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Low-Carbon Building Materials: An Overview of Innovative Alternatives to Traditional Materials

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Abstract

The building industry is a major contributor to global greenhouse gas emissions, accounting for approximately 40% of global energy-related emissions. Low carbon building materials offer a promising opportunity to reduce the environmental impact of the building sector.

Low carbon building materials are those that have a low embodied carbon, meaning that they require less energy and resources to produce. They can be made from a variety of materials, including recycled materials, natural materials, and sustainable materials.

This study will examine the benefits, limitations, challenges, and opportunities associated with the use of low carbon building materials. The study will focus on the different types of low carbon building materials and technologies currently available, including straw bale, bamboo, fly ash and CEB. The study will examine the benefits, limitations, and challenges associated with using these materials and explore the opportunities provided by their adoption. A review of academic literature, industry reports, and case studies will be conducted as part of this study.

Keywords: Low carbon building materials, architecture, Compressed earth blocks (CEBs), Fly ash bricks, Bamboo, Straw bales, sustainability.

INTRODUCTION

1.1 Background

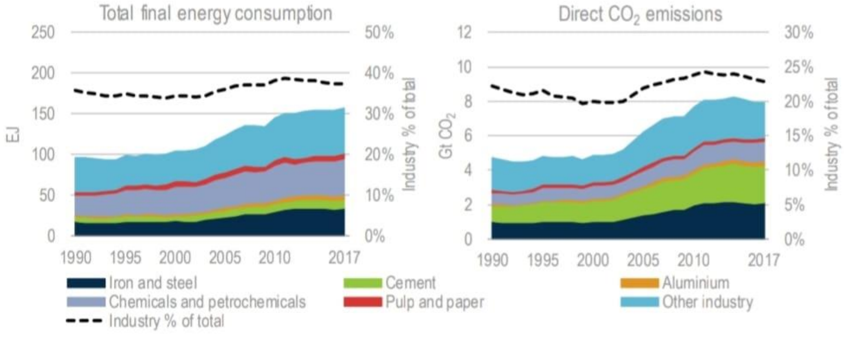


Figure 1 Global energy consumptions and CO2 emissions Source: iea.org

With a growing emphasis on decreasing the carbon footprint of buildings across the complete lifespan of materials, construction, usage, and disposal, the current state of low carbon building materials in construction is fast evolving. The building industry, which contributes significantly to the world's greenhouse gas emissions, is being increasingly recognised for its negative environmental effects.
Low carbon building materials have become more prevalent in recent years as a result of this awareness. By utilising environmentally friendly production techniques, lowering energy consumption during usage, and limiting trash during disposal, these materials are intended to lessen the carbon footprint of buildings.

1.2 What are low-carbon building materials?

Low carbon building materials are materials that have a low embodied energy, which means they have a minimal impact on the environment during their production and transportation.

To reduce the carbon footprint of building construction, low carbon building materials must be used. In walls, these materials may include compressed earth blocks, fly ash bricks, bamboo, and straw bales.

1.3 Aim of the study

The aim of this study is to evaluate the benefits, limitations, challenges, and opportunities associated with the use of low carbon building materials and building technologies.

1.4 Objectives

1. To identify the different types of low carbon building materials available and their properties.
2. To examine the environmental benefits of using low carbon building materials.
3. To identify the limitations and challenges associated with the use of low carbon building materials in terms of availability and performance.
4. To provide recommendations for the wider adoption of low carbon building materials in the construction industry.

1.5 Scope

The study will focus on the different types of low carbon building materials and technologies currently available, including straw bale, bamboo, fly ash and CEB. The study will examine the benefits, limitations, and challenges associated with using these materials and explore the opportunities provided by their adoption. A review of academic literature, industry reports, and case studies will be conducted as part of this study.

1.6 Limitations

The study will not cover the full lifecycle assessment of low carbon building materials. Additionally, the study will focus on the current state of low carbon building materials and may not account for new developments that may occur during the study period.

