

**EVALUATING THE USE OF GLASS IN ARCHITECTURAL
DESIGN AND CONSTRUCTION.**

(A CASESTUDY OF BENIN CITY, EDO STATE.)

BY

OSAYUKI BRAIN JEGEDE

MAT. NO: ENV1704548

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DECLARATION

I declare that this project, **EVALUATING THE USE OF GLASS IN ARCHITECTURAL DESIGN AND CONSTRUCTION** is based on a study undertaken by me (**OSAYUKI BRAIN JEGEDE**) in the Department of Architecture, University of Benin, under the supervision of **ARC. CHRISTIAN E. AGBO**.

JEGEDE BRAIN OSAYUKI

.....

Signature & Date

CERTIFICATION

We, the undersigned certify that this research work was carried out by JEGEDE BRAIN OSAYUKI with Matriculation Number ENV1704548. It is adequate in scope and quality and hereby approved for the partial fulfillment of the award in Bachelor of Science (B. Sc.) Department of Architecture, University of Benin.

Arc. Christian E. Agbo

Project Supervisor

Date: _____

Arc. Felix Omobude

Project Coordinator/
H.O.D Architecture

Date: _____

DEDICATION

I dedicate the work to the Master Architect; the almighty God, who has kept me throughout my four years of study and has brought me to the end of the first stage of my professional academic journey. Also, to my lovely family who have always supported me all through my life.

ACKNOWLEDGEMENT

I want to express my profound gratitude to God almighty for giving me the life and strength to carry out this work. Special thanks to my parents Mr. and /Mrs. Jegede for providing me with the necessary resources and encouragement throughout the project.

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ABSTRACT

This study investigated the various applications of glass in construction to educate readers on the social, economic, and environmental advantages of using glass in Nigeria's construction sector. The study examined how glass has been used in most of Nigeria's building design and construction sector. Although glass has played a significant role in the construction industry and has to a large extent improved the quality of buildings, there is still a great deal of unrealized potential that can be used in construction for novel purposes. Therefore, to broaden people's perspectives and educate them about the significance of glass in daily life, the research compared the usage of glass in the local area to a building internationally acclaimed in the aspects of function, aesthetics and the sometimes-overlooked structural capabilities of glass.

CHAPTER ONE: INTRODUCTION

1.1 PREAMBLE

Glass is a dependable, cost-effective, and versatile building material. The uninterrupted view of the outdoor scene from the interior of the buildings is one of its many features that has encouraged the use more than any of the building's other features while shielding the interior from inclement weather. It improves the exterior of landmark structures like banks and hotels and lets in daylight to brighten a workspace or create a pleasing interior. However, there are some issues related to the use of glass that go along with the numerous advantages. Any glass structure, whether a window, a partition, or a door, needs to be designed to reduce glare, noise, and unwelcome heat gain. It might be necessary in exceptional circumstances to minimize reflection, protect privacy, or ensure security from fire, accident damage, or vandalism. A lot has been done to solve these issues. These take the form of improved glazing techniques and the development of new glass types tailored to specific applications.

1.2 BACKGROUND TO THE STUDY

Glass is an inorganic solid that is typically translucent or transparent, as well as tough, brittle, and weatherproof. Glass has been used to create functional and decorative items since antiquity, and it is still crucial in industries as diverse as building construction, home goods, and telecommunications. To avoid the development of visible crystals, it is made by quickly cooling molten components such as silica and sand (BRITANNICA, 2022.)ⁱ Commercial glasses are primarily silicates that have been chemically combined with a variety of other oxide substances. They are formed by melting the source materials together and forming fluids in various ways. Since glasses have been created without necessarily quenching a melt, these definitions are susceptible to some objections. For instance, glasses may be produced without cooling a melt, as demonstrated by radiation damage, vapor deposition, and solution reactions. Glass is increasingly used in building construction, so it's

important to fully understand its properties, manufacturing process, types, and applications. Glass is typically lightweight, and it is used extensively in building construction because of this. It lessens the dead load on the structure of the building. Glass is used in buildings because of both its functional and aesthetically pleasing qualities. Glass has a lustrous quality that enhances the beauty of construction.

Glass can be labelled as a synthetic material. It is composed of metallic tri-oxo-silicates (iv). It is made by heating a mixture of silicon (iv) oxide, metallic oxides, and tri-carbonate (iv) at 1300 °C - 1400 °C. Small amounts of powdered glass and coke are usually added to improve the quality. The composition of the glass determines its qualityⁱⁱ.

Glass, whether used for windows, facades, or interior partitions, connects space, improves space quality, transmits adequate light, and modern types of glass may contribute to energy savings. It is widely acknowledged that energy is one of the most significant architectural challenges of our time. (Vigener, N., Brown M.A 2009).ⁱⁱⁱGlass must now conform to high safety sustainable standards for end users and passersby; thus, they are made resistant to shocks and abrupt temperature changes, and they will not break easily. In this way, the manufacturer attempted to reduce the risk of injury as may be occasioned by sudden breakage. (Vigener, et al, 2009)

1.3 STATEMENT OF THE RESEARCH PROBLEM

Although glass has played a significant role in the construction industry and has significantly improved the quality of buildings, there is still a great deal of untapped possibilities that can be used in construction for novel purposes. Therefore, to broaden people's perspectives and educate them more about the significance of glass in daily life, the research will go into depth on the numerable uses and applications of glass in various aspects of architectural designs and construction.

1.4 RESEARCH QUESTIONS

- i. Why is glass significant to the building and construction sector?
- ii. What untapped potential applications for glass in Nigerian construction exist?
- iii. What impact does glass have on the environment?
- iv. How can professionals in the built environment learn more about the uses of glass in construction?

1.5 AIM OF THE STUDY

The purpose of this study is to assess how glass is used in Architectural design and Construction in Nigeria. To do this, it will examine the construction sector and determine the extent to which glass is used and how to increase it sustainably.

1.6 OBJECTIVES OF STUDY

- i. To investigate how glass has been used in Benin City Metropolis.
- ii. To highlight new ways of utilizing glass as an aesthetic component of buildings
- iii. To consider the utility of glass and glazing in buildings
- iv. To highlight innovations in the use of glass as a structural component of buildings.

1.7 JUSTIFICATION OF THE STUDY

Potentially, this study will shed more light on glass and how it is used in building construction. Professional builders, civil engineers, architects, quantity surveyors, and others involved in the building and construction industries will be interested in the outcome of this project. This study will also help to promote the use of glass and its application in high-rise buildings, bungalows, and story buildings, not only in Benin City but the entire in Nigeria. It will also assist in educating people on the importance of glass as a building component in the construction of buildings.

1.8 SCOPE OF THE STUDY

This study aims to investigate the various applications of glass in construction and educate readers on the social, economic, and environmental advantages of using glass in Nigeria's construction sector. The current study examines how glass is used in Nigeria's construction sector. The use of glass in residential and commercial buildings is the subject of this study. The importance of glass in structures as well as the different types of glass and their characteristics are also emphasized. Innovative designs are possible with glass, which can also be treated to increase insulation and energy efficiency. Large glass envelopes are now widely used, especially in cities. But because there are so many kinds of glass, choosing the right one for a project can be technically difficult.

