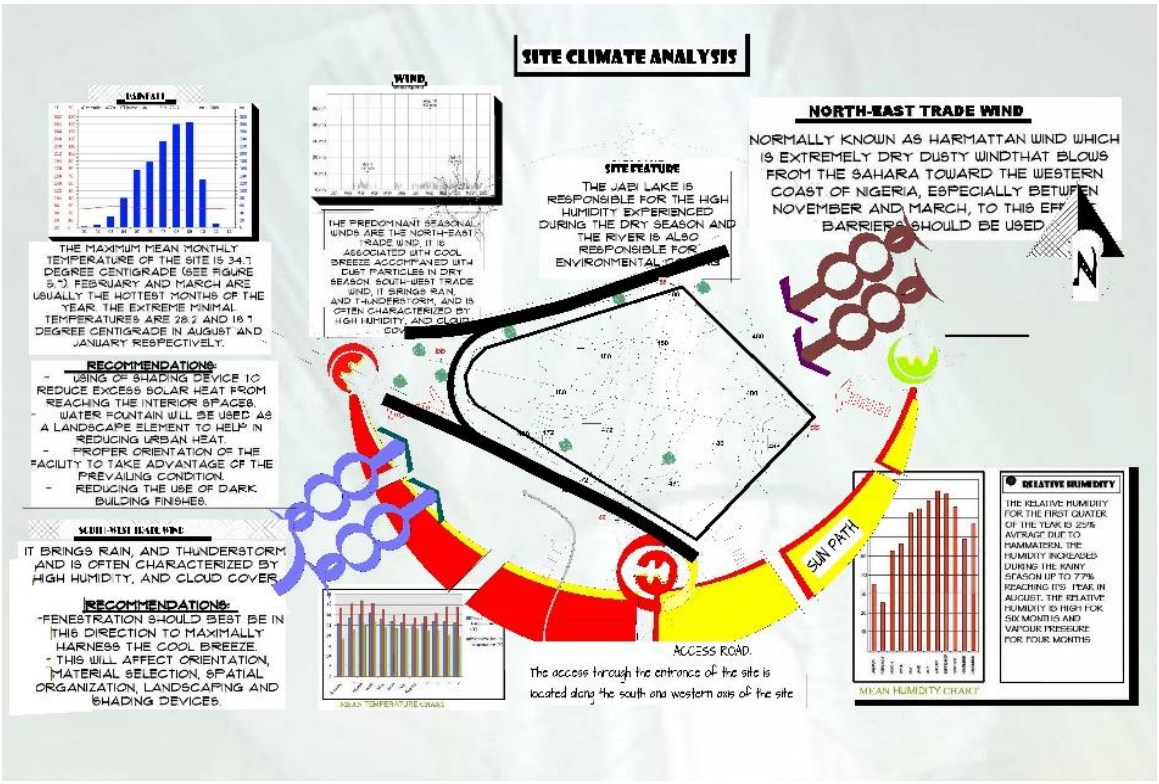



Figure 5.7: Site climatic analysis

Source: Author's field study (2016)

### 5.4.4 Site Vegetation

The nature of the vegetation on site is sparsely green, the site being covered by few trees, shrubs, and grasses. Some of these features should be retained to enhance comfortable landscape environment.

### 5.4.5 Site Topography

The 2/3$^{rd}$ of the site slopes gently towards the South-west direction of the site and toward the end form a valley of about 7m different in height. The slope in these directions is due to the presence of erosion around site however, the site is located some few meters away from the erosion. The direction of this slope should be used for drainage, because it is easier due to the natural force of gravity

### 5.4.6 Sources of Noise

The major sources of noise at the site are from the vehicles moving along the roads around the site. Another source of noise is from the neighbouring commercial activities taking place around the site. These noises can be minimised by the uses of trees buffer zones.

### 5.4.7 Access to Site

The site is located along the Sani Abacha road which brings in the flow of traffic from Abuja major way as well as the immediate environs of the site. The main access into the site is directly from the dual carriage roads.

### 5.4.8 Site Drainage

The general drainage of both foul water and rainwater from the site is in a direction of the slope of the site. Building has to be located on the upper part of the site to reduce risk of flooding.

## 5.5 Design Parameters from the Site Analysis

From the site analysis conducted, the following parameters shall be used in the proposed design:

i. Access into the site shall be via then North.
ii. The orientation of the building shall be done to maximize natural lighting and ventilation.
iii. Existing tress shall be retained and more shall be planted in order to create a shade onsite especially along pedestrian walkways.
iv. The parking will be located towards the Northern part of the site to allow view.
v. Provision of basement park for staff and delivery bay
vi. The eastern part of the site will be left future expansion of the museum.

## 5.6 Design brief and requirement

### 5.6.1 Building Materials and Technology

The major building material to be use for the construction of the edifice include; Stone titanium, reinforced concrete and glass

5.6.1.1 *Reinforced concrete:*

The fluidity of reinforced concrete makes it a good construction material for the swooping shells and curved columns.

5.6.1.2 *Stone*

Stone is the oldest sustainable material and it is abundant around the Country.

5.6.1.3 *Titanium*

Titanium's properties, which are a combination of high strength, stiffness, toughness, low density, and good corrosion resistance provided by various titanium alloys at very low to elevated temperatures, allow weight savings in aerospace structures and other high-performance applications. Titanium is fast becoming a competitive building material. It is known for its corrosion immunity, strength, durability and low maintenance cost. Physical attributes include:

i. Low thermal expansion: Titanium's coefficient of thermal expansion is half that of stainless steel and copper and one-third that of aluminium. It is virtually equal to that of glass and concrete, making titanium highly compatible with these materials. Consequently, thermal stress on titanium is very low.
ii. Immunity to environmental attack: corrosion resistance results from its stable highly-adherent, protective surface oxide film.
iii. Light weight: The specific gravity of titanium is 4.51 g/cm$^3$ about 60% that of steel, half that of copper and 1.7 times that of aluminium. Being such a lightweight metal,

titanium imposes lesser burden on structure. It is easily fabricated and permits ease of installation.

iv. Strength: In addition to having excellent mechanical strength (comparable to mild steel), titanium is durable and shock resistant. Its modulus of elasticity (a measure of strain rate) is half that of stainless steel. This means titanium is more flexible than other architectural metals during earthquakes and other periods of violent movement.

v. Environmentally Safe: Due to its relative inertness in most atmospheres, titanium is considered environmentally friendly. It is 100% recyclable and the product of a renewable resource.

vi. Energy Efficiency: For a metal, titanium is an excellent insulator. Its thermal conductivity which is very low (one-tenth that of aluminium) increasing a building's energy efficiency

vii. Aesthetic qualities: titanium is available in its natural finish silver grey colour or it can be anodized to a spectacular range of colours see.

#### 5.6.1.4 *PTFE Polytetrafluoroethylene*

PTFE is a coated fiberglass, with high strength and long service life. PTFE shall be used as a covering for the entrance podium and roof covering for the theatre building

#### 5.6.1.5 *UV filter*

UV light is invisible to the naked eye but capable of causing both short term and long-term harm with exposure. The opening shall be glass with UV filter material to avoid art work deterioration. The light tube collecting dome will be made of UV filter.

### 5.6.2 Brief formulation and development

One of Nigeria leading artist's Dr Bruce Onobrakpeya has called on the federal government to set up a national art museum to store up the best art work in the country.

Onobrakpeya made this call in an interview with New Agency of Nigeria on (Monday 10, 2015 news), he also urged the Government to rectify the National cultural policy to enable the artist to take advantages of the business opportunity of the trade.

In response to this call by Nigerian Artist, the Federal Government in order to encourage the artist in various field like painting, sculpture, fabrics, ceramics, class work and wood carving etc, have decided to establish Modern Art Museum in Federal Capital Territory Abuja using modern technique and material. The museum should incorporate Modern conceptual design representing the Nation at international stage. It should have contained modern facilities and services with respect to temporary and permanent exhibition. representing modern trend in art and architecture.

5.6.2.1 *Deduction from the brief*

It is important that the proposed design meet the functional requirement of a public space for which it is design for and make statement about the issue at stake, this is achieved through selection of viable site and analysis and understanding of the site. A thorough analysis of the functional and organizational requirement of the museum of the various units and reflecting the interrelated nature of the units in a facility which is a single integrated unit for disseminating information about art museum.

5.6.2.2 *Provide facilities*

i. Entrance hall: It is important for the entrance hall to seem attractive even to the casual passer-by-who is always a potential visitor to the museum. It should provide an easy introduction to the building, a point from which the individual visitor can find his way without difficulty and where large parties can be greeted and assembled. It should therefore be fairly spacious and provided with the strict minimum of sturdily

built furniture (one or two tables for the sale of tickets, a notice board, and a general plan of the museum to guide visitors. and catalogues).

ii. Reception: The reception desk should be visible to the guest immediately on entry into the entrance hall, and it should be on the route to the lifts and stairs, gallery, orientation room and waiting area.

iii. Offices: The offices should be link with the staff parking lot in other to safeguard the collections even when the building is closed to the public while the curators or office staffs are still at work. Offices: administration, curatorial, conservator, etc.

iv. Information and orientation room: Information should be open to the general public for inquiry and students so it should be close to reception hall.

v. Rental area (shops): Shops should be access and visible from the parking lots, secondly should be sufficient circulation space in the front of each shop.

vi. Exhibition podium Temporary exhibition should be visible and close to the waiting area, which is better in the central part of the museum.

vii. Gallery A ramp and landing at intervals will be used to enhance visual experience within the gallery. Snack bar will also be incorporated in other to enhance the tour around the gallery.

viii. Stores: Stores should be located within the private zone of the museum with conservator office, and an offloading bay

ix. Theatre: To foster social sustainability, a theatre can be used for conferences during the day and watching movie at night. This necessitates curving the rows of seats to allow for clear view of the stage.

x. Multi- purposed hall: Diner activities and wedding can be host within the multi-purpose hall which can function independently from the museum gallery itself.

xi. Temporary accommodation for visitors for visitors who will come for conference and tourists.

xii. Restaurant: The restaurant is going to be a traditional which will also be incorporated with a fast food restaurant.

xiii. Loading bay to deliver heavy artefacts in the museum, the loading and offloading bay have to be spacious.

xiv. Car parking: Parking lot should be on the lower part of the side and it should be safe for children. Staff parking should be located behind.

