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Optimizing Building Orientation for Passive Cooling: A Comparative Study of Museums in Lagos

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Abstract

This research paper explores the application of passive design strategies in three museums in Lagos, Nigeria: The National Museum, Jaekel House, and the Heritage Museum in Badagry. The study focuses on building orientation as a key passive design strategy and evaluates its effectiveness in enhancing energy efficiency and thermal comfort in tropical climates. With the use of data collection from Google Earth Pro, a comparative analysis examines the architectural features and design elements of each museum, highlighting their use of building orientation, shading devices, and landscaping to optimize passive cooling and natural lighting. The innovative layout and strategic orientation of the National Museum demonstrate a successful integration of passive design strategies, while Jaekel House's use of deep overhangs and vegetation showcases a deliberate commitment to sustainable architecture. The Heritage Museum in Badagry, with its historical significance, presents an intriguing case study for passive design. While limited information is available, satellite imagery suggests an optimal orientation for passive solar design, complemented by deep overhangs and a reflective roof. The findings suggest that the three museums can benefit from further enhancements to their passive design strategies, including the integration of renewable energy sources, smart building systems, green roof systems, and water harvesting and management systems. In addition, educational initiatives can raise awareness and promote sustainable practices among visitors and the local community.

Keywords: Passive Design. Building Orientation, Museum, Lagos.

Introduction

A museum is a location where valuable cultural, historical, and artistic artefacts are displayed, conserved, and shared with the general public (Antelo, 2019). Apart from its display role, museums are essential for the gathering, preserving, and safeguarding of culturally and historically significant artefacts (Makalesi et al., 2020). As they gather, record, and disseminate information about human culture and the environment, they contribute to the collective memory of society. They also educate the public and provide them with sensory experiences (Friman, 2006).

In the context of sustainable architecture, passive design strategies play a pivotal role in reducing energy consumption and enhancing indoor comfort. More over 40% of the world's energy is used by buildings, and they also produce one-third of greenhouse gas emissions

(Monis & Rastogi, 2022). Among these strategies, building orientation stands out as a fundamental approach that leverages the natural elements to achieve thermal comfort and energy efficiency (Ashmawy & Azmy, 2018). This research focuses on the application and effectiveness of building orientation as a passive design strategy in selected museums in Lagos, Nigeria. Examining how museums in Lagos are oriented and how this impacts their thermal performance, this study seeks to provide insights into optimizing building orientation for passive cooling in tropical climates.

It is impossible to overstate the importance of passive design techniques, specially building orientation, in tropical areas such as West Africa and because of the high temperatures and humidity in the area, passive cooling techniques are crucial for lowering the need on mechanical cooling systems. Buildings should be designed with floor plans that face the equator for the bulk of their rooms' windows in order to achieve energy efficiency. It was also discovered that a building's orientation affects the total amount of solar energy it receives (Sholanke et al., 2022; Onamade et al., 2022) Wind speed and direction are affected by the orientation of the structure; as a result, natural ventilation reduces the amount of heat lost by convection. In other words, to optimize natural ventilation and shade, buildings are oriented with respect to the sun's path and the direction of the prevailing winds.

In Lagos, Nigeria, several museums showcase diverse architectural styles and historical significance. However, many of these museums face challenges related to indoor comfort and energy consumption due to their design and orientation (Sharif-Askari & Abu-Hijleh, 2018). Traditional museum buildings in Lagos are often oriented without consideration for solar exposure or natural ventilation, leading to increased reliance on air conditioning and higher energy costs (Adeola, 2021).

The study of building orientation in museums is particularly relevant as these institutions require controlled environments to preserve artefacts and artworks. By analysing the orientation of selected museums in Lagos, this research aims to identify best practices and opportunities for optimizing building orientation to enhance passive cooling and reduce energy use. The choice of museums as the focus of this study is deliberate, as these buildings have specific environmental requirements and are often considered exemplars of architectural design.

National Museum Lagos

The National Museum Lagos, located in Lagos, Nigeria, is a prominent cultural institution that showcases the rich history and diverse cultural heritage of Nigeria. It is housed in a colonial-era building that served as the colonial era headquarters of the Nigerian government (Nuelson, 2023). It reflects a blend of architectural styles, including elements of British colonial architecture and traditional Nigerian design.