Additionally emphasized are the various types of glass and their properties as well as the significance of glass in structures. Glass allows for creative design possibilities and can be treated to improve insulation and energy efficiency. These days, large glass envelopes are commonly used, especially in urban areas. However, due to the wide variety of glass types, it can be challenging to choose the best one for a project. The use of glass building materials in a few Benin buildings will also be covered in this study. The study's scope is constrained to the buildings chosen for their use of glass in construction. Through interviews, the empirical study in this research will examine the views of the building's end users. The study also examines the perspectives of building industry experts on the use of glass in Nigerian construction. As a result, the focus location of this study is Benin City, Edo state.

1.9 STUDY AREA

This research will take place in Benin, the capital city of Edo State, in the South-South region. The South-South region of Nigeria is one of the six geopolitical zones which comprises six states (Akwa Ibom, Bayelsa, Cross River, Delta, Edo, and Rivers). The region experiences a humid tropical

climate characterized by wet and dry seasons. It also has an abundant presence of fertile soil and clay found in the Benin, Port Harcourt, Sapele and Ughelli areas.

Benin City is located on Latitude 06°19' E to 6°21' E and Longitude 5°34' E to 5°44' E with an average elevation of 77.8 m above sea level. Benin City is a pre-colonial city, the capital of the defunct Mid-Western Region, Bendel State and the present-day Edo State. Benin City occupies a lowland plain in the south and rises slowly to the Esan Plateau towards the north. This region is endowed with fertile soil. The city is underlain by the sedimentary formation of the Miocene-Pleistocene age often referred to as the Benin Formation. The Benin Formation comprise mainly consolidated sand, fertile humusc and clay covering the whole area.



Figure 1.1: Edo state in Nigeria. (Source: Wikipedia distributed under creative commons)

1.10 LIMITATIONS

This research was limited in the following ways:

- i. The time allocated for the completion of the research was not enough to do justice to the work, and this was a result of the truncated academic year due to the industrial action undertaken by the academic staff union lasting eight months.
- ii. Lack of sufficient access to online documents, journals, articles and a lot more, as one must pay for some of these papers, that were done by other individuals and authorities
- iii. Limit on financial resources.
- iv. The lack of proper or large-scale diverse glass processing and manufacturing factory accessible to conduct a good case study in the collection of data.

v. Restrictions on the sourcing of information from organizations involved in the built industries due to security concerns and policies.

vi. Prevailing issues of insecurity in the nation limiting the ease of access.

CHAPTER TWO: LITERATURE REVIEW

2.1 DEFINITION OF TERMS

2.1.1 GLASS:

The vast majority of glass used for building construction is made from three natural raw materials: silica, lime, and sodium carbonate. Secondary materials, which are classified into three types, may be added to help with the glass-making process or to give the glass special properties. Most of the commercially produced glass is soda-lime glass. Its silica, soda, and lime composition, used in bottles, glassware, and windows, do not resist sudden thermal changes, particularly high temperatures, or chemical corrosion. Lead glass has a soft surface and contains about 20% lead oxide, making it ideal for decorative cutting and engraving, though it cannot withstand drastic temperature changes. Borosilicate glass, defined as any silicate glass containing at least 5% boric oxide, is more resistant to thermal changes and chemical corrosion. (Julia McMorrough, 2013)^{iv}

2.1.2 PRODUCTION OF GLASS

Glass production dates back to before 2500 BC, according to archaeological evidence. What was once a rare and prized art has become a common industry as a result of the Pilkington process. For thousands of years, the recipe for making glass has remained unchanged. Its properties can only be improved by incorporating specific admixtures into the raw materials or by providing a suitable coating to meet a variety of requirements. (Jacob, O.-D. 2013).^v

2.1.2.1 Manufacturing

The volcanic glass obsidian was used as a cutting material by Paleolithic peoples, but the technique of making glass probably began in northern Syria as a byproduct of metal production. Small glass beads were made and discovered as far back as the Bronze Age. Glass was known to the Egyptians,

but it was developed by the Greeks. The word glass (Latin glesum) originated in the Roman Empire, most likely in Trier (now in modern



Germany).

Figure 2.1: Millefiori Roman cup, Image courtesy of Wikipedia / City Museum of Ljubljana

Early Roman glass was made by ‘slumping,’ a technique that involves shaping glass over moulds at high temperatures in a kiln. Open vessels, such as bowls and plates, could be created by shaping a glass sheet over a core or former. As a result, the vessel has rough surfaces that will be ground or polished to a smooth finish. Before slumping, ribs were impressed on the glass sheet using a slotted tool. As a result, the bowl has a ribbed exterior that is polished and sometimes cut with horizontal

lines on the inside for additional decoration. Today, the industries are almost entirely mechanized, though hand operations continue to be used for small-scale or low-volume glass production in highly specialized fields.

The main processes are much the same as they have been in the past. There are four processes:

- i. Melting of the raw materials.
- ii. Refining to achieve homogeneity of the molten glass.
- iii. Working to form the glass into desired shape and
- iv. Annealing to relieve internal stresses developed during the working stage.
- v. Inspection

Other stages such as toughening, or decorating may be regarded as additional stages.

The raw materials (sand, lime, soda ash, potash, water, required additives and pigment) are proportioned in a batched house. They are later conveyed using belt conveyors to a pre-heated furnace. This furnace is usually in a large compartment made up of heating and regeneration chambers. The internal walls of the furnace are lined with special bricks made up of or impregnated with feldspars, high-resistant quartz or super-high alumina silicates. The materials on the internal walls are known as “refractory materials”.

The function of the regeneration chamber is to retain heat (captive heat or energy). These furnaces are heated using gases. The materials normally get to the fusion point in the furnace. Fusion or melting point varies from one type of material to the other or from one furnace to the other.

However, the melting process begins with a chemical reaction. To assist melting, the raw materials are thoroughly mixed before entering the furnace and waste glasses of the same types known as “culets” are added. The culets melt faster than any of the separate constituents and therefore speed up the melting quite considerably. One can therefore say it acts as a catalyst. This fused material still in its molten state is extruded or injected by the use of an extruder or prism into the moulds.

