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Enhancement of Biophilic Design Through the Use of Local Bamboos for Façade Design of Senate Buildings

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ABSTRACT

Contemporary Senate Buildings in Nigeria frequently utilize curtain wall façade systems that, despite their modern appearance, often perform inefficiently in tropical climates. Intense solar radiation, high temperatures, and humidity result in excessive heat gain, glare, and increased dependence on mechanical cooling. These challenges highlight the need for façade strategies that are both environmentally responsive and supportive of occupant well-being. Biophilic design promotes reconnecting the built environment with nature to enhance productivity and cognitive performance. Bamboo, as a rapidly renewable and structurally resilient local material, offers strong potential for sustainable façade applications, yet remains underutilized in institutional architecture. This research explores the integration of locally sourced bamboo into Senate Building façades to enhance biophilic performance, thermal comfort, and institutional identity. Using a mixed-method approach—including literature review, material analysis, case studies, and climate simulations—the study aims to develop a bamboo-based façade framework that improves passive cooling, daylight control, and environmental performance in tropical settings.

Keywords: Biophilic Design, Bamboo Architecture, Façade Design, Sustainable Materials, Senate Buildings

INTRODUCTION

Background of study

The interplay between the built environment and nature has become increasingly significant in the contemporary era, particularly as rapid urbanization in tropical regions such as Nigeria has produced sprawling "concrete jungles." This transformation has contributed to both psychological and physical detachment from natural systems (Özdemİr, 2024). In Nigeria, institutional architecture has traditionally adopted Westernized paradigms—most notably "glass architecture" and reinforced concrete—which often prove unsuitable for the region's intense solar radiation and high humidity (Tolulope et al., 2025). As a result, these buildings frequently experience elevated indoor temperatures and excessive reliance on mechanical cooling, leading to substantial energy demand (Adebamowo, M., & Etana, 2025). Biophilic design has emerged as a transformative architectural paradigm aimed at re-establishing the vital connection between humans and the natural world (Gaekwad et al., 2022) (Sajadirad et al., 2025)). Grounded in the Biophilia Hypothesis, this approach is premised on the idea that humans possess an inherent affinity for living systems and life-like processes. By embedding natural elements into the built environment, biophilic design seeks to counteract the alienation produced by modern urban landscapes and foster environments that nurture well-being.

A particularly significant dimension of this philosophy is the use of Natural Analogues—design strategies that incorporate biomorphic forms, patterns, and materials reminiscent of nature. These analogues extend beyond literal greenery to include subtle cues such as organic shapes, textures, and natural finishes that evoke the presence of the natural world. Research suggests that such interventions can create restorative spaces that alleviate stress, improve emotional resilience, and enhance cognitive performance (Özdemİr, 2024); (Sajadirad et al., 2025)). In this way, biophilic design not only enriches aesthetic experience but also contributes to healthier, more sustainable, and psychologically supportive built environments. Bamboo has increasingly been recognized worldwide as a sustainable, low-carbon alternative in construction, often celebrated as the "building material of the future" due to its rapid renewability and exceptional strength-to-weight ratio (Tech & Bredenoord, 2017). Within Nigeria,

abundant reserves of Bambusa vulgaris present a particularly promising resource. This species demonstrates mechanical properties comparable to hardwood and, in certain applications, even mild steel, underscoring its potential as a viable substitute for conventional building materials (Ibitoye, 2025) (Sajadirad et al., 2025). Integrating locally sourced bamboo into the façade design of institutional structures—such as Senate buildings—offers a pathway toward innovative "bio-cooling skins." These bamboo-based systems can regulate solar heat gain, reduce dependence on mechanical cooling, and simultaneously reintroduce natural aesthetics into architectural spaces. Beyond their functional role in thermal modulation, such designs embody biophilic principles by restoring the human-nature connection within institutional environments, thereby fostering sustainability, cultural relevance, and psychological well-being(Tolulope et al., 2025) (Sajadirad et al., 2025).

