WAYS TO REDUCE CARBON FOOTPRINT IN BUILDING CONSTRUCTION

Sub theme: **Goal 9 - Industry, innovation and infrastructure**

Aditi Yadav[1]

[1][Student of S.B. Patil college of Architecture & Design, Pune, India]

Ar. Akshata Behere[2]

[2][Professor at S.B. Patil College of Architecture & Design, Pune, India]

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Abstract

The main goal of this research paper is to examine methods for lowering the carbon footprint of the construction sector. It tackles the main reasons why carbon emissions are rising, which are caused by traditional building materials and construction methods that mainly use energy-intensive materials like concrete, steel, and cement. These materials, especially those found in high-rise buildings, greatly increase carbon emissions worldwide. In order to lower these emissions, the study suggests sustainable alternatives like geopolymers, low-carbon cement, and locally produced materials like bamboo and cross-laminated timber. In order to increase energy efficiency, it also looks at alternative building techniques like waste heat recovery, modular construction, and prefabrication.

Through case studies, such as the Brock Commons Tallwood House and a net-zero energy building in Madagascar, the paper demonstrates the effectiveness of these strategies in reducing carbon emissions. However, it is acknowledged that there are obstacles to adopting sustainable construction practices, including high upfront costs, a lack of knowledge, supply chain problems, and regulatory barriers.

Keywords

Carbon Emission; Building construction; Sustainable materials; Construction techniques

1. Introduction

High rise buildings are becoming more and more common because of the rapid urbanization of cities, which helps accommodate the increasing population in a narrow land area. Such buildings, however, are a threat to environment because their construction and even the operation of the buildings throughout consumes a lot of energy including energy intensive materials such as steel and concrete which raises the carbon emission. As a result of their construction, it has been stated that construction of buildings contributes approximately to 40% of world carbon emissions, with a substantial share originating from high-rise developments. (Huang, 2018). Many concerns such as air pollution, depletion of resources (raw material) and the climate change have worsened the situation. (Giesekam, 2016)

Due to environmental factors that enhance such impacts, it is much needed to lower the carbon footprint of high-rise construction by using eco-friendly materials, (Giesekam, 2016) better energy generation, and energy efficiency, and applying clean energy technologies. Thus, lowering the carbon footprint of high-rise building is essential to ensuring the long-term economic viability of urban developments, improving public health, minimizing the effects on the environment, and aligning with sustainability goals.

2. Causes of increasing Carbon Emissions-

The use of high-energy materials, like concrete, steel, and bricks, which have significantly embodied carbon footprints, is the main cause of the rise in carbon emissions in building construction caused by conventional materials and techniques. Conventional building techniques frequently depend on energy-intensive procedures, such as the extraction, manufacturing, and transportation of raw materials. Furthermore, traditional designs frequently overlook opportunities to lower emissions through the use of low-carbon materials and more efficient building techniques in favour of durability and affordability over environmental impact.

Because conventional construction methods rely on energy-intensive materials and processes, they are a significant source of carbon emissions. Large volumes of CO_2 are released during the cement production process for concrete, and conventional on-site batching frequently results in material waste. The production of bricks in kilns that burn fossil fuels also releases a lot of greenhouse gases, and the use of diesel-powered equipment and the transportation of bulky materials increase the carbon footprint even more. Furthermore, these techniques rarely use energy-efficient designs and produce a lot of waste, which raises emissions over the course of a building's lifecycle. In order to lessen these effects, sustainable alternatives are crucial.

The carbon footprint of buildings can be significantly decreased by switching to sustainable materials and cutting-edge techniques like prefabrication, modular construction, and the use of recycled or bio-based materials.