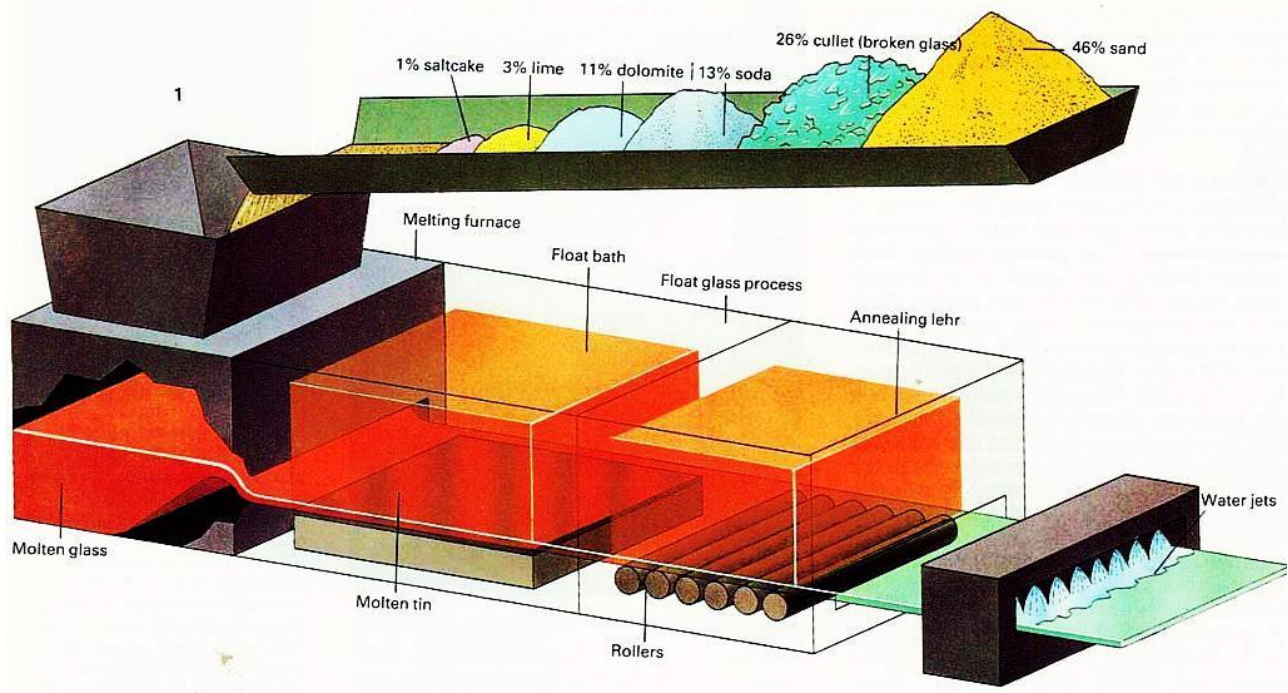


Figure 2.2: visual representation of the glass production process source:2022 Trydale.com

The produced glass is further passed through a compartment known as “lehrs”. These lehrs usually have centrifugal industrial blowers that cool the product over a distance before getting to the stage where they are shaped or cut into shape by the shaping or cutting machines. The finished products are then stamped and packaged and ready for the market.



Figure 2.3: Finished glass panel after cooling.

2.1.2.2 COLOURING OF GLASS PRODUCTS

According to Bourhis, E. L. (2014), there are three main ways to produce colored glass, though there are other ways as well. The first entails coating the glass with a transition metal or rare earth metal oxides. Metal oxides are typically added to the glass to achieve this. The appearance of color is caused by the metal ions' absorption of particular light wavelengths, which varies depending on the metal.

Another way to add color is through the formation of colloidal particles. Simply put, these are substance fragments dispersed throughout the glass. Heat treatment of these particles frequently results in what are known as "striking colors." The colloidal particles scatter light at specific frequencies as it passes through the glass, resulting in coloration. These colloidal particle colorants include gold, which has a ruby-red hue, and selenium. They both produce colors ranging from pink to bright red^{vi}.

The addition of already colored particles to the glass is the final major method for introducing color. Milk glass and smoked glass are two examples of this type of coloration; milk glass is achieved by adding tin oxide.^{vii}

Some of the colorants and their relative color on glass are listed below.

- i. Red glass: Cup roux – oxide, Selenium compound
- ii. Yellow glass: Antimony, Silver salt, Sodium oxide, Nickel oxide, Organic substances, Cerium oxide, Cadmium supplied, and Ferric oxide
- iii. Green glass: Chromium compound (chromate), Uranium oxide, and Ferrous oxide
- iv. Violet glass: Manganese and cobalt oxide, and Nickel and cobalt oxide
- v. Brown glass: Iron and manganese oxide, and Copper sulphides
- vi. Grey glass: Manganese dioxide and graphite, and Manganese alongside copper and iron oxide.
- vii. Black glass: Iron oxide (Nigeria local soda ash), Basalt, Manganese dioxide, Uranium dioxide
- viii. White glass: Calcium phosphate, Cryolite, Manganese, Calcium fluoride

2.1.2.3 SURFACE FINISHING ON GLASS PRODUCTS

- i. Brilliant cutting: very precise incisions of various shapes, tapering at their ends, made with a stone wheel, smoothed with a willow wheel, powered pumice, and polished with a felt buffing wheel.
- ii. Chipping: This gives the glass a jewel-like quality and is mostly done by hand (hand chipping).
- iii. Grinding: Abrasives are used to grind the surface glass to achieve a degree of coarseness and very fine texture.
- iv. Engraving: The process of making or giving very fine incisions on a glass surface with a small copper wheel that has been fed with oil and powder polish for brilliant cutting.

- v. Sandblasting: This is a technique that involves directing a sand jet onto the glass. This can be used for both decoration and privacy. This method can also remove a thin layer of opal or colored flashed glass.
- vi. Acid etching: A solution of hydrochloric acid (HCL) and alkali (sodium bi fluoride) etches glass, leaving a white frosted surface that is smoother than sandblasted surfaces.
- vii. Bending: Glasses can be bent around formers after being heated (formworks). Glass, such as wired glass, may present challenges in this process. Domes, showcases, non-reflective windows, and other applications call for bent glasses.
- viii. Silvering: Glass surfaces can be decorated by depositing silver or other metals (copper, lead, foil, aluminum foil) on any glass surface (flat or textured). It can be used to provide vision around blind corners, create the one-way vision, or create interior lighting.

2.1.3 THE TRANSPARENT AND TRANSLUCENT GLASSES

Flat glass, which includes transparent and translucent glasses, is the most common type of glass used in building construction. Transparent glasses produce clear-float images, whereas translucent glasses produce blurry (not very clear) images.

2.1.4 SHEET GLASS

This type of glass is transparent and relatively thin (2-6mm). The glass having glossy, apparently plane and smooth surfaces, have characteristic waviness of surface which is visible when viewed at an acute angle or in reflected light. It transmits light rays of the visible portion of the spectrum (i.e., the light transparency of the glass ranges from 85-90% depending on its relative thickness) and blocks practically all ultraviolet (UV) rays. The density, strength and thermal conductivity of the

glass are similar to those of soda lime silica glass as a whole. This includes cylinder-drawn sheet glass and flat-drawn sheet glass. They are predominantly used for glazing purposes in places like windows, interior doors, skylights etc. while sheet glasses over 3mm thick are also employed in multiple glass units and for glazing exterior doors, shop windows and showcases.

2.1.5 FLOAT GLASS

Running molten glass continuously on the bed of molten tin on which the glass float and flows until the surfaces are flat, parallel and cool produces this type of glass. The natural thickness of the glass is 6.5mm. The glass is transparent and has a flat parallel bright fire polish surface with no distortion. However, its present cost of operation is such that it is not yet replaced the sheet and plate glass. To produce thinner float glass, the molten ribbon of glass is cooled and stretched between rollers and to make thicker float glass, the spread of the molten ribbon is restricted to produce the required thickness. They are used for glazing shop windows, showcases and partitions in which exceptional clarity is required. It also finds application in public buildings (such as schools). Fenestrations.

