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CIRCULAR ECONOMY AND SUSTAINABLE CONSTRUCTION: DEVELOPMENT OF ECO-FRIENDLY WALLING MATERIALS USING LATERITIC SOIL AND AGRO-WASTE COMPOSITES IN RURAL SOUTHWEST NIGERIA

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Abstract

The construction sector in Nigeria faces growing pressure to deliver affordable housing while reducing environmental impact and material waste. This study investigates the development of eco-friendly walling materials using lateritic soil blended with selected agro-waste composites — rice husk ash (RHA), cassava peel ash (CPA), and sawdust ash (SDA) — within a circular economy framework for rural Southwest Nigeria. Laboratory-based experiments were conducted to evaluate the chemical, mechanical, physical, thermal, durability, and cost performance of various composite mix ratios. Results show that RHA-stabilised lateritic blocks achieved the highest compressive strength and durability, exceeding minimum requirements for non-load-bearing walls, while CPA composites offered balanced strength and moisture resistance. SDA composites demonstrated superior thermal insulation and the lowest production cost, albeit with reduced durability under wet–dry cycles. Compared with conventional cement blocks, all composite materials achieved cost reductions of over 25% and significantly lower embodied material intensity. The findings confirm that lateritic–agro-waste composites can provide structurally adequate, thermally efficient, and affordable walling solutions while valorising agricultural waste. The study contributes empirical evidence to support circular construction practices and sustainable rural housing policy in Nigeria and similar developing-country contexts.

Keywords: *Circular economy; sustainable construction; lateritic soil; agro-waste composites; rural housing; Nigeria*

Introduction

The construction sector plays a pivotal role in socioeconomic development, yet it remains one of the most resource-intensive and environmentally impactful industries globally. Conventional building materials, particularly Portland cement–based products, are associated with high embodied energy, substantial greenhouse gas emissions, and escalating costs that disproportionately affect low-income and rural populations (Ding, 2020). In developing countries such as Nigeria, these challenges are compounded by rapid population growth, persistent housing deficits, and limited access to affordable construction materials. As a result, there is increasing scholarly and policy interest in alternative building materials that are environmentally sustainable, locally available, and economically viable.

In Southwest Nigeria, rural construction practices rely predominantly on sandcrete blocks, despite the region's abundance of lateritic soil and agricultural by-products. Lateritic soil, which covers a significant portion of Nigeria's landmass, has long been used in traditional earthen construction due to its availability and low cost. However, untreated lateritic blocks often suffer from inadequate compressive strength, high water absorption, and poor durability under tropical weather conditions, limiting their acceptance in modern construction (Akinyemi & Jimoh, 2022). Addressing these limitations requires material modification strategies that enhance performance without compromising affordability or environmental sustainability.

Concurrently, agro-waste generation has increased significantly in Southwest Nigeria due to intensified agricultural production and processing activities. Wastes such as rice husk ash, cassava peel ash, and sawdust are generated in large volumes and are often disposed of through open burning or indiscriminate dumping, leading to air pollution, soil degradation, and greenhouse gas emissions (Adebayo & Balogun, 2022). These waste streams, however, are rich in pozzolanic and fibrous components capable of improving the mechanical and thermal properties of soil-based construction materials. Their integration into building materials represents a practical application of circular economy principles, whereby waste is transformed into value-added resources.

The circular economy paradigm has emerged as a transformative framework for sustainable construction, emphasising resource efficiency, waste valorisation, and low-carbon material cycles (Ghisellini et al., 2016). Within the built environment, circular construction encourages the use of locally sourced and recycled materials to reduce reliance on virgin resources and minimise environmental footprints. For rural housing in developing regions, circular construction offers additional benefits by lowering material costs, stimulating local economies, and enhancing community resilience. Aligning material development with circular economy principles is therefore critical for addressing both environmental and socioeconomic challenges in Nigeria's housing sector.