Scope Location

The geographical focus of this study encompasses the legislative heart of Nigeria, specifically the National Assembly Complex in the Three Arms Zone, Abuja. Abuja experiences intense heat during the dry season, with daytime temperatures often rising into the upper thirties degrees Celsius, creating considerable thermal performance challenges for curtain wall office buildings (Mashi et al., 2022). Additionally, the study considers the situational context of university Senate buildings, such as the proposed administrative infrastructure at Caleb University, Imota, Lagos State, which faces similar tropical humid conditions.

Plate 1.1: Caleb University's main campus location Calebn University location, maps, satellite and street views | uniRank.org

1.1 Problem Statement

Senate buildings in Nigeria reveal a pronounced misalignment between architectural form and climatic performance, particularly in relation to thermal efficiency. The dominant reliance on glass curtain walls and concrete façades exposes these structures to excessive solar heat gain, which in turn drives indoor temperatures beyond internationally accepted comfort standards. This thermal imbalance not only compromises occupant well-being but also necessitates heavy dependence on mechanical cooling systems, thereby escalating energy demand and operational costs (Adebamowo, M., & Etana, 2025)

Beyond physical discomfort, the absence of biophilic elements within these institutional spaces contributes to cognitive fatigue among lawmakers and administrative staff. These individuals are tasked with complex, high-stakes decision-making, yet they operate in environments devoid of natural connectivity. Such sterile settings foster "directed attention fatigue," a condition that diminishes focus, reduces productivity, and undermines mental resilience, ultimately impairing institutional effectiveness (Sajadirad et al., 2025); (Adebamowo, M., & Etana, 2025)

A further challenge lies in the socio-material perception of indigenous resources. Materials such as bamboo or earth are often stigmatized as symbols of poverty, discouraging their adoption in prestigious institutional architecture. This cultural bias perpetuates a preference for imported, energy-intensive

systems, reinforcing unsustainable design practices and distancing Nigerian architecture from its rich vernacular heritage. The persistence of this "poverty stigma" not only undermines sustainability but also erodes opportunities to celebrate local identity in high-status buildings (Ibitoye et al., 2022).

Finally, the environmental consequences of conventional construction materials cannot be overlooked. Reinforced concrete and glass façades contribute significantly to carbon emissions, exacerbating ecological degradation in a region already vulnerable to climate change. In contrast, Nigeria's abundant reserves of bamboo represent a carbon-neutral alternative with immense potential to reduce environmental footprints. Yet, despite its mechanical strength and renewability, bamboo remains largely untapped in institutional design, leaving a critical opportunity for sustainable innovation unrealized(Tech & Bredenoord, 2017)(Sajadirad et al., 2025).

Aim and Objectives

Aim: To develop a façade design framework for Senate Buildings that enhances biophilic performance through the strategic use of locally sourced bamboo as a sustainable, climate-responsive architectural material.

Objectives:

i. To examine the principles of biophilic design and their application in façade systems for institutional and administrative buildings.
ii. To investigate the structural, environmental, and aesthetic properties of locally available bamboo species suitable for façade construction in tropical climates.
iii. To design a bamboo-integrated façade system for a Senate Building that improves thermal comfort, visual connection to nature, and institutional identity.

Research Questions

i. How can bamboo be effectively integrated into façade systems to enhance biophilic design performance in Senate Buildings?
ii. What structural and environmental characteristics of locally available bamboo make it suitable for façade applications in Lagos' tropical climate?
iii. In what ways can bamboo-based façade systems improve user well-being, daylight modulation, and passive cooling in administrative environments?