Fig. 1: National Theatre Lagos (Trip Advisor, n.d.)

One of the key aspects of the National Museum Lagos is its architectural design and orientation, which plays a crucial role in its thermal performance and energy efficiency. The museum's location in a tropical climate zone, characterized by high temperatures and humidity levels, necessitates the use of passive design strategies to maintain comfortable indoor conditions while minimizing energy consumption (Adewumi et al., 2023; Ogwu et al., 2022).

Jaekel House Lagos

Nigerian Railway Legacy Museum popularly known as Jaekel House, located in Lagos, Nigeria, is a prominent cultural institution dedicated to preserving and showcasing the rich history and heritage of the region. As a museum, it plays a crucial role in educating and engaging the public about the cultural significance of various artefacts and artworks.

Fig. 2: Jaekel House (Radio Museum, n.d.)

Like many museums in Lagos, the Jaekel Museum faces challenges related to energy consumption and indoor comfort due to its architectural design and location in a tropical climate.

Heritage Museum Badagry

The Heritage Museum in Badagry, Lagos, stands as a testament to Nigeria's rich history and cultural heritage.

Fig. 3: Heritage Museum Badagry (Awofeso, 2016)

As a museum dedicated to preserving and showcasing artefacts and stories from the past, the Heritage Museum also provides an intriguing case study for passive design strategies, particularly building orientation, in tropical climates.
These museums in Lagos provides an excellent case study for examining the application of building orientation as a passive design strategy. By analysing the museum's orientation in relation to solar exposure and natural ventilation, this study can provide valuable insights into how building orientation can be optimized to enhance passive cooling and reduce energy use in cultural institutions in tropical climates.

Problem Statement

Museums in tropical climates, such as those in Lagos, Nigeria, face significant challenges in maintaining thermal comfort and energy efficiency due to high temperatures and humidity. Efficient building design is essential to minimize energy consumption and create a comfortable environment for preserving artefacts and enhancing visitor experiences. Building orientation, as a passive design strategy, can significantly enhance thermal comfort by leveraging natural light and airflow. However, the impact of building orientation on passive cooling and energy efficiency in Lagos museums has not been thoroughly explored. Museums like the National Museum, Jaekel House, and the Heritage Museum in Badagry offer unique opportunities to study the effects of building orientation on energy efficiency and thermal comfort.

Research Gap

There is a lack of comprehensive research on the impact of building orientation on passive cooling in Lagos museums has resulted in missed opportunities to maximize energy efficiency and thermal comfort. This study seeks to fill this gap by conducting a comparative analysis of building orientation's effectiveness as a passive cooling strategy in Lagos museums. The research aims to provide actionable insights that could lead to more sustainable and energy-efficient museum environments in tropical climates.

Literature Review

Passive design strategies, including building orientation, have been extensively studied and applied in various architectural contexts to improve energy efficiency and indoor comfort(Asaju et al., 2024). In tropical climates like West Africa, where high temperatures and humidity levels are prevalent, the effective use of passive design strategies is particularly crucial. This literature review examines existing studies and research related to building orientation as a passive design strategy in tropical climates, with a focus on museums and cultural institutions. One of the key studies in this area is the work of Santamouris and Asimakopoulos (2016), who conducted a comparative analysis of building orientation in tropical climates. The study found that proper building orientation can significantly reduce the need for mechanical cooling and improve indoor comfort. Similarly, a study by Odeleye and Aderonmu (2018) focused on the impact of building orientation on energy consumption in tropical climates, highlighting the importance of proper orientation in reducing energy use.

In the context of museums, several studies have examined the use of passive design strategies to enhance energy efficiency and preserve artefacts. For example, the work of Chappells and Shove (2005) explored the role of building orientation in museum design, emphasizing the need to balance the preservation of artefacts with the provision of a comfortable environment for visitors. Similarly, the study by Hesp and Loo (2010) investigated the use of natural ventilation and building orientation in museum design, highlighting the potential for significant energy savings.

