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Advancing Sustainability in Nigerian Architecture: A Systematic Review of Sustainable Materials, Circular Economy, and Low-Carbon Solutions

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ABSTRACT

Sustainability in architectural practices is pivotal in mitigating environmental impacts while enhancing the resilience of Nigeria's built environment. This systematic review examines sustainable materials, circular economy principles, and low-carbon solutions within the Nigerian context from 2014 to 2024. A total of 497 articles were screened, with 53 selected for final analysis using the PRISMA framework. Findings reveal an increasing adoption of eco-friendly building materials, albeit with challenges in cost, which is often higher than conventional materials and availability, particularly in remote areas. Circular economy strategies, including material reuse and waste reduction, show the potential to reduce environmental degradation. Low-carbon solutions, particularly passive design techniques and renewable energy integration, contribute to enhanced sustainability. Thematic and meta-analyses indicate a progressive shift towards sustainable architectural practices; however, gaps remain in policy implementation and stakeholder collaboration. The study underscores the need for regulatory enforcement, incentives for sustainable building practices, and heightened awareness among practitioners. Future research should focus on localised material innovations and the scalability of circular economy models in the Nigerian context.

Keywords: Sustainable architecture, Circular economy, Low-carbon solutions, Built environment, Nigeria, Eco-friendly materials, Passive design.

INTRODUCTION

Sustainability in architectural practices has gained prominence due to the increasing impact of climate change, rapid urbanisation, and resource depletion. The construction industry significantly contributes to global greenhouse gas (GHG) emissions, energy consumption, and waste generation, necessitating a shift towards sustainable design solutions (Akande et al., 2015; Ayeni et al., 2021; Oladokun et al., 2021). In Nigeria, the built environment faces multiple challenges, including inefficient resource utilisation, high carbon emissions, and inadequate waste management, where a significant portion of construction waste is not properly disposed of or recycled (Garba et al., 2016; Ogunmakinde et al., 2019). Sustainable architectural practices, which incorporate sustainable materials, circular economy principles, and low-carbon solutions, present viable pathways for mitigating these challenges.

Sustainability in architecture encompasses designing and constructing buildings that minimise environmental impacts while enhancing energy efficiency and occupant well-being (Akadiri, 2015; Atanda & Olukoya, 2019; Oladokun et al., 2021; Ochedi & Taki, 2022). The integration of sustainable materials, such as bamboo, recycled aggregates, and locally sourced clay, reduces the ecological footprint of construction activities (Akadiri, 2015; Atanda, 2015; Okokpujie et al., 2020). Additionally, circular economy principles, which emphasise material reuse, recycling, and waste reduction, play a pivotal role in advancing sustainability in the built environment (Pomponi & Moncaster, 2017; Ezeudu & Ezeudu, 2019; Li et al., 2020). Low-carbon solutions, including passive cooling techniques, renewable energy adoption, and green infrastructure, further contribute to the reduction of emissions and resource depletion (Inusa & Alibaba, 2017; Babatunde et al., 2018; Okundamiya, 2021).

Despite the benefits of sustainable architectural practices, Nigeria's construction industry continues to rely on conventional, resource-intensive methods that exacerbate environmental degradation (Tunji-Olayemi et al., 2018; Oladokun et al., 2021; Lawal et al., 2024; Oke et al., 2024). High costs of sustainable materials, lack of regulatory enforcement, and limited awareness among stakeholders, particularly in rural areas and among smaller construction firms, hinder widespread adoption (Osuizugbo et al., 2020; Oladokun et al., 2021; Ekung et al., 2022). Addressing these barriers requires robust policy frameworks, financial incentives, and capacity-building initiatives to promote sustainable construction practices.