5.6.2.3 *Schedule of Accommodation*

Table 5.3: Schedules of accommodation for reception hall

| **Space** | **Space requirement** | **units** | **Floor area($m^2$)** |
|---|---|---|---|
| Reception area | | | 16-18$m^2$ |
| Orientation room | 2.8 $m^2$ per person | 1 | 45-60$m^2$ |
| Waiting area | 2.8 $m^2$ per person | 1 | 28-30$m^2$ |
| Restrooms | 1.8 $m^2$ each + 10$m^2$ | 2 | 20$m^2$ |

Source: Author's field study (2016)

Table 5.4: Accommodation schedules for administrative spaces/offices

| **Space** | **Space requirement** | **units** | **Floor area($m^2$)** |
|---|---|---|---|
| Curator office | | 1 | 25-30 m2 |
| Accounts office**.** | 5$m^2$ per person | 1 | 20-25 m2 |
| Store office | | 1 | 25-30$m^2$ |
| Education office | 5$m^2$ per person | | 25-30$m^2$ |
| Artefacts store | | 3 | 30-35m2 |
| Pro office | 5$m^2$ per person | 1 | 20-25$m^2$ |
| Conservation/restoration | | | |

Source: Author's field study (2016)

Table 5.5: Schedules of accommodation for art gallery

| **Space** | **Space requirement** | **units** | **Floor area($m^2$)** |
|---|---|---|---|
| Temporary gallery | | 8 | |
| Permanent gallery | 70% Storage | 1 | |
| Souvenir shops | 0.95$m^2$ per person | 1 | 25-30$m^2$ |

Source: Author's field study (2016)

Table 5.6: Accommodation schedules for Theatre

| **Space** | **Space requirement** | **units** | **Floor area($m^2$)** |
|---|---|---|---|
| Banquet hall | Allow a minimum of 2.2$m^2$ per person | 1 | 150-170$m^2$ |
| Store cold/dry | | 1 | 12 -15 $m^2$ |
| Kitchen | About 1/3 dinning space | 1 | 50$m^2$ |
| Dining | 1.5$m^2$ person | 1 | 150$m^2$ |
| Outdoor kitchen | 1.8 $m^2$ each – 6nos + 10m2 | | 20- 25$m^2$ |
| Shops | | 10 | 12$m^2$ |

Source: Author's field study (2016)

Table 5.7: Schedules of accommodation for Multipurpose hall/cafeteria

| **Space** | **Space requirement** | **units** | **Floor area($m^2$)** |
|---|---|---|---|
| Theatre | 0.65$m^2$ per person | | 195-225$m^2$ |
| Stage | | 1 | 15.5-25$m^2$ |
| Back stage | 0.95$m^2$ per person | 1 | 25-30$m^2$ |
| Control room | | | 25-30$m^2$ |

Source: Author's field study (2016)

### 5.6.3 Concept development

The building was design bearing the mind the need for it to look like a museum of cultural significant while providing visual comfort and protection of art work from daylight. As such a cultural element talking drum is use for the building form. The site also influences the choice of the circular form for the design.

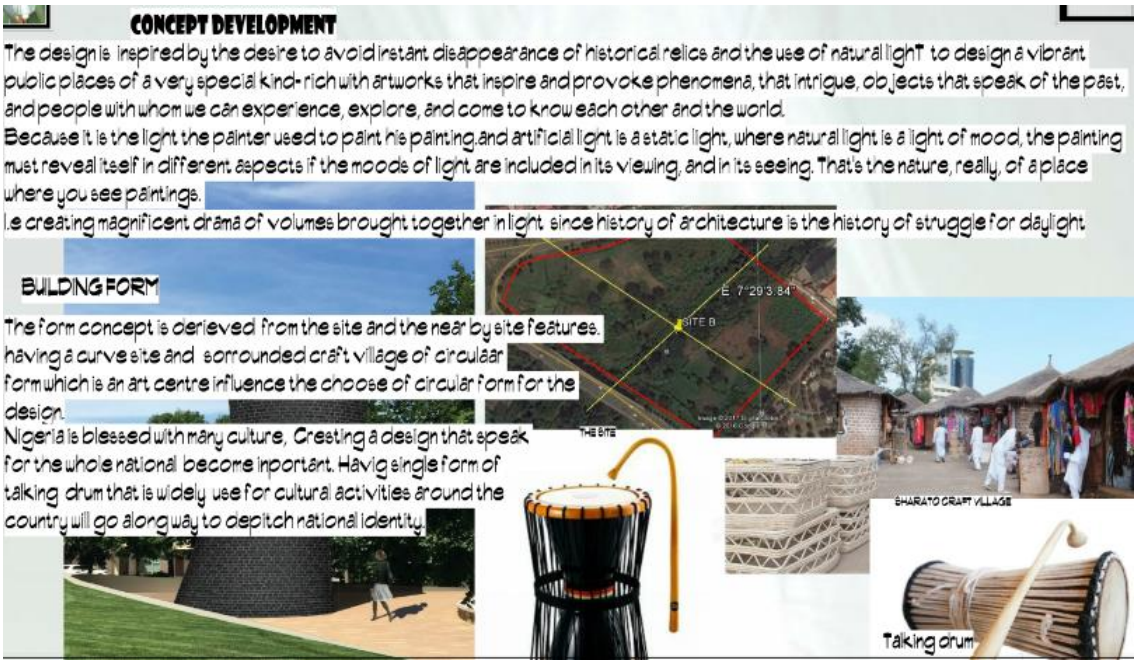



Figure 5.8: Concept development

Source: Author's work (2016)

### 5.6.4 General design consideration: Site Planning and Landscaping

The museum was design with the purpose of providing a visually stimulating environment through the use of both soft and hard landscaped elements. The site was incorporated with adequate walkways made up of interlocking coble stone while the driveway areas are made up of compacted 100mm concrete blocks demarcated by 80mm pin kerb, the site was also provided with abundant soft landscape elements which help in reducing the intensity of urban heat island.

Proper consideration was given in providing trees that will not serve as an obstruction to the provision of daylighting the potential of this features can be seen in site plan (figur5.9) and (figure 5.10, 5.11,5.12) shows design consideration and application of light pipe in the proposed design.




Figure 5.9: Site planning/ landscaping

Source: Author's work (2016)

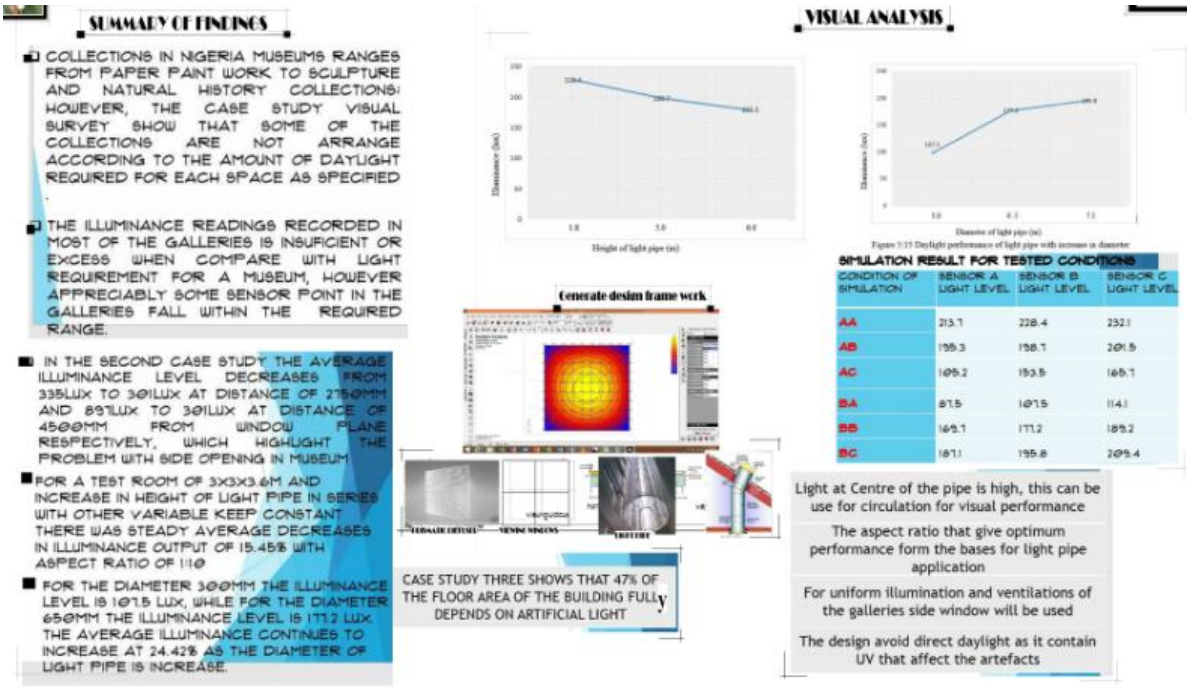



Figure 5.10: Design Frame Work

Source: Author's work (2016)