Justification of study

This study is justified by the pressing need for climate-adaptive architecture across Sub-Saharan Africa, where conventional construction practices often exacerbate environmental and energy challenges. Among the region's ecological assets, bamboo stands out as a particularly promising material. Local species such as Bambusa vulgaris are capable of sequestering up to 259 and reach maturity within just three to five years, making them both renewable and highly efficient resources (Ibitoye, 2025) (Sajadirad et al., 2025). By harnessing bamboo's low embodied energy and high thermal resistance, institutional buildings can be reimagined as prototypes of national sustainability. Such structures would not only reduce reliance on energy-intensive cooling systems but also demonstrate the viability of indigenous materials in high-status architecture, thereby challenging entrenched socio-material stigmas. In addition to its ecological benefits, the integration of biophilic interventions within institutional spaces has been shown to yield significant human-centered advantages. Research indicates that environments enriched with natural elements can increase productivity by up to 15 percent while simultaneously reducing stress levels among occupants (Özdemİr, 2024) (Sajadirad et al., 2025). Thus, the adoption of bamboo and biophilic strategies offers a dual pathway: advancing environmental sustainability while enhancing cognitive and psychological well-being in institutional settings.

Significance of study

This study establishes an empirical framework that enables architects to move beyond sterile, energy-intensive institutional models toward the development of dynamic, "living" façades. In doing so, it contributes to the revalorization of indigenous resources, particularly bamboo, by challenging entrenched socio-material biases. What has long been dismissed under the "poverty stigma" can instead be reframed

as a sophisticated, high-performance architectural component, capable of meeting both functional and aesthetic demands in prestigious institutional contexts (Ibitoye et al., 2022). Moreover, the research aligns with global sustainability imperatives by directly supporting the United Nations Sustainable Development Goals, specifically SDG 11 (Sustainable Cities and Communities) and SDG 13 (Climate Action). By promoting resilient, climate-adaptive, and ecologically responsible institutional infrastructure, the study underscores the potential of architecture not only to mitigate environmental challenges but also to serve as a catalyst for cultural transformation and sustainable development at the national scale.

Scope and Limitation of study

The scope of this study is deliberately defined to focus on the potential of bamboo as a secondary façade system, functioning primarily as a shading or "skin" for Senate buildings in Nigeria. Rather than addressing bamboo in its structural capacity, the investigation concentrates on its role in modulating solar exposure and improving thermal comfort within institutional environments. From a technical perspective, the research emphasizes the physical and thermal properties of Bambusa vulgaris, a species widely available in Nigeria and recognized for its mechanical resilience and ecological benefits. In addition, the study applies the framework of the 14 Patterns of Biophilic Design, exploring how bamboo façades can simultaneously enhance environmental performance and foster psychological well-being by reconnecting occupants with natural systems. Geographically, the scope is limited to the Abuja and Lagos regions, two urban centers that exemplify Nigeria's rapid institutional development and climatic challenges. By situating the research within these contexts, the study provides a targeted yet representative analysis of how bamboo-based biophilic interventions can reshape institutional architecture in tropical urban environments

LITERATURE REVIEW

Biophilic Principles and Institutional Architecture

Biophilic design is commonly understood through three experiential categories: Nature in the Space, which emphasizes the direct presence of natural elements; Natural Analogues, which evoke nature through indirect representations such as materials, patterns, and forms; and Nature of the Space, which focuses on spatial configurations that mirror natural environments (Özdemİr, 2024) (Sajadirad et al., 2025). Within the context of Senate buildings in Nigeria, the application of Natural Analogues through bamboo façades offers a particularly effective strategy. Unlike living walls, which demand intensive maintenance and are often impractical in dry climates such as Abuja, bamboo provides a tactile and visual connection to nature that is both sustainable and manageable. Its organic textures and natural warmth create an atmosphere that subtly reintroduces occupants to the rhythms of the natural world, without the logistical challenges of maintaining vegetation indoors (Sajadirad et al., 2025), (Tolulope et al., 2025). Empirical research further demonstrates that such biophilic interventions facilitate Attention Restoration, a process through which higher cognitive functions recover from the fatigue associated with prolonged concentration and complex decision-making. For lawmakers and administrative staff engaged in intensive legislative work, these restorative qualities are invaluable, as they enhance focus, reduce stress, and improve overall productivity (Özdemİr, 2024); (Adebamowo, M., & Etana, 2025). In this way, bamboo façades serve not only as climate-responsive architectural solutions but also as catalysts for cognitive resilience within institutional environments.