In the specific context of West Africa, studies focusing on building orientation in tropical climates are limited but growing. For example, the study by Aina and Fagbenle (2017) examined the impact of building orientation on thermal comfort in residential buildings in Nigeria, highlighting the need for proper orientation to reduce reliance on mechanical cooling. However, more research is needed to understand the specific challenges and opportunities related to building orientation in West African climates, particularly in the context of museums and cultural institutions.

Overall, the literature suggests that building orientation is a critical factor in passive design strategies, particularly in tropical climates. By optimizing building orientation, architects and designers can enhance energy efficiency, improve indoor comfort, and preserve cultural heritage in museums and other buildings in tropical regions like West Africa.

In the present era, the escalating demand for continuous energy, the surge in carbon emissions, and the reliance on non-renewable resources collectively contribute to heightened health, environmental, and economic risks (Sangkakool et al., 2018). Of the total energy demand, buildings account for 16–50%, underscoring the crucial role of energy management in buildings and emphasizing the necessity for architects and decision-makers to strategically plan the design process from the outset (Johansson et al., 2009; Monna et al., 2021). Studies indicate that making informed design choices in the initial stages can lead to a significant reduction of up to 60% in a building's energy consumption (Petersen & Svendsen, 2010).
Addressing this issue begins with identifying sustainable approaches to heating, cooling, and lighting within a building. In response to the imperative to diminish dependence on non-renewable energy sources, researchers have explored the concept of passive design (Mushtaha et al., 2021). This approach serves as a cost-effective strategy to curtail building energy consumption without heavy reliance on mechanical systems. Consequently, it becomes evident that the need for cooling or heating and the overall thermal performance of a building are significantly influenced by its geographical location (Mushtaha et al., 2021).

Museums
Museums situated in tropical climates have the opportunity to enhance thermal comfort(Asaju et al., 2022) by incorporating passive design strategies, such as strategic building orientation. A noteworthy example is the Indonesian Plantation Museum in Medan, which adeptly adapts to the local climate by featuring roofs with slopes exceeding 30 degrees, cross-ventilation openings, and substantial concrete walls (Kolani et al., 2023). Similarly, traditional Malaysian buildings have evolved over centuries to effectively respond to the local climate, ensuring comfortable indoor conditions without relying on mechanical systems. However, the contemporary architectural landscape in Malaysia often falls short of embracing these traditional strategies, leading to a heavy reliance on mechanical systems for thermal comfort(Asaju et al., 2024).
Studies have indicated that passive design strategies, including thoughtful building orientation and the optimization of solar exposure and ventilation through shading devices, can have a significant positive impact on the productivity of workers in office buildings within tropical climates (Oleiwi & Mohamed, 2022). Consequently, the passive design of museums in tropical climates stands to benefit from the integration of building orientation and other strategies to achieve optimal thermal comfort and enhance overall productivity.

Passive Design Strategies in Museums
Passive design strategies implemented in museums involve leveraging architectural features and building materials to control temperature and humidity, thereby reducing dependence on mechanical systems like air-conditioning. These approaches play a pivotal role in enhancing energy efficiency and sustainability in museum design (Cole et al., 2020;

Li & Zhu, 2018; Osello et al., 2018). Examples of passive design strategies encompass the utilization of local materials, integration of cultural elements, adjustment of lighting and room temperature, orientation, and consideration of sloping field topography (Mushtaha et al., 2021).

Passive design approaches leverage a building's inherent energy resources, considering factors such as its location, the local climate, and the construction materials employed(Onamade et al., 2022). The primary objective is to enhance overall building energy efficiency. These strategies prove particularly effective in minimizing the reliance on extensive cooling systems by maximizing the utilization of natural ventilation. While passive design methodologies do influence the initial project costs, they ultimately contribute to cost reduction by diminishing the demand for heating and cooling systems.