1.7 Methodology

- literature study
- case studies
- inferences
- conclusion

LITERATURE STUDY

1.8 Low carbon building materials used in walls in hot and humid climate zones in India:

1.8.1 Compressed earth blocks (CEBs)

- Made by compressing moistened soil and stabilizers like cement or lime.
- Good thermal mass and insulation properties, which can help keep buildings cool in hot weather.
- Can be made on-site, reducing transportation costs and emissions.
- Requires a certain level of skill and equipment to produce.
- Vulnerable to water damage if not properly stabilized or protected.

The global market for CEBs is expected to grow at a CAGR of 4% from 2020 to 2025.

Here is a brief overview of the various stages involved in the production of CEBs:

- **Material Extraction**: Usually, local quarries or borrow pits supply the raw materials for CEBs. Debris, pebbles, and other contaminants shouldn't be present in the soil or sand utilised in CEBs.
- **Manufacture**: In order to produce a homogeneous mixture, the soil, sand, and water must be mixed in a particular ratio. The blocks are then created by compressing the mixture using a hydraulic press.
- **Construction**: Walls, foundations, and roofs are just a few of the building projects that CEBs can be utilised for. To create a solid and stable framework, they are often set out in a stacked or interlocking pattern. When compared to burned clay bricks, much less mortar is used (50 to 60% less).
- **Operation**: The least maintenance-intensive building materials are CEBs. Since they are resistant to termites, moisture, and other environmental factors, they are a reliable solution for building construction.
- **Demolition**: When a structure formed with CEBs has served its purpose, it can be disassembled and the blocks recycled or used again in new construction. Buildings made of CEBs can be taken down in a relatively quick and clean manner without creating any trash or pollution.

1.8.2 Fly ash bricks

- Made by mixing fly ash (a waste product from coal-fired power plants) with cement and water.
- Low water absorption, which makes them suitable for humid climates.
- Can be mass-produced in factories, reducing production time and costs.
- Contains heavy metals and other pollutants, which can affect air and water quality if not disposed of properly.
- The use of fly ash bricks in construction can reduce the amount of waste generated from power plants.
- Fly ash bricks can be manufactured using a variety of binding agents, including cement, lime, and gypsum.
- The demand for fly ash bricks in India is expected to grow at a compound annual growth rate (CAGR) of 7% from 2020 to 2025.

Here is a brief overview of the various stages involved in the production of fly ash bricks:

- **Material Extraction**: Fly ash is collected from coal-fired power plants and transported to a processing plant.
- **Manufacture**: To create a slurry, the fly ash is combined with water and a little cement. After that, this slurry is poured into molds and left to dry. The bricks are removed from the molds once they are dry and heated in a kiln.
- **Construction**: Fly ash bricks are used in the construction of walls, foundations, and other structural elements. They are strong and durable and can withstand heavy loads. The bricks are laid in a stacked or interlocking pattern to form a strong and stable structure.
- **Operation**: Fly ash bricks require minimal maintenance and can last for many years with proper care.
- **Demolition**: Fly ash bricks can be disassembled, recycled or used again for other construction projects after they have served their purpose in a building. Fly ash brick buildings are easy to tear down and don't create any waste or pollution in the process.

1.8.3 Bamboo

- A fast-growing and renewable resource.
- Bamboo can be used as a substitute for timber and steel in construction.
- The demand for bamboo in construction is expected to grow at a CAGR of 8% from 2020 to 2025.

Here is a brief overview of the various stages involved in the production of bamboo:

- **Material Extraction**: Bamboo is a type of grass that grows in many parts of the world. It is typically harvested when it reaches maturity, which can take anywhere from 3-5 years depending on the species.
- **Manufacture**: Once the bamboo is harvested, it is cut into usable pieces and processed in a variety of ways to make it suitable for construction use. This can include stripping the bamboo of its outer layers, treating it to make it more durable, and cutting it into the desired size and shape.
- **Construction**: Bamboo can be used in a variety of ways in construction, such as in the form of beams, columns, walls, flooring, and roofing. It is strong and durable and can be used to create structures that are both sustainable and aesthetically pleasing.
- **Operation**: Bamboo structures require minimal maintenance and can last for many years with proper care. They are also resistant to earthquakes and other natural disasters, making them a safe and reliable choice for building construction.
- **Demolition**: When a bamboo structure has served its purpose, it can be disassembled and the bamboo can be recycled or used again in other buildings. Buildings made of bamboo may be destroyed in a reasonably quick and clean manner without creating any trash or pollution.

