Evaluating Sustainable Building Practices for Carbon Reduction in Nigerian Housing

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Abstract
Sustainable building materials play a crucial role in reducing the carbon footprint of the housing sector, which is significant in Nigeria due to rapid urbanisation and increasing housing demands. This study provides a comprehensive narrative review of 60 published journal articles from 2010 to 2023, focusing on identifying, evaluating, and applying sustainable building materials for low-carbon housing in Nigeria. The review method critically analyses existing literature to highlight the most effective materials and techniques contributing to carbon reduction. Findings reveal that materials such as bamboo, recycled concrete, and earth-based materials show promise in achieving sustainability goals. Additionally, the study underscores the importance of integrating traditional construction practices with modern technologies to enhance environmental performance. The barriers to adopting these materials, including economic constraints, lack of awareness, and policy challenges, are also discussed. The insights derived from this review aim to guide policymakers, architects, and builders in promoting sustainable construction practices.

Keywords: *sustainable building materials, low-carbon housing, Nigeria, bamboo, recycled concrete, earth-based materials, construction practices.*

1. Introduction

The increasing global concern over climate change and environmental degradation has significantly emphasised the need for sustainable development practices across various sectors, including the construction industry. In Nigeria, the construction sector is a major contributor to greenhouse gas emissions and environmental pollution due to the extensive use of conventional building materials and practices. As the demand for housing escalates with the country's growing population and rapid urbanisation, mitigating the environmental impact of construction activities becomes more pressing. This study addresses this challenge by exploring sustainable building materials that can contribute to low-carbon housing solutions in Nigeria.

Sustainable building materials encompass products with a minimal environmental footprint throughout their life cycle, from extraction and production to usage and disposal. Such materials are often renewable, recyclable, and locally sourced, reducing the energy and resources needed for transportation and processing. Examples include bamboo, recycled concrete, and earth-based materials, identified for their low carbon emissions and energy efficiency (Vitale et al., 2017; Nwodo & Anumba, 2019; Minunno et al., 2021). These materials benefit the environment and hold economic and social advantages, such as affordability, durability, and cultural appropriateness, making them suitable for the Nigerian context.

Bamboo, for instance, is a rapidly renewable resource that grows abundantly in many parts of Nigeria. Its high strength-to-weight ratio and ability to sequester carbon make it an excellent alternative to conventional timber and steel (Obia et al., 2016; Ameh et al., 2019; Ameh & Shittu, 2021). Similarly, (Visintin et al., 2020; Xiao et al., 2020; Sabau et al., 2021). Earth-based materials, such as adobe and rammed earth, have been used traditionally in Nigeria and are known for their thermal mass properties, which enhance energy efficiency in buildings (Ashour et al., 2015; Wati et al., 2020; Qin et al., 2021).

However, integrating these sustainable materials into the Nigerian construction sector faces several challenges. Economic constraints are a major barrier, as the initial costs of adopting new materials and technologies can be prohibitive. Despite their long-term savings, the upfront investment can deter developers and homeowners (Zuo, Read, Pullen, & Shi, 2012). Furthermore, there is a significant lack of awareness and education about the benefits and applications of sustainable building materials. This knowledge gap extends to policymakers, builders, and the general public, leading to a preference for conventional, familiar materials (Akadiri, 2015; Darko & Chan, 2017; Krueger et al., 2019).

Policy and regulatory frameworks also play a crucial role in adopting sustainable building practices. In Nigeria, the existing regulations often do not adequately support or incentivise using sustainable materials. The absence of stringent environmental standards and enforcement mechanisms means many developers opt for cheaper, less sustainable options (Abisuga & Okuntade, 2019; Tunji-Olayeni et al., 2020; Ochedi & Taki, 2021). To overcome these barriers, comprehensive policy reforms are needed, including providing financial incentives, subsidies, and technical support to encourage the use of low-carbon materials (Häkkinen & Belloni, 2011; Liu & Qin, 2016; Nußholz et al., 2019).

The objectives of this study are twofold: firstly, to identify and evaluate the most effective sustainable building materials suitable for low-carbon housing in Nigeria, and secondly, to provide actionable recommendations for policymakers, architects, and builders to promote the adoption of these materials. The study utilises a narrative review research method, systematically analysing 60 published journal articles from 2010 to 2023. This method allows for a holistic examination of existing literature, providing a thorough understanding of the current state of sustainable building materials and practices.