### 5.6.5 Light pipe application

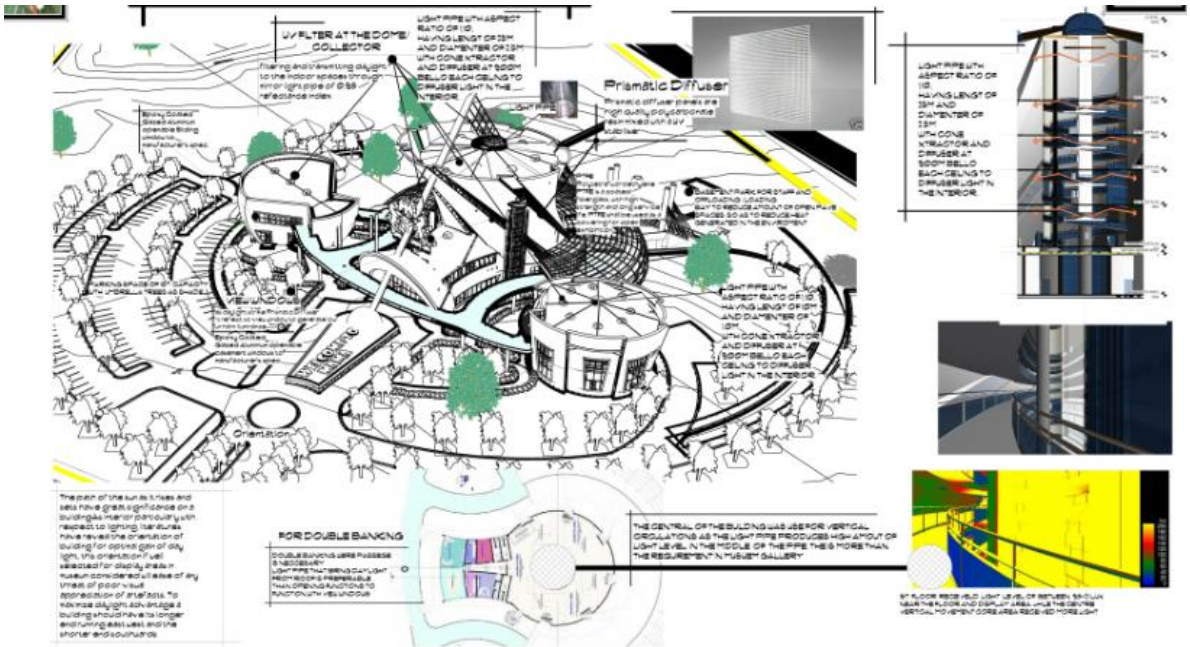



Figure 5.11: Design consideration

Source: Author's work (2016)

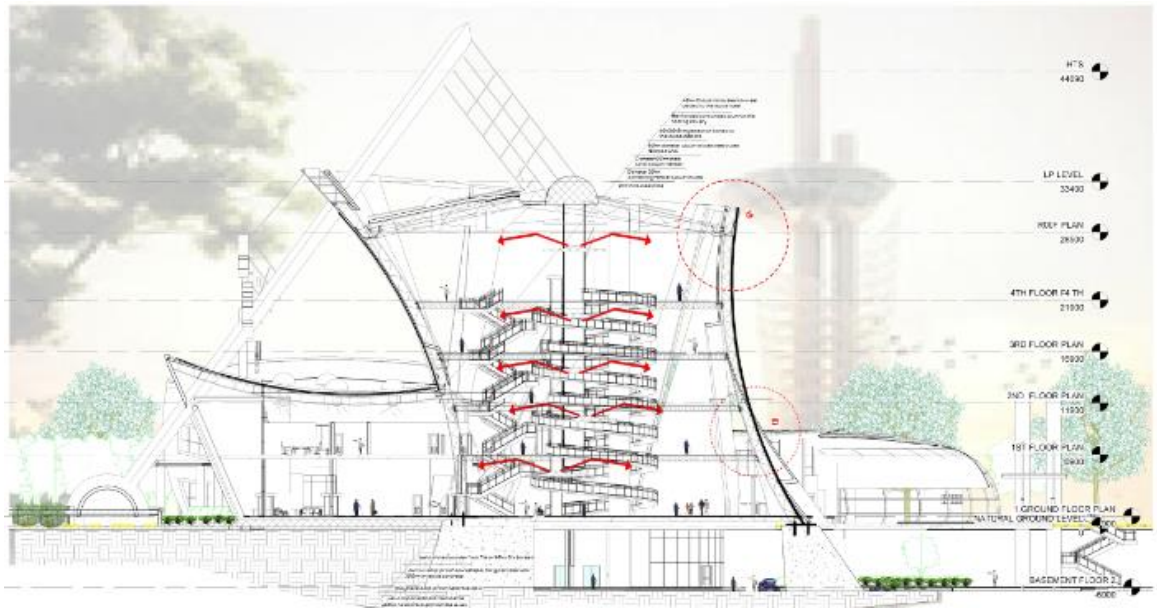



Figure 5.12: Section Y-Y showing light pipe application

Source: Author's work (2016)

# 6.0 SUMMARY, CONCLUSION AND RECOMMENDATIONS

## 6.1 Summary

The research focused on the daylight performance and optimization with light pipe in the design of modern art museum within tropical wet and dry climate of Nigeria. The major problem being identified as light contains rays which have potential of causing deterioration to the collections which makes achieving daylight into display areas challenging and has resulted in overdependence on artificial light. The fact that, better daylight when incorporated within a learning and historical space can provide many important benefits to both the users and owners of facility influence the research.

The researcher went further to conduct case studies on three of the Nigeria museum within the three-daylight classification zone and also conducted a validation study on those samples as well as performing a computer simulation with Ecotect and Daysim in addition to evaluate the performance of light pipe. Findings from the research is the basis for the design of a Modern Art Museum Abuja.

## 6.2 Conclusion

This study is on light pipe as an effective daylighting system in building. The emphasizes is not only the studies of theory and performance of light pipe, but also an overview of Nigeria climate in optimising daylighting using light pipe system. In addition, this dissertation also discussed the common advantages of using light pipe as a daylighting system. With the advantages offered by light pipe system, it has the potential to be widely used in Nigeria buildings. Light pipe system as practical application in many buildings whether in deep plan building or link building.

## 6.3 Recommendations

From the research conducted, the major findings suggested a comprehensive way that architects can follow in providing a museum that is less dependent on artificial lighting

within the tropical wet and dry climate of Nigeria. The analysis has shown that problems associated with light use and control technique, as regards artefacts conservation and display is common concern in almost all museums. The shortcomings are tailed towards the fact that most of the museum buildings were not purposed built. After much observation and discussions, it was revealed that measures were not put in place in considering the effective use of day lighting in the museum, where the other museums are housed in inherited buildings, this shows that it's about time that the bodies in charge of museum establishment in the country stop adopting and rather start building museum, because it is usually difficult and expensive to achieve optimal lighting with inherited buildings by retrofitting, if such buildings have so much history and require preservation it can be preserved as a monument building rather than being used as a museum building so as to avoid the constant need for intervention and start thinking prevention.

These can primarily be achieved as follows;

i. Efforts should be made by the design leader to ensure that day lighting design is achieved and integrated at all design stages and contribute to the design and construction process.
ii. To encourage architects to design museums with much considerations of daylight concept instead of shy away from it and looking for alternative measure.
iii. Relevant bodies or authorities should allow for museum designs as purpose made not as a make shift building or structure.
iv. For optimum performance of light pipe in museum in tropical wet and dry climate of Nigeria the aspect ratio should not be more than 1/10
v. All the opening to the gallery and sensitive space in museum should have UV filter and designer should avoid as much as possible direct light in to the museum spaces

## 6.4 Contribution to Knowledge

The study made the following contribution to knowledge:

i. Evaluate that light level decreases at an average of 15.45% admitting daylight level of between 213.7lux to 195.3lux to 105.2lux as the height of light pipe increases while the illuminance level continues to increase at 24.42% as the diameter of light pipe increases, so that the diameter of light pipe has much effect on it daylight output than it height

ii. Determined that for optimum performance of light pipe in museum of tropical wet and dry climate the aspect ratio limit should be 1/10 in Nigeria context

iii. Demonstrated technological approach for the application of light pipes in the design of modern art museum Abuja, which will serve as a guide for daylight design of museums in Nigeria

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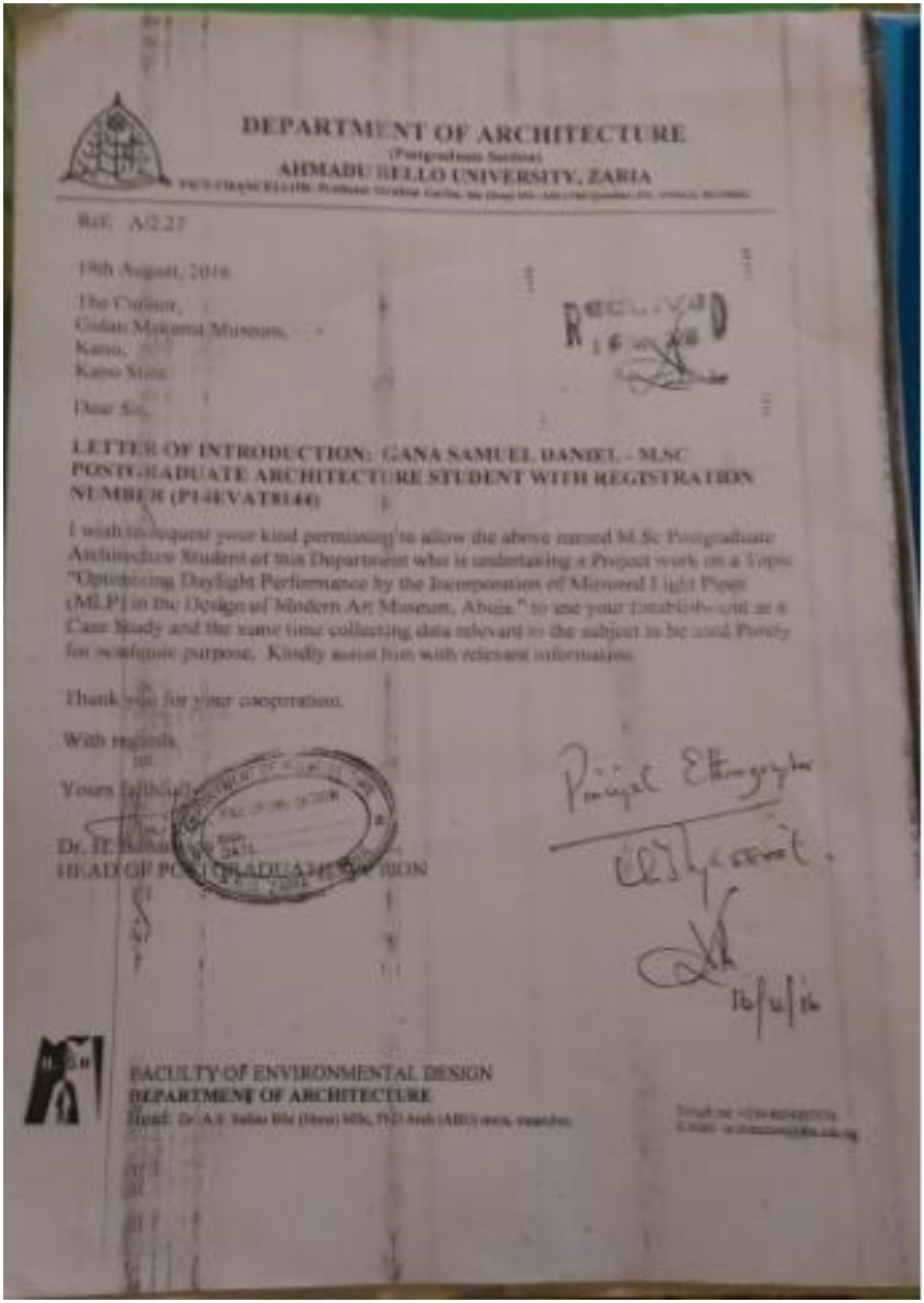
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**APPENDICES:**