2.1.6 PLATE GLASS

These are thicker than sheet glasses (over 6.5mm). It is of better quality than sheet glass and shows no distortion of vision when viewing objects through it at any angle. It may be both polished and unpolished. The polished plate glass has a very high compressive strength (up to 1200mpa). It is obtained by mechanical grinding and polishing or by floating the molten glass on the surface of the molten tin in a tank. They have similar applications to float glasses.

2.1.7 TEMPERED GLASS

It has high mechanical strength and heat resistance. They are produced by heating the sheet (5mm thick) to a temperature of 700 - 900°C and then rapidly and uniformly cooling it with a stream of air or in a liquid (by immersion and spraying). Tempered glasses are fully shaped in advance because they cannot be cut, ground, drilled or otherwise worked. The bending and impact strength is approximately 5-6 times and heat resistance is 2 times as great as those of sheet glasses. Tempered glass is used for glazing shop windows and showcases. It is also an excellent choice in public building fenestration, flush doors, partitions and other structures which must stand up well to impact loads.

2.1.8 WIRED GLASS

This glass contains wire mesh embedded centrally in the sheet during manufacturing. It constitutes no hazard when shattered because the wire mesh will hold the pieces together if it breaks into mechanical or thermal stresses. Wire glass is fabricated by continually passing the melt, through rolls. The mesh made of heat-treated steel wire (0.35 – 0.45mm) in diameter is unreel from a drum and placed throughout the glass sheet at depth of not less than 1.5mm. In some areas, the mesh used may be square 12.5 – 25mm sides or polygonal. The made wire mesh is available in sheets up to 2m long, 1.5m wide and 5-7mm thick. The light transmission of wire glass is at least 65%, the compressive strength is 600mpa and the bending strength is from 30 – 40mpa. The maximum density of 17mm wired glass is 1000 x 1500mm. It is obtainable either transparently (polished), translucent (cast), or figured. It may be flat or corrugated, plain or colored (the golden stain is produced by a thin coat of metallic oxides applied on the outside). It is used in architectural buildings where breakage from an impact may be expected to occur and where the danger of flying glass is to be avoided, such areas include windows, sashes, doors, skylights, balconies and logging facing, elevators, shafts, staircase,

smaller dome, translucent roof, partitions and other purposes (especially where safety and fire resistance are critical).

2.1.9 FIGURED GLASS

This type of glass has an obscured vision which is a result of the roughened surface produced in rolling (in which case a design is produced or out in one top roll) or by the impression of a large variety of decorative designs on one or both (less frequently) surface of the sheet. A considered or desired decorative effect is achieved by the figured glass. Its thickness ranges from 2 – 6mm. The depth of hills and valleys on the pattern surface is 0.5 – 1mm. The glass may be colored or plain, wired or non-reinforced or have a painted surface which makes light scatter. It protects against exposure to direct sun rays and gives a soft light. Widely used for glazing doors, partitions and various filler structures. The opaque figured glass can be used for facing purposes

2.1.10 LAMINATED GLASS

Another name for laminated glass is “shatter-proof glass”. It is formed by combining two or more sheets of plate glass with one or more interposed sheets of plastic to form a unit or unitary structure. It is referred to as shatterproof because it does not shatter and merely cracks. The transparent plastic used in holding the glass sheet together is usually polyvinyl butyryl firm. The layers of glass are clamped together under a pressure of about 2mpa and a temperature of 50°C (which exceeds the flow point of the film). They are colored or patterned. Color printing, transfer printing and other method using transparent and opaque paints can produce the pattern. They are mainly used for decorative stained-glass panels, ornamental partitions, balcony fancy and many other applications where there is a danger of impact such as sports arena.

2.2 GLASS IN ARCHITECTURE

In prehistoric times, Obsidian (Naturally occurring glass found near volcanic regions) and fulgurite (glass formed naturally after lightning strikes sand) were used to make weapons. The man-made glass was used as a luxury material was used in decorations, jewelry, vessels and crockery. Glass blowing was discovered in the 1st century in Europe, and this revolutionized the glass-making industry. The technique spread throughout the Roman Empire. Production of Clear glass, by the introduction of manganese dioxide, saw glass being used for architectural purposes. Cast glass windows began to appear in the most important buildings and villas in Rome and Pompeii. By the 11th-century sheet, glass was made by the crown glass process. In this process, the glassblower would spin molten glass at the end of a rod until it flattened into a disk. The disk would then be cut into panes. By the 13th century, this technique was perfected in Venice. Stain glass windows were used in gothic renaissance and baroque architecture from the 11th to the 18th century. Glass was still an item of luxury as it took large resources, brilliant skill and immense energy to be produced. In 1958 Pilkington and Bickerstaff introduced the revolutionary float glass process to the world. This method gave the sheet uniform thickness and very flat surfaces. Modern windows are made from float glass (Jacob, O.-D. 2013)^{viii}.

