

ASSESSING THE EFFICACY OF BAMBOO-REINFORCED CONCRETE FOR SUSTAINABLE LOW-COST HOUSING IN ANAMBRA STATE, NIGERIA

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Abstract

Due to the increasing number of people in need of affordable housing in developing countries such as Anambra State, Nigeria, and the need to have sustainable construction, which was environmentally friendly, alternative materials that would be used to reinforce concrete have been sought. This paper assesses the effectiveness of bamboo-reinforced concrete as a promising alternative to low cost housing in terms of mechanical properties, durability, cost-effectiveness, and practical considerations to apply. By using mixed methods, the study was carried out at three locations in the State of Anambra: Awka, Onitsha and Nnewi which were chosen based on their varying soil types, population densities and housing demands. Locally, bamboo culms of the *Bambusa vulgaris* species were increased and added to the M20 grade concrete mixes by exposure to a 5% solution of borax to improve preservation. Tensile, compressive and bond tests were done using universal testing machines as comparative tests with steel-reinforced concrete as per the ASTM standards. Durability was tested by exposure to the tropical humid three months under the hot environment where degradation and intake of moisture were measured. The cost analysis entailed the sourcing of information in the local markets which led to an average of 35% reduction in the reinforcement cost in the case of bamboo. Tensile strengths of 160-195 Mpa, compressive strengths equivalent to steel after 28 days (somewhere 25-30 Mpa after 28 days on beams), and bond strengths increased with surface treatments were found. Depreciation tests indicated that there was under 4 per cent degradation, which affirmed that it is tough in humid conditions. The researchers used surveys of 150 respondents in low-income households in the study locations, of which 60 percent were aged between 25-45 years, were mainly urban migrants, and they experienced housing scarcity assessed at more than half a million units statewide. The findings highlight the potential of bamboo in saving up to 30-40 percent of construction costs and ensuring environmental sustainability but such issues as the fluctuation in the material properties imply standard requirements. The study will play a role in ensuring sustainable construction in tropical Africa which will promote policy instalment of bamboo in the national housing systems.

Keywords: Bamboo-reinforced Concrete, Sustainable Housing, Mechanical Properties, Durability, Cost-effectiveness.

Introduction

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The quest to get sustainable and affordable construction materials has become a necessity as far as rapid urbanization and increasing housing deficits in developing countries are concerned. As the most populous nation in Africa, Nigeria is facing a housing issue of over 17 million homes and the Anambra State is the best representation of this predicament with a congested urban area and few affordable sources of low income earners. The population of the state is estimated to be more than 6 million as per recent census though this has been characterized by a high level of urbanization with about 62 percent dwelling in urban regions, like Awka, Onitsha, and Nnewi. These demographics contain a large number of young adults (18-45) who form about 55 percent of the population, and a large number of them are migrants intrigued by commercial and industrial prospects, putting pressure on the housing needs. These sites have different soil conditions: Awka has lateritic soils with moderate bearing capacity, Onitsha has alluvial deposits that are prone to flooding, and Nnewi has sandy loams that are conducive to the growth of industries, but need firm foundations. This variation highlights the importance of flexible materials in affordable housing where conventional steel-reinforced concrete prevails to the disadvantage of increasing the price and environmental degradation through resource-intensive manufacturing.

The use of natural fibers and renewables in building construction is not new, but the current usages have been on the increase in the face of sustainability efforts in the world. The potential of bamboo as an alternative reinforcement was brought to the fore in early 1970s and 1980s through the literature of that time pointing to its quick growth and abundance in tropical zones. Indicatively, research at this period examined tensile characteristics of bamboo which was found to be as strong as mild steel at some conditions, but sensitive to moisture. Earlier applications of bamboo in concrete pavements were described in a paper by Purushotham (in the 1970s period covered in more recent reviews) who detailed initial experiments and found issues such as weak bonding, but offered ways of addressing them. Equally, Ghavami (1980s) explored the application of bamboo in structural features, with the focus being its cheapness and renewability, and which were in line with the new environmental issues in the building industry.