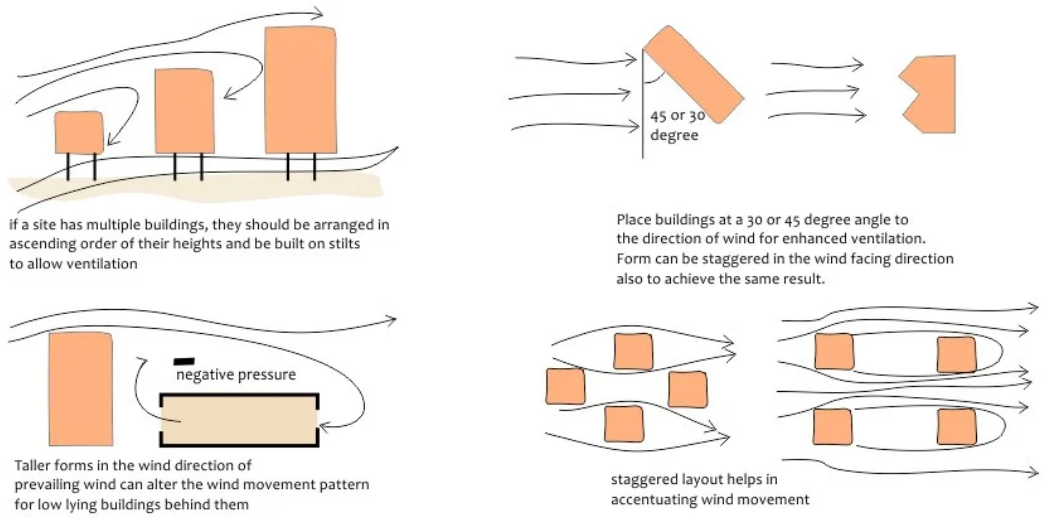

Fig. 4: Figure showing arrangement of buildings for effective passive design (Goyal, 2023)

Building Orientation

In tropical regions, extensive research has been conducted on passive design strategies, particularly building orientation, with the aim of attaining thermal comfort and reducing dependence on mechanical cooling systems. Traditional Malaysian buildings, developed over centuries, have demonstrated an effective response to the local climate, providing comfortable indoor conditions without the necessity of mechanical systems (Oleiwi & Mohamed, 2022).

Similarly, a study in Lagos, Nigeria, revealed that passive design strategies, such as optimal building orientation and the use of shading devices, significantly influence the productivity of workers in office buildings (Oluwatayo & Pirisola, 2021). The Faculty of Engineering building at Syiah Kuala University in Indonesia also showcases the application of tropical architectural concepts, including strategic building orientation and the incorporation of shading devices, with the objective of achieving thermal comfort in the tropical climate

(Khidmat et al., 2020). These findings underscore the significance of passive design strategies, including building orientation, in realizing thermal comfort in tropical regions.
In tropical regions, the optimal orientation for buildings in passive design is typically to have a significant portion of the building facing north or south (Aste et al., 2020). This orientation allows for effective utilization of natural ventilation and sunlight while minimizing direct exposure to the intense tropical sun. The general recommendation is to have the longer sides of the building facing north and south, with minimized east and west-facing openings (Energy5 your way, 2024).
North-facing orientation allows for consistent and controlled natural lighting throughout the day without excessive heat gain, while south-facing orientation can be beneficial for capturing prevailing breezes and optimizing natural ventilation. This design approach helps in reducing the reliance on mechanical cooling systems, enhancing energy efficiency, and achieving thermal comfort in tropical climates.
It's important to consider local climate conditions, site-specific factors, and the potential for prevailing winds when determining the best orientation for buildings in a particular tropical location. Additionally, incorporating features such as shading devices, overhangs, and landscaping can further contribute to passive cooling strategies in tropical passive design (Onamade et al., 2022).

Methodology

This study employed case study approach. This enables a concentrated examination of how building orientation impacts elements like natural lighting, cross-ventilation, and the incorporation of shading devices in tropical museums.
Satellite imagery from Google earth Pro was used to capture the buildings layout on site as well as other existing site conditions. This approach allows researchers to assess the effectiveness of diverse architectural elements across different climates and contexts, facilitating a nuanced understanding of their performance.

Results

National Museum Lagos

The National Museum was meticulously designed to incorporate a courtyard system, featuring interconnected subsections linked by walkways that seamlessly connect the entire structure. This innovative layout not only enhances the museum's aesthetic appeal but also serves a functional purpose by facilitating the penetration of natural light and ventilation into all areas of the museum passively.