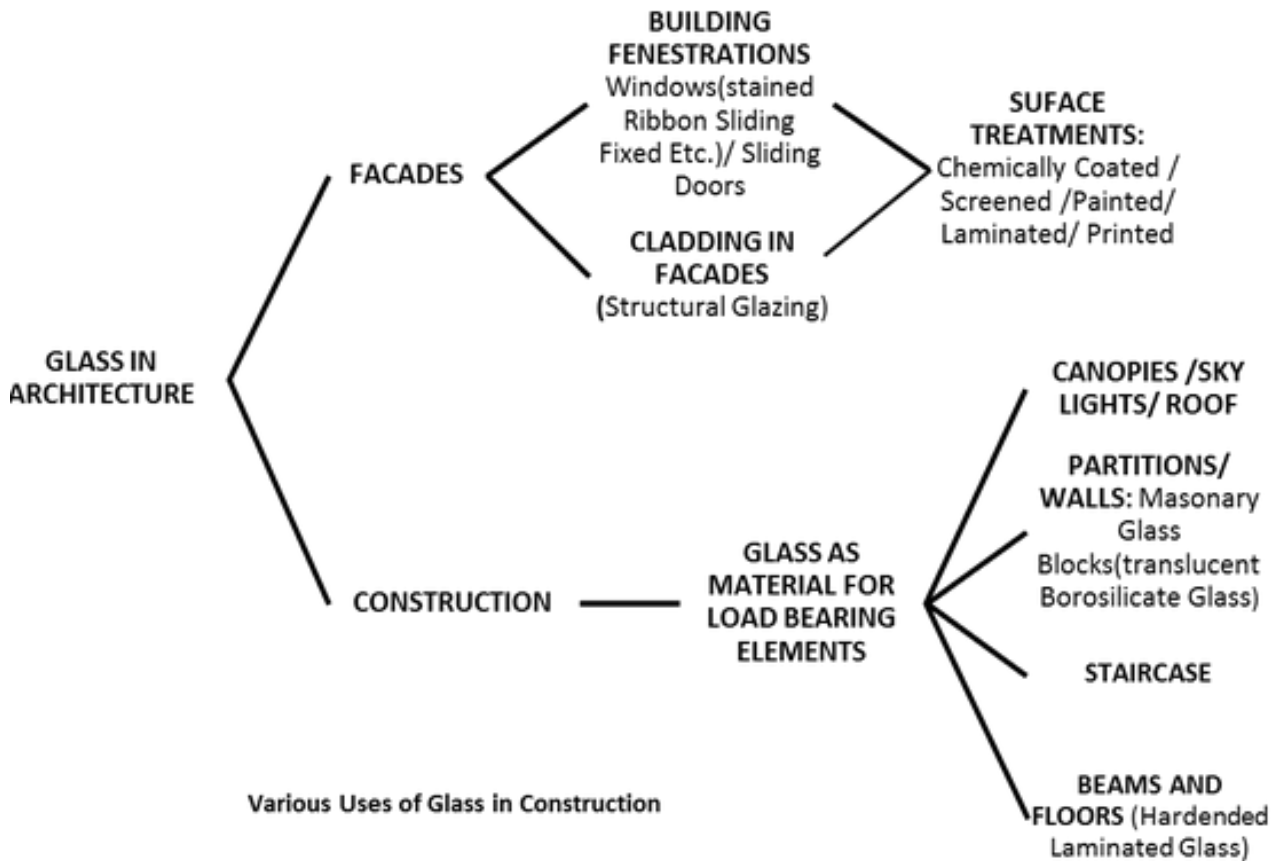


Figure 2.4: Various Uses of Glass in Construction

2.2.1 THE AESTHETICS QUALITIES OF GLASS

2.2.1.1 APPEARANCE:

The appearance of a glass surface as a construction material can be formed directly from the kiln that is by making the appearance brighter and lustrous through a fire finish. The appearance of different types of glass such as transparent, translucent and opaque can be colored in four ways:

- i. Pots color in uniform throughout its thickness
- ii. By painting
- iii. Colored ceramic pigment fused on one side

iv. Flashed glass has an extremely thin layer of transparent colored glass applied to one surface during manufacturing. Ordinary glass is transparent and more or less colorless, but the processed glass which has many patterns with varying characteristics gives a pleasing appearance.

2.2.1.2 FACING GLASS

The French word façade, which means the front face, refers to the pleasing effect as a result of proper arrangement of components in the front of the building. Glass façade refers to the exterior glass covering of a building. The increasing use of glass can be attributed to the fact that it gives building occupants a brighter and pleasant environment. A glass façade is one of the most popular ways to instantly raise a tall building's style factor. They are a popular choice because they offer sound and heat insulation in addition to giving modern buildings a contemporary yet open appearance. Due to the ease of use of the materials and the wide range of designs made possible by the various design options, glass facades are used extensively in modern building designs and constructions. They are mostly of the following:

i. COLOURED FACING GLASS

They are made up of thick opaque-tinted glass sheets. The opaque nature of the glasses is achieved by adding special substances to the batch-by-phase separation achieved by setting its treatment. The latter approach makes it possible to produce milk-white glass i.e., the degree of its whiteness being almost 95%. Its compressive strength is 100 – 1200mpa, its static bending strength of 40 – 50mpa, its impact bending strength of 0.2mpa and a coefficient linear thermal expansion of 8×10^{-6} to 9×10^{-6} . The oxides determine the color of the glass e.g., cobalt (blue), Nickel (violet), Manganese (black), and Chromium (green). The glass may be given a single tint throughout or colored to initiate the appearance of marble. They are used for exterior and interior facing walls in form of tiles and sheets 6 – 12mm thick.

ii. ENAMELLED FACING GLASS

They are made up of unpolished sheet or plate glass 6 – 12mm thick and given a coat of opaque ceramic paint or enamel on one side. The enamel side is the backside while the other is the front which may be smooth or figure. Its compressive strength is up to 900mpa, and its bending strength is up to 180mpa. Like colored-facing glass, it has appreciable durability, weather resistance, heat resistance and a pleasing appearance. They are mostly used in residential and public buildings for exterior and interior wall-lining panels.

iii. SMALT FACING GLASS

They are also known as mosaic glass consisting of split or cut opaque tinted glass pieces of irregular shape. The size of the glass pieces depends on the dimension of the panel where they are used and the scale of the design. Smalt-facing glass as well as mosaic tiles are available in about 1000 colors and shades permitting subtle color gradations. They are used in decorating walls of buildings.

iv. MIRROR FACING GLASS

The term mirror as commonly used refers to a sheet of glass 4-10mm thick which has one surface (back) which has continuous metal layer deposit (silver or aluminum) covered with a protective coating the primary/main function of the mirror is to reflect images. For facing purposes, use may be made of mirror tiles and strips produced from waste and breakage. In presenting-day interior architecture, they are mostly used to serve as decorative articles and to create an illusion of space.

2.2.2 THE UTILITY OF GLASS

Glass has been used extensively in the construction industry to enable results other than aesthetic qualities. Glass has contributed to keeping internal spaces at an appropriate temperature and has helped direct light from the outside of the building into interior spaces. Glass has been used extensively as a major lighting feature in the construction industry for opening windows, skylights, and various other features.

2.2.2.1 INSULATION WITH GLASS

Glass performs without a doubt well when used in certain operations, such as double skin façade systems, but generally speaking, glass is a terrible regulator of internal temperature. In such systems, the inner glass is warmer than it would be without the outer in the cooler months^{ix}. This has been proven to be true for structures in areas farther from the equator, but in more tropical areas, it would appear that the opposite is true. the opposite may happen in summer due to the high glass temperature, which may be uncomfortable, especially for those close to the glass surfaces. Thus, a modified approach is used, with a smaller vacuum-sealed space between the glass panes and extensive use of shading devices as shown in the experiments conducted by Lei, W., et al (2020)^x.

SOUND INSULATION:

Glass gives a measure of energy lost by impact air and structural-acoustic waves as they propagate through the filler structure of a building. This means that glass is a good sound insulator. This insulation can be strengthened through double glazing in which wider gaps are left between them. However, hollow glass blocks give a 35-40 decibels (dB) reduction.

THERMAL INSULATION:

Since glass is dense, its surface resistance is high so doubling the thickness of 6mm glass pane increases the overall thermal resistance by only 3%. This means that in double glazing, almost half the heat is lost through a single pane; the optimum gap being about 20mm. Typical double glazing provides thermal insulation approximately that of a 150mm brick wall.

VISIBLE LIGHT TRANSMISSION:

The visible light transmission of glass as a building material is its ability to allow light to pass through it without its direction being altered. This can be done in two ways: by directing light or diffusing light. Table 1 below shows how different types of glass direct and diffuse light.

The refractive index of building glass which is between (1.50 – 1.52) governs its reflectivity and transparency for different angles of incidence. Thus, when the angle of incidence varies from 0°C (i.e., normal to the glass plane) to 75°C, the transparency of the glass decreases from 92-50%.