By synthesising the findings from diverse studies, this research aims to highlight sustainable building materials' environmental, economic, and social benefits. It also seeks to address the challenges and barriers to their adoption, offering insights into how these obstacles can be overcome. The ultimate goal is to contribute to developing a more sustainable construction sector in Nigeria, aligned with global efforts to combat climate change and promote environmental sustainability.

2. Methodology

The methodology for this study involves a comprehensive narrative review of the existing literature on sustainable building materials for low-carbon housing in Nigeria. The narrative review method is chosen for its ability to provide a qualitative synthesis of findings from a wide range of studies, allowing for a thorough exploration of the topic. This approach is particularly suited for examining complex issues where multiple factors and perspectives must be considered (Baumeister & Leary, 1997).

The selection of articles for this review follows a systematic process. Initially, a broad search was conducted using academic databases such as Google Scholar, PubMed, Scopus, and Web of Science. The search terms included "sustainable building materials," "low-carbon housing," "Nigeria," "bamboo," "recycled concrete," "earth-based materials," and "sustainable construction." The search was restricted to articles published between 2010 and 2023 to ensure the relevance and currency of the data. The initial search yielded several hundred articles, which were then screened based on their titles and abstracts to identify those that specifically addressed the use of sustainable building materials in the context of low-carbon housing.

After the initial screening, the selected articles were subjected to a more detailed evaluation. This involved reading the full text of each article to assess its relevance and quality. Articles that provided empirical data, theoretical insights, or case studies related to the use of sustainable building materials in Nigeria were included in the review. Articles that discussed these materials' environmental, economic, and social impacts were considered valuable. Studies that did not meet these criteria were excluded from the review. Ultimately, 60 articles were selected for inclusion in the narrative review.

The data extraction process involved systematically summarising the key findings from each article. This included information on the types of sustainable building materials discussed, their environmental benefits, economic feasibility, and challenges associated with their adoption. The extracted data were then organised thematically to facilitate analysis. The Themes identified included sustainable building materials' environmental impact, economic implications, technical performance, and barriers to adoption.

The narrative review's analysis phase involved synthesising the findings of the selected articles to draw comprehensive conclusions. This qualitative synthesis identified the literature's patterns, commonalities, and divergences. The goal was to provide a holistic understanding of the current knowledge on sustainable building materials for low-carbon housing in Nigeria and highlight gaps in the literature and areas for future research.

The narrative review methodology has several strengths, including its ability to provide an in-depth analysis of a broad topic and incorporate diverse evidence types. However, it also has limitations. One limitation is the potential for bias in selecting and interpreting articles. To mitigate this risk, the selection process was designed to be as systematic and transparent as possible, with clear inclusion and exclusion criteria. Additionally, efforts were made to include diverse studies, including those with differing perspectives and methodologies, to ensure a balanced and comprehensive review (Westgate & Lindenmayer, 2017; Greenhalgh et al., 2018; Arroyave et al., 2020).

3. Sustainable Building Materials: Overview and Identification

The concept of sustainable building materials is rooted in the broader sustainable development framework, which seeks to balance environmental, economic, and social considerations. Sustainable building materials have a minimal environmental impact throughout their life cycle, from extraction and production to usage and disposal (Vitale et al., 2017; Nwodo & Anumba, 2019; Minunno et al., 2021). These materials often include renewable resources, recycled materials, and products that enhance energy efficiency.

Historically, sustainable construction practices in Nigeria have been influenced by traditional building methods that utilise locally available materials. Earth-based construction, for example, has a long history in Nigeria, particularly in rural areas where adobe, rammed earth, and laterite blocks are commonly used (Taiwo & Adeboye, 2013; Akadiri, 2015; Oladokun et al., 2020). These materials are known for their thermal mass properties, which help regulate indoor temperatures and reduce the need for artificial heating and cooling, thereby lowering energy consumption.

In recent years, there has been a growing interest in integrating traditional materials with modern construction techniques to improve their performance and broaden their application in urban settings. For instance, stabilised earth blocks, which combine earth with a small amount of cement or lime, offer improved strength and durability while retaining the environmental benefits of traditional earth construction (Malkanthi et al., 2020; Islam et al., 2020; Ciancio et al., 2014).

