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Artificial Intelligence for Sustainable Building Materials

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ABSTRACT

This paper reviews the role of artificial intelligence (AI), with a focus on machine learning (ML) and tools like ChatGPT, in advancing sustainable building materials. As the construction industry seeks to reduce its environmental footprint, AI offers innovative methods for discovering low-carbon alternatives, optimizing material composition, and designing bio-inspired structures. A narrative literature review was conducted, synthesizing peer-reviewed publications from 2014 to 2024. The findings are categorized into three main areas: low-carbon material discovery, ML-based material optimization, and generative AI for bio-inspired design. Results show that AI technologies significantly contribute to improving sustainability and performance while identifying key barriers such as high computational costs, limited interdisciplinary collaboration, and slow industry adoption. The paper concludes that while AI shows strong potential, further research and institutional support are essential for widespread implementation.

KEYWORDS

Artificial Intelligence; Sustainable Construction; Green Building Materials; Machine Learning; ChatGPT; Bio-inspired Design

1. INTRODUCTION

The construction sector remains a major contributor to global carbon emissions, resource depletion, and environmental degradation. In response, the industry is increasingly prioritizing sustainable building materials to reduce ecological impact while maintaining performance standards. Artificial intelligence (AI), particularly machine learning (ML) and large language models (LLMs) such as ChatGPT, is emerging as a valuable tool in this transformation. AI allows for the efficient analysis of complex datasets, accelerates the identification of low-impact materials, and supports design optimization.

This review explores how AI is facilitating advancements in sustainable material development, specifically focusing on low-carbon material discovery, material composition optimization through ML, and bio-inspired design using generative AI. The paper also addresses key challenges and future research directions necessary for AI to become integral in sustainable construction practices.

2. METHODOLOGY

This study employs a narrative review methodology, with the aim of synthesizing academic and technical literature that intersects AI with sustainable building materials. The review process involved three stages:

First, Literature Search: Academic databases including IEEE Xplore, ScienceDirect, SpringerLink, and Google Scholar were queried using terms such as “AI in construction,” “sustainable building materials,” “ChatGPT in engineering,” and “machine learning in material design.” Studies published between 2014 and 2024 were prioritized.

Second, Thematic Categorization: Selected literature was grouped into three themes: AI for low-carbon material discovery, ML for optimizing material composition, and generative AI for bio-inspired material innovation. Within each category, recurring AI techniques and use cases were identified.

Third, AI-assisted Analysis: ChatGPT was used as a secondary tool to summarize papers, detect patterns, and assist in synthesizing insights. It was not used for data generation but improved the review's coherence and efficiency.

No experimental testing was conducted; instead, the focus was on qualitative analysis of existing research to inform the current and future state of AI-assisted sustainable construction.

3. RESULTS AND DISCUSSION

As the construction industry evolves, there is an increasing need to adopt sustainable practices to address growing environmental challenges [1-4]. Historically, the industry has significantly contributed to environmental damage through high energy consumption, resource depletion, and excessive waste production. However, with rising awareness about environmental responsibility, sustainable construction practices are gaining prominence. These practices focus on using eco-friendly materials, enhancing energy efficiency, and adopting environmentally conscious methods throughout the construction lifecycle [5, 6].

ChatGPT, developed by OpenAI, is playing an essential role in promoting sustainability within the construction industry [7, 8]. This advanced AI tool can process vast amounts of information, generate human-like text, and engage in interactive conversations, making it a valuable resource for architects, engineers, and construction professionals [9, 10]. By staying updated on regulations, certifications, and best practices, ChatGPT helps professionals ensure their projects meet environmental standards and qualify for green building certifications [8-15].

3.1. AI for Low-Carbon Material Discovery

New and advanced building materials are changing the way sustainable construction is done. These materials help lower carbon emissions and improve the strength and durability of buildings, making them more environmentally friendly and resilient:

a. Cross-laminated timber (CLT): An engineered wood product with low environmental impact and high strength, often recommended through AI-aided life cycle assessments.

b. Carbon capture and utilization concrete (CCU): Uses CO_2 captured from industrial sources. AI helps in optimizing the carbon curing process for enhanced sustainability.

c. Green concrete: Incorporates industrial by-products like fly ash and slag to reduce cement use. ML models assist in finding optimal mix ratios.

d. Low-carbon steel production: AI supports material researchers in modeling and testing production methods that reduce emissions during steel manufacturing.

The following examples demonstrate how ChatGPT can contribute to the development of sustainable, low-carbon material alternatives:

a. Advancing material research and development: ChatGPT aids researchers in developing eco-friendly concrete materials by analysing datasets and academic papers. It identifies low-carbon

material combinations that maintain strength, driving innovation and promoting more sustainable concrete production.

b. Guiding life cycle assessment: ChatGPT assists in life cycle assessments of construction materials by analysing data on extraction, manufacturing, transportation, installation, and disposal, helping evaluate environmental impacts and supporting informed material selection for sustainable construction projects.