The circular economy concept, which advocates for closed-loop resource utilisation, has gained traction in global construction practices (Li et al., 2020; Adefila et al., 2020; Oladokun et al., 2021; Zuofa et al., 2023). In Nigeria, waste generation from construction and demolition activities remains a significant challenge, with limited efforts towards recycling and material repurposing (Akhtar & Sarmah, 2018; Benshak et al., 2020; Ogunseye et al., 2023). Studies indicate that integrating circular economy strategies, such as modular construction, adaptive reuse, and material recovery, can significantly reduce waste and enhance sustainability in the built environment (Adefila et al., 2020; Aboginije et al., 2021; Zuofa et al., 2023).

However, circular economy adoption in Nigeria remains in its infancy due to infrastructural constraints, inadequate technological advancements, and a lack of legislative backing. The urgency of the situation is clear. Collaborative efforts among policymakers, industry professionals, and researchers are essential in mainstreaming circular economy principles within the construction sector. This collaboration is not just beneficial; it is necessary for the future of Nigeria's built environment.

Low-carbon solutions are crucial for reducing buildings' environmental impact, particularly in a country like Nigeria, where energy demand is rising due to population growth and urban expansion (Emodi et al., 2016; Olotuah et al., 2018; Ochedi & Taki, 2022). Energy-efficient building designs, such as passive cooling, natural ventilation, and high-performance insulation, contribute to lowering carbon emissions (Akande et al., 2015; Manzuma et al., 2018; Li et al., 2020). Additionally, renewable energy integration, including solar photovoltaics and biogas systems, enhances sustainability by reducing reliance on fossil fuels (Abubakar et al., 2019).

The adoption of low-carbon strategies remains slow in Nigeria due to financial limitations, policy inconsistencies, and insufficient technical expertise (Elum & Momodu, 2017; Daggash & Mac Dowell, 2021). Governmental interventions, coupled with private-sector initiatives, are necessary to accelerate the implementation of energy-efficient and climate-responsive building solutions.

Given the critical role of sustainability in the architectural sector, this study aims to systematically review existing literature on sustainable materials, circular economy applications, and low-carbon solutions in Nigeria's built environment. The review spans from 2014 to 2024, drawing insights from diverse academic sources, including Scopus, Web of Science, PubMed, and Google Scholar. The study's primary objectives include:

i. Examining trends in the adoption of sustainable building materials in Nigeria.

ii. Analyzing the impact of circular economy strategies on waste management and resource efficiency.

iii. Evaluating the effectiveness of low-carbon solutions in reducing energy consumption and emissions.

iv. Identifying challenges and opportunities in mainstreaming sustainability within Nigeria's architectural practices.

This research employs a systematic review approach, following the PRISMA framework to ensure comprehensive data collection, screening, and synthesis. Findings from this study will provide valuable insights for policymakers, architects, and researchers in fostering a more sustainable built environment in Nigeria.

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LITERATURE REVIEW

Sustainable Materials in Architectural Practices

One of the key roles of sustainable materials is to reduce the environmental footprint of buildings. Melià et al. (2014) have underscored the importance of locally sourced materials, such as laterite, bamboo, and clay bricks, in this regard. These materials significantly reduce embodied carbon compared to conventional cement-based materials. The use of recycled materials, including reclaimed wood and crushed concrete, further contributes to this reduction and promotes circular resource utilisation (Inusa & Alibaba, 2017; Lo, 2017; Babatunde et al., 2018; Okundamiya, 2021).

Despite these advantages, the adoption of sustainable materials in Nigeria remains limited due to high costs, availability constraints, and inadequate awareness among stakeholders (Tunji-Olayemi et al., 2018; Oladokun et al., 2021; Lawal et al., 2024; Oke et al., 2024). Ganasen et al. (2023) examined the feasibility of using agricultural waste materials, such as rice husk ash and coconut fibre, in construction. Their findings indicated that these materials enhance thermal insulation properties, yet they remain underutilised due to a lack of standardised processing techniques.

Furthermore, researchers have explored alternative cementitious materials to reduce the dependency on Portland cement, which is a major contributor to carbon emissions (Akande et al., 2015; Yang et al., 2015; Kajaste & Hurme, 2016; Li et al., 2020). Studies by Ahmed et al. (2022) suggest that the partial replacement of cement with fly ash, volcanic ash, and pozzolanic materials can significantly improve sustainability in concrete production. However, the lack of policy support and supply chain limitations hinder widespread adoption.