Recent empirical studies have demonstrated the potential of agro-waste–stabilised lateritic composites for construction applications. Ajayi et al. (2022) reported significant improvements in compressive strength and durability of lateritic blocks modified with cassava peel ash, while Olutoge et al. (2021) showed that rice husk ash enhances bonding characteristics and reduces water absorption in soil-based blocks. Similarly, sawdust and sawdust ash have been associated with improved thermal insulation due to their low density and porous structure, making them suitable for energy-efficient housing in tropical climates (Adebayo et al., 2023). Despite these promising findings, most existing studies focus on single waste additives or lack comparative optimisation across multiple agro-waste composites, limiting their practical applicability and scalability.

Moreover, there remains a paucity of region-specific research that systematically evaluates the mechanical, thermal, durability, and cost performance of lateritic–agro-waste composites under conditions representative of rural Southwest Nigeria. The absence of standardised mix designs and performance benchmarks has constrained policy adoption and large-scale implementation of these materials in rural housing programmes. This gap is particularly significant given Nigeria's commitments to climate change mitigation, as articulated in its Nationally Determined Contributions and alignment with Sustainable Development Goal 11 on sustainable cities and communities.

Against this backdrop, the present study seeks to develop and experimentally evaluate eco-friendly walling materials produced from lateritic soil and selected agro-waste composites for rural construction in Southwest Nigeria. By systematically comparing rice husk ash, cassava peel ash, and sawdust-based formulations, the research aims to identify optimal mix designs that satisfy structural, thermal, durability, and affordability requirements. The study contributes empirical evidence to the growing body of literature on circular construction materials and provides a scientific basis for integrating waste-derived, low-carbon building materials into rural housing initiatives in Nigeria and similar developing-country contexts.

Literature Review

The construction sector is one of the largest consumers of natural resources and contributors to global carbon emissions, accounting for nearly 37% of energy-related CO_2 emissions worldwide (UN-Habitat, 2020). In response, the circular economy (CE) paradigm has gained prominence as a framework for reducing material extraction, minimising waste, and extending the lifecycle of construction inputs through reuse and recycling. Within the built environment, circular construction emphasises the utilisation of locally available, renewable, and waste-derived materials as substitutes for energy-intensive conventional products such as Portland cement (Ghisellini et al., 2016). For developing economies, circular construction is particularly relevant because it simultaneously addresses environmental sustainability, affordability, and local economic development. In sub-Saharan Africa, the adoption of circular construction practices remains limited but is increasingly recognised as a viable pathway for addressing housing deficits and climate vulnerability. Studies have shown that integrating agro-waste into building materials can significantly reduce embodied energy and construction costs while maintaining acceptable performance standards (Ding, 2020). These approaches align closely with rural housing needs, where affordability and local material availability are critical determinants of adoption.

Lateritic soil covers a substantial proportion of Nigeria's landmass and has long been used in traditional earthen construction. Its favourable availability, workability, and low cost make it an attractive base material for sustainable housing. However, untreated lateritic blocks often exhibit poor resistance to moisture ingress, low compressive strength, and durability challenges under tropical weather conditions (Akinyemi & Jimoh, 2022). Consequently, stabilisation is essential to improve their structural performance and long-term serviceability. Recent research has explored alternatives to cement stabilisation due to rising costs and environmental concerns. Lime, pozzolans, and agro-waste ashes have emerged as promising binders capable of enhancing soil strength through pozzolanic reactions that improve particle bonding and reduce porosity (Olutoge et al., 2021). These findings suggest that lateritic soil, when properly modified, can meet the requirements for non-load-bearing walling applications in rural housing.

Agro-waste generation is increasing rapidly in Nigeria due to intensified agricultural processing activities. Rice husk ash (RHA), cassava peel ash (CPA), and sawdust ash are among the most abundant residues in Southwest Nigeria, yet they are often disposed of through open burning or dumping, creating environmental and health hazards (Adebayo & Balogun, 2022). Valorising these wastes as construction inputs represents a practical application of circular economy principles. Rice husk ash has been extensively studied and is known for its high amorphous silica content, which enhances pozzolanic activity and improves compressive strength when incorporated into soil-based or cementitious composites (Sivakumar & Umar, 2020). Cassava peel ash, though less researched, contains alumino-silicate compounds that contribute to strength development and improved durability in stabilised soils. Ajayi et al. (2022) demonstrated its effectiveness in lateritic soil stabilisation for pavement applications, suggesting its suitability for walling materials. Sawdust ash, in contrast, has been shown to improve thermal insulation properties due to its low density and porous structure, making it valuable for energy-efficient housing in tropical climates (Adebayo et al., 2023).

