SUSTAINABLE BUILDING MATERIALS: A PATHWAY TO SUSTAINABLE DEVELOPMENT

Rohit Kumar, Dr. Arun Kapur,

Amity School of Architecture and Planning, AUUP, Lucknow campus.

ABSTRACT: - Sustainability in building construction is now a major priority as it has various advantages. The global trend is moving towards sustainability and hence sustainable building construction has prime importance in the construction industry. Due to huge urbanization activities a lot of environmental issues are originating. Building construction using sustainable materials will lead to a reduction in pollution and also improve the existing situation of environmental problems. This paper discusses the use of recycled design products in the construction industry. Affordable, sustainable housing projects made from locally available construction materials are in high demand. It safeguards the natural ecosystem, economy, and energy. As a result, the

construction. The primary goal of this research is to do a comparative review to determine the viability of using recycled building materials instead of conventional building materials. The construction industry is a significant contributor to environmental degradation, necessitating a shift towards sustainable practices. This research examines the use of sustainable green materials in the construction of green buildings, emphasizing their role in promoting sustainable development. The study investigates various eco-friendly materials, including recycled aggregates, bamboo, straw bales, and low-emission concrete, assessing their environmental, economic, and social benefits.

Through a comparative analysis of traditional construction methods versus green building practices, the research highlights the potential for reduced energy consumption, lower carbon emissions, and improved indoor air quality. Case studies illustrate successful implementations of green materials in diverse projects, demonstrating their viability and performance.

The findings underscore the importance of policy frameworks, stakeholder collaboration, and education in advancing the adoption of sustainable materials. This research contributes to the body of knowledge on sustainable construction and offers practical recommendations for architects, builders, and policymakers to foster a more sustainable built environment.

Index Terms: - *Sustainability, Sustainable Design, Sustainable Materials, Construction, Energy Efficiency.*

1. INTRODUCTION

India, with a population of around 145 crores as of 2024, is undergoing rapid urbanization and infrastructure development. The government's 100 Smart Cities initiative is driving a trend toward sustainability, with sustainable building construction becoming crucial in minimizing environmental impacts. Urbanization

consumes massive amounts of materials and energy, leading to high carbon emissions, pollution, and adverse health effects. These factors contribute significantly to climate change and related disasters.

Sustainable or “green” buildings are designed to reduce negative environmental impacts and enhance human well-being. They utilize eco-friendly materials and energy-efficient systems throughout their life cycle—from planning and construction to operation and demolition. Unlike conventional buildings, green structures use resources efficiently, improve indoor comfort, and are healthier for occupants. Studies show they can lower indoor temperatures by up to 5°C in summer and stay 2°C warmer in winter. Additionally, they consume about 30% less energy, highlighting their superior performance. Certifications like LEED help assess and validate these sustainable practices, and buildings achieving net-zero energy—where energy produced equals or exceeds energy consumed—are the gold standard in eco-friendly design. Green buildings use local, eco-friendly materials to reduce environmental impact, improve indoor air quality, and enhance energy efficiency. They offer long-term economic benefits, promote occupant well-being, and support climate goals. Adopting sustainable construction practices drives resilient urban development and encourages broader policy and industry shifts toward sustainability.

1.1 SUSTAINABLE MATERIALS

Green buildings require specialized materials and systems to achieve sustainability, distinguishing them from conventional structures. In India, the green building materials and services sector is rapidly growing alongside the push for eco-friendly development. Sustainable construction integrates various practices across design, construction, and operation phases, with green materials playing a central role. These materials are environmentally responsible, reducing negative environmental impacts and supporting energy efficiency, resource conservation, and healthy indoor environments.

Key characteristics of sustainable building materials include:

1. **Environmental Impact**: Green materials have low embodied energy and minimal environmental harm throughout their lifecycle, from extraction to transportation.

2. **Resource Efficiency**: Often made from recycled or rapidly renewable resources, these materials help conserve raw materials and reduce construction waste.

3. **Indoor Air Quality**: Green materials emit fewer volatile organic compounds (VOCs), supporting healthier indoor air and improved occupant well-being.