Bamboo is recognised as one of the most promising sustainable building materials due to its rapid growth rate and high carbon sequestration capability. Bamboo can grow up to 91 cm per day under optimal conditions, making it a rapidly renewable resource (Song et al., 2011; Okonkwo et al., 2021; Yadav & Mathur, 2021). Its strength-to-weight ratio is comparable to steel's and has been used in various structural applications, including frames, scaffolding, and flooring (Javadian et al., 2016; Li et al., 2020; Chen et al., 2020). Bamboo's environmental benefits extend beyond its growth phase; it also contributes to reducing carbon emissions during construction. For example, using bamboo instead of steel and concrete can significantly lower the embodied energy of buildings (Dudhatra et al., 2017; Chiniforush et al., 2018).

Recycled concrete is another material with substantial environmental benefits. The construction industry generates much waste, much of which comes from demolishing old buildings. Recycling this concrete waste into new construction materials can reduce the demand for virgin aggregates and decrease the carbon emissions associated with cement production (Kou & Poon, 2013; Behera et al., 2014; Robalo et al., 2021). Studies have shown that recycled concrete can achieve similar structural performance as conventional concrete when properly processed and applied. Additionally, using recycled concrete helps in waste management and reduces landfill usage, contributing to overall environmental sustainability (Mah et al., 2018; Merli et al., 2020; Tran et al., 2021).

Earth-based materials, such as adobe, rammed earth, and compressed earth blocks, have a long history of use in Nigeria and other parts of the world. These materials are known for their excellent thermal mass properties, which help maintain stable indoor temperatures by absorbing and slowly releasing heat (Ashour et al., 2015; Wati et al., 2020; Qin et al., 2021). Adobe is made from a mixture of clay, sand, and water, with or without organic materials, and is shaped into bricks and dried in the sun. Rammed earth involves compacting damp soil into moulds to form solid walls. Compressed earth blocks are similar to adobe but are mechanically pressed to achieve higher density and strength (Walker, 2004).

The use of earth-based materials offers several advantages for sustainable construction. Firstly, they are locally available and often inexpensive, reducing the need for transportation and associated emissions. Secondly, their low-energy production and construction processes do not require significant fossil fuel inputs. Finally, buildings made with earth-based materials can be more comfortable and energy-efficient, reducing the need for artificial heating and cooling (Minke, 2001).

Despite these advantages, there are challenges to the widespread adoption of these materials in Nigeria. One major challenge is perceiving these materials as inferior or suitable only for low-cost housing. There is a need to change this perception through education and demonstration projects that showcase sustainable building materials' durability and aesthetic potential (Akadiri, 2015; Darko & Chan, 2017; Krueger et al., 2019). Additionally, technical expertise in modern applications of these materials is limited, requiring capacity-building efforts to train architects, engineers, and builders.

Another challenge is the regulatory environment. Current building codes and standards in Nigeria may not fully support using non-traditional materials. Updating these regulations to include guidelines for sustainable materials can facilitate their adoption and ensure that buildings constructed with these materials meet safety and performance standards (Windapo & Rotimi, 2012; Akadiri, 2015; Atanda & Olukoya, 2019).

4. Evaluation of Sustainable Building Materials

Evaluating sustainable building materials involves a detailed analysis of their environmental impact, economic feasibility, and technical performance. This section delves into these aspects to determine the suitability of bamboo, recycled concrete, and earth-based materials for low-carbon housing in Nigeria.

The environmental impact of sustainable building materials is a primary consideration, given the urgent need to reduce carbon emissions in the construction sector. Bamboo, for instance, is celebrated for its rapid growth and high carbon sequestration capabilities. Bamboo plantations can absorb more CO2 and release more oxygen compared to equivalent stands of trees (Obia et al., 2016; Ameh et al., 2019; Ameh & Shittu, 2021). Additionally, bamboo requires minimal processing, which translates to lower energy consumption and reduced emissions during the production phase (Restrepo & Becerra, 2016; Patel et al., 2020). Its use as a substitute for traditional materials like steel and concrete further reduces the overall carbon footprint of construction projects.

Recycled concrete also offers significant environmental benefits. Concrete production is a major source of CO2 emissions due to the energy-intensive process of cement manufacturing. Recycling concrete from demolished structures reduces the demand for new cement, leading to lower emissions. Studies indicate that recycled concrete can cut CO2 emissions by up to 65% compared to traditional concrete (Yang et al., 2014; Akhtar & Sarmah, 2018; He et al., 2019). Moreover, incorporating recycled concrete in new construction helps manage waste by diverting demolition waste from landfills, contributing to a circular economy (Visintin et al., 2020; Xiao et al., 2020; Sabau et al., 2021).

