International Journal of Science and Research (IJSR)
ISSN: 2319-7064
Impact Factor 2024: 2.102

Sustainable Construction Practices: Advancements in Carbon - Neutral Building Materials

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Abstract: ***The construction industry comprises a huge chunk of global carbon emissions, contributing approximately 39% of energy related global CO_2 emissions. Over the past few years, sustainable construction practices have become a key remedy for buildings' contribution to the environment. The development and application of carbon neutral building materials, including bio - based materials, recycled aggregates as well as innovative low carbon cement alternatives of geopolymer concrete and carbon sequestering materials are explored in this paper. Their integration not only reduces embodied carbon but also increases energy efficiency and lifecycle sustainability of structures. Recent studies show that with bio - based materials, such as cross laminated timber (CLT) emissions can be reduced by up to 50% relative to conventional construction materials. Additionally, the innovative techniques of carbon capture and storage (CCS) in cement production have also proved to be successful in decreasing industrial emissions. The work presented is a comprehensive review of state of the art, challenges and opportunities associated with carbon neutral building materials, which takes a view on how these materials can play a part in achieving global sustainability goals and carbon neutrality in the built environment. Claims are supported with in text citations and the latest advancements in research and industry practices are referenced.***

Keywords: Sustainability in construction, carbon neutral materials, biobased materials, low carbon cement, carbon capture and storage (CCS), cross laminated timber (CLT), geopolymer concrete, recycled aggregates, carbon emissions, sustainability in the full life cycle

1. Introduction

Over the last few decades rapid urbanization and development of infrastructure have escalated demand for construction materials at an unprecedented rate. However, the production and use of conventional materials, such as cement, steel, and bricks, have been major GHG emitters. Almost 39% of energy related carbon dioxide (CO_2) emissions globally are caused by the building and construction sector, according to the International Energy Agency (IEA) [1]. The urgency to tackle climate change has caused researchers, policymakers, and industry stakeholders to take up sustainable practices and look for carbon neutral options in construction.

Over the years, carbon neutral building materials have been gaining attention as possibly addressing the environmental footprint of the construction industry. Consequently, these materials are designed to maximize reduction in embodied carbon emissions across the production, transportation, construction, and disposal phases of their lifecycle. The recent developments in the field of material science and innovative engineering techniques contribute to the creation of sustainable materials, recycled aggregates, and concrete with safe, alternative chemical compounds, which are not only environmentally friendly but also economically viable [2]. For instance, cross laminated timber (CLT) has gained momentum as a low carbon and renewable, safe alternative to conventional steel and concrete in structural applications [3]. Likewise, geopolymer concrete, utilizing industrial by products such as fly ash and slag, has also shown great potential to decrease carbon footprints over Ordinary Portland Cement (OPC) [4].

The purpose of this paper is to present a general view of sustainable construction and explain the advances in carbon neutral building materials. The objectives of this study include:

1) An analysis of environmental impact of traditional construction materials.
2) Novel carbon neutral materials and their applications in construction.
3) Sustainable Materials: Challenges & Opportunities for Adoption.
4) Case studies and real - world implementations of carbon neutral building materials.

This work addresses these objectives, adding to ongoing efforts to meet global sustainability goals for carbon neutrality in the built environment. The next few sections will go on to discuss the environmental challenges associated with conventional construction practices, review recent research on the use of more sustainable materials, and assess the degree to which these new materials can reduce our carbon footprint.

Environmental Challenges of Conventional Construction Materials

Significant materials carbon emissions are incurred by the construction industry using cement, steel, and bricks. Together, cement production alone contributes 8% of the world's CO_2 emissions, mainly arising from the energy intensive process of cement calcination and fuel combustion [5]. In addition, there are an additional 7 - 9% in emissions from the steel manufacturing as the high temperature processes required to convert iron ore to a usable steel [6]. As well as these emission materials generate large volumes of CO_2 when produced, plus have environmental impact throughout their life cycle, which is extraction, transportation, and disposal of them.