Façade Strategies and Building Performance

In tropical climates, the building façade serves as the primary interface between architecture and the external environment, accounting for as much as 50 percent of overall energy consumption (Adebamowo, M., & Etana, 2025). The performance of this envelope is therefore critical, with high-performance façades designed to minimize unwanted heat gain while still ensuring adequate levels of natural daylight. One promising innovation in this regard is the development of bio-cooling façades (BCF), which employ bamboo as an external shading system. Empirical studies have demonstrated that such façades can lower average indoor temperatures by approximately to , while simultaneously reducing cooling loads by 25 to 35 percent (Tolulope et al., 2025). These reductions not only enhance occupant comfort but also significantly decrease reliance on mechanical cooling, thereby cutting energy demand and associated carbon emissions. Optimal configurations typically combine a glazing ratio of around 40 percent

with external shading devices, striking a balance between thermal efficiency and visual comfort. This design approach highlights the potential of bamboo-based shading systems to serve as both climate-responsive and sustainable solutions for institutional architecture in Nigeria (Adebamowo, M., & Etana, 2025).

Bamboo: Composition, Properties, and Sustainability

Bamboo is a perennial woody grass distinguished by its rapid growth cycle, reaching maturity within three to six years—significantly faster than conventional timber resources (Tech & Bredenoord, 2017)(Ibitoye, 2025). *In Nigeria, Bambusa vulgaris is the most prevalent species, notable for its impressive mechanical properties. With a density ranging between 600 and 800 and tensile strength values from 140 to 370 , it demonstrates performance comparable to hardwood and, in certain applications, even mild steel* (Ibitoye, 2025). Chemically, bamboo is composed primarily of cellulose, hemicellulose, and lignin, which together provide structural rigidity and durability. These natural polymers not only contribute to its mechanical resilience but also enhance its suitability as a construction material. Furthermore, bamboo's low thermal conductivity makes it an effective insulator, reducing heat transfer in tropical climates (Anthony, 2023).

Equally significant is its ecological contribution: bamboo is capable of sequestering up to 259 , positioning it as a powerful carbon sink and a renewable resource for sustainable architecture (Ibitoye, 2025) (Sajadirad et al., 2025). Taken together, these attributes—rapid renewability, mechanical strength, thermal efficiency, and carbon sequestration—underscore bamboo's potential as an ideal material for climate-responsive and sustainable architectural applications in tropical regions.

Historical and Architectural Overview of Senate Buildings in Nigeria

The architectural evolution of Nigeria's legislative buildings illustrates a shift from colonial neoclassical traditions to modernist "glass box" aesthetics. The Old Secretariat in Lagos, constructed in 1893, embodied the order and authority of British colonial rule, prominently featuring Doric and Ionic pilasters as markers of classical influence (Anabaraonye, 2025). By contrast, the contemporary National Assembly complex in Abuja, completed in 1999, presents a neoclassical composition distinguished by its iconic green dome and stark white walls. This design was intended to symbolize democratic stability and institutional permanence (Anabaraonye, 2025; Julius Berger, 2021).

However, the adoption of expansive glazing in these modern structures has introduced significant climatic challenges. While visually striking, the reliance on large glass surfaces has resulted in poor thermal performance, with interiors subject to excessive solar heat gain and increased dependence on mechanical cooling systems. These shortcomings underscore the tension between imported architectural paradigms and the environmental realities of Nigeria's tropical climate (Tao et al., 2021).

Theoretical and Conceptual Framework

This study is anchored in three interrelated paradigms that collectively shape its conceptual foundation. The first is Sustainable Construction, derived from the Brundtland framework, which emphasizes efficiency in resource use and the minimization of ecological footprints (Ibitoye, 2025). This paradigm situates bamboo as a renewable material that can advance environmentally responsible architectural practices (Sari et al., 2022). The second paradigm is Performance-Based Design, which shifts architectural evaluation away from tradition and aesthetics toward measurable outcomes. Here, parameters such as -values, compressive strength, and thermal resistance become central indicators of success, ensuring that design decisions are grounded in empirical performance rather than stylistic convention (Ibitoye, 2025).

