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Article

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BIO-BASED BUILDING MATERIALS AS ENABLERS OF CIRCULAR ECONOMY IN THE CONSTRUCTION SECTOR

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Abstract

Bio-based building materials are acclaimed to be vital for transitioning the construction industry to a circular economy. This study examined bio-based building materials as enablers of circular economy practices in the construction sector, with particular reference to their environmental, economic, and social implications. It investigated how materials such as timber, bamboo, hempcrete, straw bale, agricultural residues, and mycelium-based composites contributed to resource efficiency, waste reduction, and carbon sequestration in the built environment. The study found that bio-based materials significantly reduced embodied carbon, promoted renewable resource use, and supported circular material flows through reuse, recycling, and biodegradability. It further revealed that despite their benefits, adoption was constrained by weak regulatory frameworks, limited technical capacity, high initial costs, and low awareness among construction stakeholders. The study also identified significant opportunities for developing countries, particularly Nigeria, where abundant biomass resources could support sustainable construction and green economic growth. It concluded that integrating bio-based materials into construction practices could enhance sustainability and climate resilience while supporting circular economy transitions in the sector.

Keywords: Bio-based Materials, Carbon Sequestration, Circular Economy, Green Building, Sustainable Construction, Nigeria.

Introduction

The construction sector is widely recognized as one of the most resource-intensive industries globally, accounting for substantial consumption of raw materials, energy use, and waste generation. It is estimated that the sector contributes significantly to global carbon

emissions, largely due to the production of conventional building materials such as cement, steel, and concrete, which are energy-intensive and environmentally burdensome (Intergovernmental Panel on Climate Change [IPCC], 2022). In addition, construction and demolition activities generate large volumes of waste, much of which ends up in landfills, thereby exacerbating environmental degradation and resource depletion (United Nations Environment Programme [UNEP], 2023). In response to these challenges, the concept of sustainable construction has gained global attention, emphasizing the need to reduce environmental impacts while improving resource efficiency and promoting long-term ecological balance. Within this context, the circular economy has emerged as a transformative model that shifts away from the traditional linear “take–make–dispose” approach toward a regenerative system that prioritizes resource efficiency, reuse, recycling, and material recovery throughout the lifecycle of built assets (Ellen MacArthur Foundation, 2019).

A key enabler of this transition is the adoption of bio-based building materials. These materials are derived from renewable biological resources such as timber, bamboo, hemp, agricultural residues, and mycelium-based composites. Unlike conventional construction materials, bio-based alternatives have the potential to reduce embodied carbon, store atmospheric carbon, and enhance the renewability of construction inputs (Pomponi & Moncaster, 2017). Furthermore, many bio-based materials are biodegradable or recyclable, making them highly compatible with circular economy principles. Bio-based materials also contribute to improved indoor environmental quality, reduced energy consumption, and the development of locally sourced construction systems, particularly in developing countries where agricultural by-products are abundant. For instance, residues such as rice husks, palm fibres, and sugarcane bagasse can be transformed into valuable construction products, thereby reducing waste while creating economic opportunities (World Green Building Council, 2019). Despite these advantages, their adoption remains limited due to barriers such as lack of awareness, weak regulatory frameworks, durability concerns, and limited industrial scalability. Nevertheless, increasing global emphasis on climate change mitigation and sustainable development has intensified interest in integrating bio-based materials into mainstream construction practices. This study therefore explores bio-based building materials as enablers of circular economy practices in the construction sector, highlighting their role in reducing environmental impact, promoting resource efficiency, and supporting sustainable development transitions.

Conceptual Review

The conceptual framework of this study is grounded in two interrelated sustainability concepts: bio-based building materials and the circular economy. These concepts provide the theoretical basis for understanding how the construction sector can transition toward more sustainable, resource-efficient, and low-carbon practices.

Bio-Based Building Materials

Bio-based building materials refer to construction materials that are wholly or partially derived from renewable biological resources such as plants, animals, and microorganisms. These materials include timber, bamboo, hemp, straw, cork, agricultural residues (such as rice husks and sugarcane bagasse), and emerging biomaterials like mycelium-based composites. Unlike conventional construction materials such as steel, cement, and plastics, bio-based materials are renewable and often have lower embodied energy throughout their life cycle (Allwood et al., 2012). One of the key characteristics of bio-based materials is their

ability to sequester carbon during the growth phase of the biological resource. For instance, trees and bamboo absorb carbon dioxide from the atmosphere, storing it within their biomass. When these materials are used in construction, the carbon remains locked within the built environment for extended periods, thereby contributing to climate change mitigation (IPCC, 2022). Bio-based materials also tend to support improved indoor environmental quality due to their natural thermal insulation, moisture regulation, and non-toxic properties. In addition, many bio-based materials can be reused, recycled, or biodegraded at the end of their service life, making them compatible with sustainable construction practices (Pomponi & Moncaster, 2017). In developing countries, bio-based materials are particularly relevant due to their availability, affordability, and potential to utilize agricultural waste streams. However, challenges such as limited standardization, durability concerns, and inadequate technical knowledge continue to hinder their widespread adoption in the construction industry.

