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# The Role of Bamboo as a Sustainable Building Material

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***ABSTRACT***
*Bamboo is a hollow, fast-growing, and renewable resource which is a symbol of cultural heritage and diversity. The need to achieve energy-efficient buildings with low-carbon and locally sourced building materials that reduce construction waste and encourage reuse/recycling gave rise to its relevance in the building industry where it exhibits aesthetic, tensile, and compressive strength comparable to concrete, making it an ideal material for structural applications. Furthermore, bamboo is a lightweight material that decreases the dead load of components on the foundation and structure of the building. This research paper explores the concept of using bamboo in building construction. It begins with an introduction to the plant highlighting its common species such as Bambusa oldhami, Bambusa Lako, Dendrocalamus Asper species, Dendrocalamus Brandisii, Dendrocalamus Yunnanicus species, Gigantochloa Apus, Gigantochloa atroviolacea, Gigantochloa Atter, and Gigantochloa Pseudoarundinacea, while also stating their potential heights. The aim and objectives are to investigate the potential of bamboo as a sustainable building material as well as the impact of bamboo on the built environment. The research goes on to identify the agricultural and architectural impact of bamboo emphasizing its aesthetic, and carbon sequestration characteristics. It further explores the bamboo cultivation process, and treatment techniques, as well as the issues and challenges associated with the adoption of bamboo in building projects, and it concludes with recommendations on strategies to maximize the potential of bamboo in building projects.*

***KEYWORD****: Bamboo, Sustainable, Environment, Architecture, Cultivation*

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## I. INTRODUCTION

*1.1. Bamboo Plant*

Bamboo is a fast-growing and renewable resource that is a symbol of cultural heritage and diversity. It is a plant with a hollow stem comprising of a culm and node, sclerenchyma cells, parenchyma cells, vascular system (divided into the phloem, and the xylem) that reproduces through both sexual and asexual reproduction (Long, Minghui, Wenjing, Yulong, and Shuyan, 2023).

It is a naturally occurring plant that grows in the wild but can be cultivated through clumping or when running bamboo species grow by aggressively spreading their roots underground. Asian nations like India and Japan have well-established farms while in South America and Africa, most bamboo is harvested from the wild.

Though a nontimber forest product, it is considered a superior herb with large applications in product design and buildings providing both aesthetic and structural functions (Emamverdian, Ding, Ranaei, and Ahmad, 2020) all of which significantly impact the economy, ecosystem, and livelihood of the people (Tahera & Rani, 2023), offering

Research done by Hossain, Islam, and Numan (2016) identifies the possibility of bamboo in easing social and environmental problems ranging from its use as food, a component of medicine in traditional treatment, to its use as a chemical composition. It is relevant Architecturally due to its aesthetically pleasing nature, its tensile strength estimated to be higher than that of steel, and its compressive strength comparable to concrete, making it an ideal material for structural applications. Furthermore, bamboo is lightweight, which decreases the dead load of components on the foundation and structure of the building.

*1.2. Common species of bamboo*
•Bambusa oldhami (Giant Timber Bamboo) species
native to China
potential height - approximately 65 feet, maximum diameter of 4 inches.
•Bambusa Lako
potential height - fifty feet
widespread application in furniture manufacturing.
•The Dendrocalamus Asper species
originates from Southeast Asia
potential height of approximately 65–100 feet
diameter of approximately 3–8 inches.
Acknowledged for its high resilience
•The Dendrocalamus Brandisii
potential height of approximately 60 feet and a diameter of 6–8 inches.
Common in Southeast Asia
excellent as a building material.
•The Dendrocalamus Yunnanicus species
potential height is approximately 70 feet and has robust and straight canes.
Possible use as Bamboo lumber and for building construction.
•Gigantochloa Apus
potential height is approximately 60 feet
diameter of 4 inches.
The Indonesian culture has a long history of employing this particular species in the construction industry.
•Gigantochloa atroviolacea straight growing species with strong black canes capable of a potential height approximately 50 feet and a good 4-inch diameter. useful for the construction of furniture.
•Gigantochloa Atter potential height of roughly 60 feet and a diameter of 4 inches, and its canes are straight and powerful.
•Gigantochloa Pseudoarundinacea is a species that has twisted canes.