**Appendix I:** Case Introduction Letter



DEPARTMENT OF ARCHITECTURE
(Postgraduate Section)
AHMADU BELLO UNIVERSITY, ZARIA

Ref: A/2.27

18th August, 2016

The Curator,
Gidan Makama Museum,
Kano,
Kano State

Dear Sir,

RECEIVED
16 AUG 16

**LETTER OF INTRODUCTION: GANA SAMUEL DANIEL – M.SC POSTGRADUATE ARCHITECTURE STUDENT WITH REGISTRATION NUMBER (P14EVAT8144)**

I wish to request your kind permission to allow the above named M.Sc Postgraduate Architecture Student of this Department who is undertaking a Project work on a Topic "Optimizing Daylight Performance by the Incorporation of Mirrored Light Pipes (MLP) in the Design of Modern Art Museum, Abuja." to use your Establishment as a Case Study and the same time collecting data relevant to the subject to be used Purely for academic purpose. Kindly assist him with relevant information.

Thank you for your cooperation.

With regards,

Yours faithfully,

Dr. H. [illegible]
HEAD OF POST GRADUATE SECTION

Principal Ethnography
16/8/16

FACULTY OF ENVIRONMENTAL DESIGN
DEPARTMENT OF ARCHITECTURE
Head: Dr. A.S. Sadiku BSc (Hons) MSc, PhD Arch (ABU) [illegible]

**Appendix II:** Case introduction letter



DEPARTMENT OF ARCHITECTURE
(Postgraduate Section)
AHMADU BELLO UNIVERSITY, ZARIA

Ref: A/2.27

19th August, 2016

The Curator,
National Museum of Colonial History,
Lokoja,
Kogi State.

Dear Sir,

**LETTER OF INTRODUCTION: GANA SAMUEL DANIEL - 16/SC POSTGRADUATE ARCHITECTURE STUDENT WITH REGISTRATION NUMBER (P16EVAT8164D)**

I would to request your kind permission to allow the above named M.Sc Postgraduate Architecture Student of this Department who is undertaking a Project work on a Topic "Optimizing Daylight Performance by the Incorporation of Mirrored Light Pipes (MLP) in the Design of Modern Art Museum, Abuja." to use your Establishment as a Case Study and the same time collecting data relevant to the subject to be used Purely for academic purpose. Kindly assist him with relevant information.

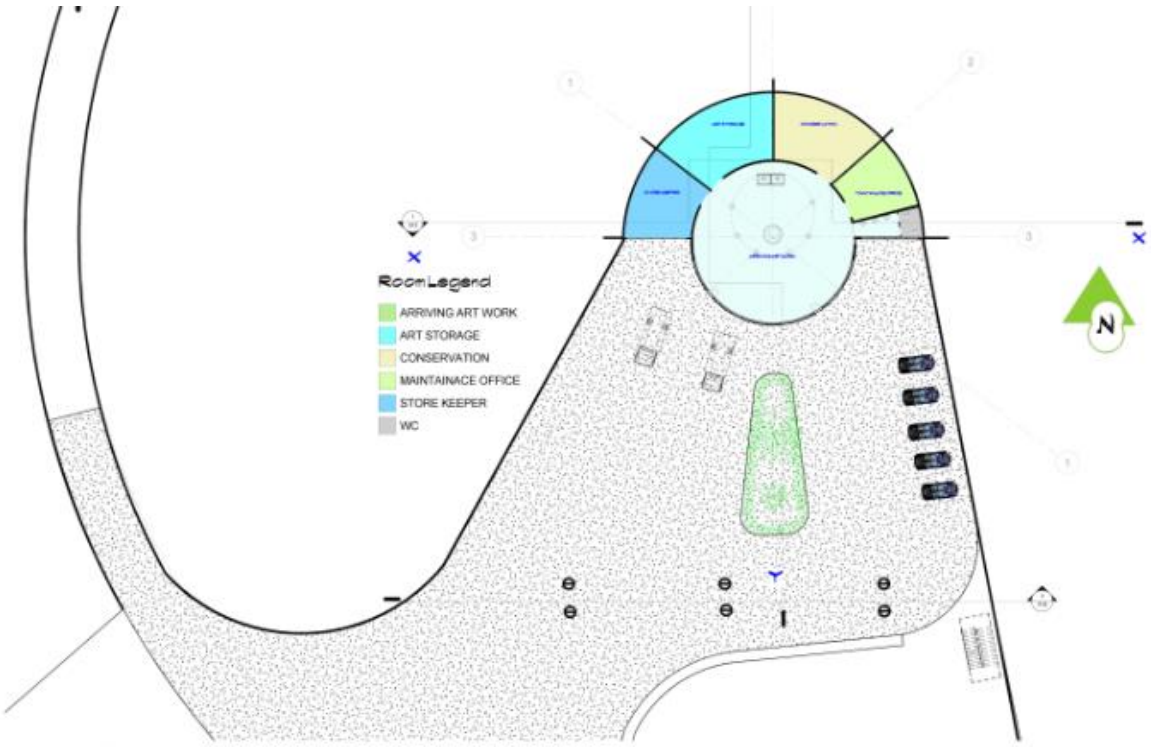
Thank you for your cooperation.