3. Conventional Material and Construction Techniques

3.1 Materials-

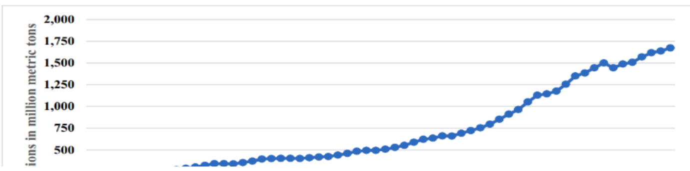

Figure 1 2.1.1 Carbon dioxide emissions from the manufacture of cement worldwide
Source- (Oluwafemi Ezekiel Ige, 2024) (Garside 2022a)

3.1.1 Cement:

India is one of the most significant contributors to carbon emissions in construction, the production of cement which raised up-to 1750 million metric ton in 2020 involves the calcination of limestone, which releases CO2. It is estimated that producing one ton of cement emits approximately 0.7 to 0.99 tons of CO_2.

3.1.2 Concrete-

Since cement is the primary ingredient in concrete, concrete inherits the carbon emissions related to cement production. Because concrete is manufactured using energy-intensive processes, it has a significant overall carbon footprint.

3.1.3 Steel-

The production of steel, particularly from iron ore, is highly energy-intensive and results in significant CO2 emissions. The carbon footprint is especially high when using virgin materials rather than recycled steel.

3.1.4 Bricks-

The bricks are manufactured by baking them in high temperature which causes high carbon emission as it consumes a lot of energy in fire. This energy contributes to overall carbon footprint of bricks.

3.1.5 Glass-

The production of glass involves raw material at high temperature, this heating contributes in carbon footprint of glass because high energy consumption in heating, especially if the glass is newly made and not from recycled glass.

3.1.6 Asphalt-

Asphalt is majorly used in road construction, which is derived from petroleum products. The production process leads to Greenhouse gas emission.

3.1.7 Aggregates-

The extraction and processing of natural aggregates like sand, gravel and crushed stone also contributes in carbon emission, as the mining and transportation of these materials is energy consuming.

These raw materials are essential in the construction industry but are associated with high levels of carbon emissions, making them critical targets for strategies aimed at reducing the carbon footprint of construction practices.

3.2 Conventional Construction Techniques-

Through a number of processes, the production of steel and cement is one of the main ways that conventional construction techniques significantly increase carbon emissions. When limestone is calcined (which accounts for 50% of the global CO2 emissions) and fossil fuels are burned (which accounts for 40% of the emissions) during the kiln heating process, cement production alone accounts for about 8% of CO2 emissions worldwide. The use of electricity, transportation, and production process inefficiencies all contribute to additional emissions. Cement is one of the biggest emitters in the construction industry, releasing 0.5 to 0.9 tons of CO2 for every ton produced.

Similar to how steel production accounts for 7-9% of global CO2 emissions, steel is another essential component of reinforced concrete structures. This is mostly because blast furnaces use coal, and the extraction and processing of iron ore are energy-intensive processes. The carbon footprint of traditional construction is further increased by the production and delivery of steel.

Emissions are also a result of the production of bricks, mainly from the energy-intensive firing of clay bricks in conventional kilns. These kilns, which are frequently inefficient, burn fuel at high temperatures, which causes considerable CO2 emissions while the product is being produced. Furthermore, 5–10% of the total emissions are caused by the transportation of materials to construction sites, such as steel, cement, and bricks, depending on the distances and modes of transportation. In general, the carbon footprint of traditional construction methods is greatly increased by the manufacturing of building materials, their transportation, and the on-site use of large machinery. (Oluwafemi Ezekiel Ige, 2024)

4. Alternative Material and Techniques

4.1 Alternate Materials-

4.1.1 Geopolymers-

Made from aluminosilicate materials such as fly ash, metakaolin, and industrial by-products like red mud, geopolymers are inorganic polymers. These materials are made without the use of high temperatures, unlike traditional cement production, by a polycondensation reaction in an alkaline medium. Due to their low energy consumption during production which takes place at temperatures below 120°C, geopolymers are a sustainable substitute for Portland cement. This lowers the CO2 emissions that are typically associated with cement. In addition to their advantages for the environment, geopolymers have a high compressive strength, which qualifies them for use in high-rise buildings' load-bearing structures. They also extend the life of buildings because of their exceptional resistance to fire, acids, and thermal deterioration. Their versatility in sustainable construction is demonstrated by their use in the production of eco-friendly concrete and mortar, as well as in specialized applications like the encapsulation of toxic waste. (Carlos Sotelo-Piña, 2018)