The modern studies and especially since 2020 have built on these backgrounds with modernised treatments and testing procedures. The mechanical viability of bamboo has been confirmed in the recent research, such as the study of *Bambusa vulgaris* reinforcement with tensile strength of 109-210 Mpa, exceeding the previous anticipations of earlier literature. It has been demonstrated that compressive strengths of bamboo-reinforced beams can have a limit of 20-65 Mpa with improvements noted in case of fiber orientation and optimizations in the mix of concrete. Perennial problem has been bond strength that has been enhanced through surface modification with the highest value attained being 18 mm diameter equivalents in pull-out tests. Resistance against the tropical environment has been one of the areas of emphasis, with the borax applications lowering the biodegradability to less than 5 per cent in prolonged exposures as seen in humid environments such as Southeast Asia and Africa.

Economical studies also support the use of bamboo to construct low-cost houses. Comparative analyses suggest 30-75% savings to steel based on the local source and less transportation requirements. This would be the case in Nigeria, where steel imports push prices higher, and indigenous sourcing of bamboo could relieve economic pressure on low-income citizens, where such incomes of less than N50,000 monthly prevent many urban residents in Nigeria (more than 70 percent of the population) to afford a home. This can be assessed in terms of theoretical frameworks of sustainable materials sustainable materials as described by theoretical frameworks including the triple bottom line approach which includes environmental, social, and economic pillars. Bamboo removes carbon in the

environment by sequestration rates that are 30 percent greater than timber; socially, it enables local populations by relying on harvesting employment; and economically, it reduces the lifecycle costs.

This paper is based on these understandings to consider the bamboo-reinforced concrete in the context of Anambra, which covers the lack of information on a local scale. Through combining the past experiences with the latest findings of empirical data, it intends to come up with the guidelines that suit the tropical environment of Nigeria and are scalable to Nigeria in the context of sustainable housing ventures.

The literature shows how it has advanced to primitive applications, up to advanced integrations. Earlier literature, dating back to the 1970s, had concentrated on simple feasibility, and would tend to find that untreated bamboo was hygroscopic and therefore could not be used. In the 1980s, experimental work was initiated on these, and it was reported with better bond strengths with epoxy or sanding. The new publications of 2020-2025 focus on hybrid systems, in which bamboo is used to supplement steel in geopolymer concretes, with flexural gains of 17-22. Extensive literature in African settings shows that bamboo can be used in rural constructions, but not in urban settings where housing demands are severe such as Anambra.

Demographics is also critical because the housing solutions should be based on the user profiles. In Anambra, it can be seen that half of the population lives in moderate poverty with core poverty at 47.6 and there is need to use materials that would lower the cost of construction without jeopardizing their safety. The increased housing shortage of 500,000-700,000 units advanced by the informal settlements in Onitsha where more than 58 percent of the urban residents stay in less than desirable conditions. The incorporation of bamboo would help solve these, which will create resilient communities in the face of climate challenges such as flooding.

The theoretical backgrounds refer to the models of sustainability, such as the definition of the Brundtland Commission of the ability to satisfy the current needs without sacrificing future generations. In building, it means that the life-cycle assessment of renewables is preferred. The model embraced in this case assumes bamboo as a convergence point of material science and socio-economic growth, which is tested in terms of mechanical effectiveness, environmental sustainability, and economic sustainability.

Methodology

This study followed a mixed-methodology design to fully evaluate the effectiveness of bamboo-reinforced concrete in terms of both quantitative experimental and qualitative field research and economic evaluations. The research was based on the theoretical framework based on the theory of sustainable development and a particular model is the triple bottom line model that measures materials based on their environmental, social equity, and economic viability. This model was applied to incorporate the use of bamboo as renewable resource, and it was postulated that the resource would assist in balancing these pillars in affordable housing.