1.8.4 Straw bales

Made from baled straw, a waste product of agriculture

The demand for straw bale in construction is expected to grow at a CAGR of 5% from 2020 to 2025.

- **Material Extraction**: Straw is a by-product of cereal crops such as wheat, barley, and oats. It is typically harvested in the late summer or fall and then dried to reduce its moisture content.

- **Manufacture**: The dried straw is then typically bundled into bales that are typically 4 feet wide, 8 feet long, and 4 feet high. The bales are tightly compressed to increase their strength and stability.
- **Construction**: Straw bale construction involves stacking the bales vertically and then securing them together with a combination of wooden laths and a wire mesh. The bales are then covered with a layer of plaster or stucco to provide insulation and protect the structure from moisture.
- **Operation**: Straw bale buildings are typically well insulated and can maintain a comfortable temperature year-round. They are also resistant to fire and pests.
- **Demolition**: When a straw bale building reaches the end of its useful life, it can be dismantled, and the straw bales can be reused or recycled for other construction projects. The process of demolishing a straw bale building is relatively simple and does not produce any waste or pollution.

1.9 Review of the different qualities of the materials

Table 1

Materials	CEBs	Fly ash	Bamboo	Straw bale
Advantages	Durable, stable, fire-resistant, soundproof, good insulation	Durable, high strength, good insulation properties, Low water absorption: resistant to erosion and deterioration.	Good insulation properties, strong and durable, less time-consuming construction process, requires less skilled labour.	Good insulation properties, relatively simple construction process, strong and durable Good tensile strength and flexibility, making it resistant to earthquakes and high winds
Disadvantages	Heavy, requires skilled labour. Availability: CEBs may not be readily available in all locations. The quality of CEBs can vary depending on the mixture of soil, sand, and cement used.	Requires skilled labour, time-consuming construction process. The availability of fly ash may depend on the location and the capacity of nearby power plants.	Requires proper treatment to prevent decay and insect damage, The quality of bamboo can vary depending on the species and the growing conditions,	Requires proper moisture management, may attract pests, The quality of straw bale can vary depending on the moisture content and the processing method. Straw bale may not be as fire-resistant as other building materials.
Cost	CEBs are generally less expensive than	Fly ash bricks can be more expensive	Bamboo may be more expensive	Low cost (Since, India is the second largest

	conventional bricks	compared to conventional bricks.	compared to other building materials.	producer of rice and wheat)
Market status	Increasing popularity in rural areas due to low cost and durability (approx. Rs. 861/m^2)	Widely used in urban and rural areas due to low cost and good strength (approx. Rs. 754/m^2)	Increasing popularity in urban areas for its sustainability and aesthetic appeal (approx. Rs. 3200/m^2)	Limited use due to lack of awareness and expertise in construction

1.10 Comparison of physical and chemical properties of the materials with Country Fired Bricks

Table 2

Material	CEBs	Fly ash	Bamboo	Straw bale	Country fired Brick
Fire resistance	High	High	Moderate	Moderate	High
Ignition point	600°C to 700°C.	600°C to 700°C.	400°C to 500°C	450°C to 550°C	600°C to 700°C
Compressive strength(MPa)	10 MPa to 40 MPa	20 MPa to 40 MPa	20 MPa to 65 MPa	5 MPa to 20 MPa	10 MPa to 20 MPa
Tensile strength (MPa)	0.5 MPa to 1.5 MPa	2.5 MPa to 4.5 MPa	2.5 MPa to 5.0 MPa	0.5 MPa to 1.0 MPa	1.0 MPa to 3.0 MPa
Thermal conductivity	Low	High	Low	Low	High

Note: These values are approximate and can vary depending on the specific composition and manufacturing process of the materials.