4.1.2 Low-carbon cementitious materials-

Low-carbon cementitious materials are substitutes for conventional cement that are designed to lower the high CO2 emissions connected to cement manufacturing, especially from the limestone calcination process. Clinker substitution is a crucial tactic that lowers the carbon intensity of cement by substituting parts of the clinker with materials like fly ash, slag, and limestone. Fly ash, a by-product of burning coal in power plants, is frequently used to make cement because it greatly reduces CO2 emissions while also enhancing the strength and durability of concrete. Similarly, clinker can be substituted with slag, a byproduct of steel production, increasing cement's sustainability. In addition to helping to lessen the carbon footprint associated with cement production, these alternatives offer additional technical advantages like better workability and durability for the concrete mix. The cement industry can significantly lower greenhouse gas emissions globally by incorporating these low-carbon alternatives, particularly in large-scale construction projects like high-rise buildings. (Federico Orsini*, 2019)

4.1.3 Natural and Local Materials-

Another sustainable option is to build high-rises using natural materials like bamboo, rammed earth, and wood. Not only do these materials lower the embodied carbon in buildings, but they also sequester carbon during the growth phase—especially wood. Particularly wood has been more and more popular because it can be used in tall buildings instead of traditional steel and concrete, and engineered wood products like cross-laminated timber (CLT) are strong enough structurally to be used in high-rise applications. They are also environmentally friendly since they use locally sourced materials, like sandstone, clay, or stone, which helps to further reduce emissions related to processing and transportation. When compared to conventional building materials like steel and concrete, these locally sourced and naturally occurring materials can drastically lower the carbon footprint of construction by as much as 90%. They can also encourage sustainable building practices that boost regional economies. (Federico Orsini*, 2019), (Oluwafemi Ezekiel Ige, 2024)

4.1.4 Alternative Fuels and Clinker Substitution-

The use of alternative fuels and clinker substitutes in cement production is another promising strategy for lowering the carbon footprint of construction. The conventional method of producing cement is primarily dependent on fossil fuels, which account for a substantial amount of the $CO2$ emissions produced by the sector. By substituting for traditional fossil fuels, alternative fuels can reduce the carbon intensity of the production process. Examples of these fuels include biomass, waste-derived fuels, and even processed municipal waste. Furthermore, other materials such as fly ash, slag, or limestone can be used in place of clinker, the primary ingredient in traditional cement, lowering the energy needed to produce it and subsequently lowering emissions overall. By using these techniques, the cement industry can cut its carbon emissions by up to 40% and help create a more sustainable building industry without sacrificing the high-rise buildings' necessary structural integrity.

Alternative Fuels (AFR): A major reduction in carbon emissions can be achieved by replacing conventional fuels with fuels derived from waste, such as plastics, rice husk, and industrial waste. For instance, up to 40% thermal substitution has been achieved in European cement plants; this could lead to an annual reduction of more than 13.77 million tons of $CO2$.