Earth-based materials, such as adobe and rammed earth, are notable for their low environmental impact. These materials are abundant, locally available, and require minimal processing, which reduces energy use and emissions. The production of adobe bricks, for example, involves mixing earth with water and straw, then drying them in the sun—processes with negligible carbon footprints (Taiwo & Adeboye, 2013; Akadiri, 2015; Oladokun et al., 2020). Additionally, buildings constructed with earth-based materials exhibit superior thermal mass properties, helping to maintain stable indoor temperatures and reducing the need for artificial heating and cooling, which can lower operational energy use (Walker, 2004).

Economic feasibility is another critical factor in evaluating sustainable building materials. Despite the long-term cost savings associated with energy efficiency and durability, the initial costs of sustainable materials can be higher than conventional options. For example, the establishment of bamboo plantations and the development of processing facilities require significant upfront investment. However, bamboo's rapid growth and high yield can offset these initial costs, making it an economically viable option in the long run (Song et al., 2011; Okonkwo et al., 2021; Yadav & Mathur, 2021). Additionally, bamboo's versatility allows it to be used in various applications, potentially reducing overall construction costs.

Recycled concrete, while potentially more expensive due to the processing required to ensure quality and performance, can also result in cost savings through reduced material costs and landfill fees. The economic feasibility of using recycled concrete largely depends on the availability of local recycling facilities and the proximity of construction sites to these facilities (Kou & Poon, 2012; Behera et al., 2014; Robalo et al., 2021). In regions with well-developed recycling infrastructure, recycled concrete can be cost-effective and environmentally beneficial.

Earth-based materials, such as adobe and rammed earth, are often more cost-effective due to their local availability and low production costs. The use of locally sourced earth reduces transportation costs and supports local economies. Additionally, the construction techniques associated with these materials, while labour-intensive, can be less expensive than conventional methods, especially in regions with abundant labour (Minke, 2001). However, the economic feasibility of earth-based materials can be influenced by factors such as the need for stabilisation with cement or lime and the cost of skilled labour for specific construction techniques.

Technical performance is the third crucial aspect in evaluating sustainable building materials. Bamboo, for example, boasts a high strength-to-weight ratio, making it suitable for structural applications. However, its performance can be affected by factors such as susceptibility to pests and environmental degradation, which require proper treatment and maintenance (Javadian et al., 2016; Li et al., 2020; Chen et al., 2020). Bamboo treatment and preservation methods have improved its durability and longevity, making it a reliable construction material (Dudhatra et al., 2017; Chiniforush et al., 2018).

Recycled concrete, when processed correctly, can achieve strength and durability comparable to conventional concrete. The quality of recycled concrete depends on the source of the demolition waste and the processing techniques used to remove contaminants and ensure uniformity. Research indicates that with proper quality control, recycled concrete can be used in various structural applications, including foundations, pavements, and load-bearing walls (Kou & Poon, 2012; Behera et al., 2014; Robalo et al., 2021). However, the variability in the properties of recycled aggregates requires careful assessment and standardisation to ensure consistent performance (Mah et al., 2018; Merli et al., 2020; Tran et al., 2021).

Earth-based materials offer excellent thermal properties, enhancing energy efficiency in buildings. Their ability to regulate indoor temperatures by absorbing and releasing heat reduces the need for artificial climate control, leading to lower energy consumption. However, their structural performance can be variable, depending on the composition of the soil and the construction techniques used. Stabilising earth with cement or lime can improve its strength and durability, making it suitable for a wider range of applications (Walker, 2004). The technical performance of earth-based materials also depends on factors such as moisture resistance and the quality of construction, which require proper design and skilled labour (Ashour et al., 2015; Wati et al., 2020; Qin et al., 2021).

5. Application of Sustainable Building Materials in Nigeria

The application of sustainable building materials in Nigeria involves integrating these materials into construction practices to develop low-carbon housing solutions. This section examines specific projects, integration with traditional construction practices, and adoption and implementation strategies for materials such as bamboo, recycled concrete, and earth-based materials.