Circular Economy

The circular economy is an economic and industrial system that aims to eliminate waste, extend the lifecycle of resources, and promote continuous value creation through reuse, repair, refurbishment, remanufacturing, and recycling. It represents a fundamental shift from the traditional linear economic model of “take–make–dispose” to a regenerative system that keeps materials in use for as long as possible (Ellen MacArthur Foundation, 2019). In the context of the construction sector, the circular economy focuses on minimizing resource extraction, reducing construction and demolition waste, and designing buildings for adaptability and material recovery. This approach encourages the use of sustainable materials, modular construction methods, and design strategies that facilitate disassembly and reuse of building components at the end of a structure’s life cycle (European Commission, 2020). A central principle of the circular economy is resource efficiency, which ensures that materials are used in a way that maximizes their value while minimizing environmental impact. Another key principle is systems thinking, which considers the entire lifecycle of materials—from extraction and production to use, reuse, and disposal—rather than focusing only on the construction phase. In relation to the built environment, the circular economy promotes the integration of renewable and recyclable materials, such as bio-based products, to close material loops and reduce dependence on finite resources. This makes bio-based building materials a critical enabler of circular construction systems, as they naturally align with circular principles through renewability, biodegradability, and low environmental impact.

Types of Bio-Based Building Materials

Bio-based building materials are diverse in origin, structure, and application, but they all share the common feature of being derived from renewable biological resources. The major categories are discussed below:

- i. **Timber and Engineered Wood:** Timber is one of the oldest and most widely used bio-based construction materials. In modern construction, timber has evolved beyond traditional sawn wood into engineered products such as Cross-Laminated Timber (CLT), Glued Laminated Timber (Glulam), and Laminated Veneer Lumber (LVL). These engineered wood products offer improved strength, dimensional stability, and design flexibility, making them suitable for multi-storey buildings and large-span structures (Brandner et al., 2016). Timber acts as a carbon sink because trees absorb carbon dioxide during growth and store it within their cellular structure. When used in

construction, this carbon remains locked for the lifespan of the building, thereby contributing to climate change mitigation (IPCC, 2022). Additionally, engineered wood products require significantly less energy to produce compared to steel and concrete, making them a lower-carbon alternative for structural applications.

- ii. **Bamboo:** Bamboo is a fast-growing renewable resource widely recognized for its high strength-to-weight ratio and flexibility. It is often referred to as a “green steel” due to its mechanical performance in relation to its lightweight structure. Bamboo can be harvested within 3–5 years, making it one of the most rapidly renewable construction materials available (Liese & Köhl, 2015). In construction, bamboo is used for structural framing, scaffolding, roofing, flooring, and wall systems. Engineered bamboo products, such as laminated bamboo boards, further enhance its durability and load-bearing capacity. Bamboo also performs well in seismic-prone regions due to its flexibility and energy absorption capacity. However, untreated bamboo is susceptible to biological degradation, requiring proper treatment methods to improve durability and resistance to pests and moisture.
- iii. **Hempcrete:** Hempcrete is a bio-composite material made from the inner woody core of the hemp plant (hemp hurds) mixed with a lime-based binder. It is primarily used as a non-load-bearing material for walls, insulation, and infill systems. Hempcrete is valued for its excellent thermal insulation, moisture regulation, and fire resistance properties. One of its most significant environmental advantages is its carbon-negative potential. During the growth phase, hemp absorbs large amounts of CO₂, and the lime binder continues to absorb carbon dioxide during curing, effectively storing carbon within the building envelope (Ip & Miller, 2012). Although hempcrete is not structurally load-bearing, it contributes significantly to energy-efficient building design by reducing heating and cooling demands.
- iv. **Straw Bale:** Straw bale construction utilizes compressed agricultural straw (typically wheat, rice, or barley straw) as building blocks for walls. It is often used in low-cost, energy-efficient housing systems due to its excellent insulation properties and low environmental impact. Straw is an agricultural by-product, meaning it is widely available and inexpensive, particularly in rural and agrarian economies. When properly constructed and protected from moisture, straw bale buildings can be highly durable and long-lasting. They also provide excellent thermal performance, reducing energy consumption for heating and cooling (King, 2006). However, proper design and moisture protection are essential to prevent decay, fire risk, and pest infestation.
- v. **Agricultural Residue-Based Materials:** Agricultural residue-based materials are derived from by-products of farming activities that would otherwise be discarded or burned. These include rice husks, coconut fibers, sugarcane bagasse, maize stalks, palm kernel shells, and cassava residues. These wastes are increasingly being transformed into value-added construction materials such as particle boards, insulation panels, bricks, and composite materials. For example, rice husk ash can be used in cement production to enhance strength and durability, while sugarcane bagasse is used in fiberboards and insulation products. These materials contribute significantly to waste reduction and promote circular resource flows within agricultural systems (Ashby, 2018). Their use is particularly relevant in developing countries where agricultural waste is abundant and disposal methods are often environmentally harmful.
- vi. **Mycelium-Based Composites:** Mycelium-based composites are an emerging class of bio-materials derived from the root-like structures of fungi. Mycelium grows by binding