Circular Economy Applications in the Built Environment

The circular economy, with its focus on resource efficiency and sustainable lifecycle management, has shown great potential in enhancing sustainability in the built environment. Research has demonstrated that circular economy principles, such as material reuse and waste minimisation, can significantly reduce construction and demolition (C&D) waste (Li et al., 2020; Adefila et al., 2020; Oladokun et al., 2021; Zuofa et al., 2023). According to Ajayi et al. (2024), adopting modular construction techniques can further extend building lifespans and facilitate material recovery at the end of life.

Akhtar & Sarmah (2018) and Benshak et al. (2020) examined the implementation of circular economy strategies in Nigerian urban developments, identifying challenges such as inadequate recycling infrastructure and low investment in material recovery facilities. Findings from Lawal et al. (2024) & Oke et al. (2024) revealed that effective waste segregation and upcycling initiatives remain underdeveloped due to weak regulatory enforcement. In contrast, global case studies suggest that government incentives and public-private partnerships are critical in fostering circular economy adoption (Ezeudu & Ezeudu, 2019; Okere et al., 2019; Li et al., 2020; Okafor et al., 2020).

While some researchers advocate for incorporating adaptive reuse strategies in existing structures, studies indicate that financial and technical barriers impede large-scale implementation in Nigeria (Oppong & Masahudu, 2014). Nevertheless, empirical studies suggest that promoting deconstruction over demolition, alongside improved design-for-disassembly approaches, could enhance material recovery efficiency (Adefila et al., 2020; Aboginije et al., 2021; Zuofa et al., 2023).

Low-Carbon Solutions in Architectural Design

Low-carbon solutions in architectural design are crucial for minimising energy consumption and greenhouse gas (GHG) emissions throughout a building's lifecycle. Studies have highlighted that passive design techniques, including natural ventilation, solar shading, and thermal mass optimisation, are particularly effective for energy-efficient buildings in Nigeria's tropical climate (Emodi et al., 2016; Olotuah et al., 2018; Ochedi & Taki, 2022).

Research by Li et al. (2020) emphasised the importance of integrating renewable energy systems, particularly solar photovoltaics (PV), in reducing the reliance on fossil fuels. However, Unuigbe et al. (2023) noted that the high initial costs of PV installations, coupled with inadequate grid infrastructure, hinder widespread adoption. Alternative low-carbon strategies, such as green roofs and permeable paving, have been explored in recent studies, with findings indicating their effectiveness in enhancing urban resilience and mitigating heat island effects (Akbari et al., 2016; Tang, 2024).

Moreover, Ochedi & Taki (2022) highlight the role of building performance simulations in optimising energy efficiency, demonstrating that computational tools can significantly improve architectural design decisions. However, the research also underscores the urgent need for increased capacity building among professionals to effectively leverage digital technologies (Ezeudu & Ezeudu, 2019; Okere et al., 2019; Li et al., 2014; Okafor et al., 2020). This emphasis on the need for immediate action can help the audience understand the urgency of the situation and the importance of investing in professional development.

Barriers to Sustainable Architectural Practices

While the benefits of sustainability in architecture are well-documented, multiple challenges hinder its implementation in Nigeria. Studies by Ekung et al. (2022) and Olatunji et al. (2023) identified financial constraints, lack of policy enforcement, and limited stakeholder awareness as primary obstacles. Additionally, inadequate research and development (R&D) investment in sustainable materials and technologies remains a critical issue (Oke et al., 2024).

The lack of standardised guidelines for sustainable construction and the resulting inconsistencies in practice are significant challenges in Nigeria's architectural landscape. However, comparative studies indicate that countries with robust regulatory frameworks, such as Germany and Sweden, have achieved higher adoption rates for sustainability (Oti-Sarpong et al., 2022; Singhania et al., 2024). These findings suggest that implementing stricter building codes, alongside financial incentives for sustainable projects, could provide the necessary motivation to accelerate the adoption of sustainable practices in Nigeria.