ULTRAVIOLET TRANSMISSION:

Ordinary glass transmits a very small proportion of the sun's ultraviolet (UV) rays and virtually none in the so-called health band which is about 35% at 334nm and less than 2% of 314nm. Glass reduces a large percentage of ultra-violet rays which bleaches colored fabrics.

2.2.2.2 SUSTAINABILITY OF GLASS

Although there are many definitions of sustainability, they all agree that the minimum standard is the minimal use of non-renewable resources, compatible with the functions that the building must provide and with economics. This idea should, of course, be applied to the entire life cycle of the building's components as well as to the structure itself, meaning sustainability claims can only be made following a Life Cycle Assessment (IEA, 2000).^{xi}

Fully glazed structures, according to Federico Butera, are possibly the most hazardous kind of structure from the perspective of a mindless and uncritical replication. They are hardly sustainable if well designed, and they are definitely unsustainable if poorly designed (F.M. Butera 2005)^{xiii}. This may be seen as one side off the broad spectrum as The properties of glass have also become multifaceted, capable of carrying out a wide range of functions, like Solar Control to Thermal Insulation.

2.2.3 STRUCTURAL ABILITY OF GLASS

Today, glass is recognized as a practical building material that can be used structurally to design fascinating structures. Building glass must be able to withstand wind load, dead loads, imposed loads, animal and human impact, and occasionally thermal and other stresses. An ordinary single-glazed plane can safely deflect up to 1/125th of its span because glass is elastic until it breaks. Given that there is no permanent set in which inductile material provides a warning of impending failure, this is a very difficult situation to reconcile. The ability to connect structural elements has been another restriction on the use of glass. However, a number of tried-and-true solutions are now readily available. For example, structurally glazed systems produce more transparency than conventional captured systems because there are fewer visual breaks caused by the absence of metal on the exterior (and possibly the interior), giving the appearance of a continuous sheet of glass. (Stephen R. Ledbetter, 2006)

By cooling the surface of the glass more quickly than the interior, a process known as tempering can strengthen glass as a material. The interior cools and contracts first, making the surface rigid, which then pulls on the surface's residual compressive stress. Additionally, chemical tempering can be used to fortify glass. Tempering (heat treatment) is the key processing step for structural glass applications. the plan to produce a favorable residual stress field with compressive stress on the surfaces and

tensile stress in the glass's interior. The glass core provides good resistance to tensile stress because it is free of flaws. Only when they are subjected to an effective tensile stress will the inevitable flaws on the glass surface begin to spread. There is no such effective tensile stress and consequently no crack growth as long as the tensile surface stress caused by actions is less than the remaining compressive stress.

2.2.3.1 BEHAVIOUR IN FIRE

Although non-combustible, ordinary glass breaks and later melts in the fire. Nevertheless, certain types of glass have sufficient thickness and are suitably fixed to provide a useful degree of fire resistance which is the ability of glass to retain its physio-mechanical properties when it is subjected to fire or elevated temperature (up to 1000°C) caused by fire. Glass has half (1/2) an hour rating and one (1) hour rating. In comparison to other materials like steel which has 1900°C and Aluminum which has 660°C as their melting point, glass has an approximate melting point of 1500°C.

2.2.3.2 THERMAL MOVEMENT:

Glass has a coefficient of thermal expansion of $76 - 80 \times 10^{-7} \text{oc}$. Because it is not fixed like other materials and is also lower, there is an allowance known as "thermal allowance movement" that allows for movement. Furthermore, thermal stresses arise as a result of the magnitude of thermal stress caused by the temperature difference between the hottest gradient across the glass. Their edges, like heat-rejecting glasses, are clearly cut, nipped, or shelled so that they do not create points of weakness in critical shade zones. The thermal properties of glass influence crack sensitivity. Because glass is a poor heat conductor, any sudden temperature change at the surface is transmitted very slowly to the interior. Internal stresses are created as a result of temperature change expansion or contraction, which can lead to crack propagation.

2.2.3.3 DURABILITY:

Glass is extremely durable in normal conditions. The durability of glass also depends on the strength of different types of glass compositions, structures and quality. Glass weighs 2.5kg/m² / mm thickness and 2560 kg/m³ density when compared to other building materials. It is however noteworthy that its density varies with the type of glass composition available. This means that glass has resulted in different densities. For example, structural glass has a compact density, average density and porosity of 3g/cm⁻³, 2500 – 3000kg/m³ and 0 (zero) respectively.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 PREAMBLE

The collection and interpretation of data for fixing a specific hassle is paramount to a research study. Hence, this Chapter defines the research strategies that have been carried out in the process of collection and evaluation of data. It consists of the data sources, the modes of collection and the types, in addition to the approach utilized in narrating the results.^{xiii}

3.2 RESEARCH DESIGN

The research design is a tool for preparing a research proposal in the form of a complete and thoughtful package (McCombes, S. 2021)^{xiv}. It describes the research design and also includes a brief description of the goals achieved. The case study method is the research design used in this study. This method was chosen because of the nature of the research. The case study method is the preferred strategy for asking how, who, why, and what questions due to the researchers' lack of control over the events that occurred during the implementation of the project^{xv} (Mishra, S. B., & Alok, S. 2017). Therefore, the case study method provides researchers with a very broad subject perspective. Therefore, this method would; be used as a pilot for further research studies. Allow the subject to explore objects in the natural environment. Allow multiple sources of information. An in-depth study of the subject is allowed, so the study includes a study of buildings utilizing high volumes of glass found in Benin City, Edo state. A field study is being conducted on a building in Nigeria to determine the ways glass has been employed from a functional, aesthetic and structural perspective, the processes involved and the conditions leading to the design choices made. Data collected through observations, interviews and online journals during the research period were analyzed and processed to help answer research questions.

3.2.1 PURPOSE OF RESEARCH

The purpose of this research is further to educate construction professionals on the use of glass in buildings and strive to make them an even more utilized material in construction.

3.2.2 APPROACH TO RESEARCH

The approach used in this research was an analytical study and research of some foreign and local buildings, examining their advantages, problems and adaptability to the local environment, carrying out and analyzing field research, and providing important information through interviews. In order to get an overview of the glass construction process, the relevant literature on the subject was also reviewed. The steps that were taken include.

- I. Technical literature study on the buildings.
- II. Description of the project process.
- III. Consideration of glass usage information.
- IV. Comparing of design choices and eventual outcomes.

3.2.3 DATA TYPE AND SOURCES

The type of data applicable to this study was qualitative, which involves collecting descriptive data on various natural settings to understand the subject matter and answer questions such as how and why variables become the way they are. The results of this study were descriptive and narrative in nature.

3.2.4 DATA SOURCES

The data sources used in this study include:

Primary data: The data is collected and processed by the researchers. The photos, sketches, etc. were obtained during the research work and through personal interviews with the participants or personnel involved in the construction of buildings in the Nigeria construction industry and other buildings they might find.

Secondary data: The secondary data collected in this study comes from related literature searches in libraries, the Internet, papers, journals, and newspaper publications.