With regards,

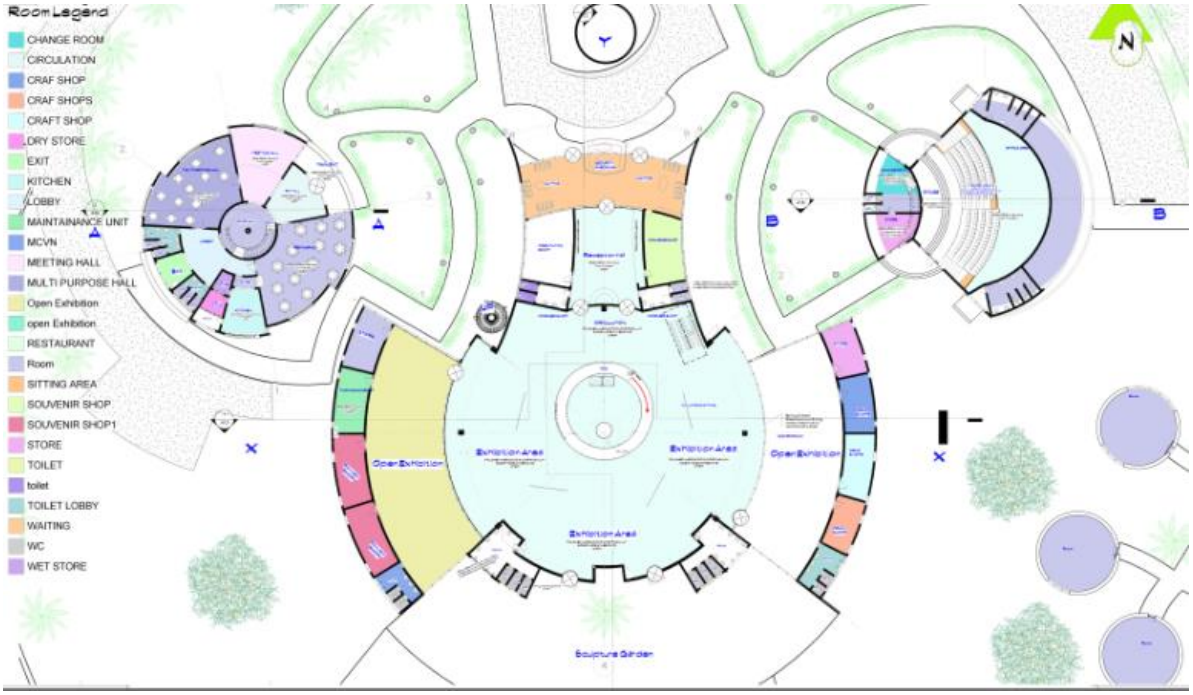
Yours faithfully,

Dr. H. [illegible]
HEAD OF [illegible] SECTION

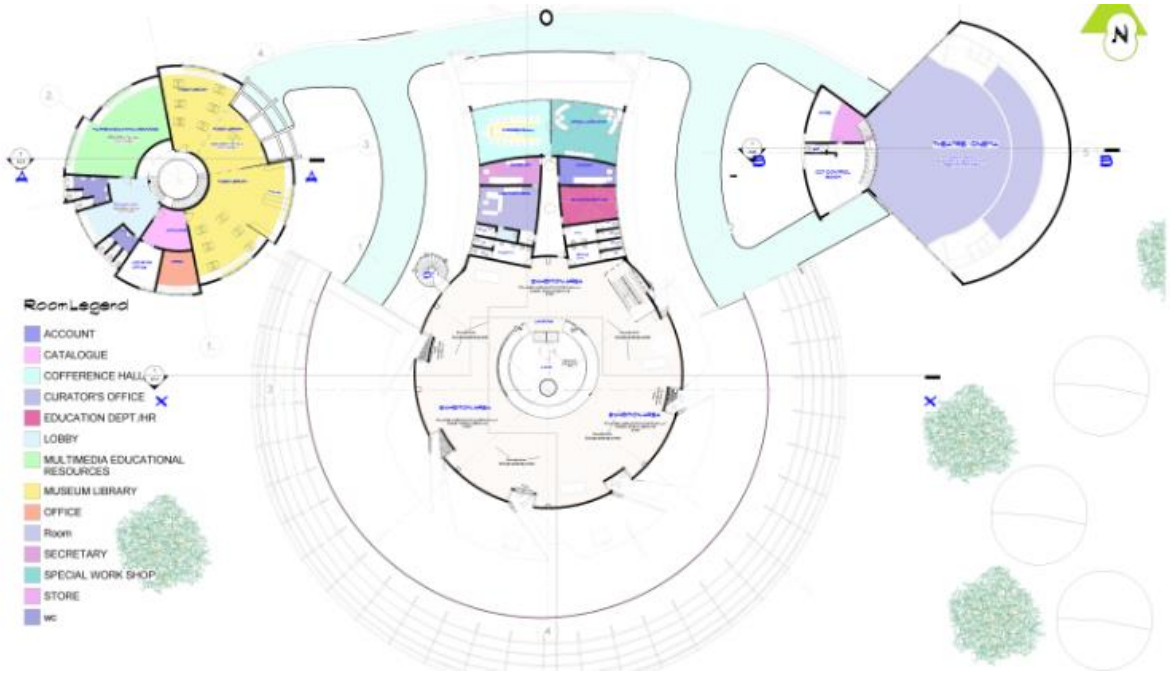
FACULTY OF ENVIRONMENTAL DESIGN
DEPARTMENT OF ARCHITECTURE



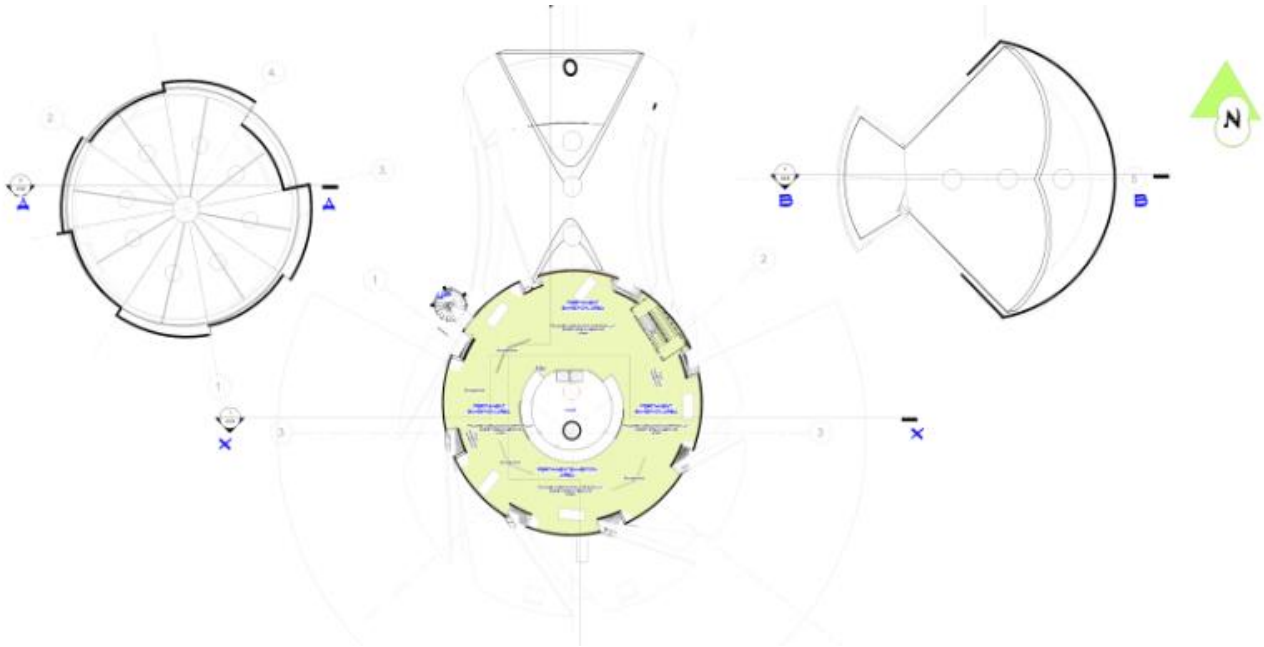

**Appendix III:** Basement Floor Plan



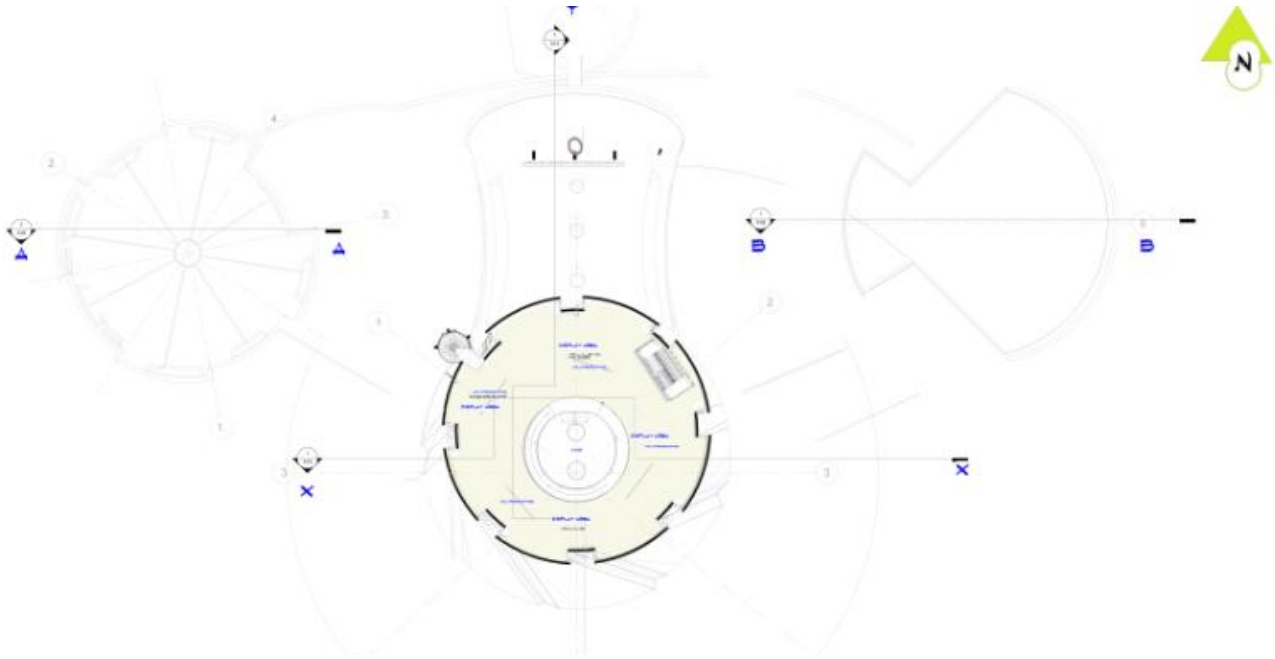

