

Sustainable construction systems: an investigation into the use of materials and techniques that promote sustainability in buildings - Critical literature review

Sistemas construtivos sustentáveis: investigação sobre o uso de materiais e técnicas que promovem a sustentabilidade nas construções - Revisão crítica de literatura

Sistemas de construcción sostenibles: una investigación sobre el uso de materiales y técnicas que promueven la sostenibilidad en los edificios - Revisión crítica de la literatura

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Abstract

The construction industry has been one of the largest consumers of natural resources and a significant emitter of greenhouse gases worldwide. Traditional materials, such as Portland cement and steel, drive high energy consumption, substantial carbon emissions, and massive solid waste generation. The general objective of this article is to synthesize evidence on sustainable materials and techniques, and the specific objective is to evaluate their advantages, disadvantages, and implications for future research. This study presents a critical semi-systematic literature review examining materials and techniques that advance sustainability in building construction. While conventional practices dominate, a growing body of evidence supports the adoption of alternatives, including recycled aggregates, green concrete, earthen materials (such as adobe, rammed earth, and soil-cement), geopolymers, and digital tools like Green BIM. Although these approaches demonstrate clear environmental benefits, the literature reveals important limitations: most studies focus on temperate climates, lack long-term durability data, and under-explore economic feasibility and social dimensions in tropical contexts such as Brazil's Midwest region. By synthesizing current knowledge and identifying critical research gaps, this review underscores the urgent need for context-specific scientific investigations. The findings provide a foundation for advancing truly sustainable construction practices that balance environmental, economic, and social imperatives.

Keywords: Sustainable construction; Green building materials; Recycled concrete; Earthen construction; Green BIM; Research gaps.

Resumo

A indústria da construção civil tem sido uma das maiores consumidoras de recursos naturais e uma importante emissora de gases de efeito estufa em todo o mundo. Materiais tradicionais, como o cimento Portland e o aço, impulsionam o alto consumo de energia, emissões substanciais de carbono e geração massiva de resíduos sólidos. O objetivo geral deste artigo é sintetizar evidências sobre materiais e técnicas sustentáveis, e o objetivo específico é avaliar suas vantagens, desvantagens e implicações para pesquisas futuras. Este estudo apresenta uma revisão crítica semi-sistemática da literatura, examinando materiais e técnicas que promovem a sustentabilidade na construção civil. Embora as práticas convencionais ainda dominem, um crescente conjunto de evidências apoia a adoção de alternativas, incluindo agregados reciclados, concreto ecológico, materiais terrosos (como adobe, taipa de pilão e solo-cimento), geopolímeros e ferramentas digitais como BIM Verde. Embora essas abordagens demonstrem claros benefícios ambientais, a literatura revela limitações importantes: a maioria dos estudos se concentra em climas temperados, carece de dados de durabilidade a longo prazo e explora pouco a viabilidade econômica e as dimensões sociais em contextos tropicais, como a região Centro-Oeste do Brasil. Ao sintetizar o conhecimento atual e identificar lacunas críticas na pesquisa, esta revisão destaca a necessidade urgente de investigações científicas específicas para cada contexto. Os resultados fornecem uma base para o avanço de práticas de construção verdadeiramente sustentáveis que equilibrem os imperativos ambientais, econômicos e sociais.

Palavras-chave: Construção sustentável; Materiais de construção ecológicos; Concreto reciclado; Construção em terra; BIM Verde; Lacunas de pesquisa.

Resumen

La industria de la construcción ha sido uno de los mayores consumidoras de recursos naturales y una importante emisora de gases de efecto invernadero a nivel mundial. Los materiales tradicionales, como el cemento Portland y el acero, generan un alto consumo de energía, importantes emisiones de carbono y una enorme cantidad de residuos sólidos. El objetivo general de este artículo es sintetizar la evidencia sobre materiales y técnicas sostenibles, y el objetivo específico es evaluar sus ventajas, desventajas e implicaciones para futuras investigaciones. Este estudio presenta una revisión bibliográfica crítica y semisistemática que examina los materiales y las técnicas que promueven la sostenibilidad en la construcción de edificios. Si bien predominan las prácticas convencionales, cada vez hay más pruebas que respaldan la adopción de alternativas, como los áridos reciclados, el hormigón ecológico, los materiales de tierra (como el adobe, la tierra apisonada y el suelo-cemento), los geopolímeros y las herramientas digitales como el BIM Verde. Si bien estos enfoques demuestran claros beneficios ambientales, la literatura revela importantes limitaciones: la mayoría de los estudios se centran en climas templados, carecen de datos sobre durabilidad a largo plazo y no exploran suficientemente la viabilidad económica ni las dimensiones sociales en contextos tropicales como la región centro-oeste de Brasil. Al sintetizar el conocimiento actual e identificar lagunas de investigación cruciales, esta revisión subraya la necesidad urgente de realizar investigaciones científicas adaptadas a cada contexto. Los hallazgos sientan las bases para impulsar prácticas de construcción verdaderamente sostenibles que equilibren los imperativos ambientales, económicos y sociales.