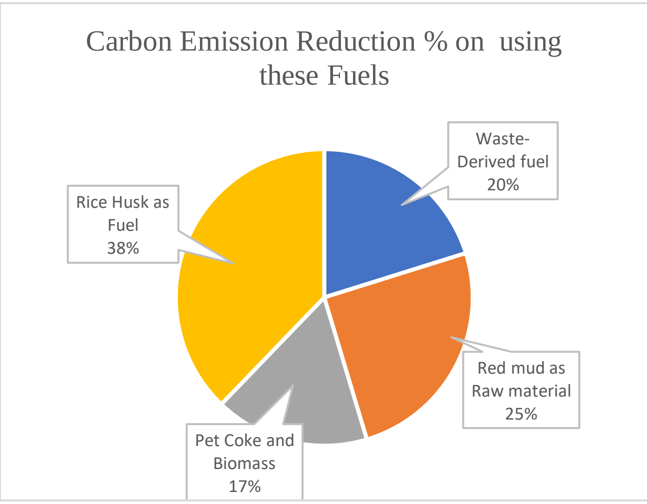

Figure 2 Alternative fuels 4.1.4

Pet Coke and biomass: It has been demonstrated that using pet coke in conjunction with biomass such as agricultural waste reduces emissions while preserving high energy efficiency. This is a standard procedure in many cement factories which reduces up-to 17% of carbon emission as shown in **figure 2.**

Rice Husk: Because it is a biomass fuel, rice husk significantly lowers carbon emissions to 38% when used as an alternative fuel. Compared to coal, it contains less carbon and contributes to a decrease in GHG emissions overall.

Red mud as Raw Material: Red mud reduces emissions about 25% by preventing the calcination of virgin materials, which lowers $CO2$ emissions during production. Red mud can be used as an alternative raw material in place of conventional inputs like limestone. ((CII), 2011)

4.2 Alternative Techniques-

4.2.1 Energy Efficient Equipment's-

The utilization of energy-efficient construction equipment contributes to a decrease in fuel consumption and the consequent release of greenhouse gases. Similar to hybrid or electric cars, modern construction equipment uses less fuel than conventional diesel or gasoline-powered equipment.

By using fewer fossil fuels, the installation of energy-efficient equipment on building sites directly reduces operational emissions. Lower CO_2 footprints when compared to conventional counterparts are made possible by energy-efficient equipment such as electric cranes, lifts powered by batteries, and other machinery.

For instance, on green building sites, electric bulldozers and hybrid excavators—which combine electric and fuel power—are growing in popularity. These devices maintain the same levels of productivity as conventional devices while using less fuel and producing less noise.

4.2.2 On-Site waste management

Recycling, material reuse, and waste reduction are all important components of effective on-site waste management. Instead of dumping the on-site waste to some other location which will lead to more carbon emission due to transportation, these wastes can be used on some other site as landfill to smoothen the irregular land surface. Lowering material waste results in less resources needed to replace lost materials, which lowers emissions related to the production, transportation, and disposal of materials. It also reduces landfill waste, which is a major source of the powerful greenhouse gas methane.

For instance, recycling old concrete and using it as aggregate in new construction projects can cut down on the amount of new concrete required and consequently the emissions associated with the cement industry.

4.2.3 Waste Heat Recovery (WHR)-

Waste heat recovery systems are designed to collect and repurpose heat produced by processes that take place on-site. Many processes in construction generate heat that can be turned to good account instead of wasting. The need for external energy sources can be decreased by using WHR systems to transform this captured heat into energy for use in other on-site operations. Reusing waste heat locally lowers energy use overall. On construction sites, energy generation from waste heat can reduce dependency on fossil fuels or grid electricity. For example, on-site power generators or large machinery heat can be captured by WHR technology and used to power other equipment or heating materials on site.

Table 1 Comparison of 3 & 4

Aspect	Conventional Material & techniques	Alternative Material & techniques
Carbon Emissions (CO_2)	Cement: 70-90% (0.5-0.9ton CO_2/ton) produced.	Geopolymer: 30-80% less than cement
	Steel: 7-9% produced.	CLT: 60-70% less than steel
Energy Use	Cement: 50% manufacturing process emission.	Geopolymer: 40% less than cement.