**Appendix IV:** Ground Floor Plan



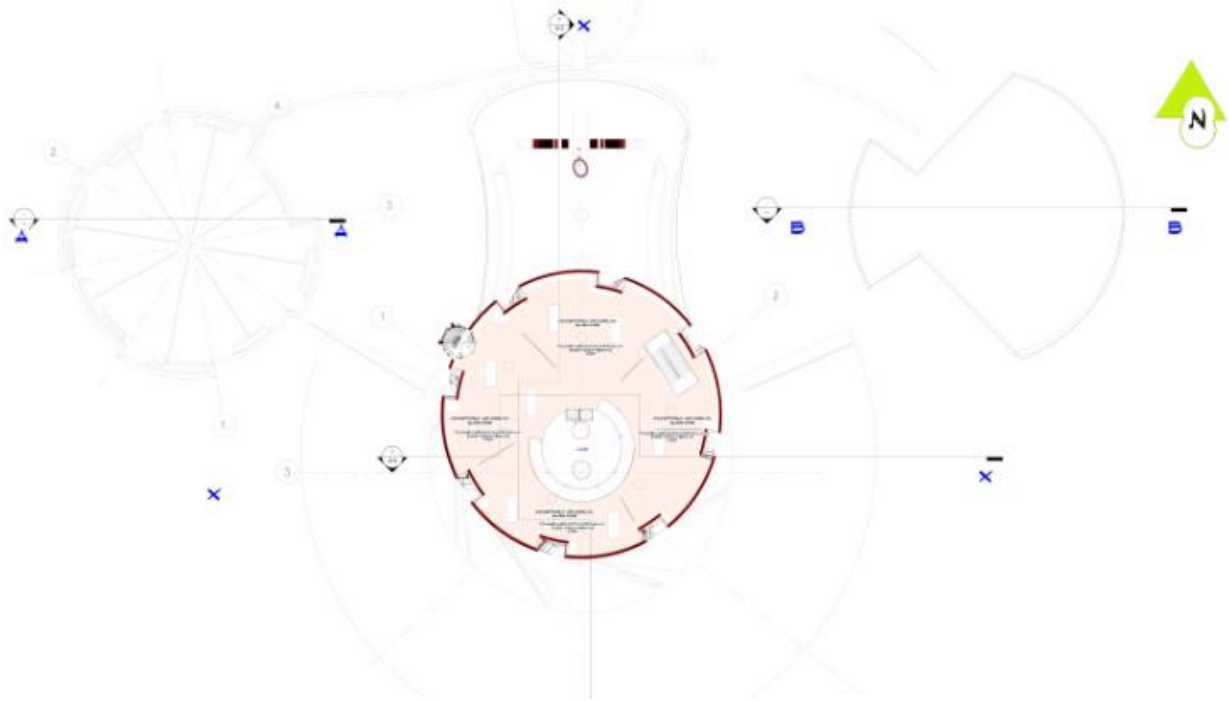

**Appendix V:** First Floor Plan



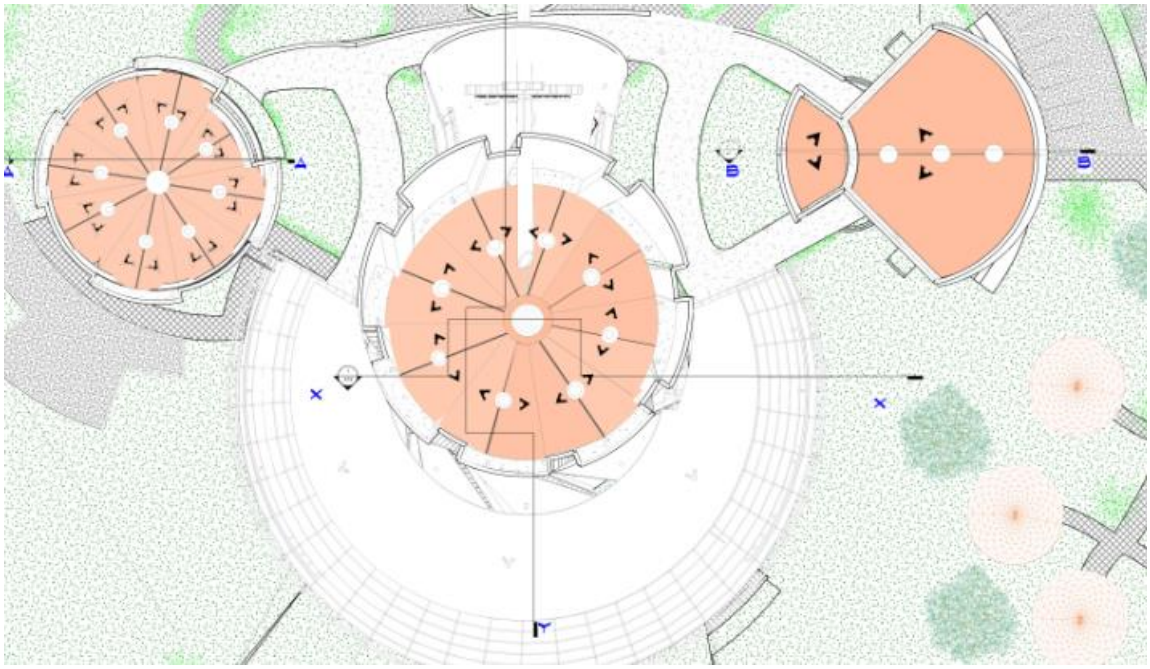

**Appendix VI:** Second Floor Plan



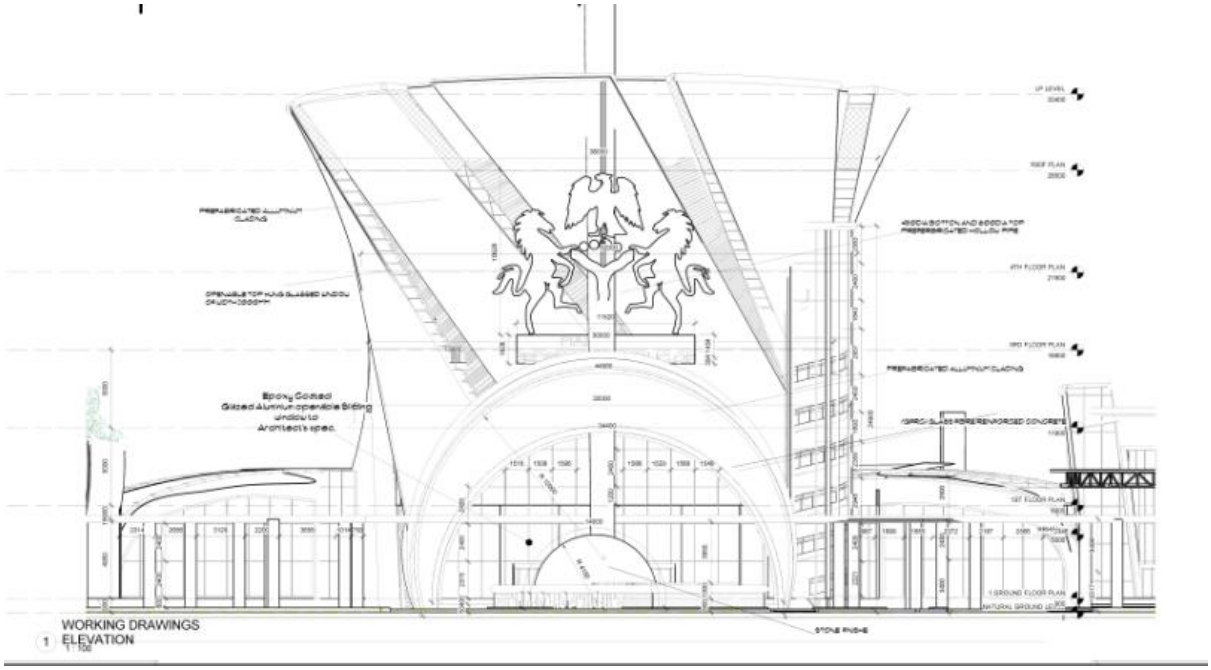
**Appendix VII:** Third Floor Plan



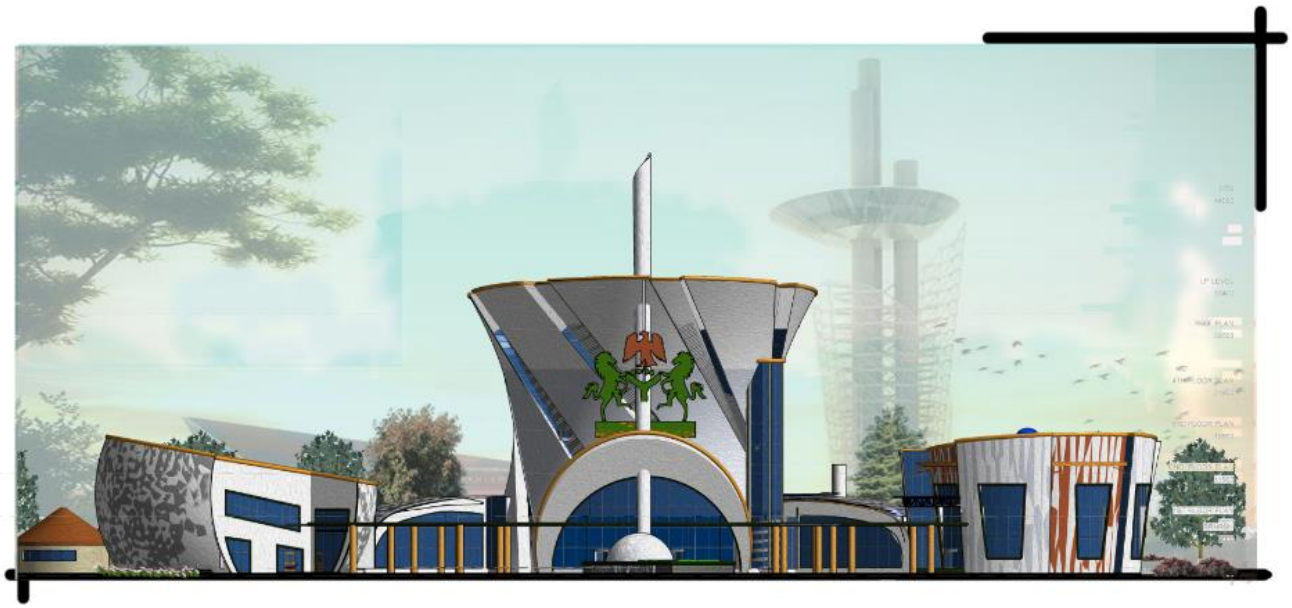
**Appendix VIII:** Fourth Floor Plan



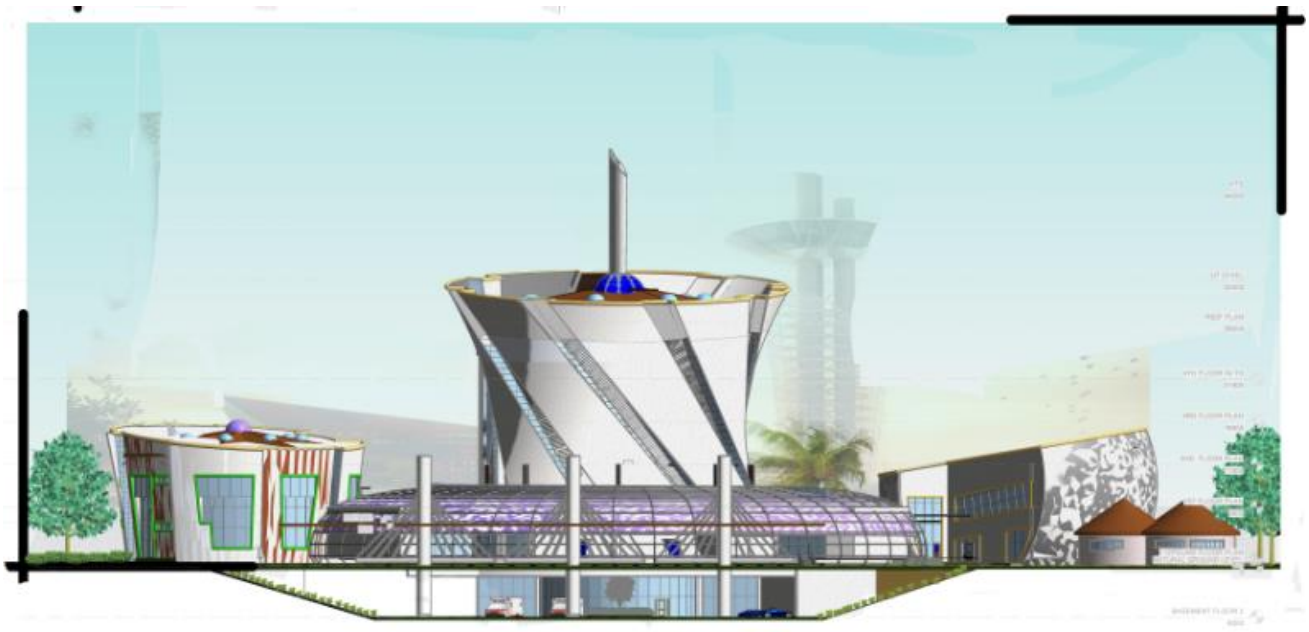