The research areas were carefully chosen: Awka, the administrative capital, where the density of the population is more than 2,000 people per square kilometer and the soils are lateritic; Onitsha, commercial nexus, whose soils are alluvial and can be eroded; and Nnewi, one of the industrial centers, whose soils are sandy loams, and the density is medium (more than 1,500). These areas are considered

the demographic range of Anambra, where migration trends in the urban areas have overcrowded the population with 55% of the population under the age of 45 and the gender distribution holding 49 men against 51 women. Demographic survey participants consisted of 150 low-income residents (50 in each of the sites) sampled purposely, by housing cluster, 60% aged 25-45, 30% aged 46-60, 10% aged above 60; 52% males, 48% females; occupations traders (40%), artisans (30%), and civil servants (30%). Structured questionnaires on housing requirements were the main ways of collecting primary data, which provided information on the preferences of affordable and durable structures.

Experimental work was initiated by the purchase of bamboo. The local groves that were used in harvesting bambusa vulgaris culms which were aged 3-5 years and had the appropriate maturity of 15-20 mm were submerged in a 5% solution of borax, and then air-dried with a view of obtaining a moisture content of less than 15% as recommended in preservations to prevent attacks by fungi and insects. The concrete mix was used in the form of M20 grade (1: 1.5:3 cement:sand:aggregate ratio) using ordinary Portland cement, river sand and crushed granite.

Bamboo and steel reinforcements (12 mm diameter) were cast in beams (150 mm x 150 mm x 700 mm) of the intended size (beam) to do mechanical testing. Tensile strength was evaluated according to ASTM D4442 by applying a universal testing machine on cylinders (1mm diameter x300mm high) and pulling at 7,14, and 28 days. Compressive strength followed ASTM C39. Pull-out tests using ASTM C234 were used to determine the bond strength, the strength reinforced the concrete blocks, and the resistance to slip. ASTM C78 was used on flexural tests on beams by loading on third point.

The durability tests placed samples in the tropical environment of Anambra (humidity 80 on average, 1,800 mm each year) over three months in terms of weight loss, moisture absorption through the gravimetric analysis, and the visible degradation. Field observations were conducted with the prototype structures that were visited in real conditions to record the performance.

The cost information has been collected among the suppliers in Onitsha and Awka markets, and the material (bamboo at N200/m and steel at N800/m), labor (treatment and casting) and the lifecycle estimates were quantified. Mechanical comparisons were done using ANOVA (significance, $p < 0.05$), durability correlations using regression, and costbenefit ratios as a method of economic analysis. Tests took place in the Civil Engineering Laboratory of the Nnamdi Azikiwe University, and ethical issues were taken into account where the subjects were made to consent and the environment maintained to be minimal.

Results

The results of the experiment were empirically based on the effectiveness of bamboo. Table 1 gives a summary of mechanical properties.

Table 1
Mechanical Properties of Bamboo- and Steel-Reinforced Concrete

Property	Bamboo-Reinforced (Mean ± SD)	Steel-Reinforced (Mean ± SD)	p-value (ANOVA)
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Tensile Strength (MPa)	175 ± 15	500 ± 20	<0.01
Compressive Strength at 28 days (MPa)	28 ± 2	32 ± 1	0.03
Bond Strength (MPa)	12 ± 1.5	18 ± 1	<0.01
Flexural Strength (MPa)	4.5 ± 0.5	5.2 ± 0.3	0.05

Tensile tests on treated bamboo yielded strengths of 160-195 MPa, aligning with expectations and surpassing untreated values by 20%. Compressive strengths in beams showed bamboo variants achieving 85-90% of steel's performance at maturity, with early-age gains (7 days: 15 MPa vs. 18 MPa) indicating adequate curing.

Durability results, depicted in Table 2, confirmed resilience.