*1.3. Impact Of Bamboo*
Environmental Impact: it has a higher $CO_2$ sequestration rate than other plants, making it an effective carbon sink thus significantly reducing its environmental impact on the building industry.
Agriculture: it withstands a wide variety of weather and soil conditions, including drought, flood, and high winds, and replenishes soil nutrients. It prevents erosion and improves soil health. It is also credited with “ecological engineering” as it helps with erosion control, and soil stability owing to “its soil-grabbing roots” which also “leach heavy metals from the soil, and efficiently draw water closer to the surface due to its strong water absorption capability” (Li and He, 2019).
Architectural Impact: it is a sustainable building material and has been used for temporary works (scaffolding), reinforcement bars for wattle and daub houses in rural dwellings as well as modern concrete reinforcement, roof skeleton, doors and window shutters, corrugated sheets, and laminates for floor.

*1.4. Objectives of Study*
To demystify in lucid terms the nature of bamboo.
To explore the potential of bamboo as a sustainable building material

*1.5. Research Question*
What is bamboo?
What is the environmental impact of bamboo in the built environment?

## II. ANALYSIS OF BAMBOO

*2.1. The Biological Composition of Bamboo*
A bamboo stem is hollow and contains nodes. When bamboo is dried, the sap in the vessels dries up, and the vessels fill with air, but the pits are closed and so form an important bearing for the preservation. The layers of bamboo are heavily cutinized with a heavy deposit of silica that sometimes renders bamboo impervious to moisture, useful as a whetstone, with increased strength. The outer wall has the power to resist tearing as much as ten times over ordinary cellulose walls.
Bamboo is composed of atoms and molecules. At the atomar level (10-9 - 1 -I0 m), atoms share a pair of electrons and are kept together by hard covalent bonds, resulting in a spatial molecular structure; and at the molecular level (10'8_ 10’9 m), the molecules are kept together by hydrogen bonds.
Bamboo is also composed of different layers of cell walls deposited on the inner side of its lamella, and tissues consisting of cytoplasma usually enclosed by a central nucleus surrounded by a rigid cell wall plant. It is also

composed of tissues consisting of parenchyma epidermis, the structural or mechanical tissue, the conducting tissue consisting xylem, and phloem, meristema-tissue found in each bamboo internode to increase the length.

*2.2. Bamboo Cultivation*

The cultivation of bamboo is a practice with gains that positively impact the economy, environment, and ecosystem (Isukuru, Ogunkeyede, Adebayo, and Uruejoma, 2023). Its propagation occurs sexually (through seeds) or asexually (using vegetative material) in patterns called "clumping" or "running"(Brias and Hunde, 2009) in adherence to the following practices:

a) Preliminary: Bamboo cultivation begins with a selection process based on their growth habit, potential height, intended use, soil conditions, sunlight exposure, and climate resilience. As well as following the basic agricultural soil preparation techniques achieved through weeding and evacuation of rocks, and debris, and improvement of soil quality through the application of organic fertility. To achieve adequate irrigation, bamboo is planted during the rainy season.

b) Cultivation: bamboo is cultivated by burying its underground stem (bamboo rhizome) spaced adequately based on the specifics of the chosen species.

c) Post Cultivation: Regular irrigation is carried out to keep the soil moist but not waterlogged, application of mulch to conserve soil moisture and control weed infestation, and improve soil nutrients. Fertilization is practiced at this point based on the soil needs of the bamboo species.

d) Harvesting: Bamboo is harvested at an appropriate age based on its intended use usually around a 3 to 5-year cycle by cutting ripe canes 1 to 2 feet above ground using traditional or mechanized farming equipment where the former supports the selective harvesting of matured or weathered culms and allows younger culms reach maturity.