1.11 Assessment of environmental impact:

The data in the table is a summary of the environmental impact of different building materials based on various studies and research.

According to GRIHA, CEBs consume 7.9 times less energy than Country fired bricks.

Table 3

Material	CEBs	Fly ash	Bamboo	Straw bale
Embodied Energy (MJ/m^3)	572.6	1,000	150	100
Global Warming Potential (kg CO2e/m^3)	170	300	50	30
Acidification Potential (kg SO2-eq/m^3)	0.01	0.02	0.005	0.003

Eutrophication Potential (kg N-eq/m^3)	0.005	0.01	0.002	0.001

Note: The data may vary depending on the specific conditions of the material's production, use, and disposal. Additionally, some studies may use different methods to calculate the environmental impact, so the values in the table should be considered as a rough estimate rather than definitive data.
It is also important to note that Fly ash is an industry waste, so the embodied energy is high but use of fly ash bricks in construction can reduce the waste generated from industrial plants.

1.12 Study of material's potential in India

1.12.1 Fly ash

According to a case study of fly ash brick manufacturing units at Kota in Rajasthan conducted by IOP Conference Series: Materials Science and Engineering, the Government of India is moving in the right direction by making rules for the utilization of fly ash-based products.

In the financial year 2015-16, only 61% of the fly ash generated in India was utilized. However, Kota Super Thermal Power Station was successful in utilizing more than 100% of the fly ash it generated.

Of the total fly ash utilized in India during this period, 36.06% was used to produce bricks, tiles, and blocks. Fly ash bricks cost consumers Rs. 2.50 each, while conventional fired clay bricks cost Rs. 3.50 each. The manufacturing units that produce fly ash bricks make a profit of Rs. 0.40 per brick. This means that unit one and unit two make a profit of Rs. 6,000 and Rs. 8,000 per day, respectively.

The government's rules on fly ash utilization are a positive step. They will help to reduce the environmental impact of fly ash, and they will also create new opportunities for businesses.

1.12.2 Straw bale

According to data, India is severely lacking in conventional and traditional building materials. All sand mining operations in the nation are currently prohibited by a restraint order issued by the National Green Tribunal (iasscore.in). The official procedure of getting EC for sand mining activities would therefore require more time, which could have a significant influence on the ready supply of sand in the near future.

This suggests that as knowledge grows in the coming years, the manufacturing of clay-burnt bricks will gradually decrease.

On the other hand, the growing population in rural areas necessitates a lot of construction work. Building supplies that are readily available are always in demand in rural areas. For construction projects in rural settings, designers and architects are looking for sustainable, alternative, locally accessible building materials. To close the gap, strawbale building is a suitable replacement.

Since rice is the nation's main crop, India has the most land under rice production. With over 130 million tonnes of straw, India produces 98 million tonnes of paddy. Farmers attempt to get their fields ready for

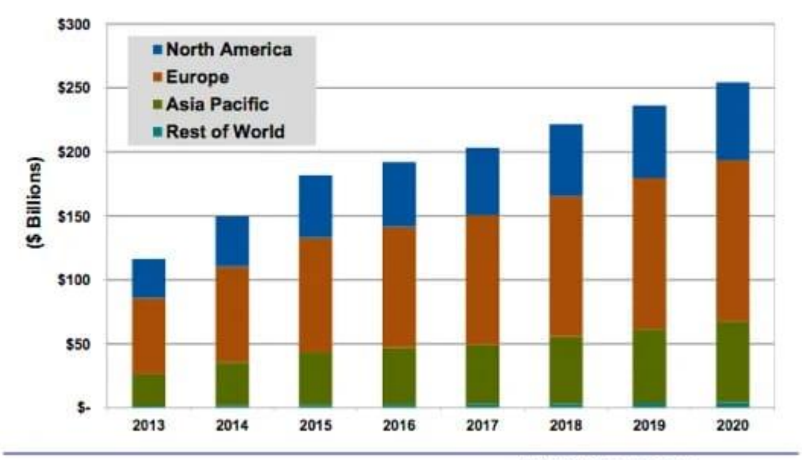
the following crop in order to increase crop production. Consequently, handling the leftover straw for site clearance is a constant challenge. The quickest way to get rid of these leftovers is to burn them.
Straw is widely accessible in India and has the potential to be used to construct millions of homes. Given that strawbale construction is a cheap building material and can use up to 60% to 70% less energy than traditional buildings, it can be an excellent option for inexpensive housing in India.