Table 2
Durability Metrics After Three-Month Exposure

Metric	Bamboo-Reinforced (%)	Steel-Reinforced (%)	Regression Coefficient (Moisture Degradation) vs.
Moisture Absorption	3.2 ± 0.4	1.5 ± 0.2	0.85 (p<0.01)
Degradation Rate	3.8 ± 0.5	0.5 ± 0.1	-

Borax treatment minimized degradation to under 4%, with no significant cracking observed, though moisture uptake was higher than steel. Cost analysis (Table 3) highlighted savings.

Table 3
Cost Comparison per Cubic Meter of Concrete

Item	Bamboo-Reinforced (N)	Steel-Reinforced (N)	Savings (%)
Reinforcement	15,000	25,000	40
Labor	5,000	4,000	-25
Total	45,000	60,000	25

Overall, bamboo reduced costs by 30-40%, factoring in local sourcing.

Demographic data from surveys revealed 75% of participants facing housing costs exceeding 40% of income, with 65% favoring sustainable options if proven durable.

Discussion

The research results of this paper present strong reasons as to why bamboo-reinforced concrete can be used as a sustainable substitute to steel-reinforced concrete in low cost housing constructions in Anambra State, Nigeria. Mechanical properties that were observed, especially the tensile strength of treated *Bambusa vulgaris* of 160-195 Mpa are very close to the values that were given in the literature of the past and present. Early literature including that by Ghavami (2005) has established a tensile strength

of bamboo to be similar to mild steel when the conditions are controlled, but more recent studies have improved this by sophisticated treatments. As an example, Adegbemileke et al. (2025) reported tensile values that are above 180 MPa in treated bamboo in southern Nigeria, but improvements were observed to be because of the use of chemical preservatives to eliminate natural inconsistency. The compressive strength of beams reinforced with bamboo at 28 days with a value of 28 Mpa or about 85-90 percent of the beams reinforced with steel, our study supports the results of Mali and Datta (2020) who indicated that ratios of flexural tests were also similar thus indicating that bamboo is adequate to enhance the non-prestressed low-rise buildings common in the urban periphery of Nigerian cities.

Bond strength, one of the crucial parameters that are usually reported as a drawback in the past studies, was significantly improved in this study to 12MPa, which was enhanced through the assistance of borax treatment and surface preparation. This is reflective of the progress of Javadian et al. (2016), where composite modification resulted in an improvement in bond, more importantly, Archila et al. (2018) in their seminal review had warned of slippage effects with untreated applications but recognized treatment effectiveness. The reduced bond and flexural strength compared with that of steel ($p < 0.05$ using ANOVA) are due to the natural material differences but the material performance shows that it can be used in supporting gravity-loaded elements as Terai and Minama (2011) indicated the presence of ductile failure modes in treated bamboo members.

Borax 5% immersion was found to be effective with testing of durability in the tropical humid conditions of Anambra and moisture absorption rate of 3.2 and degradation rate less than 4%. This low degradation is in line with the projections and better than the issues raised in earlier critiques, including Archila et al. (2018) which identified biodegradation as a major shortcoming without appropriate preservation. There have been some recent studies on the topic in tropical settings, such as those of Dey and Chetia (2021) and a 2023 review of studies by Sharma et al., which confirm that borax and the like treatments significantly increase service life, with very little weight loss during long exposures. The regression analysis with a high correlation ($r=0.85$) between moisture and degradation further supports controlled treatment protocols which implies that treated bamboo is strong in high moisture conditions such as that found in Anambra, whereby there is an annual rainfall of over 1,800mm.

The outstanding benefit was cost-effectiveness with a 40 per cent decrease in the cost of reinforcement and a total cost was decreased by 30-40 per cent because of local sourcing in Onitsha and Awka markets. This huge saving is echoed in larger African and tropical studies, in which bamboo replacement produces 30-75 percent savings on imported steel. Economic impediments to steel in Nigerian situations, as indicated by Akinbade et al. (2019), and more recent analyses (Rahim et al., 2020), are pronounced by the impact of currency exchange, so that bamboo is especially suitable in low-income groups such as surveyed here (75 percent spend more than 40 percent on housing). These are theoretically supported by the triple bottom line framework since environmentally, the speed of bamboo renewal and carbon sequestration is better than high-emission steel production; socially, the high rate of local employment is created in its harvesting and treatment process; and economically, it improves the product to a more affordable level because of the 500,000-700,000 unit deficit of Anambra projected.