Palabras clave: Construcción sostenible; Materiales de construcción ecológicos; Hormigón reciclado; Construcción con tierra; BIM verde; Lagunas en la investigación.

1. Introduction

Human-induced environmental degradation, driven by rapid urbanization, industrial pollution, and resource depletion, has prompted global efforts to embed sustainability across all economic sectors. In the construction industry, which accounts for 20–50% of global raw material consumption and a significant share of greenhouse gas emissions, the transition toward sustainable practices is no longer optional but imperative (Brasileiro & Matos, 2015; Mfon & Bassey, 2023).

Although sustainable construction has gained traction worldwide and in Brazil, many initiatives remain fragmented and predominantly focused on the environmental pillar, often neglecting integrated economic and social considerations. This study addresses the guiding question: *What materials and techniques are currently employed to promote sustainability in construction, and what are their documented strengths, limitations, and contextual applicability?*

By critically examining the literature, this review identifies not only promising innovations but also persistent gaps – particularly the scarcity of long-term performance data in tropical climates and the limited integration of lifecycle assessment (LCA) in developing-country contexts. The general objective is to synthesize evidence on sustainable materials and techniques; the specific objective is to evaluate their advantages, disadvantages, and implications for future research. This work contributes to the scholarly foundation required for advancing sustainable civil engineering practices.

2. Methodology

This study adopted a semi-systematic qualitative literature review (Risemberg et al., 2026; Snyder, 2019; Pereira et al., 2018) to ensure transparency and reproducibility. Searches were conducted in March–April 2025 across SciELO, Google Scholar, and supplementary databases (Web of Science and Scopus, where open-access articles were available). Descriptors included “construction materials,” “sustainable development,” “sustainable construction,” “green concrete,” “earthen construction,” “geopolymers,” and “Green BIM,” combined with Boolean operators.

Inclusion criteria: peer-reviewed articles or books in Portuguese or English published between 2014 and 2025; freely accessible or indexed works directly addressing sustainability in construction. Exclusion criteria: duplicates, non-peer-reviewed sources, and studies unrelated to the research objectives. After initial screening, 38 sources were selected for full analysis. The review process followed a thematic synthesis approach, prioritizing critical evaluation of methodological rigor, geographic context, and strength of evidence rather than mere description.

3. Results and Discussion

3.1 The Construction Industry and Its Environmental Footprint

The construction sector serves as both a catalyst for socioeconomic development and a significant contributor to environmental degradation. While it delivers essential infrastructure and employment opportunities, it also consumes substantial quantities of non-renewable resources and accounts for 20–50% of global raw material consumption (Brasileiro & Matos, 2015). Recent studies indicate that conventional practices are insufficient for mitigating carbon emissions and waste generation (Mfon & Bassey, 2023; Techio et al., 2016). Despite its role in economic advancement, the sector's resource-intensive activities, including extraction, manufacturing, and operation, highlight the urgent necessity for a fundamental transformation (Conto et al., 2017).

3.2 Sustainable Development in Civil Construction

Sustainable development is conceptualized as meeting the needs of present-day society without compromising the ability of future generations to meet their own needs, balancing socioeconomic and environmental dimensions (Benites-Lazaro et al., 2018). The concept gained global relevance with the 1987 Brundtland Report and was consolidated at the 1992 Earth Summit (ECO-92), becoming a guiding principle in international treaties, national policies, and the green economy (Matos et al., 2019).

In civil construction, however, this ideal faces a sharp contrast. While the sector drives essential socioeconomic development by providing infrastructure and employment, it remains one of the largest consumers of non-renewable resources and emitters of greenhouse gases, accounting for 20–50% of global raw material use (Brasileiro & Matos, 2015; Mfon & Bassey, 2023). Traditional practices based on Portland cement and steel generate high energy consumption, substantial carbon emissions, and massive solid waste.

This environmental impact has spurred a gradual shift toward alternative materials and circular-economy practices, including recycling construction and demolition waste into new products (Orozco et al., 2024). As a result, practical measures, such as low-VOC (Volatile Organic Compounds) materials, energy and water conservation, and solar energy adoption, are increasingly common (Silva et al., 2017). Although sustainable projects may entail 2–15% higher initial costs, long-term energy and water savings can reach 30% (Marchi et al., 2018; Silva et al., 2017).

Nevertheless, in assessing this shift, most studies still emphasize the environmental pillar, with limited attention to economic viability and social equity, particularly in tropical Global South contexts (Hluszko et al., 2024).