1.13 Opportunities:

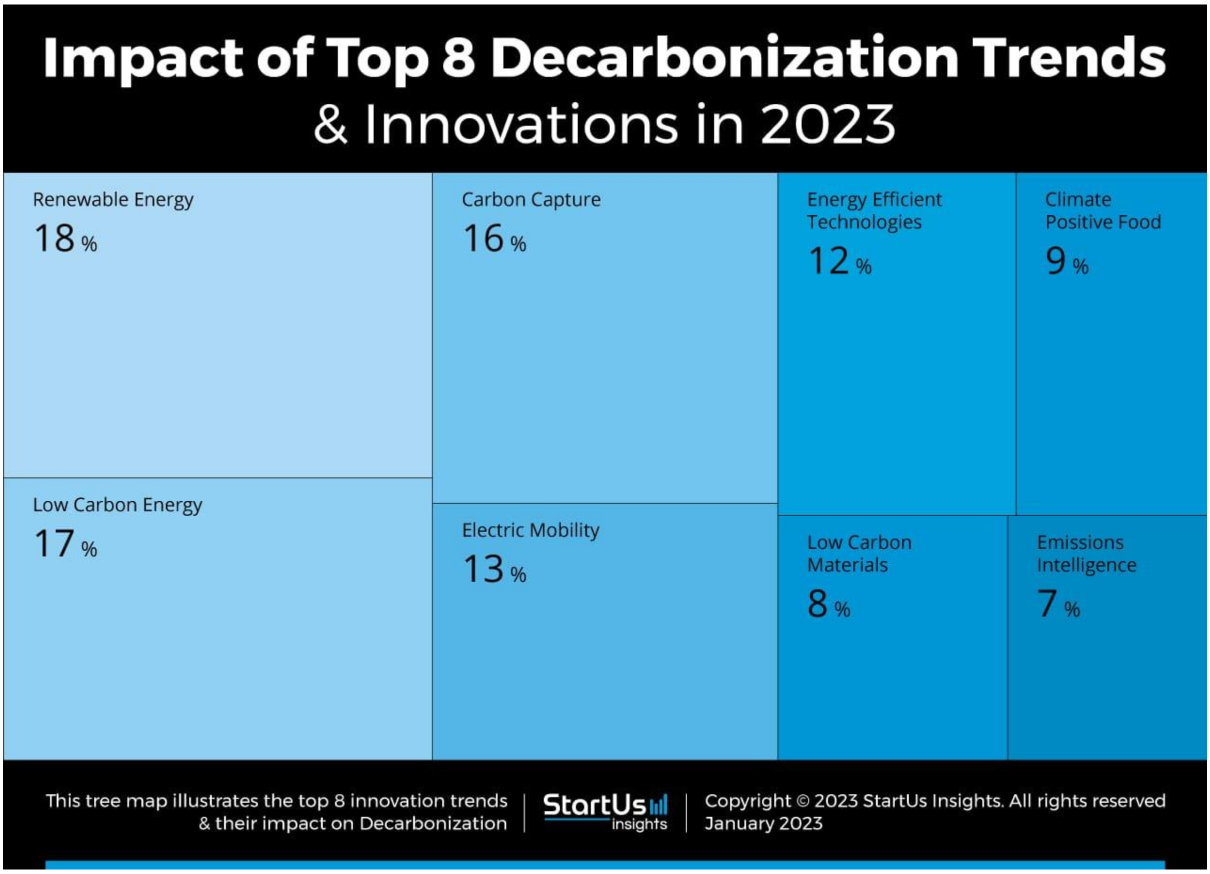
1.13.1 Innovation:

As the demand for low carbon building materials increases, there are numerous opportunities for innovation in construction materials and building technologies.