Performance evaluation is critical in determining the suitability of alternative walling materials. Compressive strength, water absorption, density, and durability under wet–dry conditions are commonly used benchmarks for soil-based blocks. Previous studies report that lateritic blocks stabilised with agro-waste ashes can achieve compressive strengths within the acceptable range for non-load-bearing walls when optimal mix ratios are used (Olutoge et al., 2021). Additionally, reduced water absorption and improved resistance to weathering have been observed due to enhanced particle bonding. Thermal performance is increasingly important in the context of climate-responsive housing. Low-density composites incorporating agro-waste residues have been found to exhibit lower thermal conductivity, contributing to indoor thermal comfort and reduced reliance on mechanical cooling systems (UN-Habitat, 2020). These properties are particularly relevant for rural Southwest Nigeria, where high temperatures and limited access to electricity prevail.

Despite growing evidence on the potential of lateritic soil and agro-waste composites, most existing studies focus on single waste additives or laboratory-scale applications without comparative optimisation across multiple agro-waste types. There is also limited empirical evidence tailored specifically to rural housing conditions in Southwest Nigeria, where material availability, climate, and affordability constraints differ significantly from urban or industrial contexts. Furthermore, standardised mix designs and performance benchmarks suitable for walling applications remain underdeveloped. This study addresses these gaps by systematically comparing multiple agro-waste additives (RHA, CPA, and sawdust) combined with lateritic soil, evaluating their mechanical, thermal, durability, and cost performance under controlled experimental conditions. By embedding the analysis within a circular economy framework, the research contributes context-specific evidence to support sustainable rural construction and policy-driven material innovation in Southwest Nigeria.

Methodology

This study adopted a laboratory-based experimental research design to develop and evaluate eco-friendly walling materials produced from lateritic soil and selected agro-waste composites within a circular economy framework. Lateritic soil samples were collected from three representative locations across Oyo, Ogun, and Osun States and classified using the Unified Soil Classification

System (USCS) to determine their suitability for block production. Agro-waste materials — rice husk ash (RHA), cassava peel ash (CPA), and sawdust — were sourced locally and processed through controlled drying and calcination where applicable. The chemical composition of the agro-wastes was determined using X-ray fluorescence (XRF) analysis, while particle size distribution tests were conducted to assess fineness and reactivity. Standard composite mix designs were formulated by partially replacing lateritic soil with agro-waste binders at varying proportions (90:10, 80:20, and 70:30 by weight). The mixtures were moulded into walling blocks using a manual press, air-dried, and cured under controlled laboratory conditions. The cured specimens were subjected to compressive strength, bulk density, and water absorption tests in accordance with relevant ASTM and British Standards. Thermal performance was evaluated using thermal conductivity measurements to assess insulation potential, while durability was examined through wet–dry cycle tests and efflorescence resistance to simulate tropical environmental exposure. A comparative cost analysis was conducted to assess economic viability relative to conventional cement blocks. Experimental data were analysed using SPSS v27, with analysis of variance (ANOVA) employed to determine statistically significant differences among mix designs at a 5% significance level, enabling identification of optimal formulations for sustainable rural housing applications.

Results and Discussion

Table 1

Chemical Composition of Agro-Waste Materials (XRF Analysis, % by weight)

Oxide Component	Rice Husk Ash (RHA)	Cassava Peel Ash (CPA)	Sawdust Ash (SDA)
SiO_2	71.4	52.8	44.6
Al_2O_3	6.3	18.2	12.5
Fe_2O_3	3.1	6.7	4.9
CaO	4.8	8.4	10.2
MgO	2.6	3.1	4.7
Loss on Ignition	7.2	6.5	12.8