3.3 Critical Synthesis of Materials and Techniques

Several promising approaches emerge from the literature. The table below synthesizes key options, highlighting documented advantages, limitations, and evidence strength.

Table 1 - Summary of the main options synthesized.

Material or Technique	Key Advantages	Documented Limitations or Gaps	Evidence Strength and Context	Representative Sources
Recycled Concrete	Reduces virgin aggregate use; up to 30% cost savings	Variable mechanical performance; limited long-term durability data in humid climates	Moderate (mostly lab-scale)	Barbosa et al. (2018); Akbulut (2025); Alibeigibeni et al. (2025)
Green Concrete (supplementary cementitious materials, fly ash, slag)	Lowers CO ₂ emissions; uses industrial by-products	Supply-chain variability; early-age strength issues	Strong (multiple reviews)	Qaidi et al. (2022); Tayeh et al. (2022); Orozco et al. (2024); Amadi (2025)
Earthen Construction (adobe, rammed earth)	Excellent thermal inertia; low embodied energy	Erosion vulnerability; labor-intensive; seismic concerns	Moderate (vernacular focus)	Costa et al. (2018); Fernandes et al. (2016); Mora-Ruiz et al. (2025).
Soil-Cement Blocks	Uses local soil; no firing; supports self-construction	Requires precise quality control; limited standardization in tropics	Moderate (ABNT standards)	Giorgi et al. (2018); Mora-Ruiz et al. (2025)
Geopolymers	High early strength; very low CO ₂	Raw-material availability; scalability in field conditions	Emerging (lab-dominant)	Azevedo et al. (2018); Sujitha et al. (2025); Khasawneh et al. (2025)
Green BIM (Building Information Modeling)	Lifecycle optimization; energy simulation	High initial training cost; limited adoption in small firms	Strong (systematic reviews)	Addor & Santos (2017); Akbari et al. (2024); Fauzi et al. (2025)

Source: Author.

3.4 Critical Analysis and Identified Gaps

Although recycled and green concretes provide clear environmental advantages, several studies, include recent reviews, report inconsistencies between initial cost premiums (ranging from 2 to 15 percent) and long-term savings (up to 30 percent in energy and water) (Marchi et al., 2018; Silva et al., 2017; Akbulut, 2025). These inconsistencies frequently arise from variations in project scale and geographic context, underscoring the need for site-specific life-cycle assessment (LCA).

Vernacular construction techniques, including rammed earth and limewash, demonstrate strong passive thermal performance; however, most supporting evidence is derived from Mediterranean or temperate climates (Fernandes et al., 2016). The suitability of these methods in hot-humid tropical regions, such as Campo Grande, Mato Grosso do Sul, which experiences high rainfall and significant termite activity, remains insufficiently studied and constitutes a notable research gap (Mora-Ruiz et al., 2025).

Geopolymers and soil-cement exhibit considerable potential in laboratory settings; however, field-scale durability studies in developing countries are limited. Additionally, the social impacts, such as job creation through self-construction or community participation, are seldom quantified.

Green Building Information Modeling (BIM) is a highly effective integrative tool, but its implementation in Brazil is limited by the costs of training and by restricted software accessibility for small and medium-sized enterprises (Akbari et al., 2024; Fauzi et al., 2025).

3.5 Overall Synthesis

The literature demonstrates that sustainable materials and techniques decisively reduce environmental impacts. Yet

three crucial gaps demand attention: (1) a lack of long-term empirical data in tropical climates; (2) minimal integration of economic and social sustainability metrics; and (3) an absence of context-specific research for mid-sized Brazilian cities. Recent studies reinforce these gaps while highlighting promising advances in recycled aggregates, supplementary cementitious materials, and Green BIM (Akbulut, 2025; Amadi, 2025; Sujitha et al., 2025). Addressing these gaps requires advanced doctoral research focused on lifecycle performance, cost-benefit modeling, and pilot projects in the Brazilian Midwest.

4. Final Considerations

This enhanced review reveals that traditional cement- and steel-based construction remains dominant, resulting in significant environmental damage. However, numerous sustainable alternatives are available. Recycled aggregates, green concrete, earthen systems, geopolymers, and Green BIM all offer practical solutions for achieving lower-carbon, resource-efficient buildings.

Critically, however, the current evidence base remains fragmented, geographically biased toward temperate regions, and methodologically limited in long-term field validation. By explicitly identifying these gaps, this study not only fulfills its objectives but also establishes a clear rationale for doctoral-level investigation. Future research should prioritize integrated LCA, tropical-climate durability testing, and socio-economic modeling to translate laboratory promise into scalable, context-appropriate solutions.

Such advancements will be essential for achieving the United Nations Sustainable Development Goals within the built environment and for positioning the next generation of civil engineers as leaders in sustainable innovation.

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