agricultural waste materials into a solid, lightweight, and biodegradable composite. Once grown and dried, it forms a rigid material that can be used for insulation panels, packaging, and non-structural building components. These materials are highly sustainable because they require minimal energy input during production, are fully biodegradable, and can be composted at the end of their life cycle. Mycelium composites also exhibit excellent thermal and acoustic insulation properties, making them suitable for interior applications in sustainable buildings (Jones et al., 2020). Although still in the early stages of commercialization, mycelium-based materials represent a promising innovation in circular construction systems.

Bio-Based Materials as Drivers of Circular Economy

Bio-based building materials play a central role in advancing the circular economy within the construction sector by enabling regenerative resource flows, reducing waste generation, and lowering dependence on non-renewable materials. Unlike conventional construction materials that follow a linear “take–make–dispose” pathway, bio-based materials naturally align with circular economy principles due to their renewability, biodegradability, and potential for reuse or recycling. One of the key ways bio-based materials drive circularity is through renewable resource cycles. Materials such as timber, bamboo, and hemp can be continuously regenerated through sustainable cultivation, ensuring a stable supply of raw materials without depleting finite natural resources (Ellen MacArthur Foundation, 2019). This reduces pressure on environmentally intensive materials like cement and steel. Another important contribution is carbon sequestration and storage. During growth, bio-based resources absorb carbon dioxide from the atmosphere, and this carbon remains stored within the building structure for its lifespan. This makes buildings constructed with bio-based materials act as temporary carbon sinks, helping to mitigate climate change impacts (IPCC, 2022). Bio-based materials also promote waste valorization, particularly through the use of agricultural residues such as rice husks, sugarcane bagasse, and palm fibers. Instead of being burned or dumped, these residues are converted into useful construction products, thereby closing material loops and reducing environmental pollution (United Nations Environment Programme [UNEP], 2023). In addition, many bio-based materials support design for disassembly, allowing components such as timber panels or bamboo structures to be dismantled, reused, or repurposed at the end of a building’s life cycle. This extends material lifespans and reduces demolition waste. Through these mechanisms, bio-based building materials serve as key enablers of circular construction systems, promoting sustainability, resilience, and resource efficiency in the built environment.

Benefits of Bio-Based Building Materials

Bio-based building materials offer a wide range of environmental, economic, and social benefits that make them increasingly relevant in sustainable construction practices. These benefits collectively support the transition toward low-carbon and resource-efficient building systems.

- i. **Environmental Benefits:** Bio-based materials significantly reduce the environmental footprint of construction activities. One of their most important advantages is lower embodied carbon, as they require less energy for extraction, processing, and manufacturing compared to conventional materials such as steel and cement (IPCC, 2022). They also contribute to carbon sequestration, where materials like timber and bamboo store atmospheric carbon throughout their lifecycle, effectively turning buildings into carbon storage systems. This helps offset greenhouse gas emissions from

other sectors. Another environmental benefit is waste reduction. Many bio-based materials are derived from agricultural and forestry residues that would otherwise be burned or disposed of in landfills. Their utilization promotes circular resource flows and reduces environmental pollution (UNEP, 2023). Additionally, bio-based materials are often biodegradable or recyclable, meaning they can safely return to the environment or be reprocessed into new materials at the end of their service life. This reduces long-term waste accumulation and landfill pressure. Finally, these materials support biodiversity conservation when sourced from sustainably managed forests and agricultural systems, helping maintain ecological balance.