Another problem concerns resource depletion. For example, the raw materials extraction including limestone, sand and clay has caused habitat destruction and loss of biodiversity; it has also resulted in land degradation [7]. There is also a growing problem of the disposal of construction and demolition waste (CDW). It is estimated that in the European

Union nearly 25 - 30% of all waste is due to CDW [8]. Also land and water pollution is further aggravated by the use of inappropriate methods of disposal, which may pose harmful impacts on the environment and public health.

In addition, the embodied energy carried by conventional materials also plays an important role in buildings' lifecycle sustainability. Embodied energy is the total energy used in producing, transporting, and installing materials. It has been shown that embodied energy can actually represent up to 30% of the total energy consumption of a building throughout its entire lifecycle [9].

The solutions to these environmental challenges necessitate a paradigm shift in the way we construct. This includes lowering the carbon intensity of materials, supporting recycling and reuse, and pioneering technologies to decrease resource consumption and waste production. This paper presents an exploration of advanced carbon neutral building materials in the following sections to address these challenges.

Advancements in Carbon - Neutral Building Materials

Advancements in carbon neutral building materials have become part of a wider strategy to decarbonize the construction industry. The aim of these materials is to reduce the carbon footprint created during production, use and disposal of traditional building materials. Innovations in material science, coupled with sustainable engineering practices, have led to the development of several promising alternatives:

Renewable bio - based materials, including cross laminated timber (CLT), bamboo, and straw bales, also received attention because they are renewable and act as carbon sinks. CLT is widely used as an economical and low - carbon structural material for low - rise, mid - rise, and high - rise buildings. Studies have shown that although CLT can sequester up to 1.8 tons of CO_2 per cubic meter, it is an alternative that can achieve carbon neutrality [10]. Additionally, bamboo, a renewable construction material, grows quickly with high strength to weight ratio [11].

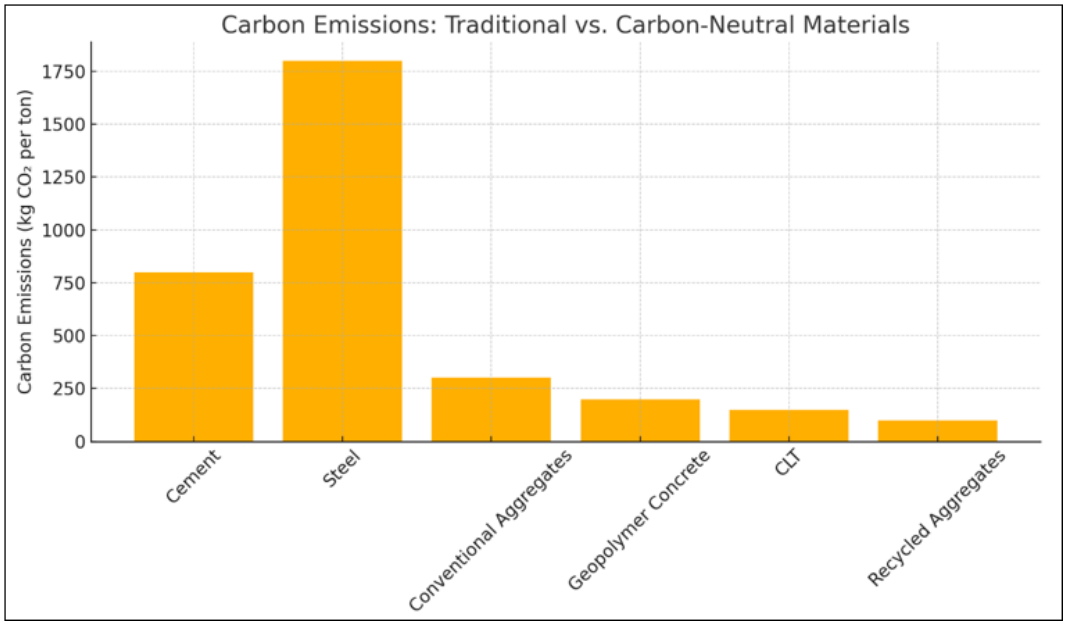

Figure 1: Comparison of Carbon Emissions (kg CO_2 per ton) for Traditional and Carbon - Neutral Building Materials.