**Appendix IX:** Roof Plan



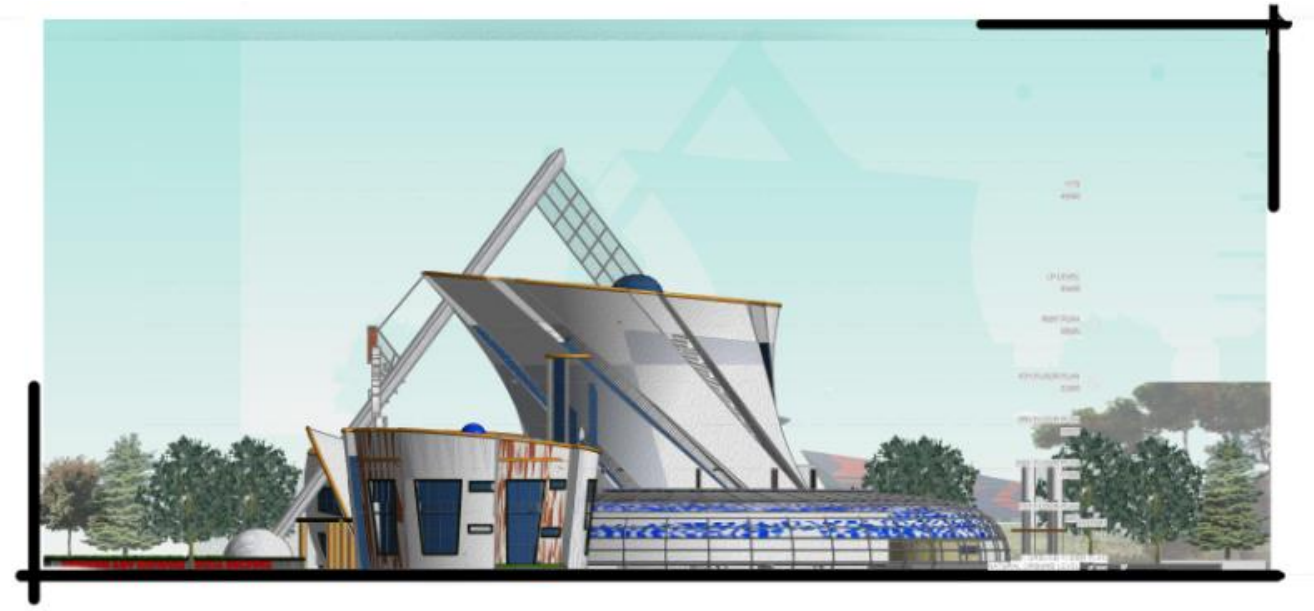

**Appendix X:** Working Drawing Elevation



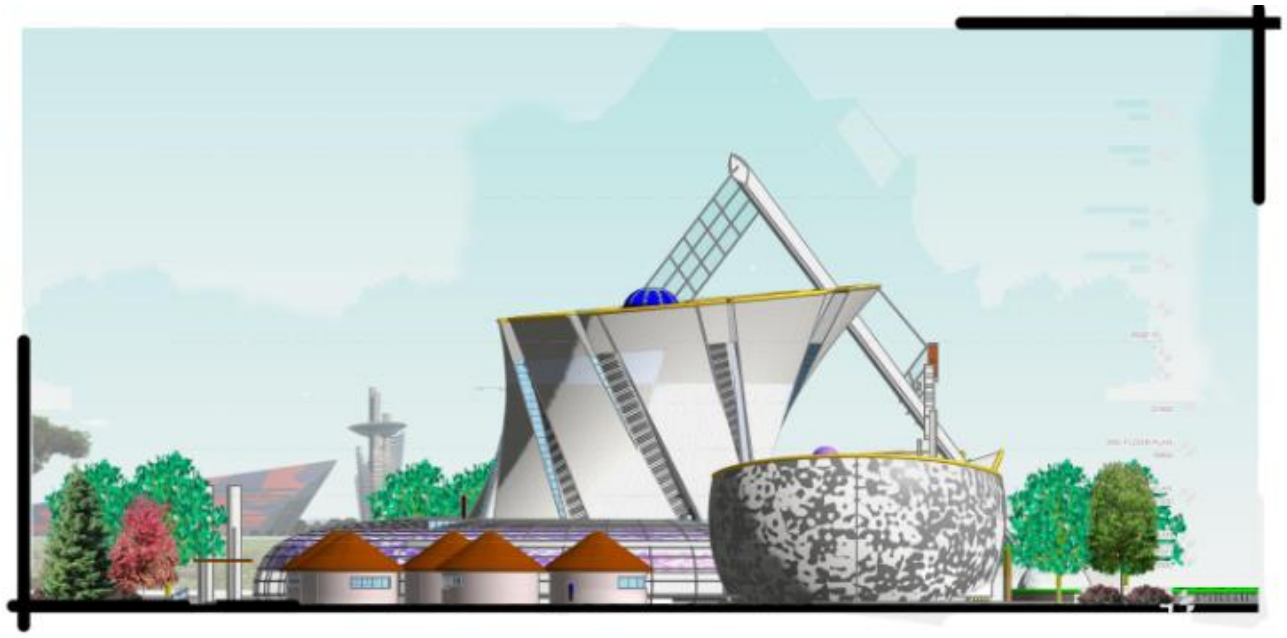
**Appendix XI:** North Elevation



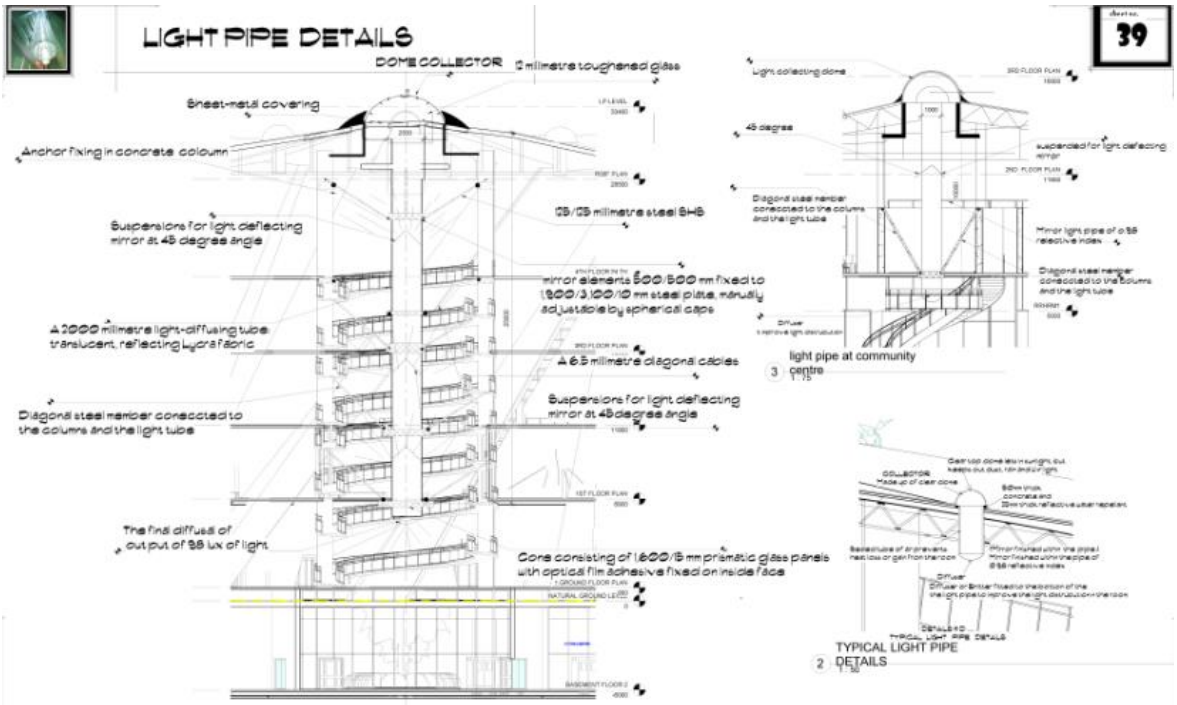
**Appendix XII:** South Elevation



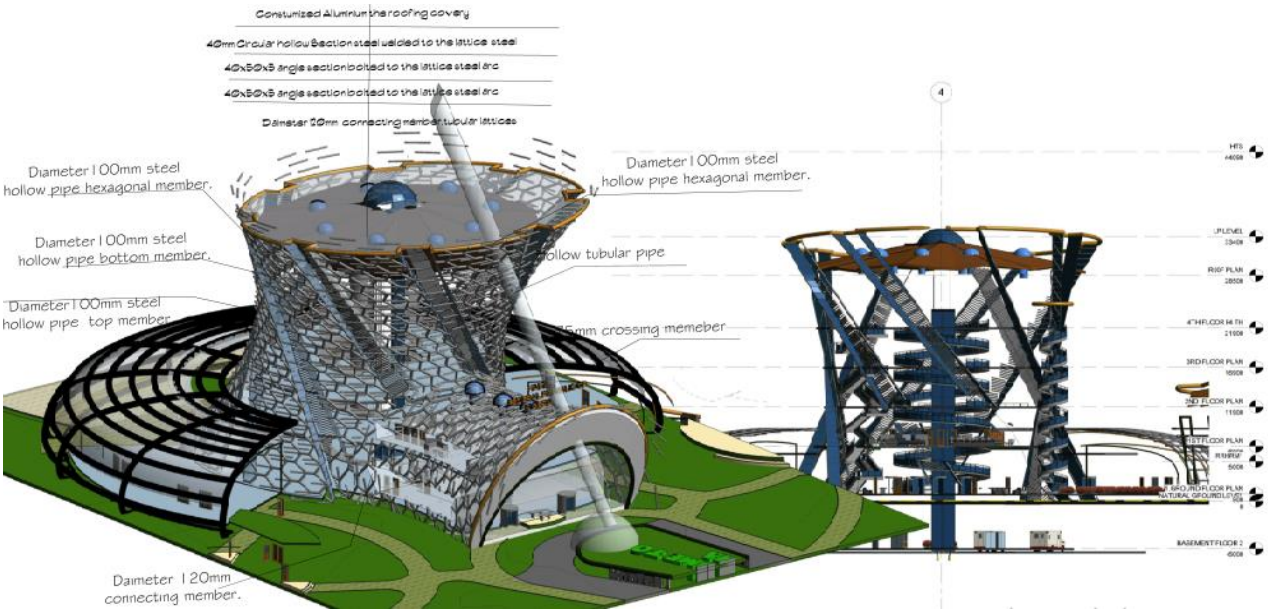