	Steel: 40 % manufacturing process emission	40-60% less than that of steel.
Alternative Fuels & WHR	100% reliance on fossil fuels.	Use of alternative fuels like rice husk reduces carbon emissions by 38%.
Waste Management Impact	5-10% energy consumption in transport of on-site waste.	25% less as the waste is reused or recycled on site.
Sustainability	70% of emission in entire construction process.	30-40 % emission reduced by using sustainable construction material

The comparison in **Table 1.** shows how using alternative building materials and methods, like cross-laminated timber (CLT) and geopolymer concrete, can significantly reduce the carbon footprint of construction. In comparison to traditional materials like steel and cement, these substitutes cut energy use by 40–60% and CO2 emissions by up to 80%. Emissions are further reduced by employing sustainable practices like using alternative fuels and recycling waste on-site. All things considered, these modifications lead to more environmentally friendly building methods and a notable decrease in the environmental effect of the sector.

5. Case Studies

4.1Brock Commons Tallwood House-

One example of the potential of mass timber in high-rise construction is the eighteen-story hybrid residential building Brock Commons Tallwood House at the University of British Columbia (UBC). The project, which was finished in 2017, incorporates steel, concrete, parallel strand lumber (PSL), glued-laminated timber (GLT), and cross-laminated timber (CLT). It sets a new benchmark for sustainable building practices with its mix of studio and four-bedroom apartments that house 404 students and include public and study spaces.

Figure 3 Construction method ((CWC), 2017)

Figure 4Building View ((CWC), 2017)

The building's podium and elevator cores are made of concrete, while the upper stories are made of mass timber. The floors are composed of CLT panels that are held up by GLT and PSL columns. Steel connectors do away with the need for beams. The concrete components guarantee adherence to safety regulations by offering lateral stability and fire resistance. Labor and waste were decreased by using off-site manufacturing for prefabricated components. The project avoided 679 metric tons of CO2 emissions (equivalent to taking off 511 cars off the road for whole year) and sequestered 1,753 metric tons of CO2. By achieving a two-hour fire-resistance rating and encasing timber elements with Type X gypsum board, fire safety was guaranteed. By avoiding design conflicts and coordinating schedules, virtual design technology (VDC) expedited construction. Architects, engineers, and contractors worked together to optimize the design in terms of efficiency and performance. Future sustainable high-rise structures will be guided by the low-carbon high-performance model set by the Brock Commons Tallwood House.

4.2 Net Zero Energy Buildings and Low Carbon Emission-

In this case study, the application of sustainable building methods in Madagascar-more specifically, in Antananarivo is presented. The study discusses the difficulties brought on by climate change and the requirement for environmentally friendly, energy-efficient buildings in Sub-Saharan Africa.

The building was designed using a holistic approach that maximized sustainability and energy efficiency. The procedure started with a study of the climate and comfort, taking into consideration the tropical high-altitude climate of Antananarivo, which is distinguished by warm, rainy summers and cool, dry winters. Fifteen years of weather data were collected using Meteonorm software, and thermal comfort parameters like operating temperature and predicted mean vote (PMV) were evaluated using Design Builder software. In order to improve insulation and reduce carbon impact, the building materials selection was centred on sustainability, using 80% local resources such as wood, limestone silicon, and hemp. These resources also offered low thermal conductivity, emissions, and cost. Design Builder was used during the modelling and optimization stage to optimize the building's performance and achieve zero heating and cooling energy requirements with an optimal 11 cm insulation thickness.

Despite an initial 40% cost increase, the results show a 99% reduction in CO_2 emissions and annual savings of $475 beginning in 2030. The integration of wind turbines and photovoltaic panels, which can produce energy up to 13 times that of the building and make it energy-positive, is another feature of the research that is highlighted. In order to combat power shortages and climate vulnerability, the study recommends government support for the widespread adoption of ecological buildings in Madagascar, despite their higher initial costs.