The third paradigm is the Theory of Perception, which addresses the socio-cultural biases surrounding indigenous materials. By reframing bamboo and similar resources as "Engineered Natural Analogues," this perspective challenges the entrenched "poverty stigma" and positions local materials as sophisticated, high-performance components suitable for prestigious institutional architecture (Ibitoye et al., 2022). Bringing these paradigms together, the study proposes a Conceptual Synthesis in the form of a Biomorphic-Regenerative Skin. This model envisions bamboo shading systems that mimic natural patterns, filtering solar heat while simultaneously fostering psychological restoration through biophilic engagement. In this way, the façade becomes more than a climatic buffer—it evolves into a regenerative interface that integrates environmental sustainability with human well-being (Sajadirad et al., 2025).

RESEARCH METHOD

Research Design

This study employs a qualitative research design, a methodological choice well-suited to investigating complex intersections between human psychology and material performance within institutional environments (Tolulope et al., 2025). By prioritizing depth over breadth, this approach allows for nuanced insights into how architectural interventions—such as bamboo façades and biophilic strategies—affect both cognitive well-being and thermal efficiency. The exploratory orientation is particularly appropriate given the limited precedent for integrating indigenous materials into high-status institutional architecture in Nigeria, enabling the research to uncover new conceptual and practical pathways for sustainable design. (Yin, 2014).

Data Collection Instruments

Data for this study were collected through three complementary methods. First, a literature synthesis was undertaken, drawing on secondary climatic data and peer-reviewed scholarship to establish a theoretical and environmental foundation for the research (Tolulope et al., 2025). This provided critical insights into regional climate dynamics and existing architectural responses. Second, observational guides were employed to document the current conditions of Senate buildings and their immediate surroundings. This included site-specific observations of flora and architectural features at locations such as Caleb University and the National Assembly in Abuja, offering contextual evidence of how institutional environments interact with local ecosystems (Tokun-Pedro, 2024).

Third, a case study analysis was conducted to evaluate the thermal performance of bamboo finishes in practice. Lagos-based boutique hotels, such as Bogobiri House, served as reference points, demonstrating how bamboo has already been applied in real-world architectural contexts and providing empirical data on its effectiveness in moderating indoor climates (Adebamowo, M., & Etana, 2025)

Presentation of Qualitative Data

The data are organized thematically to highlight three key dimensions of analysis. First, the study examines biophilic design patterns, focusing on how natural analogues and spatial strategies can be integrated into institutional architecture. Second, it evaluates thermal performance metrics, including -values and measurable reductions in indoor temperature, to assess the efficiency of bamboo façades as climate-responsive systems. Finally, the research considers socio-material perceptions, exploring cultural attitudes toward indigenous resources and the ways in which bamboo can be repositioned as a sophisticated material rather than one burdened by stigma.

Journal-Based Analysis Requirement

The analysis is conducted in accordance with the criteria established by the Caleb International Journal of Development Studies. To ensure consistency and scholarly rigor, all findings—both within the architectural discipline and across related fields—are presented using the APA 7th edition referencing format. This methodological choice provides a standardized framework for documenting sources and enhances the credibility of the study's interdisciplinary insights.

Discussion of Findings

Comparative analysis of bamboo façades versus conventional façade materials in Senate buildings.

` The findings reveal that bamboo façades deliver superior thermal stability when compared to conventional concrete and glass systems. In particular, steel–bamboo composite walls demonstrate notable improvements in thermal efficiency, with reductions in -values ranging from 26 to 48 percent. This enhancement translates into a significant decrease in cooling energy demand, especially during peak daytime conditions in tropical climates. By moderating heat transfer and lowering reliance on mechanical cooling, bamboo-based façade systems emerge as a viable pathway toward sustainable and climate-responsive institutional architecture (Tao et al., 2021).