Fig. 5: National Museum Lagos building's orientation

In a strategic move to optimize energy efficiency and thermal comfort, the building is oriented to have its approach facade facing the South-West. This orientation is a deliberate choice, as it aligns the building to receive the majority of the solar radiation from the south. To mitigate the potential heat gain from direct sunlight, the museum is equipped with deep overhangs and vertical shading devices along the South-West and South-Eastern facades. These architectural features effectively minimize direct exposure of the external walls to the sun's rays throughout the day, thereby reducing the need for mechanical cooling systems and enhancing indoor comfort levels.

Furthermore, the museum's landscape design plays a significant role in enhancing its passive cooling capabilities. Soft landscaping elements, such as trees and shrubs, are strategically placed on the southern parts of the site. This placement not only enhances the aesthetic appeal of the museum's surroundings but also contributes to reducing the local temperature of the site and its immediate environment. The presence of vegetation provides natural shade, further diminishing the heat absorbed by the ground and structures, thus creating a more comfortable microclimate around the museum.

The National Museum's design exemplifies a thoughtful integration of passive design strategies to enhance energy efficiency, promote thermal comfort, and create a sustainable architectural solution. Through its innovative layout, strategic orientation, and thoughtful landscaping, the museum stands as a testament to the potential of passive design strategies in tropical climates.

Jeakel House

Fig. 6: Jaekel House building's orientation.

Jaekel House is a remarkable architectural example, prominently facing south-west with its longest sides measuring 21 meters along the north-east and south-west axes. Its design is particularly noteworthy for its strategic placement of deep overhangs, offering effective protection against solar radiation. This architectural feature not only enhances the building's aesthetic appeal but also serves a crucial role in passive solar design, minimizing heat gain and optimizing natural lighting.

With an average orientation of 45 degrees on the coordinate system, Jaekel House aligns its shortest sides towards the east and west, the directions of the greatest solar exposure. This deliberate orientation demonstrates a thoughtful approach to passive design, capitalizing on natural elements to regulate indoor temperatures and reduce reliance on mechanical cooling systems.

The building's integration with its surrounding environment further enhances its thermal performance. The abundance of site vegetation plays a significant role in reducing local site temperatures, creating a microclimate that benefits both the building and its occupants. Additionally, the vegetation contributes to the overall aesthetic appeal of the site, blending harmoniously with the architectural design.

Jaekel House exemplifies an intentional approach to sustainable architecture, combining thoughtful design elements with environmental considerations. Its orientation, deep overhangs, and integration with site vegetation showcase the potential of passive design strategies in mitigating solar heat gain and enhancing thermal comfort. As a case study, Jaekel House serves as an inspiring example for architects and designers seeking to create sustainable, climate-responsive buildings in tropical climates.

Heritage Museum Badagry

Fig. 7: Heritage Museum Badagry building's orientation

The Heritage Museum in Badagry has been found to have an average orientation of 30 degrees along the east and west directions, as observed from Google satellite imagery. This orientation aligns with the optimal angle for passive solar design, allowing the building to harness natural light and passive cooling effectively. The windows of the museum are strategically positioned to face the equator, maximizing daylight penetration and minimizing solar heat gain.

The museum's design features include deep overhangs and a bright-coloured roof, which are key elements of passive design strategies. The deep overhangs provide shade and protection from direct sunlight, reducing the need for artificial cooling. The bright-coloured roof reflects solar radiation, preventing heat absorption and improving the building's overall thermal coefficient.

Its orientation, deep overhangs, and reflective roof not only contribute to the museum's aesthetic appeal but also ensure a comfortable indoor environment for visitors and preservation of artefacts.

Conclusion

While this research analysis the orientation data of the selected buildings, more data is required on variables such as internal temperature and humidity at various times of the day, indoor air quality and to fully determine the extent of practical thermal comfort .Both the National Museum and Jaekel House stand as exemplary models of sustainable architecture, particularly in the context of tropical climates. Through meticulous design and strategic planning, these structures showcase the effective integration of passive design strategies to enhance energy efficiency, promote thermal comfort, and contribute to a sustainable built environment.