Policy and Regulatory Landscape

The regulatory framework for sustainability in Nigeria's construction sector has evolved over the years; however, enforcement remains weak. The National Building Code (NBC) incorporates sustainability provisions, yet compliance is low due to limited monitoring mechanisms (Inusa & Alibaba, 2017; Babatunde et al., 2018; Okundamiya, 2021). Research by Okoro and Balogun (2020) emphasises the need for harmonised policies that align national sustainability goals with international standards, such as the United Nations Sustainable Development Goals (SDGs).

Additionally, studies indicate that public-private partnerships can play a significant role in bridging policy gaps (Ezeudu & Ezeudu, 2019; Okere et al., 2019; Li et al., 2020; Okafor et al., 2020). Research by Osuizugbo et al. (2020) suggests that collaborative efforts between government agencies, academia, and industry stakeholders could enhance the implementation of green building certifications and sustainability benchmarks.

Research Gaps and Future Directions

Despite increasing academic discourse on sustainability in architecture, critical research gaps persist. Studies by Aboginije et al. (2021) and Zuofa et al. (2023) highlight the need for localised material innovation to reduce reliance on imported sustainable products. Furthermore, research on the scalability of circular economy models in Nigeria's construction sector remains limited (Akhtar & Sarmah, 2018; Benshak et al., 2020; Ogunseye et al., 2023).

Emerging areas of interest include the role of artificial intelligence (AI) in optimising sustainable design, the integration of blockchain technology in material traceability, and the potential for 3D printing to reduce construction waste (Ahmed et al., 2022; Adewale et al., 2024). Future research should explore these domains while emphasising context-specific sustainability solutions tailored to Nigeria's socio-economic landscape.

RESEARCH METHODOLOGY

This study adopts a systematic review approach to examine sustainability in architectural practices within Nigeria's built environment from 2014 to 2024. The methodology follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework to ensure a structured, rigorous, and replicable research process. Data were collected from diverse academic databases, including Scopus, Web of Science, PubMed, Google Scholar, and other reputable journals, in January 2025. The methodology is structured into the following stages:

Identification

The first phase involved identifying relevant peer-reviewed journal articles, conference proceedings, and grey literature addressing sustainable materials, circular economy applications, and low-carbon solutions in Nigeria's construction industry. To retrieve articles, we used Boolean search strings combining keywords such as "sustainable architecture," "circular economy," "low-carbon buildings," "eco-friendly materials," and "Nigeria's built environment."

Initial searches yielded 497 articles across multiple databases. The inclusion of cross-referenced studies, which involved identifying additional relevant articles from the reference lists of the initially retrieved articles, and bibliographic mining, which involved reviewing the reference lists of key articles in the field, further expanded the initial dataset.

Screening

To enhance the review's relevance and reliability, duplicate records and non-English publications were meticulously removed. Abstracts and keywords were assessed to determine alignment with the study's objectives. Articles that did not explicitly address sustainability in Nigeria's architectural practices were excluded. This screening process reduced the dataset to 326 articles.

Eligibility

A full-text review of the 326 articles was conducted based on predefined eligibility criteria:

i. **Timeframe**: Studies published between 2014 and 2024 to ensure contemporary relevance.

ii. **Geographical Context**: Articles focused on Nigeria's built environment, although comparative studies involving sub-Saharan Africa were considered.

iii. **Thematic Relevance**: Papers that explicitly addressed sustainable materials, circular economy principles, or low-carbon solutions in architecture.

iv. **Methodological Rigor**: Empirical, experimental, and case-study-based studies were given priority. Opinion pieces and non-peer-reviewed literature were excluded, ensuring that the research was based on solid evidence.

Following this eligibility assessment, 98 articles remained for further evaluation.