Discussion of bamboo's contribution to biophilic design principles (visual connection, natural materials, environmental integration).

Bamboo establishes a profound material connection with nature while simultaneously embodying biomorphic form (Browning et al., 2014). In contrast to the static and inert qualities of concrete, the rhythmic arrangement of bamboo culms introduces a dynamic interplay of light and shadow across architectural surfaces. This natural modulation creates environments that are visually engaging and psychologically restorative. Empirical studies have shown that such biophilic effects can contribute to measurable physiological benefits, including reductions in heart rate and blood pressure among occupants (Chen, 2025) (Sajadirad et al., 2025).

Interpretation of sustainability outcomes based on observed data and literature.

The integration of bamboo into façade systems aligns strongly with the principles of the circular economy, as it reduces construction waste while offering superior ecological benefits. Notably, bamboo sequesters carbon more efficiently than any other fast-growing woody plant, reinforcing its role as a renewable and climate-positive resource (Ibitoye, 2025). When applied as external shading at a glazing ratio of approximately 40 percent, bamboo façades achieve an optimal balance between daylight penetration and solar protection. This configuration ensures sufficient natural illumination while effectively limiting heat gain, thereby enhancing both energy efficiency and occupant comfort in tropical architectural contexts (Tao et al., 2021).

Analysis of conflicting perspectives, limitations, and areas requiring further inquiry.

The most significant barrier to the adoption of bamboo in institutional architecture remains the persistence of the "poverty stigma" and the generally low level of awareness among practitioners regarding its potential (Tolulope et al., 2025) (Ibitoye et al., 2022). Although bamboo is structurally resilient and mechanically comparable to conventional materials, its long-term durability depends on appropriate treatment processes. Specifically, boron-based or vacuum-pressure preservation techniques are required to extend its service life, enabling bamboo components to remain effective for up to 40 years (Ibitoye, 2025). Addressing both the cultural stigma and the technical treatment requirements is therefore essential to reposition bamboo as a credible, high-performance material for sustainable institutional design.

CONCLUSION

Summary of major findings from qualitative assessment and literature review.

The research establishes that Bambusa vulgaris possesses both the mechanical strength and thermal efficiency necessary for application in high-performance institutional façades. Beyond its technical attributes, the incorporation of bamboo as a biophilic intervention has been shown to enhance the cognitive focus and overall comfort of administrative users. By fostering a restorative connection with nature, bamboo façades contribute not only to environmental sustainability but also to improved psychological well-being within legislative and institutional settings.

Conclusion on the suitability and performance of bamboo as a façade material for Senate buildings.

Bamboo emerges as an optimal material for the façades of Senate buildings in Nigeria. Its integration directly addresses the thermal sink effect characteristic of current neoclassical structures, which rely heavily on concrete and expansive glazing. At the same time, bamboo establishes both a cultural resonance and a biological connection with the Nigerian landscape, reinforcing identity while enhancing environmental performance. In this way, bamboo façades serve not only as climate-responsive solutions but also as symbolic architectural interventions that bridge tradition, ecology, and institutional modernity.

RECOMMENDATIONS

The recommendations emerging from this study emphasize distinct responsibilities across professional domains. For architects, the priority is to design "second-skin" façades that employ engineered bamboo to shield primary building envelopes from direct solar exposure, thereby improving thermal performance. For policy makers, the integration of bamboo into the Nigerian Building Code is essential, alongside the creation of incentives that encourage bio-based construction as a strategy to mitigate urban heat island effects(Tolulope et al., 2025).

For facility managers, the focus should be on implementing scheduled maintenance and preservation treatments, ensuring that bamboo components achieve their maximum service life and remain durable over time.

Suggestions for further research on biophilic design and local sustainable materials in institutional architecture.

Further field studies should quantify the longitudinal restorative effects of bamboo facades using VR and EEG biosensors to confirm productivity gains in legislative environments (Chen, 2025).

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