3.2.5 TECHNIQUES OF DATA COLLECTION

Methods used by the researcher were interviews, observations, document analysis, and actual fieldwork:

- i. **Interviews:** Interview techniques were obtained through verbal information on exploratory questions to the construction personnel involved in the planning of steel prefabricated houses.
- ii. **Observation:** It involves identifying and recording facts, circumstances and events. The purpose of this method is to provide observations with information that staff may not want to share with the researcher for some known reasons.
- iii. **Actual fieldwork:** Actual fieldwork includes a physical inspection of buildings and interviews with project control engineers and artisans. Further data were obtained through interviews with employees involved in glass construction.

CHAPTER FOUR: CASE STUDY DATA

4.1 PRESENTATION OF DATA

The collected data is recorded in written form. The sketches are used to analyze the data. The narrative description of the collected data is organized and grouped by subtopics. All diagrams and pictorial data are labelled with a short description of the picture. Chapter 5 of this research work explains the result of the analysis.



Figure 4.1: Showing the aerial view of the secretariat complex Edo state. (Source: Field work 2022)

4.1.1 CASE STUDY 1: THE EDO SECRETARIAT COMPLEX, SAPELE ROAD, BENIN CITY, EDO STATE.

4.1.1.1. INTRODUCTION

Edo State Government Secretariat is the permanent administrative office of Edo State's agencies and parastatal. The complex is composed of 4 high rise building blocks with over 150 office spaces, and annex buildings, that accommodate over 500 civil servants, a library, a civic center and security posts. The Secretariat complex also contains a Treasury House for the staff of the Ministry of Finance. Food courts, a rooftop restaurant and terrace, dedicated commercial spaces, and a venue for events. The design of the complex's main square was designed to represent the traditional Idia Mask, a key cultural symbol of Benin's ancient Kingdom.



Figure 4.2: Google earth imagery of the site showing its extents located along Benin-Sapele Road. (Source: google earth satellite imagery retrieved 2022.)

4.1.1.2. CONSTRUCTION CONTEXT/ PURPOSE

The complex owned by the Edo state government was commissioned during the military regime of general Yakubu Gowon by Brigadier general Samuel Osaigbovo Ogbemudia, the then military governor of the mid-western state of Nigeria. The construction of the first of the office blocks, the palm house, began in February of 1973. After the completion of the palm house and the beginning of the other blocks, the project was placed on hold about forty years. Work was resumed on the complex when governor Obaseki came into office. The contract for the completion and renovation of the secretariat complex was awarded to A&K construction company. The project valued at around USD 22.9 million as at the time of this research has undergone a series of facelift taking it from abandoned concrete frames to actual usable office spaces worthy of the civil staff it was intended for. As at the time of writing two out of the four main office blocks have been fully revitalized and are now in use with a third roughly ten percent from completion. The supervision and part redesign of the buildings was handled in house by the Edo state public building and maintenance agency though some minor design decisions were left in the hands of the contractor. In consideration of this research the revitalized office block B is studied on the basis of the significant use of glass in its construction in similar fashion to the other office blocks in the complex.



Figure 4.3: A view of fully renovated office Block D. Showing the extensive use of glass on the elevation. (Source Field work 2022)

4.1.1.3 BUILDING DESCRIPTION AND DESIGN PRINCIPLES



figure 4.4: A view of on-going renovation of office Block B, 90% completion.

(Source Field work 2022)

Entering into the secretariat complex from the main gate along Sapele road, the towering form of office block b can be seen by slightly inclining one's eyes to the right. As it is on the opposite side of the main complexes road to the civil service commission building. The renovation of the contemporary office block as valued in the Edo state procurement schedule is one hundred and thirty-five million Naira (NGN 135,000,000)

As an office complex the building has a minimalist style to its facades with a rhythmic flow of black aluminum framed reflective glass panes and gray concrete panels alternating at different spacing on both of the primary building faces. The height of the building is about 35 meters above ground level

housing 9 floors of administrative spaces and roof top cafeteria and service floor. The renovation process involved stripping the building of all its previous enveloping elements leaving just the skeletal frame. The high-rise was then re-clad with prefabricated cementitious board panels and single glazed windows taking up to forty percent of the two primary building faces and ten percent of the other two.

4.1.1.4 GLASS USAGE

The office block is characterized by its use of repeating slender glass panes alternating with cement fiber panels coming together to form the building envelope. The glass used to enclose the space provides natural lighting to the interior spaces with some sections working as open-able windows to aid natural ventilation to an approximate 30% opening range. The glass panels are set within aluminum frames connecting them to the buildings main frame work. the aluminum frame of the glass is finished in a black color which creates a contrast with the highly reflective glass panes and gray wall panels to give the building a sleek modern appearance.



Figure 4.5: A view of the unclad frame structure of Block B during the renovation. (Source: Field work 2022)

The glass used on the building's exterior is coated with a reflective film on the exterior but transparent on the inside, allowing for an unobstructed view of the exterior surroundings. Overall, the glazing envelope of the building plays a significant role in establishing the buildings character, providing lighting into the building and creating a sense of openness in the interior spaces to boost productivity of staff.

4.1.2 CASESTUDY 2: MUSÉE ATELIER AUDEMARS PIGUET, LE CHENIT, SWITZERLAND.



Figure 4.6: Aerial view of the Musée Atelier Audemars Piguet (Source: Iwan Baan, retrieved from Arch daily 2022)

4.1.2.1. INTRODUCTION

The 140-year-old, family-owned watch company Audemars Piguet takes great pride in its history and in the creation of items that are uncommon, valuable, and invariably one of a kind. This philosophy

is embodied in a classic, double spiral-shaped pavilion that serves as their heritage museum and is firmly planted in the ground. (Block, I. 2020).^{xvi}

4.1.2.2. CONSTRUCTION CONTEXT

ARCHITECTS: ATELIER BRÜCKNER,

DESIGN ARCHITECTS: BJARKE INGELS GROUP

LOCAL ARCHITECTS: CCHE

PROJECT LEADER: DANIEL SUNDLIN

CLIENT: AUDEMARS PIGUET

STRUCTURAL ENGINEER: DR. LÜCHINGER + MEYER BAUINGENIEURE AG

MECHANICAL ENGINEER: FONDATION PIERRE CHUARD INGÉNIEURS-CONSEILS SA

GLASS FITTINGS: GUARDIAN GLASS

Bjarke Ingels Group, also known as BIG, is a major name in architecture and has locations in both Copenhagen and New York. The development of BIG' architecture came about after a careful examination of how modern life is transforming and evolving. The winning entry was made by the team for The Musée Atelier Audemars Piguet, which was completed and opened to the public in 2020. Teams of experts and craftspeople worked on the challenging architectural project, including CCHE, the local architecture firm that built the building..^{xvii}

4.1.2.3. BUILDING DESCRIPTION AND DESIGN PRINCIPLES

Architecture giant Bjarke Ingels Group, also known as BIG, has offices in Copenhagen and New York. BIG' architecture is the result of a careful examination of how modern life is constantly changing and evolving. The group submitted the winning design for The Musée Atelier Audemars

Piguet, which was finished and made public in 2020. Teams of professionals and artisans, including CCHE, the local architecture firm that constructed the structure, completed the complex architectural project. ^{xviii} . The spiral-shaped structure has curved walls made of load-bearing structural glass and is incorporated into the landscape. The exhibition features transitions that flow optically. The general impression varies depending on the season and the time of day. A spectacle that captures the passage of time is produced by the interaction of reflections and shadows. The spiral-shaped pavilion for the Musée Atelier, created by the Swiss architecture firm CCHE under the direction of BIG, rises steadily on walls of structural curved glass. It is the first building of its kind to be built at such an altitude, making it an engineering and design marvel. The steel roof is entirely supported by the curved glazing, and the exterior surface is covered in a brass mesh that controls temperature and light. The green roof also absorbs water while regulating temperature. (Pintos, P. 2020) ^{xix} .