ChatGPT and other LLMs can support life cycle assessments (LCA) by interpreting large environmental datasets, offering actionable insights for sustainable material selection and substitution

3.2. Machine Learning for Material Composition

Machine learning (ML) is increasingly used to enhance material performance while reducing carbon footprints. Applications include:

a. Green concrete: Traditional concrete production releases high carbon emissions due to cement use. Green concrete reduces this by using alternatives like fly ash and slag. ChatGPT helps professionals explore and improve green concrete mixes for more sustainable construction practices.

b. Geopolymer concrete: Geopolymer concrete replaces regular cement with aluminosilicate materials, cutting down carbon emissions and improving durability [16-20]. ChatGPT helps improve mix designs by suggesting suitable precursor combinations and providing insights into the long-term performance of geopolymer concrete.

c. Recycled aggregate concrete: Using recycled aggregates from construction and demolition waste in concrete supports sustainability. ChatGPT helps by identifying suitable waste materials, improving mix designs, and solving issues related to the use of recycled aggregates in concrete production.

d. Recycled and upcycled roofing materials: Derived from recycled or upcycled sources, sustainable roofing materials reduce construction's environmental impact. ChatGPT explores innovative ways of repurposing materials such as recycled metal, rubber, or plastic into durable and efficient roofing components.

The followings are Applications of ChatGPT in optimizing material composition:

a. Material research and development: ChatGPT supports research by reviewing large volumes of scientific literature and suggesting material combinations that improve sustainability. It also offers insights into the properties and performance of eco-friendly materials, helping researchers make better decisions in material development.

b. Optimizing material properties: ChatGPT helps improve sustainable construction materials by adjusting properties like strength, durability, thermal performance, and environmental impact. This supports the development of materials that meet both building performance needs and sustainability goals in modern construction.

c. Refining mix design: Concrete mix design is key to reducing its environmental impact. ChatGPT works with engineers to improve mixes by using alternative binders, recycled aggregates, and other materials, helping lower carbon emissions while maintaining strength and durability in construction projects.

ChatGPT aids by scanning large volumes of scientific literature to suggest novel combinations, improve formulation accuracy, and assist in resolving potential compatibility issues.

3.3. Bio-Inspired AI Material Design

The incorporation of generative artificial intelligence (AI) into mechanical and bioinspired material design, alongside additive manufacturing workflows, has revolutionized engineering and materials

science by enabling cross-disciplinary exploration—such as bridging mechanics with biology or linking failure mechanics to 3D printing. Advanced generative AI methodologies, such as generative adversarial networks (GANs), genetic algorithms, and large language models (LLMs) [23-25], provide adaptable frameworks to refine material characteristics, lower manufacturing expenses, and expedite innovation cycles.

In mechanical material engineering, generative AI accelerates the discovery of innovative architectures with superior strength, durability, and functionality. Meanwhile, bioinspired material development leverages the fusion of generative AI, biological principles, and additive manufacturing to replicate nature's efficiency. Through generative algorithms and topology optimization, intricate biological systems are decoded and transformed into high-performance engineering designs. Furthermore, LLMs are increasingly pivotal in additive manufacturing, where they streamline parameter calibration, troubleshoot printing anomalies, and boost operational output. Collectively, these AI-driven strategies not only enhance precision in material synthesis but also foster sustainable practices by minimizing resource waste. By merging computational creativity with manufacturing technologies, generative AI establishes a paradigm shift toward data-driven, multifunctional material innovation across industries.

4. CHALLENGES AND CONSIDERATIONS

Despite notable advancements, the integration of AI in sustainable material development is hindered by several factors:.

a. High Data and Computational Costs: High-performance computing resources are required for simulations and training ML models, increasing project expenses [21].

b. Interdisciplinary Gaps: Effective AI integration requires collaboration between computer scientists, material engineers, and construction professionals—expertise that is rarely found in a single team.

c. Data Scarcity and Industry Resistance: Limited datasets and conservative industry practices slow the adoption of AI-driven materials [22].

Addressing these limitations requires:

a. Development of shared, standardized databases,

b. Certification protocols for AI-assisted material design,

c. Interdisciplinary education and partnerships,

d. Ethical and regulatory frameworks to ensure safety and accountability.

5. CONCLUSION

AI technologies, particularly machine learning and language models like ChatGPT, are playing a transformative role in the development of sustainable building materials. These tools assist in the discovery of low-carbon alternatives, enable fine-tuned material optimization, and promote innovative, bio-inspired designs. Despite existing challenges related to data costs, interdisciplinary communication, and industry inertia, the potential benefits are substantial.

Future progress depends on building unified knowledge systems, fostering cross-disciplinary collaboration, and developing validation frameworks that support ethical and effective AI application. As AI tools evolve, they are likely to become indispensable in shaping a more sustainable and efficient construction industry.

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