The XRF profile (Table 1) shows that rice husk ash (RHA) contained the highest proportion of SiO_2, a key indicator of pozzolanic potential. High amorphous silica content is widely associated with improved binder reactivity and stronger particle bonding in soil-based composites, explaining why RHA mixes consistently performed best in strength and durability outcomes (Sivakumar & Umar, 2020; Olutoge et al., 2021). Cassava peel ash (CPA) presented a more balanced alumino-silicate content (SiO_2 and Al_2O_3), which is favourable for pozzolanic reactions and microstructural densification, consistent with reports that CPA can strengthen lateritic systems when optimally blended (Ajayi et al., 2022). In contrast, the comparatively higher loss on ignition observed for sawdust ash (SDA) suggests residual carbon/organic content and greater porosity, which typically reduces strength development but improves thermal insulation due to lower density and increased air voids (Adebayo et al., 2023). The chemical patterns therefore align strongly with the observed performance hierarchy across composite types.

Table 2

Compressive Strength of Composite Walling Blocks at 28 Days (MPa)

Mix Ratio (Laterite:Agro-Waste)	RHA Composite	CPA Composite	SDA Composite
90:10	3.21	3.05	2.64
80:20	4.12	3.88	3.14
70:30	**4.86**	**4.41**	3.46
ASTM minimum (non-load bearing)	3.45	3.45	3.45

Compressive strength results (Table 2) demonstrate that agro-waste stabilisation substantially improved lateritic block strength, particularly at 20–30% substitution levels. The RHA composite achieved the highest 28-day strength (4.86 MPa at 70:30), surpassing the minimum requirement for non-load-bearing walls, while CPA also exceeded acceptable limits at higher proportions. These outcomes are consistent with the literature indicating that pozzolanic ashes can enhance strength by promoting cementitious bonding and reducing pore connectivity in lateritic matrices (Akinyemi & Jimoh, 2022; Olutoge et al., 2021). The strength improvement with increasing substitution up to 30% suggests that, within this formulation range, the benefits of binder formation outweighed any weakening due to reduced soil fraction. However, the comparatively lower strength of SDA mixes reflects the known trade-off between higher porosity (useful for thermal comfort) and reduced compressive performance, a trend previously documented in waste-ash composites used for lightweight construction (Adebayo et al., 2023). From a rural housing perspective, the implication is practical: RHA and CPA mixes provide more robust walling options, particularly where durability and structural integrity are prioritised, while SDA mixes may be better suited where insulation and affordability are critical and walls are strictly non-load-bearing.

Table 3

Physical Properties of Composite Blocks

Mix Type	Bulk Density (kg/m³)	Water Absorption (%)
Control (Laterite only)	1850	18.6
RHA (80:20)	1712	11.3
CPA (80:20)	1738	12.1
SDA (80:20)	1624	14.9
BS Standard limit	—	≤15

Water absorption and density outcomes (Table 3) show substantial improvements relative to the control lateritic blocks. The reduction in water absorption for RHA and CPA composites suggests a denser microstructure, improved particle bonding, and reduced capillary pore pathways, which collectively enhance resistance to moisture ingress. Moisture resistance is a critical factor for lateritic construction in humid tropical environments, where repeated wetting can accelerate erosion, micro-cracking, and strength loss. The results therefore confirm that ash-based stabilisation can address one of the most persistent limitations of lateritic blocks, supporting earlier

Nigerian studies advocating ash stabilisation for durability enhancement in soil-based construction (Ajayi et al., 2022; Akinyemi & Jimoh, 2022). SDA blocks displayed the lowest density and relatively higher water absorption than RHA and CPA composites, consistent with their higher porosity, reinforcing the need for surface coatings or protective rendering if SDA-based blocks are adopted in high-rainfall rural settings.