4. **Energy Efficiency**: Their production consumes less energy, and many—such as reflective roofing or advanced insulation—boost building energy performance.

5. **Affordability**: Although initial costs can be higher, the long-term savings in energy and maintenance make green materials cost-effective over time.

1.2 NEED AND SIGNIFICANCE

1. Environmental Necessity

1. Traditional construction methods rely heavily on non-renewable resources and generate considerable waste.
2. Sustainable green materials like recycled aggregates, responsibly sourced timber, and low-VOC products reduce ecological footprints.
3. These materials help combat climate change by lowering carbon emissions and conserving natural resources.
4. They also minimize pollution and habitat destruction, preserving biodiversity and natural ecosystems.

2. Economic Advantages

1. Though green materials may have higher upfront costs, they offer long-term savings through:
    i. Lower energy consumption (up to 30% less than conventional buildings).
    ii. Reduced maintenance and operational expenses.
    iii. Eligibility for government tax incentives and subsidies.
2. Green buildings have rising market demand, enhancing property value and attracting environmentally conscious buyers and investors.

3. Health and Well-being

1. Green materials improve indoor air quality by reducing harmful emissions such as volatile organic compounds (VOCs).
2. Use of non-toxic materials like low-VOC paints and natural insulation enhances occupant health and comfort.
3. Better air quality and thermal regulation contribute to improved productivity and reduced healthcare costs.

4. Social Responsibility

1. Incorporating sustainable materials demonstrates ethical and responsible construction practices.
2. Aligns with growing public demand for eco-conscious development.
3. Build community trust and support long-term sustainability goals, including the UN Sustainable Development Goals (SDGs).
4. Promotes a culture of sustainability in the construction industry and among stakeholders.

2. AIM

Environmental Responsibility:

1. Reduce ecological footprint through use of recycled, renewable, and low-impact materials.
2. Lower greenhouse gas emissions and conserve natural resources.
3. Help mitigate climate change and protect biodiversity.

- **Resource Efficiency**:
  1. Optimize energy, water, and raw material use throughout the building lifecycle.
  2. Promote a circular economy with reduced waste and increased reuse/recycling.
  3. Lower overall construction and maintenance costs.
- **Health and Well-being**:
  1. Improve indoor air quality by minimizing VOCs and other harmful emissions.
  2. Use natural, non-toxic materials for greater occupant comfort and health.
  3. Boost productivity and reduce health-related costs.
- **Economic Viability**:
  1. Achieve long-term cost savings through energy efficiency and waste reduction.
  2. Increase property value and attract environmentally conscious buyers.
  3. Encourage market growth and innovation in green construction.
- **Social Responsibility**:
  1. Demonstrate ethical, community-focused building practices.

3. OBJECTIVE

1. **Reduce Environmental Impact**: Use recycled, rapidly renewable, and low-impact materials to cut waste and emissions, helping to conserve ecosystems and mitigate climate change.
2. **Enhance Energy Efficiency**: Incorporate high-performance insulation materials and renewable energy solutions (e.g., solar panels) to reduce energy consumption and greenhouse gas emissions.
3. **Promote Resource Conservation**: Prioritize recyclable and sustainably sourced materials, encouraging a circular economy that minimizes waste and preserves finite resources.

4. **Improve Indoor Environmental Quality**: Use non-toxic, low-VOC materials, along with good ventilation and natural lighting, to enhance occupant health and comfort.
5. **Support Economic Sustainability**: Though initially more expensive, green materials lead to long-term cost savings through reduced energy use, maintenance, and higher property value.
6. **Encourage Community Engagement and Social Equity**: Involve local communities and use locally sourced materials and labor to support local economies and promote social responsibility.

4. METHODOLOGY

1. **Data Collection**: Gather quantitative and qualitative data from academic journals, reports, and case studies on green materials and practices.
2. **Defining Sustainability Criteria**: Evaluate materials based on environmental impact, energy efficiency, health and safety, and economic viability.
3. **Material Selection**: Identify and compare sustainable materials (e.g., bamboo, reclaimed wood, low-VOC paints) against conventional ones using performance and cost criteria.
4. **Design and Planning**: Collaborate with architects and use BIM to integrate and optimize sustainable materials in building designs.
5. **Implementation**: Train workers on green materials, ensure quality control, and manage construction waste efficiently.
6. **Monitoring and Evaluation**: Post-construction, assess energy use, air quality, and gather user feedback to identify improvements.
7. **Stakeholder Engagement**: Partner with local entities and raise awareness through workshops and campaigns.
8. **Documentation**: Report processes, outcomes, and best practices to inform future sustainable construction efforts.