*2.3. Challenges to the Use of Bamboo*

(Long, Minghui, Wenjing, Yulong, and Shuyan, 2023) identified overexploitation of bamboo resources as a challenge impairing the use of bamboo, stating that abuse by local residents due to illiteracy hampers regeneration, creates scarcity, and "compromises bamboo diversity and productivity".

Susceptibility to insects and fungi such as mold, fungi, or boring insects, all of which degrade its quality.

Limitations in the availability of usefull species, as well as their "circular hollow section and range of available sizes" which restrict their application for construction purposes (Tang, Zhou, and Li, 2021).

Ignorance of the potential and the perception of bamboo as a building material for low-income housing and its being referred to as "poor man timber" (Ray, Sharma & Kumar. 2021) has hampered its widespread application in urban areas in Nigeria.

Issues bordering on the structural integrity owing to the limitation in the availability of useful species for construction purpose poses another challenge.

## III. BAMBOO AND THE BUILT ENVIRONMENT IN NIGERIA

3.1. Bamboo is a fast-growing, climate and soil-resistant woody plant characterised as a versatile renewable resource due to its high strength and low weight and acknowledged as one of the most important non-timber forest resources due to the tremendous socio-economic benefits derived from its products. It is estimated to have over 1000 species with classifications in about 90 genera. Earlier consumed bamboo was harvested from the wild but recent Architectural research has revealed the transformative potential of bamboo in the construction industry (Naylor & Wynne, 2023) and revealed its versatile application in a variety of construction applications (ranging from flooring, wall systems and partitions, roofs, and framing), bamboo cultivation has increased.

The use of bamboo as a building material dates back to ancient civilization when rural dwellers in Nigerian communities constructed temporary and inferior wattle and daub building housing units using bamboo as reinforcement bars. This gave birth to the myth that bamboo is an inferior material to be used for inferior buildings alone. In addition, the emergence of modern construction materials, further sidelined the use of bamboo for temporary and low-cost projects alone.

Nonetheless, a recent study in response to the towering housing deficit in Nigeria, the desire to design for sustainability, and the need to achieve energy-efficient buildings with locally sourced materials has sparked global interest and reawakened the emergence of Bamboo as a choice building material presenting possibilities with numerous benefits throughout its service life. These possibilities include its prospect as a sustainable building material with reduced CO2 emissions into the environment. It offers a sustainable alternative to traditional building materials which result in rapid changes in the climate as well as a persistent emission responsible for 30 percent of greenhouse gases emitted into the atmosphere all generated from building and construction industrys. Another potential is its ready availability, cost-effectiveness, and high strength compared to other building materials.

*3.2. Properties of Bamboo*

Bamboo presents the possibility of high quality, lifetime performance, and profitable building materials while simultaneously leading to a decrease in cost, time, defect, and health and safety hazards.
These potentials have driven up the demand for bamboo giving rise to large scale cultivation of useful species of bamboo, as well as the creation of hybrid species with improved physical properties and ensuring durability and structural integrity. The researchers identified the following properties of bamboo that makes it invaluable in the construction industry:
3.2.1. Tensile Strength: this refers to the tolerance and performance of bamboo when exposed to tensile forces. This property is based on variable factors such as culm height, climate of cultivated area, and species. It is estimated to possess a competitive tensile strength to steel but lacks the elasticity of steel thus experiencing "brittle failure" under tension, breaking abruptly unlike steel which "undergoes plastic deformation and necking before breaking" (Ogunbiyi, Olawale, Tudjegbe, and Akinola, 2015).
3.2.2. Shrinking: this is the behavior of the cell walls in a bamboo culm when dehydrated. This occurs due to the "contraction of the fiber cell" leading to cracking and decoloration (Yuan, Chen, Mi, Lei, Yan, and Fei, 2023). It is believed that bamboo exhibited shrinkage both circumferentially and longitudinally (Anokye, Kalong, Bakar, Jegatheswaran, Jawaid, Awang, 2014), and that "moisture content is directly proportional to compressive strength and is one of the main elements in determining the life of bamboo" (Kenneth and Uzodimma, 2021).
3.2.3. Compressive Strength: refers to the compressive strength and performance of bamboo when it undergoes compression, and this quality is positively influenced by "nodes along bamboo culm", and the "mechanical properties of bamboo are to some part reliant on its physical attributes" (Kenneth and Uzodimma, 2021). Compressive strength can be determined using the Hankinson formula, Norris formula, Chinese National Standard GB 50005, and the Maximum stress theory (Shangguan, Zhong, Xing. *et al.* 2015).
3.2.4. Engineered property: Bamboo can be engineered to overcome the inefficiency and durability barriers associated with traditional bamboo (Bala and Gupta, 2023). Types of engineered bamboo include strand-woven Engineered Bamboo, Plywood Engineered Bamboo, and Laminated Engineered Bamboo. Its application extends to Flooring, Furniture, Structural, and Decorative elements of a building. Challenges and Limitations of Engineered Bamboo are its low Fire resistance, unavailability of raw materials and production technology, and low market acceptance.