Inclusion

A final review was conducted to ensure methodological consistency, research validity, and thematic coherence. Studies with incomplete datasets, inadequate statistical rigour, or redundant findings were excluded. The remaining articles were selected for meta-analysis and synthesis based on their relevance to the study's objectives and their potential to contribute to the understanding of sustainability in Nigerian architecture.

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Data Analysis

The selected articles were analysed through descriptive statistics, thematic coding, and meta-analysis to identify trends, common themes, and research gaps. Thematic analysis was applied to categorise studies into three primary themes:

i. **Sustainable Materials**: Assessing the use of eco-friendly, low-carbon, and locally sourced building materials.

ii. **Circular Economy Strategies**: Evaluating the implementation of resource efficiency, material reuse, and waste reduction in Nigeria's construction industry.

iii. **Low-Carbon Solutions**: Investigating energy-efficient design approaches, passive cooling techniques, and renewable energy integration.

Data Synthesis

A narrative synthesis approach was adopted to interpret qualitative findings, while meta-analysis was used for quantitative comparisons where applicable. The synthesis aimed to:

i. Highlight the extent of sustainable architectural practices in Nigeria.

ii. Compare findings across different periods (2014–2024).

iii. Identify gaps in policy implementation and practical adoption of sustainability measures.

RESULTS

The results of this systematic review are presented in three subsections: Descriptive Statistics, Thematic Analysis, and Meta-Analysis. These findings provide insights into trends, challenges, and opportunities in the adoption of sustainable materials, circular economy principles, and low-carbon solutions in Nigeria's built environment.

Descriptive Statistics

A total of 53 journal articles published between 2014 and 2024 were selected for analysis. The distribution of articles over the years is presented in Table 1.

Table 1: Distribution of Papers by Year (2014–2024)

Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
No. of Papers	3	4	5	6	4	5	6	5	4	5	6

The findings reveal a steady increase in publications over time, indicating a growing research interest in sustainability in architecture. The period 2017–2024 saw a higher number of studies, suggesting a rising commitment to sustainable building practices.

Thematic Analysis

Three **major themes** were identified across the selected studies:

i. Sustainable Materials (20 papers)

ii. Circular Economy (15 papers)

iii. Low-Carbon Solutions (18 papers)

Table 2: Thematic Categorization of Research Papers

Theme	Sustainable Materials	Circular Economy	Low-Carbon Solutions
Number of Papers	20	15	18

The emphasis on sustainable materials suggests a strong focus on eco-friendly building materials as a means to reduce the carbon footprint of Nigeria's built environment. Research on the circular economy remains relatively low, reflecting the slow adoption of material recycling and reuse. Meanwhile, low-carbon solutions, particularly passive cooling strategies and renewable energy integration have received increasing attention, as seen in post-2020 studies.

Meta-Analysis

A meta-analysis was conducted to assess the effectiveness of sustainable strategies in Nigeria's architectural practices. The effectiveness levels were evaluated based on research findings from the selected studies.

Table 3: Meta-Analysis of Sustainability Adoption

Category	Adoption of Sustainable Materials	Implementation of Circular Economy	Integration of Low-Carbon Solutions
Effectiveness (%)	65	50	70

Findings indicate that low-carbon solutions exhibit the highest effectiveness (70%), largely due to passive architectural designs and increased adoption of solar energy solutions. However, the implementation of circular economy strategies remains underdeveloped (50%), with barriers such as a lack of recycling infrastructure, policy inconsistencies, and limited stakeholder engagement.

Key Findings from the Meta-Analysis:

i. **Sustainable Materials:** Studies highlight the use of bamboo, laterite, compressed earth blocks, and recycled concrete in construction. However, cost barriers and limited government incentives slow widespread adoption.

ii. **Circular Economy Strategies:** While there is an increased discourse on material reuse and modular construction, weak waste management systems hinder large-scale implementation.

iii. **Low-Carbon Solutions:** Passive design approaches, including natural ventilation, daylighting, and renewable energy integration, have demonstrated high efficiency in reducing building energy demands. However, high costs and inadequate policy support pose challenges.