Recycled Aggregates Recycled aggregates from construction and demolition waste (CDW) present promise to reduce environmental impact. Replacing natural aggregates with recycled alternatives will result not only in embodied energy and carbon emission reduction, but also in a reduction in disposal costs. When processed properly, recycled concrete aggregates (RCA) have been shown to achieve similar strength and durability as conventional aggregates [12].

Geopolymer concrete is a low carbon cement alternative using industrial by products like fly ash, slag, and silica fume, rather than ordinary Portland cement. The result is significantly reducing the carbon emissions linked to the process of cement production by as much as 80% [13]. Furthermore, carbon capture and storage (CCS) technologies have been found integrated into cement production process, which substantially mitigate emissions [14].

Innovative carbon – sequestering materials, including biochar infused concrete and carbon sequestering bricks, have demonstrated promising potential of pulling CO2 out of the atmosphere. These materials provide emission offset during production, and the sustainability of these buildings throughout their lifecycle is promoted [15].

The development and implementation of these materials demonstrate the potential for construction practices to contribute toward carbon emission reductions. This paper will then analyze in the next section, the challenges and opportunities that prevail in the global adoption of using carbon neutral building materials.

Challenges and Opportunities in Implementing Carbon - Neutral Materials

Carbon neutral building materials put forth by national labs show promise for environmental benefits, but large - scale adoption is challenged. The high cost of beginning to use

sustainable materials versus traditional options is one of the primary obstacles. For instance, bio - based materials such as cross laminated timber (CLT) and bamboo have higher production and transportation costs, especially in areas where supply chain is not well developed [16]. Moreover, since there are no standardized regulations and building codes for new materials, acceptance of these in mainstream construction projects is somewhat limited [17].

I have developed another significant challenge, however, the raw materials required for some sustainable alternatives are in limited availability. As an example, the manufacture of geopolymer concrete requires inclusion of industrial wastes, like fly ash and slag, that not available all over but may not be evenly available across all regions [18]. In addition, the long - term performance and durability's of these materials under different environmental conditions are still in research and are still not very conducive for industry stakeholders to consider them.

However, the opportunities that a carbon neutral material can provide are quite tremendous. As costs are reduced by advances in technological materials and as investment in research and development increases, the performance of sustainable replacement alternatives continues to improve [19]. Increasing consumer demand for sustainable infrastructure in addition to government incentives and green certifications supporting the transition towards carbon neutral construction practices [20]. In addition to these global initiatives United Nations Sustainable Development Goals (SDGs), and net zero emissions targets, are helping to bring international collaboration to develop sustainable construction solutions.

And to accelerate adoption it is critical to develop robust policies, material standards and education and training programs for construction professionals. Addressing these challenges and capitalizing on new opportunities, carbon neutral building materials can disrupt the construction industry, and provide major contribution to global sustainability goals.

2. Conclusion

Today, the construction industry is at a point that the uptake of carbon neutral building materials can take a significant part in mitigating the global climate crisis. In this paper, conventional construction practices are discussed in terms of their environmental implications, followed by an examination of a variety of low carbon construction materials including bio - based alternatives, recycled aggregate, low carbon cement, and carbon sequestering technologies. Though there are obstacles such as cost, material supply, and regulatory hurdles, yet the opportunities that come about with technological enhancements, policy aid and the universal target of sustainability make the future of electric planes bright. When these materials are integrated into mainstream construction practices, the industry can play a significant role in reducing carbon emissions, improving resource efficiency and in meeting a carbon neutral built environment. Overcoming barriers to the widespread adoption of sustainable materials that underpin a resilient and sustainable future requires a collective effort from stakeholders, policymakers, and industry leaders.

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