### *3.3. Application Of Bamboo In The Construction Industry*

The versatility of bamboo in the construction industry makes it suitable both as a structural element and building component (furniture). Its high residual strength improves its resistance to seismic and high wind forces. Bamboo along with fast-growing plantation species is very efficient in sequestering carbon and contributes to the reduction of the greenhouse effect.
Auwalu and Dickson (2019) encouraging the utilization of bamboo as a sustainable building material highlighted their potential uses in numerous building components as follows:
i) The use of Bamboo for structural works like foundations, columns, and beams. Though the use of bamboo for the foundation has attracted criticism due to the fact that it erodes and is prone to decay when exposed to moisture, they still have a potential to offer optimal structural support.
ii) The use of Bamboo for floor systems by directly tying or nailing miniature bamboo culms together, splitting the bamboo culms into wide strips along their length, nailing or tying flattened bamboo culms across the joists, weaving bamboo strips "into mats of different sizes according to construction demand and specification", or in the form of enginered-water resistant "plastic as a core".
iii) The use of Bamboo for building envelopes such as walls and partitions. This is considerably the most typical application of bamboo in the building industry in Nigeria to support the dead and live loads expected throughout the service life of the building. This is achieved by reinforcing the wall against horizontal forces.
iv) The use of Bamboo for aperture enclosures such as Doors and windows either as frames or shutters/bli ders.
v) The use of bamboo for temporary works on construction sites such as scaffolding.
vi) The use of bamboo as a roofing component such as roof trusses due to its "high strength/weight ratio, or as a roofing sheet to offer shade and protection against the elements.

### 3.4. Bamboo Treatment Techniques

Despite the incredible potential and resilience of bamboo, it is liable to defects when exposed to the elements. "High starch and water content" as well as harvesting methods were identified as causes responsible for this (Ray, Sharma, & Kumar, 2021). Putri1 and Dewi identified non-chemical techniques (traditional) and chemical techniques (modern) that can be adopted during harvest, sorting, parching, and curing to preserve bamboo from breakage and rotting and ensure durability. Without these, the service life of Bamboo is estimated at 1-3 years.

*3.4.1.* Traditional or Nonchemical Preservation of Bamboo requires immersing the bamboo either in running or still water over an extended period of time (maximum of 30 days) to decrease the starch content, making it less susceptible to bamboo pests, as well as boost their strength maximally.

*3.4.2.* Modern or Chemical Preservation of Bamboo involves the use of chemicals to improve surface protection, boost durability, and increase resistance to pest. The success rate relies on the accuracy of the concentration of the preservative solution given. The drawbacks of this technique are that they are relatively expensive and pose a hazard to health and the environment. Some of the known chemical methods of bamboo preservation are the Butt Treatment method, the open tank method, the Boucherie method, and fumigation (with methylbromide compounds).

## IV. RECOMMENDATION

The researchers recommend two types of assessments for bamboo:

a) Life Cycle Analysis or Assessment to systematically evaluate the environmental impact characteristics of bamboo throughout its service life to estimate and adequately measure its benefits, and qualities within the Nigerian context.

b) Dynamic Life Cycle Assessment (DLCA) to define the probable consequence of bamboo "in terms of time and space (Caldas, Saraiva, Andreola, and Filho, 2020).