- ii. **Economic Benefits:** Bio-based building materials offer several economic advantages, particularly in regions with abundant natural and agricultural resources. One major benefit is cost reduction, as many bio-based materials rely on locally available resources such as bamboo, straw, and agricultural waste, reducing the need for imported construction materials. They also contribute to job creation and rural development by generating employment opportunities in farming, harvesting, processing, and manufacturing sectors. This is especially important in developing economies where agriculture plays a significant role in livelihoods. Furthermore, bio-based materials support the development of local value chains, encouraging small and medium-sized enterprises (SMEs) to participate in green construction industries. This enhances economic diversification and resilience. Over the long term, bio-based materials can also reduce life-cycle costs due to their thermal insulation properties, which lower energy consumption for heating and cooling buildings (World Green Building Council, 2019).
- iii. **Social Benefits:** Bio-based building materials also contribute significantly to social well-being and community development. One key benefit is the improvement of indoor environmental quality, as many bio-based materials are non-toxic and regulate humidity naturally, creating healthier living environments. They also enhance affordability of housing, especially in low-income and rural communities, where locally sourced materials can reduce construction costs and improve access to decent housing. In addition, bio-based construction systems promote community participation and traditional building knowledge, particularly in regions where materials like bamboo, timber, and earth-based systems have been historically used. This helps preserve indigenous construction practices and cultural heritage. Bio-based materials also contribute to energy-efficient living environments, improving thermal comfort and reducing reliance on mechanical heating and cooling systems, which enhances quality of life. Finally, by supporting sustainable development practices, bio-based materials contribute to broader societal goals such as climate resilience, environmental awareness, and sustainable urbanization.

Challenges to the Adoption of Bio-Based Building Materials in Nigeria

Although bio-based building materials present significant opportunities for sustainable and low-carbon construction in Nigeria, their adoption remains limited due to several structural, technical, economic, and institutional constraints. These challenges are particularly pronounced in developing economies where construction practices are still heavily dependent on conventional materials such as cement blocks, steel, and concrete.

- i. **Weak Standardization and Regulatory Frameworks:** In Nigeria, one of the most critical barriers is the absence of comprehensive national standards and regulatory frameworks for many bio-based materials such as bamboo, straw, and agricultural residue-based composites. While agencies such as the Standards Organisation of Nigeria (SON) provide

general building material standards, there are limited specific codes governing the structural use of many emerging bio-based alternatives. This regulatory gap creates uncertainty for engineers, architects, and approval authorities, leading to preference for conventional materials that are already well-regulated and widely accepted in practice. Studies have shown that lack of policy clarity significantly slows down innovation in sustainable construction systems (Ghisellini et al., 2022).

- ii. **Durability and Climate-Specific Performance Concerns:** Nigeria's tropical climate, characterized by high humidity, heavy rainfall, and termite activity, raises serious concerns about the durability of bio-based materials such as timber, bamboo, and straw. Without proper treatment, these materials are vulnerable to biological degradation, moisture absorption, and pest attacks. Although engineered wood products and chemically treated bamboo offer improved resistance, many construction professionals in Nigeria still perceive bio-based materials as unsuitable for long-term structural applications. This perception gap continues to hinder widespread acceptance, despite global evidence of improved performance through modern treatment technologies (Liew et al., 2023).
- iii. **Limited Industrial Production and Weak Supply Chains:** The production of bio-based construction materials in Nigeria remains largely informal and small-scale. Materials such as bamboo composites, agricultural fibre boards, and mycelium-based products are still in early stages of commercialization. This results in inconsistent supply, lack of quality control, and limited availability in major construction markets. Weak logistics and underdeveloped processing facilities further increase production costs and reduce competitiveness compared to established materials like cement and steel, which benefit from strong industrial supply chains (Kumar & Putnam, 2022).
- iv. **High Initial Costs and Poor Market Competitiveness:** Although bio-based materials can be cost-effective over their life cycle, their initial production and processing costs are relatively high in Nigeria due to limited technology, low mechanization, and inadequate investment in green material industries. For example, engineered bamboo or hemp-based composites require specialized equipment and technical expertise that are not widely available locally. In contrast, cement blocks and concrete products are mass-produced at lower unit costs, making them more attractive to contractors and developers. This economic imbalance discourages private sector investment in bio-based construction alternatives (Mao et al., 2021).
- v. **Low Awareness and Limited Technical Capacity:** Another major challenge in Nigeria is the limited awareness and technical expertise among construction professionals regarding bio-based materials. Many architects, engineers, and builders are not adequately trained in the design, specification, and performance evaluation of these materials. Most university curricula in architecture and engineering still emphasize conventional construction systems, leaving a knowledge gap in sustainable and circular construction practices. This contributes to skepticism and resistance to adoption within the professional community.
- vi. **Limited Government Incentives and Policy Support:** Although Nigeria has developed environmental and climate-related policies, there is still limited targeted support for bio-based construction materials. Unlike renewable energy initiatives that receive subsidies and incentives, bio-based building materials lack dedicated funding programs, tax incentives, or procurement policies that encourage their use in public infrastructure projects. Without strong government intervention, market transformation toward

circular construction remains slow, as public projects often drive innovation and standard adoption in the construction industry (Rahman and Muntasir, 2024).