5. SCOPE

The scope of utilizing sustainable green materials in construction covers environmental, economic, social, and technological dimensions:

1. **Environmental Sustainability**:
    1. **Carbon Footprint Reduction**: Sustainable materials like recycled metals and reclaimed wood reduce emissions.
    2. **Resource Conservation**: Use of renewable materials, like bamboo, and recycling practices conserve natural resources.
    3. **Waste Minimization**: Efficient waste management and recycling promote a circular economy.

2. **Economic Benefits**:
    1. **Long-Term Cost Savings**: Energy efficiency and reduced maintenance lower operational costs.
    2. **Increased Property Value**: Sustainable buildings attract buyers due to their efficiency and cost savings.
    3. **Job Creation**: Growth in green technology and material sectors boosts local economies.
3. **Social Responsibility**:
    1. **Health & Well-being**: Improved indoor air quality enhances occupant health and productivity.
    2. **Community Involvement**: Local material sources support local economies and reduce transportation impact.
    3. **Education & Awareness**: Promotes environmental education through workshops and outreach.
4. **Regulatory Support**:
    1. **Government Incentives**: Policies like tax rebates and grants encourage sustainable construction.
    2. **Certifications**: Green building certifications, like LEED, guide sustainable practices.
5. **Technological Advancements**:
    1. **Material Development**: Innovations in bio-based, nanomaterials, and smart materials enhance sustainability.
    2. **Digital Tools**: BIM and digital modeling improve planning and material integration.

6. LIMITATIONS

1. **Higher Initial Costs**: Expensive materials and skilled labor increase upfront costs.
2. **Limited Availability**: Regional sourcing challenges and fluctuating market demand.
3. **Performance Concerns**: Durability and longevity issues with some green materials.
4. **Regulatory Barriers**: Building codes and complex certification processes.
5. **Consumer Awareness**: Resistance due to lack of knowledge and misconceptions.
6. **Training Needs**: Specialized skills required for sustainable material use.
7. **Life Cycle Assessment Complexity**: Resource-intensive evaluations and data gaps.

7. LITERATURE STUDY

7.1 Sustainable Materials in Green Construction: -

1. **Recycled Materials**: Essential in reducing resource depletion. Example: Recycled aggregates in concrete lower carbon emissions while maintaining structural integrity (Zhang et al., 2020).
2. **Rapidly Renewable** Resources: Materials like bamboo and cork are viable alternatives to traditional materials. Bamboo's fast growth makes it a suitable substitute for wood (Wang and Zhang, 2021).
3. **Low-VOC and Non-toxic Materials**: Important for indoor air quality, enhancing occupant comfort and reducing absenteeism in workplaces (Jones et al., 2019).

7.2. Examples of Sustainable Materials: -

1. **Cross-Laminated Timber (CLT)** – A strong, prefabricated wood panel made by layering and gluing several layers of lumber together. CLT is a renewable resource with a lower carbon footprint than traditional building materials like steel and concrete.

2. **Hempcrete** – A bio-based material made by combining hemp fibers with lime and water. Hempcrete is lightweight, non-toxic, and has excellent thermal and acoustic insulation properties.

3. **Rammed Earth** – A construction technique that compresses a mixture of earth, water, and natural binders to create walls. Rammed earth is durable, energy-efficient, and has a low environmental impact.
4. **Bamboo** is a rapidly renewable and versatile building material with a high strength-to-weight ratio.
5. **Recycled Steel** – Steel made from recycled materials, which significantly reduces energy consumption and greenhouse gas emissions compared to steel produced from virgin iron ore.

Mycelium – A bio-based material made from the root structure of fungi. Mycelium can be grown into various shapes and used as an alternative to plastics and other petroleum-based products in building insulation, acoustic panels, and more.