The researchers also recommend proper treatment and maintenance of bamboo culms to mitigate the challenges associated with its structural defects. This improves its durability and resistance to pests and fire. The use of sustainable substances to curb the spread of diseases and pests, pruning to maintain appearance, encourage new growth and modify pattern to suit specific construction purposes are recommended. In addition, consulting with bamboo experts as well as conducting bamboo tests prior to use are necessary. These tests include: the density test to determine the basic mass per volume or density of bamboo to ascertain its purity, the initial moisture content test to determine the maximum shrinking capacity, the water absorption test to determine its absorption rate, the compressive test to determine its compressive strength and performance when compressed, and the tension test to determine its" maximum allowable tensile stress when exposed to tensile loads (Gupta, Ganguly, and Mehra, 2015)

The researchers also recommend the sorting of bamboo culms into grades based on the specific use for which they will be applied. In the construction industry for instance, where bamboo is to be used for reinforcements, bamboo with shorter internode dimensions, little variation in diameter along the length, and zero defects are recommended. Due to their strength and durability, the researchers identified Giant Bamboo (Dendrocalamus spp.), Guadua Bamboo (Guadua angustifolia), Timor Black Bamboo (Gigantochloa atroviolacea), Bambusa spp. Phyllostachys spp, and Moso bamboo as common Bamboo species suitable for construction projects.

The researchers recommend the use of non-fixed and fixed preservation and treatment to achieve the required natural durability and lifespan to prevent insect and fungi attacks.

Also, the incorporation of technology such as topsis-fuzzy framework and surrogate modeling are recommended. Topsis-fuzzy framework is a preference style used to rate and handle uncertainty in bamboo as an alternative building material (Krishankumar, Mishra, Cavallaro, Kazimieras, Antucheviciene, and Ravichandran, 2022) while surrogate modeling is a machine learning model which automates bamboo construction process by evaluating construction safety, locate bamboo nodes and guide construction, as well as "aid designers in choosing and controlling different design strategies by providing real-time feedback on the effects of the selected parameters on the design outputs" (Zheng, Moosavi, and it Akbarzadeh, 2020).

## V. CONCLUSION

Bamboo is a sustainable resource considered to be the fastest growing woody plant in the world and acknowledged as one of the most important non-timber forest resources due to the tremendous socio-economic benefits derived from the versatile application of bamboo-based products across the building, beauty, stationary, medical, and food industry. Its characteristic affordability, renewability, low carbon footprint, quick growth rate, high strength, and ease of workability make it an invaluable building material; making it gain attention as a sustainable building material in recent years. Environmentally, it is friendly and provides protection and ecological rejuvenation, and it has a high ability to sequester carbon dioxide thus reducing the negative effects of greenhouse gases, as well as replenishing the soil nutrients.

The potential of bamboo as a building material are numerous as it combines both aesthetic appeal and sustainability. Its versatility in the construction industry makes it suitable both as a structural element and building component (furniture). Design considerations for the selection of bamboo for construction projects include its specific use, structural requirements of the project, climatic conditions, treatment, and processing techniques.

The high tensile strength and load-bearing capacity make it a sustainable replacement for steel reinforcement bars. Its high residual strength improves its resistance to seismic forces and high wind forces which can otherwise cause building failures and loss of life and property.

The lightweight, affordability, and availability render bamboo as an excellent building material for disaster-prone areas, or areas in need of rapid housing intervention due to force marjeur or war.

Although the use of bamboo is riddled with challenges with the available species having limitations to their use, the potential of bamboo remains enormous. Appropriate treatment and maintenance between harvest and installation can ensure the optimal utilization of the potential in bamboo. Treatments involve traditional or non chemical technique.

Finally, the researchers recommend sorting bamboo culms into grades based on the specific use for which they will be applied, the application of non-fixed and fixed preservation and treatment, and the adoption of topsis-fuzzy framework and surrogate modeling technology to improve the performance of bamboo throughout its service life.

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