Case studies from different regions of Nigeria illustrate the potential and challenges of using sustainable building materials. One notable example is the use of the Nigerian Building & Road Research Institute (NBRRI)'s Compressed Stabilized Earth Blocks (CSEB) across the six geopolitical zones of Nigeria. This project leverages the local availability of laterite and traditional knowledge of earth construction. The stabilised earth blocks, mixed with small amounts of cement, offer improved durability and weather resistance compared to conventional adobe bricks. These projects have demonstrated the technical feasibility of earth-based materials and their acceptability among local communities (Waziri et al., 2013; Egenti et al., 2014). Such case studies highlight the importance of combining modern stabilisation techniques with traditional materials to enhance performance and community acceptance.

Another significant project is the "Bamboo School Building Initiative" in Makoko, Southern Nigeria. Local NGOs and international partners supported Makoko Floating School in Nigeria; this project involved constructing school buildings using bamboo due to its rapid growth, strength, and renewability. The initiative included training local builders in bamboo construction techniques. The resulting structures were cost-effective, environmentally friendly, and provided a comfortable learning environment. This case study underscores the potential of bamboo as a versatile and sustainable building material, especially when coupled with capacity-building efforts (Restrepo & Becerra, 2016; Patel et al., 2020).

Integrating sustainable building materials with traditional construction practices is crucial for widespread adoption. Conventional building methods in many parts of Nigeria have been honed over centuries to suit local climates and resources. For instance, using thatch and mud in traditional Yoruba architecture provides excellent thermal insulation and minimises the need for artificial cooling. By incorporating modern sustainable materials into these conventional practices, it is possible to enhance their performance while preserving cultural heritage. For example, combining earth-based materials with modern stabilisers or integrating bamboo with traditional roofing systems can create hybrid structures that offer the best of both worlds (Arrigoni et al., 2017; Nandapala & Halwatura, 2021).

Adoption and implementation strategies for sustainable building materials must address several key factors, including education, policy support, and financial incentives. Education and training are essential to ensure that architects, builders, and homeowners know the benefits and techniques associated with sustainable materials. Workshops, demonstration projects, and inclusion in architectural curricula can help build the necessary skills and knowledge base. For instance, universities and vocational schools can play a pivotal role in disseminating information and providing hands-on training in sustainable construction methods (Abisuga & Okuntade, 2019; Tunji-Olayeni et al., 2020; Ochedi & Taki, 2021).

Policy support is equally critical. Government regulations and building codes should be updated to encourage sustainable materials. This could include setting minimum standards for energy efficiency, providing guidelines for using local materials, and offering incentives for green building certifications. Policy measures could also involve subsidies or tax breaks for projects incorporating sustainable building materials, reducing the financial burden on developers and homeowners. For example, countries like India and China have successfully implemented policies that promote bamboo and earth-based construction, providing useful models for Nigeria (Amponsah & Salhi, 2014).

Financial incentives and support mechanisms are necessary to overcome the initial cost barriers associated with sustainable building materials. This could involve low-interest loans, grants, or subsidies for projects that demonstrate significant environmental benefits. Additionally, partnerships with international development agencies and NGOs can provide funding and technical assistance for pilot projects. These projects can serve as proof of concept, demonstrating the feasibility and benefits of sustainable construction on a larger scale (Shen et al., 2016; Shan et al., 2017; Winden & Buuse, 2017).

Finally, public awareness campaigns can play a significant role in changing perceptions about sustainable building materials. Many potential users may be unaware of the benefits or may hold misconceptions about the durability and performance of these materials. Effective communication strategies, including media campaigns, community meetings, and social media, can help shift public opinion and increase acceptance. Highlighting successful case studies and providing testimonials from satisfied users can also build confidence and encourage wider adoption (Malkanthi et al., 2020; Islam et al., 2020; Ciancio et al., 2014).

6. Barriers to Adoption

6.1 Economic Constraints

One of the primary barriers to adopting sustainable building materials is the economic constraint associated with their initial costs. Although sustainable materials like bamboo, recycled concrete, and earth-based materials can offer long-term savings through reduced energy consumption and maintenance costs, the upfront investment required can be prohibitive for many developers and homeowners. For example, establishing bamboo plantations and developing processing facilities require significant capital investment (Obia et al., 2016; Ameh et al., 2019; Ameh & Shittu, 2021). Similarly, recycled concrete's processing and quality assurance can increase costs compared to virgin materials (Yang et al., 2014; Akhtar & Sarmah, 2018; He et al., 2019).