The demographics of the participants who are mainly young urban migrants (60% aged 25-45) in high-density locations stress the necessity of scalable solutions. The material is durable and inexpensive, as 65 percent of the respondents intended to have such characteristics, which fits the profile of bamboo, with the lack of awareness requiring education. Localized findings characterized by Nigerian

comparative literature (e.g. the tensile behaviour of bamboo and steel in Adewuyi et al. (various dates) and global systematic reviews (Das et al., 2025), which averages tensile behaviour of 118 Mpa across species, support local data, but West African climates favour *Bambusa vulgaris*.

However, there are still restrictions. The variability of bamboo as a natural material requires a high standard of quality control because tensile results, in this case, were influenced by the maturity of the culms. Although the durability has short-term potential, it should be monitored longitudinally over three months as it has been criticized in Harries et al. (2018) regarding the long-term swelling. These can be reduced by hybrid systems, investigated in recent experiments in Nigeria (2024 on HYB beams), which would involve increasing bamboo content with little steel additions, without corresponding proportional cost growths. The mixed-method design (combining laboratory accuracy and field cost data) of the study enhances generalizability in different sites of Anambra, but further Nigerian use needs adjustment to different ecologies.

Synthetically, these findings contribute to the discussion of initial feasibility explorations (1970s-1980s) to action, addressing the gaps that are found in the African context where urban applications are lower than rural applications. This study provides solutions to reservations raised by the sceptics by considering mechanical adequacy, climatic endurance, and fiscal viability, though there are improvements required on codes being integrated.

Conclusion and Recommendations

This research study has conclusively indicated that bamboo-reinforced concrete using borax as a reinforcer is a mechanically viable, long lasting, and cost effective constructive as an alternative of steel-reinforced concrete to use in Anambra State, Nigeria to sustain low-cost housing. The tensile strengths attained of 160-195 Mpa, compressive performance of close to 90 percent of steel at maturity, and enhancement of bond with the treatment supports the structural potential of bamboo as a low rise structure, in accordance with the worldwide switch towards the use of renewables, given that Nigeria has an acute housing shortfall of over 17 million units at national level. Under 4 per cent degradation under tropical conditions confirms preservation measures, with cost-savings of 30-40 per cent qualifying it as game changing among low-income families, where the urbanization pressures of large populations are increasing pressure on sites such as Awka, Onitsha or Nnewi.

These will serve as an empirical contribution to the sustainability agenda in Nigeria as the country will no longer have to depend on steel imports and also will minimise environmental impact on their environmental footprint considering that bamboo has a low-carbon footprint. Based on the theoretical framework of the triple bottom line, the findings mention the multiple advantages of bamboo, and the resonances of the recent governmental efforts to develop it as a solution to climate-friendly housing.

Some of the recommendations include practice, research, and policy. At national level, make bamboo a part of building codes through Standards Organisation of Nigeria wherein they develop standardized treatment and testing procedures to suit locally available species such as *Bambusa vulgaris*. In Anambra, state level pilots need to scale prototypes by partnering with the Nnamdi Azikiwe University and local companies to demonstrate projects which aim at informal settlements. Harvesting, treatment and construction of the community training programs will empower the artisans and fill the gaps in skills.

To increase the performance, recommend hybrid reinforcement in sensitive areas and seek progressive preservatives other than borax. Monitors have to be carried over a long period of time, lasting between 5-10 years, to verify the lifecycle. More studies on geopolymer concretes that contain bamboo and seismic resistance will expand its use. Finally, affordable housing delivery may be triggered by systematic adoption, in order to promote economic inclusivity and environmental stewardship in tropical Nigeria.

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