The National Museum's innovative layout, featuring interconnected subsections and well-designed walkways, not only elevates its aesthetic appeal but also facilitates the passive penetration of natural light and ventilation throughout the entire structure. The deliberate orientation of the building to face the South-West, coupled with architectural features such as deep overhangs and shading devices, minimizes direct solar exposure, reducing the reliance on mechanical cooling systems and enhancing indoor comfort.

Additionally, the thoughtful landscaping surrounding the National Museum, with strategically placed trees and shrubs on the southern parts of the site, contributes to passive cooling by providing natural shade and reducing local temperatures. This integrated approach to design results in a sustainable architectural solution that effectively responds to the challenges of tropical climates.

Similarly, Jaekel House, with its remarkable orientation facing south-west and the strategic placement of deep overhangs, exemplifies a deliberate commitment to passive solar design. The building's average orientation of 45 degrees on the coordinate system maximizes exposure to the east and west, showcasing a thoughtful approach to harnessing natural elements for temperature regulation and reducing the need for mechanical cooling systems.

Furthermore, Jaekel House's integration with site vegetation enhances its thermal performance, creating a microclimate that benefits both the building and its occupants. The abundance of greenery not only contributes to cooling the local environment but also adds to the overall aesthetic appeal of the site, emphasizing the harmonious relationship between architecture and nature.

In addition to the National Museum and Jaekel House, the Heritage Museum in Badagry contributes to the architectural diversity and historical richness of the region. While each museum has its unique features, there are overarching strategies that can be implemented to improve the passive design of all three museums, taking into account the tropical climate and the need for sustainable architectural solutions.

The Heritage Museum in Badagry, with its historical significance, could benefit from a comprehensive evaluation of its current passive design elements. Similar to the National Museum, strategic landscaping can be employed around the Heritage Museum to provide natural shading, reduce heat absorption by structures, and contribute to the overall aesthetic appeal of the site. Native trees and vegetation, chosen for their adaptability to the local climate, can be strategically placed to enhance passive cooling.

Also, the orientation of the Heritage Museum's main facade should be carefully considered. Like the National Museum and Jaekel House, optimizing solar exposure by facing the main facade towards the most suitable direction can significantly impact the building's energy efficiency. Additionally, incorporating deep overhangs and shading devices, especially on the sides exposed to intense sunlight, can mitigate heat gain and enhance the thermal performance of the museum.

To improve the overall passive design of the three museums, a holistic approach could involve:

1. **Renewable Energy Integration:** Explore opportunities to incorporate renewable energy sources, such as solar panels or wind turbines, to supplement the museums' energy needs. This could further reduce their reliance on conventional energy sources.
2. **Smart Building Systems:** Implement smart building technologies that can optimize energy consumption by monitoring and adjusting lighting, HVAC systems, and other utilities based on real-time environmental conditions.
3. **Green Roof Systems:** Introduce green roof systems to enhance insulation, reduce heat absorption, and create additional green spaces. Green roofs contribute to passive cooling and improve the overall environmental sustainability of the museums.
4. **Water Harvesting and Management:** Implement water harvesting systems to collect rainwater for landscaping and non-potable uses. Efficient water management can contribute to the sustainability of the museums and reduce their ecological footprint.
5. **Educational Initiatives:** Foster public awareness and education on the benefits of sustainable architecture and passive design strategies. Engaging the community and visitors can create a collective effort towards environmental consciousness and responsible tourism.

By incorporating these strategies, the National Museum, Jaekel House, and the Heritage Museum in Badagry can collectively serve as a model for sustainable architectural practices in tropical climates, promoting energy efficiency, enhancing thermal comfort, and preserving the cultural and historical significance of each institution.

In conclusion, National Museum, Jaekel House, and Heritage Museum serve as inspiring examples for architects and designers seeking to create sustainable, climate-responsive buildings in tropical climates. Their successful implementation of passive design strategies underscores the potential for innovative and environmentally conscious approaches in addressing the challenges of energy efficiency, thermal comfort, and sustainability in architectural design.

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