Ferrock: is a low-carbon alternative to traditional concrete made from recycled steel dust and silica.

Ferrock is more durable than conventional concrete and has a lower carbon footprint.

Biochar Cladding – A carbon-negative building material made from the pyrolysis of biomass. It can be used as cladding or insulation, offering improved thermal performance and reducing the building's carbon footprint.

7.3 Sustainable Construction Techniques: -

1. **Passive Solar Design**: Uses the sun's natural energy for heating and cooling.
2. **Green Roofs**: Absorb rainwater and provide insulation, improving urban air quality.
3. **Rainwater Harvesting**: Reduces potable water consumption by collecting rainwater.
4. **Greywater Recycling**: Recycles wastewater for non-potable uses, reducing freshwater consumption.
5. **Cool Roofs:** Reflective roofs reduce heat absorption and lower cooling costs.
6. **Building Automation Systems**: Optimizes energy use through sensor-based adjustments.
7. **Modular Construction**: Reduces waste and energy use by pre-manufacturing building components.

7.4 Green Building Certification Systems and Rating Frameworks

1. **Overview of Green Building Certification Systems**

    1. **LEED:** Recognized globally, assessing energy efficiency, water conservation, and sustainable materials. LEED-certified buildings show a 25-30% reduction in energy usage (Kibert, 2020).

    2. **BREEAM**: UK-based, evaluating sustainability across management, health, energy, and materials. BREEAM incentivizes the use of sustainable practices through a points-based rating system (Duffy et al., 2021).

    3. **Green Globes**: Offers flexibility and a tailored approach to green building certification, focusing on innovative designs and materials (Liao et al., 2021).

2. **Criteria for Green Certification**

    1. **Sustainable Material Use**: Evaluates materials' environmental impact, recyclability, and resource efficiency (Singh et al., 2020).

2. **Energy Efficiency**: Focuses on energy performance, such as Energy Use Intensity (EUI), with net-zero energy buildings being a goal (Eum et al., 2019).

3. **Water Conservation**: Encourages water-saving technologies like low-flow fixtures and rainwater harvesting (Gupta & Kumar, 2021).

4. **Indoor Environmental Quality (IEQ):** Assesses air quality, lighting, thermal comfort, and acoustics for occupant well-being (Lee et al., 2020).

3. Challenges of Green Certification Systems

1. **Cost and Complexity**: High certification fees and complex processes deter small-scale projects (Ofori et al., 2021).

2. **Variability in Standards**: Differences in certification criteria can cause confusion (Bullen and Love, 2020).

3. **Limited Awareness**: Lack of knowledge among industry professionals limits certification adoption.

7.5 Green Building Rating Systems in India

1. Griha Rating System

1. **Holistic Assessment**: Evaluates site selection, energy efficiency, and indoor environmental quality, with a focus on local materials (Khosla et al., 2021).

2. **Rating Levels**: From Griha 1 Star to Griha 5 Star, with higher ratings indicating superior sustainability (Sharma et al., 2020).

3. **Local Context**: Adaptable to India's diverse climates and conditions (Gupta & Sahu, 2021).

2. Indian Green Building Council (IGBC)

1. **Diverse Rating Programs**: Includes certifications for homes, factories, and existing buildings (Jain et al., 2020).

2. **Comprehensive Criteria**: Assesses site sustainability, water conservation, energy efficiency, and innovation (Rao and Menon, 2021).

3. **Market Impact:** IGBC-certified buildings enjoy higher market value and demand (D'Oca et al., 2021).

3. **Energy Conservation Building Code (ECBC)**

    1. **Energy Efficiency Standards**: Focuses on building design, HVAC systems, and lighting to improve energy performance (Kumar et al., 2022).

    2. **Integration with Other Systems**: Can be combined with Griha and IGBC certifications (Mehta and Singh, 2021).

    3. **Regulatory Framework**: ECBC serves as a benchmark for energy efficiency regulations (Thigpen and Rogers, 2020).

4. **Impact on Sustainable Development**

    1. **Promotion of Sustainable Materials**: Encourages the use of eco-friendly materials, reducing environmental impact (Singh et al., 2020).