Table 2 Comparative Analysis of Case Study

Aspect	Brock Common Tallwood House	Net Zero Energy Buildings
Location	University of British Columbia	Antananarivo, Madagascar
Building Type	High-rise residential (18-story hybrid building)	Sustainable, energy-efficient building
Construction Year	Completed in 2017	
Materials Used	Mass timber (PSL, GLT, CLT), concrete, steel	Local materials (wood, limestone silicon, hemp)
Structural Design	Concrete podium and elevator cores; timber for upper stories	Designed with optimal 11 cm insulation thickness
Carbon Emission Impact	Avoided 679 metric tons of CO_2 emissions; sequestered 1,753 metric tons	99% reduction in CO_2 emissions
Energy Efficiency	Focus on sustainable building practices	Achieved zero heating and cooling energy requirements
Project Benefits	Low-carbon, high-performance model for future sustainable high-rise	Energy-positive potential, annual savings, and carbon reduction

The comparison shown from **Table 2.** it is observed that how different sustainable construction methods can be used to address various environmental and regional issues. The Brock Commons project demonstrates how prefabrication, carbon sequestration, and fire safety measures can contribute to a low-carbon, high-performance structure by integrating mass timber with conventional materials like concrete and steel in a high-rise setting. By integrating renewable energy sources and attaining a 99% reduction in carbon emissions, the Madagascar case study, on the other hand, focuses on energy efficiency and the use of local materials in a tropical climate, with the possibility of making the building energy-positive.

While both projects demonstrate significant progress toward sustainability, they have different goals: In developed regions: The Madagascar initiative responds to the need for energy-efficient, climate-adapted buildings in developing regions, while Brock Commons serves as a model for urban high-rise construction in developed regions. When taken as a whole, they provide insightful information about how sustainable building methods can lessen their negative effects on the environment and increase resilience in a variety of situations.

6. Challenges to Sustainable Construction

When compared to traditional methods, sustainable construction that uses alternative materials and techniques faces a number of difficulties. Durability and performance are among the main issues. In contrast to conventional materials like concrete and steel, alternative materials—such as bio-based alternatives like bamboo and hempcrete—frequently raise concerns about their long-term efficacy and structural integrity. Even though these substitutes can drastically cut waste production and carbon emissions, it's still difficult to make sure they adhere to building codes.

Cost considerations are also very important. Although energy savings from alternative materials may result in lower lifecycle costs, their initial costs may be higher than those of conventional materials, discouraging builders from implementing them in a market that is frequently centred on short-term savings. Regulatory barriers also pose challenges because building codes usually do not keep up with technological developments. The use of sustainable materials without established compliance measures may be restricted as a result, making it more difficult to incorporate them into building projects.

Furthermore, another major obstacle is market acceptance. Due to unfamiliarity or perceived risks, stakeholders—such as clients, contractors, and financiers—may be reluctant to adopt new materials. Educational programs and successful case studies proving the feasibility of these alternatives are crucial to promoting a change in perception. Since managing waste produced during the production and use of alternative materials can negate some of their environmental benefits, waste management poses its own set of problems. Recycling procedures, for instance, may require a lot of energy, which reduces their sustainability impact. Last but not least, resource availability is a real issue; although environmentally friendly options like bamboo are ideal, their use may be limited in some areas due to their limited accessibility. (Okwandu, 2024)

7. Conclusion

In Conclusion the study emphasizes how urgent it is to cut carbon emissions in the building industry by moving away from traditional materials and methods that mainly rely on energy-intensive procedures. The carbon footprint of construction can be greatly decreased by using innovative methods like prefabrication, modular construction, and energy-efficient equipment, as well as sustainable materials like geopolymers, low-carbon cement, and local resources like bamboo and timber. Eco-friendly alternatives are available, but the industry still faces obstacles like high upfront costs, a lack of awareness, and regulatory restrictions. In order to overcome these challenges and accomplish sustainability objectives, cooperation between government organizations, developers, and construction experts is crucial.

Through successful case studies, this research demonstrates that significant reductions in carbon emissions and energy use are attainable, promoting a more sustainable future for the built environment.

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