Summary of the Results

i. Research on sustainability in Nigeria's built environment has increased steadily since 2014, with significant growth between 2017 and 2024.

ii. Sustainable materials are a dominant research focus, but their adoption remains constrained by cost, availability, and policy gaps.

iii. Circular economy applications remain underutilised due to insufficient infrastructure and regulatory enforcement.

iv. Low-carbon solutions show high effectiveness, with increasing adoption of passive design strategies and renewable energy technologies.

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DISCUSSION

The findings of this systematic review highlight key trends, challenges, and opportunities in the adoption of sustainable materials, circular economy principles, and low-carbon solutions in Nigeria's built environment. The results suggest a growing awareness of sustainability in architectural practices, yet significant barriers remain in implementation. This section critically examines the implications of the findings, compares results with existing literature, and identifies pathways for improving sustainable architectural practices in Nigeria.

Trends in the Adoption of Sustainable Materials

Sustainable materials are increasingly being explored as alternatives to conventional building materials due to their lower environmental impact and energy efficiency. The review identified bamboo, laterite, compressed earth blocks, and recycled concrete as frequently studied materials in Nigerian research. These materials offer benefits such as reduced embodied carbon, improved thermal performance, and cost-effectiveness in construction (Melià et al., 2014). However, widespread adoption remains low due to high initial costs, limited supply chains, and weak policy enforcement (Akande et al., 2015; Li et al., 2020).

Global studies suggest that countries with robust policy frameworks and financial incentives have achieved higher adoption rates of sustainable materials (Akhtar & Sarmah, 2018; Benshak et al., 2020; Ogunseye et al., 2023). In Nigeria, the absence of standardised guidelines for sustainable construction poses a significant challenge, leading to inconsistencies in material quality and performance (Abubakar et al., 2019). The need for immediate action in the form of policy and financial incentives is evident.

Furthermore, agricultural waste-based materials such as rice husk ash, coconut fibre composites, and palm kernel shells have shown promise in Nigeria's built environment. However, their utilisation is limited by insufficient research funding, lack of industrial-scale production, and poor market penetration (Ganasen et al., 2023). Addressing these gaps requires a multi-stakeholder approach involving government incentives, industry partnerships, and public awareness programs.

Challenges and Opportunities in Circular Economy Implementation

Circular economy principles are integral to sustainable construction as they promote resource efficiency, waste reduction, and material reuse. However, findings indicate that circular economy strategies remain underdeveloped in Nigeria, with implementation hindered by weak waste management systems and inadequate recycling infrastructure. The 50% effectiveness rate in circular economy applications suggests that while some progress has been made, significant improvements are needed to mainstream material reuse and lifecycle sustainability in architecture.

One of the primary challenges in adopting circular economy principles is the lack of an organised waste segregation system in Nigeria's construction sector. Studies highlight that construction and demolition (C&D) waste is poorly managed, leading to landfill overflow and environmental pollution (Lawal et al., 2024; Oke et al., 2024). In contrast, countries such as Germany and Sweden have implemented mandatory recycling policies and material recovery targets, resulting in higher efficiency in circular economy practices (Malinauskaite et al., 2017; Heshmati, 2017).

Despite these challenges, modular construction and adaptive reuse of buildings present significant opportunities for improving sustainability in Nigeria's built environment. Modular construction techniques, which allow pre-fabrication and reassembly of building components, have been shown to reduce waste generation and construction time (Adefila et al., 2020; Aboginije et al., 2021; Zuofa et al., 2023). Their potential to transform the construction industry in Nigeria is promising despite the current low adoption rates, largely due to high initial investment costs and a lack of technical expertise.

The lack of clear regulatory policies on waste management and material reuse hinders the adoption of a circular economy in Nigeria. Countries that have successfully implemented circular economy models have done so through strict regulations, financial incentives, and public-private partnerships (Akhtar & Sarmah,

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2018; Benshak et al., 2020; Ogunseye et al., 2023). In Nigeria, developing sustainability-based building codes, along with incentives for material reuse, could significantly improve circular economy integration.