Figure 4.7: View of the integrated form blending into the landscape. (Source: Iwan Baan, retrieved from Arch daily 2022)

The spiral has been designed to perfectly integrate the surrounding landscape. The floors follow different slants to adapt to the natural gradient of the land and provide the basis of the museum's

inner layout stretched into a linear continuous spatial experience. Inside, the curved glass walls converge clockwise towards the spiral's Centre, before moving in the opposite direction: visitors travel through the building as they would through the spring of a timepiece.

Musée Atelier Audemars Piguet is conceived as an oxymoron. Striking yet subtle. Contemporary yet timeless. Functional yet sculptural. Floating yet rooted. Local presence with a global resonance. A striking landmark that is seamlessly integrated in the local landscape. A contemporary yet timeless architecture that blends with the historical buildings to create an intuitive sequence of spaces - old and new. A pavilion for the art and science of watchmaking that is conceived as a storyline for the visitors - every element is governed by the functional requirements of the exhibition, while appearing as a striking sculpture conceived in a single gesture.



4.1.2.4. GLASS USAGE

Figure 4.8: Glass façade of the building forming aesthetically appealing form (Source: Iwan Baan, retrieved from Arch daily 2022)

With this spiral-shaped pavilion, BIG (Bjarke Ingels Group), a Danish architecture firm, pushed the boundaries of design by completely supporting the living roof with curved laminated-glass interior and exterior panels. This design complemented the founders' house and the first workshops, where Jules Louis Audemars and Edward Auguste Piguet founded their company in 1875.

(Ingles, 2020)

According to structural and façade engineers Lüchinger+ Meyer's Philippe Willareth, "This project touches on a number of significant subjects, including: First of all, balance. In order to build a sturdy structure, we had to structurally balance the 140 pieces of glass with the steel roof. Energy use was also a key consideration, making the materials' energy efficiency just as crucial as the structural calculations.

Willareth explains, "Structurally, we also had to consider the microclimate of the region."

The triple-glazed load-bearing curved glass is attached using structural adhesive. Instead of point fixings, use silicone to geometrically bed them into steel shoes. which lead to tension points. Another crucial component of the design was surface quality. In order to achieve the highest level of transparency, the designers had to use a glass.



Figure 4.9: Curved glass walls supporting the roof plane. (Source: Iwan Baan, retrieved from Arch daily 2022)

Additionally, mock-up modules with different panel types were developed, not just for the client to see, not only to demonstrate the load-bearing principles of the glass design, but also to demonstrate the glass quality.^{xx} Additionally, these modules were used to test different coatings and examine how they affected energy transmission. The panel formulation underwent a number of tests after it was finalized till it was deemed perfect for up-scaling on site.

The spiral form of the Musée Atelier Audemars Piguet allows for ample natural light to enter the structure and illuminate the pathways. Additionally, the use of glass in the building's design allows for views of the outside from within the museum, which can help to create a sense of connection to the surrounding environment and contribute to a feeling of spaciousness within the building.

The use of glass in the museum's design also serve functional purposes related to energy efficiency. For example, the building's glass elements are designed to optimize the amount of natural light that enters the building, in order to reduce the need for artificial lighting. This can help to save energy and reduce the building's carbon footprint.

Overall, the use of glass in the Audemar museum's design serves a number of functional purposes that contribute to the overall visitor experience and the building's energy efficiency.

CHAPTER FIVE: CONCLUSION

The purpose of this chapter is to summarize the results of this research and make a conclusion from the discoveries and emphasize other research areas on the subject that require further studies.

5.1 SUMMARY OF RESEARCH FINDINGS

- A large portion of the usage of glass in Nigerian buildings fall under functional and aesthetic considerations.
- The load bearing capabilities of glass are progressively becoming more comprehensive.
- Information regarding the properties of glass is undergoing a series of refinement as studies progress.

5.2 CONCLUSION ON RESEARCH WORK

As research into the use of glass continues, it is likely that its use will increase rather significantly in building. Already, development of such products as fiberglass, optical glass fibers and glass ceramics are finding its way into our lifestyle though not of them are currently being applied to building.

Since the desire of glass application in building construction is high but lacks knowledge of when and where to apply or use it, with this research carried out on glass and where they are relevant in building to meet or satisfy maximum requirements, the material should be used more extensively and technically because glass has good construction properties with different applications which other materials lack.

5.3 RECOMMENDATIONS

Based on my research, the following recommendations are made:

- In order to lower the overall cost of using glass in construction, more research is required, including the identification of more efficient and simple to learn construction methods.
- The Standards Associations in Nigeria, eg Standards Organisation of Nigeria (SON) should create more user-friendly manuals that specify the proper applications for safety glazing materials as well as the kinds of materials that are acceptable for use as safety materials.
- It would be advantageous to build more glass factories in order to reduce monopoly in order to lower the price of glass components.
- Glass stands out from other construction materials because it is both transparent and brittle. Any type of cracking is viewed as a failure, in contrast to the other commonly brittle materials, concrete and masonry. A new structural glass standard should be offered to make glass available to the larger design community and as a reference to the building authorities that review and monitor them.
- The absence of design standards has prevented glass from being widely used as a structural element. This has prevented non-specialist engineers and designers from using the material and also restricts the ability of building authorities to assess structures, even those made of glass specialists. In some instances, the absence of a design standard has permitted the development of subpar "copycat" installations.

5.4 CONCLUSION

Glass has undergone significant development in the building industry since it was first used as a window glazing material. Although it is still the most popular glazing material for windows, applications as diverse as doors, shopfronts, shower and bathtub enclosures, balconies, mirrors,

floors, skylights, and wall cladding have been added. The important thing is that knowledge of the types of glass and glazing systems to use in all applications must be present. In areas where injuries are likely, it is especially crucial to use the proper glass for the job. In order to achieve this, the Standards Associations in Nigeria must create more user-friendly guides that clearly outline the proper applications for safety glazing materials as well as the categories of materials that are recognized as safety materials. The standards define a proper method for fixing glass in the majority of glazing situations. Despite the growing popularity of glass in construction, little information has been written about it, according to a literature search done for this report. Maybe it's because glass is typically used in much smaller quantities in buildings than more traditional building materials like concrete, steel, or brick. However, it is believed that a sufficiently large pool of data regarding applications in Nigeria should be made available. It should be noted that doing this could have drawbacks beyond just harvesting and implementing foreign practices. Therefore, more research is required to transform these practices into options that are appropriate for Nigeria.

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