In Nigeria, where the construction industry is highly cost-sensitive, these initial financial barriers can be a significant deterrent. The higher costs associated with sustainable materials can result from limited local production capacities and the need for specialised skills and technologies. Additionally, the financial systems in Nigeria often lack the necessary support mechanisms, such as low-interest loans or subsidies, to ease the adoption of sustainable building practices (Häkkinen & Belloni, 2011; Liu & Qin, 2016; Nußholz et al., 2019). The transition to sustainable materials remains challenging without adequate financial incentives and support.

6.2 Lack of Awareness and Education

Another critical barrier is the lack of awareness and education about sustainable building materials among key stakeholders, including policymakers, architects, builders, and the general public. This knowledge gap leads to a preference for conventional building materials that are more familiar and perceived as less risky (Durdyev et al., 2018; Bohari et al., 2020; Kongela, 2021). Many stakeholders are unaware of sustainable materials' environmental benefits, long-term cost savings, and technical capabilities.

Insufficient educational and training programs often hamper efforts to promote sustainable building practices. For instance, many architecture and engineering curricula in Nigerian universities do not adequately cover sustainable construction methods or the benefits of using materials like bamboo and recycled concrete. This educational shortfall extends to vocational training for builders and contractors, who are critical to implementing these materials on the ground (Amponsah & Salhi, 2014).

Effective awareness campaigns and educational initiatives are essential to change perceptions and build the necessary skills for using sustainable materials. Demonstration projects, workshops, and inclusion in academic curricula can help disseminate knowledge and practical experience. Raising awareness among policymakers can also lead to more supportive regulatory frameworks and financial incentives.

6.3 Policy and Regulatory Challenges

Policy and regulatory frameworks play a crucial role in promoting or hindering the adoption of sustainable building materials. In Nigeria, existing building codes and standards often do not adequately support using non-traditional materials. The absence of stringent environmental standards and enforcement mechanisms means many developers opt for cheaper, less sustainable options (Akadiri, 2015; Darko & Chan, 2017; Krueger et al., 2019).

To foster the adoption of sustainable materials, it is imperative to update building codes and standards to include guidelines for their use. This could involve setting minimum standards for energy efficiency, providing specific guidelines for using local materials, and offering incentives for projects that achieve green building certifications (Shen et al., 2016; Shan et al., 2017; Winden & Buuse, 2017). For example, integrating requirements for bamboo, recycled concrete, and earth-based materials into national building standards could ensure their broader adoption and consistency in application.

The policy environment should also include financial incentives such as subsidies, tax breaks, or grants for projects that incorporate sustainable building materials. These incentives can reduce the initial cost barriers and make sustainable construction more attractive to developers and homeowners. Countries like India and China have successfully implemented such policies, providing useful models for Nigeria (Dudhatra et al., 2017; Chiniforush et al., 2018).

6.4 Overcoming the Barriers

Addressing the barriers to adopting sustainable building materials requires a multifaceted approach. Economic constraints can be mitigated through financial incentives and support mechanisms. Governments and financial institutions can offer low-interest loans, grants, or subsidies to ease the initial cost burden. Partnerships with international development agencies and NGOs can also provide funding and technical assistance for pilot projects, demonstrating the feasibility and benefits of sustainable construction on a larger scale.

Comprehensive educational programs and awareness campaigns are essential to overcome the lack of awareness and education. These programs should target all stakeholders, from policymakers and industry professionals to the general public. Universities and vocational schools can play a pivotal role in integrating sustainable construction methods into their curricula and providing hands-on training.

Policy and regulatory reforms are crucial to creating an enabling environment for sustainable building practices. Updating building codes and standards to include sustainable materials, setting minimum energy efficiency standards, and providing financial incentives can significantly promote their adoption. Additionally, robust enforcement mechanisms are necessary to ensure compliance and encourage best practices.

Public awareness campaigns can help change perceptions about sustainable building materials. Effective communication strategies, including media campaigns, community meetings, and social media, can highlight sustainable construction's benefits and success stories. Testimonials from satisfied users and demonstration projects can build confidence and encourage wider adoption.

7. Discussion

7.1 Synthesis of Findings

The review of sustainable building materials such as bamboo, recycled concrete, and earth-based materials highlights their environmental benefits, economic feasibility, and technical performance. Bamboo, with its rapid growth and high carbon sequestration capabilities, emerges as a promising material for construction. Projects like the "Bamboo School Building Initiative" in Southern Nigeria demonstrate its potential for providing cost-effective, durable, and environmentally friendly structures (Restrepo & Becerra, 2016; Patel et al., 2020).