Chart 1.1 Market Value of Green Construction Materials by Region, World Markets: 2013-2020



(Source: Navigant Research)



1.13.2 Market trends:

The demand for low carbon building materials has been on the rise due to the increasing awareness of environmental issues and the need to reduce carbon emissions. Consumers are becoming more conscious of the environmental impact of construction, leading to an increased demand for sustainable alternatives to traditional building materials. This trend is further fuelled by government policies and regulations promoting the use of low carbon materials in construction.

Conclusions

- Fly ash bricks, bamboo, and compressed stabilized earth blocks (CSEBs) are all examples of innovative building materials that offer eco-friendly, low-cost, and sustainable alternatives to traditional building materials like concrete and brick.
- Proper handling, transportation, storage, and installation are crucial for ensuring the quality and durability of building materials, and ongoing maintenance and repair can help extend the lifespan of these materials.
- Building materials can also have a significant impact on the environment, and it is important to consider the lifecycle of the material from production to disposal when selecting materials for a building project.
- CEBs, fly ash bricks, bamboo, and straw bale all have good thermal mass and insulation properties. This can help to keep buildings cool in hot weather and warm in cold weather.
- CEBs, fly ash bricks, bamboo, and straw bale are all durable building materials. They can last for many years with proper care.
- CEBs, fly ash bricks, bamboo, and straw bale are all sustainable building materials. They can be made from locally available materials and they can be recycled or reused at the end of their useful life.
- The cost of the material: The cost of the material will vary depending on the specific type of material and the location of the project.

Recommendations:

- The government should promote the use of low carbon building materials through policies such as tax breaks and subsidies.
- Construction companies should invest in research and development of new low carbon building materials.
- Consumers should demand low carbon building materials when choosing a contractor for their next project.

2 By taking these steps, we can help to reduce the environmental impact of the construction industry and build a more sustainable future.

References

1. [Estimation of Carbon Footprint of Residential Building in ...](https://www.mdpi.com/1996-1073/14/14/4237)
2. [A review of net zero energy buildings in hot and humid...](https://escholarship.org/content/qt9v60n2bx/qt9v60n2bx.pdf?t=qb1clq)
3. [Net-zero building designs in hot and humid climates](https://www.sciencedirect.com/science/article/pii/S2214157X18304131)
4. [A Hybrid Low-Cost Construction Techniques and Materials ...](https://iopscience.iop.org/article/10.1088/1757-899X/1197/1/012058/pdf)
5. [A Study of Cost-effective Building Materials and ...](https://issuu.com/segulavanyabala9783/docs/1170100706_dissertation_report)
6. "Straw Bale Housing: Sustainable Building Systems for Dry Climates" by N. O'Connor and D. H. Evans (2006)
7. https://www.researchandmarkets.com/reports/5146093/global-construction-and-building-materials-market
8. https://www.grandviewresearch.com/industry/green-building-materials
9. http://www.astrj.com/Bamboo-as-a-Construction-Material-Prospects-and-Challenges
10. Open Source Ecology
11. The Auroville Earth Institute
12. "Environmental Impact of Building Materials" by the Carbon Trust
13. "Compressed Earth Blocks: A Sustainable Building Material" by the International Association for Compressed Earth Block (IACEB)
14. "Fly Ash Bricks: A Sustainable Building Material" by the Fly Ash Brick Association of India.
15. "Bamboo as a Building Material" by the Bamboo and Rattan Development Center.
16. "Straw Bale Construction: A Sustainable Building Method" by the Straw Bale Construction Association.
17. Case study of fly ash brick manufacturing units at Kota in Rajasthan conducted by IOP Conference Series: Materials Science and Engineering
18. The viability of straw bale as a construction material in Indian context[74-The-viability-of-straw-bale-as-a-construction-material-in-Indian-context.pdf (anzasca.net)]