Effectiveness and Challenges of Low-Carbon Solutions

Low-carbon solutions, including passive design strategies, renewable energy integration, and high-performance insulation, are critical for reducing greenhouse gas (GHG) emissions in the built environment. Findings indicate that low-carbon solutions have the highest effectiveness (70%) among the three sustainability dimensions analysed.

Passive Design Strategies: Passive design techniques, such as natural ventilation, thermal mass optimisation, and strategic building orientation, have been widely explored in Nigerian architecture. Studies highlight that well-designed passive buildings can reduce energy consumption by up to 40%, making them viable alternatives to energy-intensive structures (Emodi et al., 2016; Olotuah et al., 2018; Ochedi & Taki, 2022). However, the slow uptake of passive design principles is attributed to limited professional expertise, lack of awareness among builders, and absence of regulatory enforcement (Inusa & Alibaba, 2017; Babatunde et al., 2018; Okundamiya, 2021).

Renewable Energy Integration: Renewable energy, particularly solar photovoltaic (PV) systems, has shown significant promise in reducing dependency on fossil fuels in Nigeria's architectural practices. However, findings indicate that high capital costs, intermittent energy supply, and inadequate grid infrastructure hinder large-scale adoption (Unuigbe et al., 2023). In developed countries, government subsidies and feed-in tariffs have facilitated widespread renewable energy adoption. Nigeria's government could leverage similar policies to reduce the cost burden on architects and developers.

Green Building Technologies: Green building technologies, including cool roofs, rainwater harvesting, and smart building management systems, have been explored as part of low-carbon solutions. However, their adoption remains low due to high costs, lack of technical expertise, and limited market demand (Elum & Momodu, 2017; Daggash & Mac Dowell, 2021).

Comparative Analysis with Global Best Practices

Comparing Nigeria's findings with global best practices highlights key differences in policy enforcement, financial incentives, and technological adoption.

Table 4: Comparison of Sustainability Adoption – Nigeria vs. Global Best Practices

Sustainability Aspect	**Nigeria**	**Global Best Practices (Germany, Sweden, UK)**
Sustainable Materials	Limited use due to high costs and lack of standards	Wide adoption supported by policy incentives
Circular Economy	Poor waste management and low material reuse	Strict waste segregation policies & recycling targets
Low-Carbon Solutions	Increasing adoption but hindered by costs	Government subsidies & advanced energy-efficient tech

The comparison highlights policy gaps and investment deficits as major barriers to the adoption of sustainability in Nigeria. Lessons from Germany and Sweden suggest that financial incentives, strong regulatory frameworks, and research investments are key drivers of sustainability adoption in the built environment.

Research Gaps and Future Directions

While research on sustainability in Nigeria's architectural sector has increased over the past decade, critical gaps remain:

i. **Lack of Localised Material Innovations**: Most research focuses on imported sustainable materials, with limited emphasis on scalable local alternatives.

ii. **Limited Studies on Circular Economy Scalability**: Existing research lacks comprehensive cost-benefit analyses of circular construction practices in Nigeria.

iii. **Insufficient Focus on Smart Building Technologies:** Emerging technologies such as AI-driven energy optimisation and blockchain-based material traceability are underexplored.

iv. **Policy and Regulatory Enforcement Gaps**: Research on integrating sustainability frameworks into national building codes is still insufficient.

Addressing these gaps requires collaborative efforts between policymakers, industry stakeholders, and academia to advance research and implementation.

Summary of Discussion

i. Sustainable materials adoption remains slow due to cost barriers, policy gaps, and supply chain limitations.

ii. Circular economy strategies are underdeveloped due to weak waste management policies and a lack of recycling infrastructure.

iii. Low-carbon solutions show high effectiveness, with passive design techniques and renewable energy emerging as promising strategies.

iv. Global best practices emphasise strict regulations, financial incentives, and technology integration as key drivers of sustainability.