Recycled concrete, derived from demolition waste, offers a sustainable alternative to conventional concrete. It reduces the demand for new cement, thereby lowering CO_2 emissions. Case studies like those using recycled concrete in urban housing projects illustrate its practical application and performance (Yang et al., 2014; Akhtar & Sarmah, 2018; He et al., 2019). Earth-based materials, such as adobe and rammed earth, have long been used in Nigeria. They remain viable for sustainable construction due to their low environmental impact and excellent thermal properties (Taiwo & Adeboye, 2013; Akadiri, 2015; Oladokun et al., 2020).

Despite the evident benefits, the adoption of these materials faces significant barriers. The primary challenges are economic constraints, lack of awareness and education, and inadequate policy support. The initial costs of sustainable materials can be higher than conventional options, making them less attractive to developers and homeowners (Malkanthi et al., 2020; Islam et al., 2020; Ciancio et al., 2014). Furthermore, stakeholders' limited knowledge of these materials hampers widespread use (Windapo & Rotimi, 2012; Akadiri, 2015; Atanda & Olukoya, 2019).

7.2 Comparison with Global Practices

Comparing Nigeria's experience with global practices provides valuable insights. Countries like India and China have successfully integrated sustainable materials into their construction sectors through supportive policies, financial incentives, and extensive awareness campaigns. In India, bamboo is extensively used in rural and urban housing, supported by government policies that promote its cultivation and use (Amponsah & Salhi, 2014). China has also made significant strides in using recycled materials in construction, backed by strict environmental regulations and incentives for green building practices (Dudhatra et al., 2017; Chiniforush et al., 2018).

These countries demonstrate that policy support, financial incentives, and education are crucial for successfully adopting sustainable building materials. Nigeria can learn from these examples by implementing similar strategies tailored to its context.

7.3 Implications for Policy and Practice

The findings have several implications for policy and practice in Nigeria. Firstly, there is a need for comprehensive policy reforms to support the use of sustainable building materials. Updating building codes and standards to include guidelines for bamboo, recycled concrete, and earth-based materials is essential. This should be accompanied by financial incentives such as subsidies, tax breaks, and low-interest loans to reduce the initial cost barriers (Häkkinen & Belloni, 2011; Liu & Qin, 2016; Nußholz et al., 2019).

Secondly, education and training programs are vital to bridge the knowledge gap among stakeholders. Incorporating sustainable construction methods into academic curricula and providing hands-on training through workshops and demonstration projects can build the necessary skills and knowledge base (Durdyev et al., 2018; Bohari et al., 2020; Kongela, 2021). Public awareness campaigns can also play a significant role in changing perceptions about sustainable building materials.

Thirdly, collaboration between government, industry, and academia is crucial for advancing sustainable construction practices. Partnerships with international development agencies and NGOs can provide funding and technical assistance for pilot projects, demonstrating the feasibility and benefits of sustainable construction on a larger scale (Amponsah & Salhi, 2014).

8. Recommendations

The successful adoption of sustainable building materials in Nigeria requires a multifaceted approach that addresses economic, educational, and regulatory challenges. This section provides actionable recommendations for policymakers, architects, and builders to promote sustainable materials such as bamboo, recycled concrete, and earth-based materials.

i. **Strategies for Enhancing Adoption:** To enhance the adoption of sustainable building materials, it is essential to implement financial incentives that reduce the initial cost barriers. This can include subsidies, tax breaks, and low-interest loans specifically targeted at projects incorporating sustainable materials. Providing grants or funding for pilot projects can demonstrate these materials' economic and environmental benefits, encouraging broader adoption. Additionally, establishing a green building certification system that rewards sustainable materials can incentivise developers and builders to prioritise environmentally friendly options.

ii. **Policy Recommendations:** Updating building codes and standards is crucial for supporting sustainable building materials. Policymakers should develop guidelines that include specifications for bamboo, recycled concrete, and earth-based materials, ensuring that these materials meet safety and performance standards. Creating a regulatory framework that mandates a certain percentage of sustainable materials in new constructions can drive demand and standardise their use. Furthermore, integrating sustainability criteria into public procurement policies can lead by example, showing the feasibility and benefits of sustainable building practices in government projects.

iii. **Educational Initiatives:** Education and training are vital to overcome the knowledge gap about sustainable building materials. Incorporating sustainable construction methods into architectural and engineering curricula at universities and vocational schools will equip future professionals with the necessary skills and knowledge. Hands-on workshops and training programs for builders and contractors can demonstrate practical applications and build confidence in using these materials. Establishing partnerships with international organisations and NGOs can provide additional resources and expertise for educational initiatives.