    2. **Energy and Water Efficiency**: These systems lead to significant savings in energy and water consumption, addressing resource scarcity (Jain and Rao, 2021).

    3. **Occupant Well-being**: Green buildings promote better air quality, thermal comfort, and overall health (Lee et al., 2020).

8. CASE STUDY 1: INFOSYS CAMPUS, MYSORE

Case Study: Infosys Campus, Mysore – A Model of Sustainable Green Architecture.

The Infosys Campus in Mysore, Karnataka, is a benchmark in sustainable architecture, spread across 340 acres and accommodating about 30,000 employees. Achieving *LEED Platinum* certification, the campus integrates eco-friendly materials and energy-efficient design.

Sustainable Materials Used: -

- **Recycled and Locally Sourced Materials**: Utilization of recycled steel, locally sourced granite, and bricks reduced transportation emissions.

- **Natural Materials**: Bamboo, a renewable material with high strength-to-weight ratio, was used in structural elements and finishes.

- **Low-VOC Materials**: Paints and finishes with low volatile organic compounds enhance indoor air quality, benefiting occupant health.

Sustainable Practices:

- **Energy Efficiency**: Passive design features like optimal building orientation, shading devices, and extensive glass usage reduce heat gain and minimize artificial lighting needs.
- **Rainwater Harvesting**: The system collects rainwater for irrigation and toilet flushing, cutting reliance on municipal water.

Outcomes:

- **Environmental Impact**: The campus consumes 45% less energy than conventional buildings, lowering operational costs and carbon emissions.
- **Employee Well-being**: High indoor air quality, access to daylight, and green spaces have improved employee satisfaction, productivity, and morale.

9. CASE STUDY 2: TAJ HOTEL, MUMBAI

The Taj Mahal Palace Hotel in Mumbai underwent a major renovation completed in 2016, blending historical preservation with modern sustainability. The project emphasized eco-friendly practices while maintaining the architectural legacy of the iconic structure.

Sustainable Materials Used:

- **Heritage Materials**: Reclaimed wood and locally sourced stone preserved the hotel's historical essence while reducing the environmental impact.
- **Energy-Efficient Systems**: Advanced HVAC systems and LED lighting significantly lowered energy usage and operational costs.
- **Eco-Friendly Finishes**: Low-VOC paints and adhesives improved indoor air quality, aligning with health-conscious green standards.

Sustainable Practices:

- **Water Conservation**: Rainwater harvesting and greywater recycling systems cut water consumption by about 30%.
- **Green Roofs & Landscaping**: Green roofs and native plants enhance thermal insulation, promote biodiversity, and reduce the urban heat island effect.

Together, these efforts reflect a thoughtful integration of sustainability into a historic structure, ensuring environmental responsibility without compromising cultural value.

10. ANALYSIS AND INFERENCE

The construction industry significantly contributes to environmental degradation, accounting for high energy consumption and greenhouse gas emissions. In response, sustainable green materials have become central to the global shift toward eco-friendly building practices. This analysis highlights the environmental, economic, and social impacts of using sustainable materials in green construction, supported by research and real-world case studies.

Environmental Impact:

Sustainable materials play a crucial role in minimizing the ecological footprint of construction.

- **Lower Carbon Emissions**: Materials like recycled steel, bamboo, and locally sourced products significantly reduce emissions by cutting down on extraction and transportation. Studies show a 30% reduction in carbon emissions in buildings using green materials (Kibert, 2016).
- **Resource Conservation**: By incorporating recycled content—such as reclaimed concrete—green construction reduces dependence on virgin materials, preserving natural resources and reducing landfill waste.
- **Water Efficiency**: Systems like rainwater harvesting and greywater recycling, commonly used in green buildings, reduce water usage by up to 50% (Tuan et al., 2020).

Economic Viability:

Green materials not only support environmental goals but also offer long-term financial benefits.