**Appendix XIII:** West Elevation



**Appendix XIV:** East Elevation



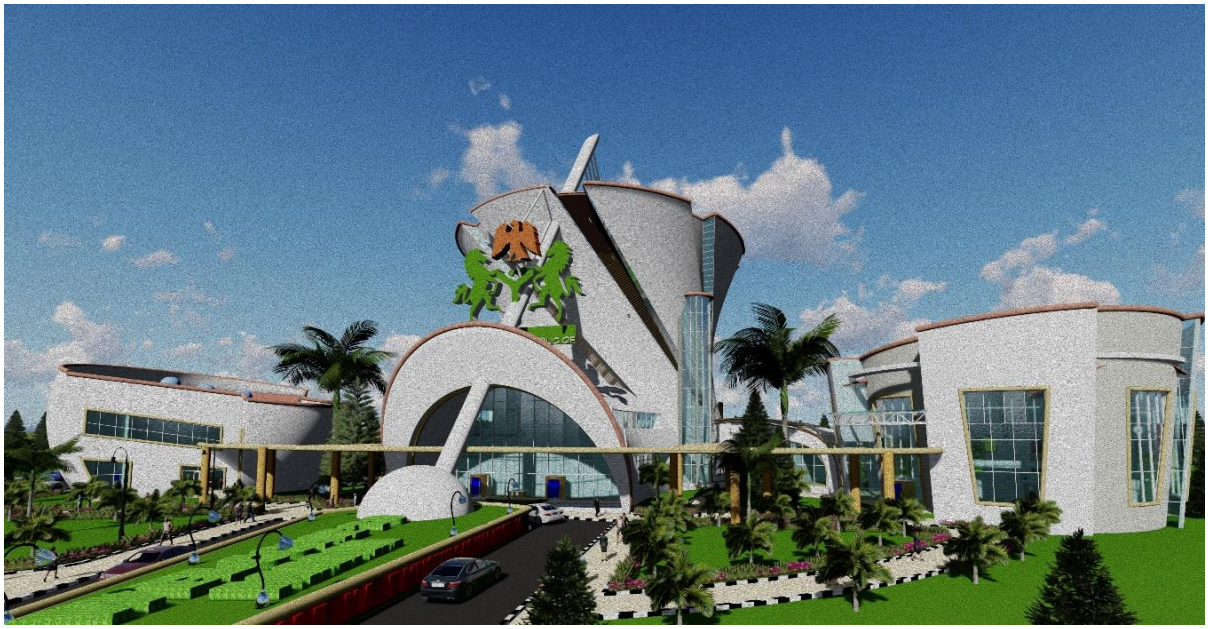

**Appendix XV:** Light Pipe Application



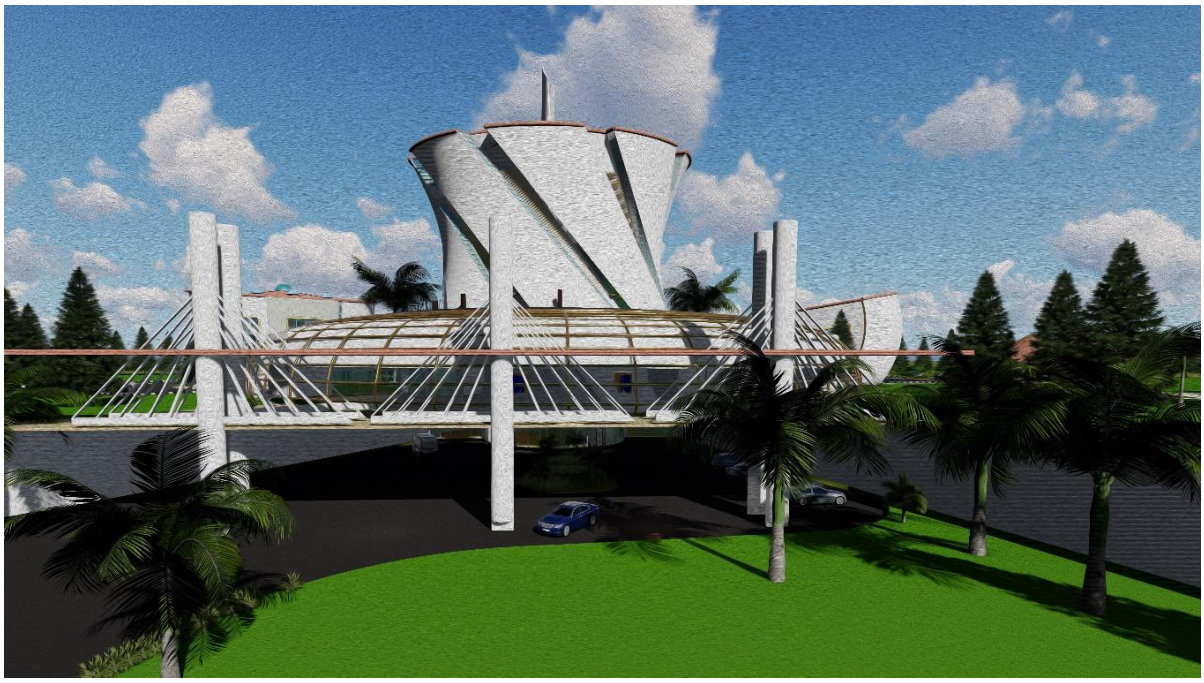

**Appendix XVI:** Structural steel frame work



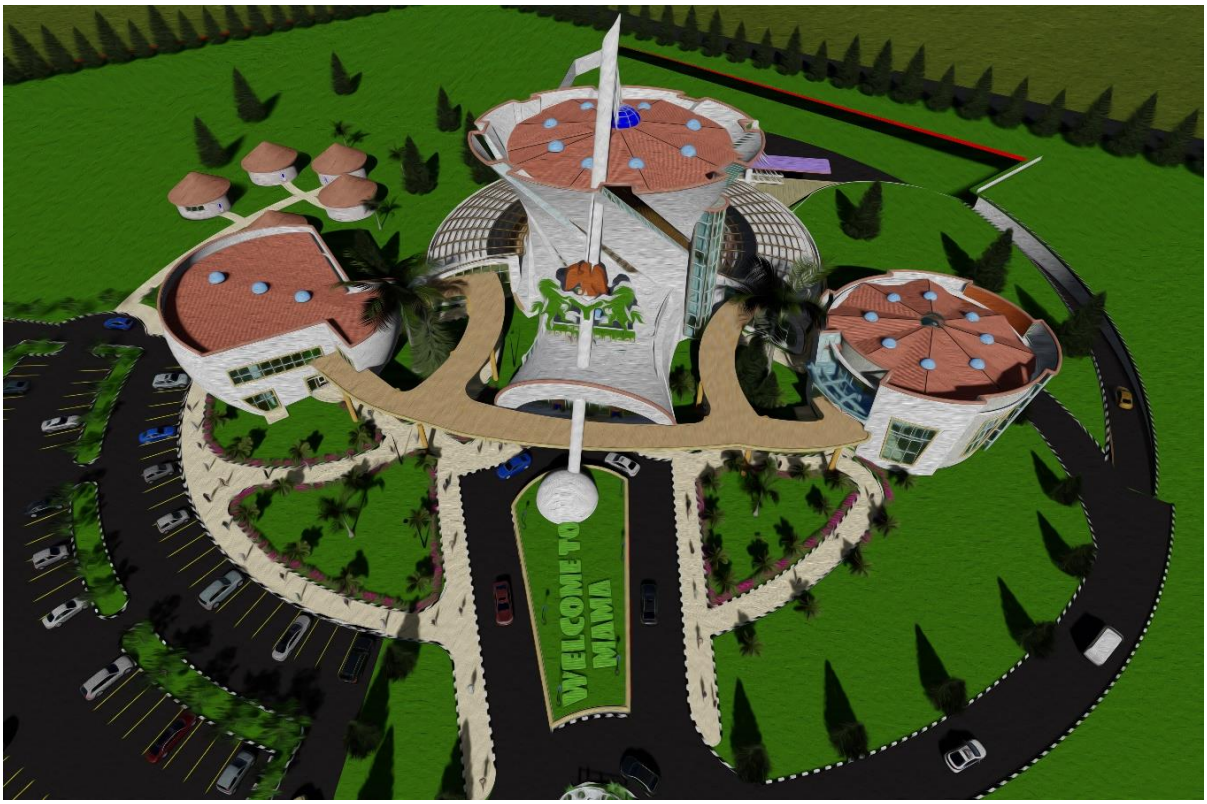
**Appendix XVII:** 3d View



**Appendix XVIII:** 3d View



**Appendix XIX:** 3d View




**Appendix XX:** 3d View