iv. **Raising Public Awareness:** Public awareness campaigns are essential to change perceptions and increase acceptance of sustainable building materials. Effective communication strategies, including media campaigns, community meetings, and engagement, can highlight sustainable construction's benefits and success stories. Showcasing demonstration projects and providing testimonials from satisfied users can build trust and encourage wider adoption. Informational materials, such as brochures and videos, can educate the general public about sustainable building materials' environmental and economic advantages.

v. **Encouraging Research and Development:** Investing in research and development is crucial for advancing the technology and applications of sustainable building materials. Funding for research projects can explore new materials, improve existing ones, and develop innovative construction techniques. Collaboration between universities, research institutions, and industry can foster the development of sustainable building solutions tailored to the Nigerian context. Establishing research centres focused on sustainable construction can serve as hubs for innovation and knowledge dissemination.

vi. **Facilitating Collaboration:** Collaboration among stakeholders is key to promoting sustainable building practices. Establishing forums and networks for architects, builders, policymakers, and researchers can facilitate the exchange of knowledge and best practices. Public-private partnerships can leverage resources and expertise from various sectors to support sustainable construction initiatives. Engaging community organisations and local leaders in the planning and implementing of sustainable building projects can ensure that these efforts meet the needs and preferences of the local population.

vii. **Monitoring and Evaluation:** Continuous monitoring and evaluation are essential to assess the effectiveness of policies and initiatives promoting sustainable building materials.

Developing metrics and indicators to measure these materials' environmental, economic, and social impacts can provide valuable insights. Regular reporting and feedback mechanisms can identify challenges and areas for improvement, ensuring that strategies remain relevant and effective. Establishing an independent body to oversee the implementation and evaluation of sustainable construction policies can enhance transparency and accountability.

9. Conclusion

Adopting sustainable building materials is crucial for reducing the carbon footprint of the construction industry in Nigeria. This study has highlighted the significant environmental, economic, and technical benefits of using materials such as bamboo, recycled concrete, and earth-based materials. These materials offer lower emissions and energy consumption during their life cycles and provide long-term cost savings and enhanced building performance.

With its rapid growth and high carbon sequestration capabilities, bamboo is a promising material for various construction applications. Recycled concrete reduces the demand for new cement, lowering CO_2 emissions and promoting a circular economy. Earth-based materials, such as adobe and rammed earth, leverage local resources and traditional knowledge to create buildings with excellent thermal properties and minimal environmental impact.

Despite these benefits, several barriers hinder Nigeria's widespread adoption of sustainable building materials. Economic constraints, including high initial costs and limited financial incentives, pose significant challenges. Additionally, stakeholders' lack of awareness and education and inadequate policy support impede progress. Addressing these barriers requires a multifaceted approach involving policy reforms, financial incentives, education, and public awareness campaigns.

Policy reforms are essential to create a regulatory environment that supports sustainable materials. Updating building codes and standards to include guidelines for these materials can ensure their safe and effective use. Financial incentives, such as subsidies, tax breaks, and low-interest loans, can alleviate the initial cost burden and encourage adoption. Educational initiatives incorporating sustainable construction methods into academic curricula and providing hands-on training are vital for building the necessary skills and knowledge base.

Public awareness campaigns can change perceptions and increase acceptance of sustainable building materials. Highlighting successful case studies and providing testimonials from satisfied users can build trust and demonstrate the practical benefits of these materials. Collaboration among stakeholders, including government, industry, academia, and community organisations, fosters innovation and shares best practices.

Research and development play a pivotal role in advancing sustainable building technologies. Investing in research can lead to the discovering of new materials and improved construction techniques tailored to Nigeria's specific needs and conditions. Continuous monitoring and evaluation of policies and initiatives can ensure their effectiveness and identify areas for improvement.

In conclusion, transitioning to sustainable building materials in Nigeria is challenging, but its potential benefits are worthwhile. Nigeria can develop a more sustainable construction sector by addressing economic, educational, and regulatory barriers and fostering collaboration and innovation. This transition will contribute to environmental sustainability, economic development, and an improved quality of life for its population. The insights from this study provide a roadmap for policymakers, architects, and builders to promote the use of sustainable building materials, paving the way for a greener future.

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