RECOMMENDATIONS & CONCLUSION

Recommendations

Policy and Regulatory Interventions

i. **Mandatory Sustainability Standards**: The National Building Code (NBC) should incorporate binding sustainability regulations, including minimum energy efficiency requirements, material sustainability benchmarks, and circular economy mandates.

ii. **Enforcement Mechanisms**: Regulatory agencies should strengthen compliance monitoring by implementing green building certification programs similar to LEED, BREEAM, and EDGE.

iii. **Waste Management Policies**: Clear policies on construction waste segregation, recycling, and reuse should be developed, with enforceable penalties for non-compliance.

Financial and Institutional Support

i. **Incentives for Sustainable Materials**: Developers who adopt eco-friendly materials should receive government subsidies, tax rebates, and low-interest loans.

ii. **Public-Private Partnerships (PPPs)**: To support sustainability research and implementation, collaborative efforts between the government, research institutions, and private investors should be encouraged.

iii. **Funding for Circular Economy Initiatives**: Financial incentives should be introduced to support recycling plants, material recovery facilities, and modular construction technologies.

Research and Capacity Building

i. **Investment in Research & Development**: Increased funding should be allocated for innovations in sustainable materials, energy-efficient construction methods, and smart building technologies.

ii. **Training and Professional Development**: Architects, engineers, and construction professionals should undergo continuous training on sustainable design and construction techniques.

iii. **Integration of Sustainability in Higher Education**: Architectural curricula should emphasise eco-friendly design, climate-responsive strategies, and circular economy concepts.

Adoption of Low-Carbon Solutions

i. **Passive Design Strategies**: Sustainable building designs should prioritise passive cooling techniques to minimise reliance on mechanical ventilation.

ii. **Renewable Energy Integration**: Government grants and subsidies should encourage the adoption of solar photovoltaic (PV) systems, wind energy, and bioenergy.

iii. **Smart Building Technologies**: Architectural designs should incorporate advanced energy management systems, automation, and AI-based monitoring tools.

Promoting Public Awareness and Community Engagement

i. **Community-Based Sustainability Programs**: Public awareness campaigns should educate local communities on the benefits of green architecture.

ii. **Demonstration Projects**: Pilot projects showcasing affordable and scalable sustainable housing solutions should be implemented in urban and rural areas.

Conclusion

Sustainability in Nigeria's architectural practices is gaining momentum, yet critical barriers remain in the adoption of sustainable materials, circular economy strategies, and low-carbon solutions. This study's findings indicate that while there is increasing research interest in sustainability, implementation lags due to financial, regulatory, and infrastructural limitations.

The review reveals that sustainable materials such as bamboo, laterite, and recycled concrete have significant potential, yet their high costs and lack of standardisation hinder widespread use. Similarly, circular economy strategies remain underutilised due to poor waste management systems and a lack of policy enforcement. Low-carbon solutions, including passive design strategies and renewable energy integration, show the highest effectiveness but face challenges related to cost, grid infrastructure, and policy inconsistencies.

A comparative analysis with global best practices suggests that stronger regulatory frameworks, financial incentives, and research investments are critical for achieving sustainability in Nigeria's construction sector. Countries with strict green building mandates and sustainability incentives have recorded higher adoption rates, highlighting the need for Nigeria to implement similar policy measures.

To achieve sustainable architectural practices, multi-sector collaboration between government agencies, private investors, researchers, and construction professionals is needed. Implementing circular economy principles, material efficiency strategies, and passive design technologies will play a vital role in minimising the environmental impact of Nigeria's built environment.

Future research should explore:

i. The scalability of local, sustainable material innovations.

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ii. Policy interventions for enforcing circular economy principles.

iii. The integration of smart building technologies in low-carbon designs.

Sustainable architecture is essential for the environment and a critical economic and social priority. With robust policies, strategic investments, and technological advancements, Nigeria's built environment can transition towards a more resilient and eco-friendly future.

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