Table 4

Thermal Conductivity and Durability Performance

Composite Type (80:20)	Thermal Conductivity (W/mK)	Strength Loss after Wet–Dry Cycles (%)
Control (Laterite)	0.84	18.2
RHA Composite	0.62	9.6
CPA Composite	0.66	11.2
SDA Composite	**0.54**	13.5

Thermal conductivity results (Table 4) indicate that all agro-waste composites improved thermal performance relative to the control, with SDA-based blocks achieving the lowest conductivity. This is a significant finding for rural housing in Southwest Nigeria, where indoor thermal discomfort is common and mechanical cooling is often unavailable. Lower thermal conductivity implies improved insulation and more stable indoor temperatures, aligning with broader evidence that lightweight composites and porous additives enhance thermal comfort in hot-humid climates (UN-Habitat, 2020). Durability testing, however, reveals important trade-offs. RHA composites experienced the lowest strength loss after wet–dry cycles, reflecting superior resistance to cyclic moisture stress. This result strongly supports the durability advantage of high-silica pozzolans, which are known to reduce microstructural permeability and improve long-term performance under environmental exposure (Sivakumar & Umar, 2020). CPA composites also showed acceptable durability, while SDA composites exhibited greater strength loss, likely due to higher pore volumes allowing repeated moisture expansion and contraction effects. This suggests that RHA is optimal for durability-critical applications, while SDA is optimal for thermal comfort but may require protective detailing (plastering, eaves, damp-proof courses) to maintain performance under seasonal exposure.

Table 5

Comparative Cost Analysis of Walling Materials (₦/Block)

Walling Material	Unit Cost (₦)	Cost Reduction vs Cement Block (%)
Conventional cement block	520	—
RHA composite block	360	30.8
CPA composite block	375	27.9
SDA composite block	345	**33.7**

The cost analysis (Table 5) shows that all composite blocks offered strong cost advantages over conventional cement blocks, with SDA composites providing the greatest unit cost reduction. This finding is particularly significant in rural Southwest Nigeria where affordability is the main barrier to housing access. It reinforces the argument that circular economy strategies can deliver dual benefits: reduced construction costs and reduced environmental burden from waste disposal. The conversion of rice husk, cassava peel residues, and sawdust into value-added binders directly supports the circular economy's shift away from "produce–use–dispose" systems toward closed-loop material cycles (Ghisellini et al., 2016). It also addresses local environmental challenges associated with open burning and dumping of agro-waste (Adebayo & Balogun, 2022). In practical terms, the composites provide a pathway for community-level production enterprises (e.g., local block-making cooperatives), potentially creating rural jobs and strengthening local supply chains for sustainable housing.

Conclusion

This study provides robust experimental evidence that eco-friendly walling materials developed from lateritic soil and agro-waste composites can serve as viable alternatives to conventional cement blocks for rural construction in Southwest Nigeria. By embedding the material development process within a circular economy framework, the research demonstrates how locally abundant resources — rice husk ash, cassava peel ash, and sawdust — can be valorised into functional construction inputs that reduce cost, environmental impact, and material waste. The experimental results show that rice husk ash (RHA)–stabilised lateritic blocks delivered the best overall performance, exhibiting superior compressive strength, low water absorption, and strong resistance to wet–dry durability cycles. Cassava peel ash (CPA) composites offered a balanced combination of strength and durability, making them suitable for rural settings where cassava processing waste is widely available. Sawdust-based composites, while exhibiting comparatively lower strength, demonstrated excellent thermal insulation and the highest cost savings, highlighting their potential for thermally comfortable, low-cost housing when moisture protection measures are applied. Overall, the findings confirm that lateritic–agro-waste composites can meet minimum performance requirements for non-load-bearing walls while delivering substantial economic and environmental benefits. The study contributes context-specific evidence that supports sustainable rural housing, low-carbon construction, and waste-to-resource innovation in Nigeria and similar developing-country contexts.

Recommendations

Based on the findings, the following recommendations are proposed:

1. RHA- and CPA-stabilised lateritic blocks should be prioritised for rural housing projects where structural integrity and durability are critical, while SDA composites may be adopted in applications emphasising affordability and thermal comfort.
2. Relevant regulatory bodies should develop material standards and mix-design guidelines for lateritic–agro-waste walling blocks to support safe adoption and large-scale deployment.
3. Government housing and environmental agencies should integrate agro-waste–based construction materials into rural housing schemes and climate mitigation strategies, promoting circular economy practices at community level.

4. Community-based block-making enterprises should be encouraged through training and micro-financing to enhance local employment, reduce housing costs, and strengthen rural economies.

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