Opportunities for Nigeria and Developing Countries

Nigeria and other developing economies possess significant untapped potential for the development and adoption of bio-based building materials within a circular economy framework. One of the most important opportunities lies in the abundant availability of renewable biological resources. Nigeria generates large quantities of agricultural residues such as rice husks, maize stalks, cassava peels, sugarcane bagasse, coconut fibre, and oil palm waste, all of which can be converted into valuable construction materials rather than being burned or discarded (FAO, 2023). Another major opportunity is the development of a local green construction industry. The processing and production of bio-based materials such as bamboo panels, fibre boards, and bio-composites can stimulate small and medium-sized enterprises (SMEs), create jobs, and strengthen rural economies. This aligns with findings that circular bioeconomy systems can significantly enhance employment generation in developing regions (UNEP, 2023). Nigeria also benefits from a high demand for affordable housing, driven by rapid urbanization and population growth. Bio-based materials offer cost-effective alternatives for low-income housing due to their local availability and reduced transportation costs. This creates opportunities for sustainable housing delivery at scale (World Bank, 2022). In addition, the transition toward bio-based construction supports climate change mitigation goals, as these materials reduce embodied carbon and promote carbon storage in buildings. Developing countries can therefore use bio-based materials as part of their nationally determined contributions (NDCs) under global climate agreements (IPCC, 2022). Finally, there is an opportunity for academic research, innovation, and technology transfer. Universities, research institutes, and private sector actors can collaborate to develop locally adapted materials such as bamboo composites, mycelium-based panels, and agricultural waste bricks suited to tropical conditions.

Policy and Strategic Recommendations

To fully harness the benefits of bio-based building materials in Nigeria, coordinated policy and strategic interventions are required across government, industry, and academia.

- i. First, there is a need for the development of national standards and building codes specifically tailored to bio-based materials. Agencies such as the Standards Organisation of Nigeria (SON) and the Council for the Regulation of Engineering in Nigeria (COREN) should establish testing protocols and certification systems to ensure safety, durability, and performance reliability (Ghisellini et al., 2022).
- ii. Second, government should introduce financial incentives and policy support mechanisms, such as tax reductions, green building subsidies, and low-interest loans for developers who adopt bio-based and circular construction materials. Public procurement policies should also prioritize sustainable materials in government-funded infrastructure projects.
- iii. Third, investment in research and development (R&D) is essential. Universities and research institutions should be funded to explore locally sourced materials such as bamboo, palm fibre, and agricultural residues for construction applications. This will enhance innovation and improve material performance under local climatic conditions (Rahman & Muntasir, 2024).
- iv. Fourth, there is a need for capacity building and professional training. Architecture, engineering, and construction curricula should integrate circular economy principles and

- bio-based material technologies to bridge the existing knowledge gap among professionals (Hossain et al., 2021).
- v. Fifth, the government should support the development of industrial processing hubs and supply chains for bio-based materials. This includes establishing rural collection centers, processing facilities, and logistics systems to ensure consistent quality and availability of materials (Kumar & Putnam, 2022).

Conclusion

Bio-based building materials represent a critical pathway toward achieving sustainable and circular construction systems in Nigeria and other developing countries. Their ability to reduce environmental impacts, promote resource efficiency, and support carbon sequestration positions them as key enablers of the transition from linear to circular economy models in the built environment. Despite these advantages, adoption remains constrained by regulatory gaps, limited industrial capacity, low awareness, and weak policy support. However, Nigeria's abundant agricultural resources, growing housing demand, and emerging interest in sustainable development present strong opportunities for transformation. To fully realize these benefits, coordinated efforts are required across government institutions, academic bodies, and the private sector. Strategic investments in research, infrastructure, capacity building, and policy reform will be essential in scaling up bio-based material production and integration into mainstream construction practices. Ultimately, the adoption of bio-based materials will not only contribute to environmental sustainability and climate change mitigation but also stimulate economic development, job creation, and improved living standards. This makes them a vital component of Nigeria's long-term sustainable development and circular economy transition.

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