- **Reduced Operational Costs**: Energy-efficient buildings like the Infosys Campus in Mysore demonstrate up to 45% energy savings, translating into lower utility expenses (Saha & Hossain, 2018).
- **Higher Property Value**: Buildings with green certifications (LEED, GRIHA) attract higher occupancy rates, rental values, and resale prices.
- **Government Support**: Incentives such as tax rebates and fast-tracked permits help offset upfront costs, making green construction more feasible.

Social Benefits:

Sustainable construction also fosters health, well-being, and community development.

- **Healthier Indoor Environments**: Low-VOC paints and materials improve air quality, reducing respiratory issues and enhancing productivity (Miller et al., 2018).

- **Occupant Well-Being**: Features like natural lighting and green spaces promote mental health and satisfaction (Kellert, 2018).

- **Community Engagement**: Using local materials and labor, as seen in projects like Pune's Green Building, stimulates the local economy and strengthens community ties.

11. CHALLENGES AND LIMITATIONS

Despite the clear benefits, several challenges hinder the widespread adoption of sustainable green materials:

1. **Higher Initial Costs**: While operational savings are substantial, the initial costs associated with sustainable materials can be higher than traditional materials. This can deter developers, especially in cost-sensitive markets. However, as technology advances and demand increases, these costs are gradually decreasing.

2. **Knowledge Gaps**: A lack of awareness and expertise regarding sustainable materials and practices among builders and contractors can impede progress. Continuous education and training programs are necessary to bridge this gap.

3. **Regulatory Barriers**: In some regions, existing building codes and regulations do not adequately support the integration of sustainable practices, creating obstacles for developers aiming to build green. Policymakers must work to create a regulatory environment that encourages sustainable construction.

12. CONCLUSION AND SUGGESTIONS

Advancing Sustainable Green Materials in Building Construction: -

The integration of sustainable green materials in building construction is vital in addressing environmental degradation, resource depletion, and the growing pressures of urbanization. As cities expand, the construction industry must adopt environmentally responsible practices to reduce its ecological footprint and promote sustainable development.

Key Outcomes of Sustainable Materials Integration:

- **Environmental.Benefits:**
  Sustainable materials—such as recycled steel, bamboo, and reclaimed wood—help lower greenhouse gas emissions, conserve resources, and improve water efficiency. These practices contribute directly to climate change mitigation and public health protection by reducing pollution and preserving natural ecosystems.

1. **Economic.Viability:-**
   Although initial investment in sustainable construction can be higher, the long-term savings are substantial. Green buildings reduce operational costs through energy and water efficiency and often yield higher property

values. As environmental consciousness grows, these buildings also attract more buyers and tenants, enhancing market appeal.

2. **Social.Impact:-**
   Sustainable buildings positively affect occupants' well-being. Features like improved air quality, natural lighting, and biophilic design elements boost health, comfort, and productivity. These factors contribute to a more socially sustainable and livable environment.

3. **Challenges: -**
   Despite the clear benefits, barriers such as higher upfront costs, limited stakeholder knowledge, and outdated regulations slow down widespread adoption. Addressing these issues is crucial for mainstreaming sustainable construction.

Strategies for Promoting Sustainable Construction:

- **Policy.and.Regulation:-**
  Governments should implement supportive policies—tax incentives, grants, and fast-tracked permits—for green buildings. Building codes should also mandate or reward the use of sustainable materials.

- **Education.andTraining:-**
  Training architects, builders, and contractors in sustainable construction methods will build capacity across the industry. Informed stakeholders are more likely to embrace and implement green solutions.

- **Research.andInnovation:-**
  Investment in R&D can drive innovation in sustainable materials, making them more accessible and cost-effective. Collaboration between government, academia, and industry can lead to breakthroughs in eco-friendly construction technologies.

- **Public.AwarenessCampaigns:-**
  Educating the public about the health and financial benefits of green buildings can increase consumer demand, pushing developers to adopt sustainable practices.

- **Collaboration.andPartnerships:-**
  multi-stakeholder collaborations, including public-private partnerships, can scale up green building efforts. These alliances pool resources and knowledge to implement sustainable solutions effectively.

- **Monitoring.andEvaluation:-**
  Establishing systems to track the performance of green buildings allows for transparency, accountability, and continuous improvement. Data-driven evaluations can guide future developments and policymaking.

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