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SUSTAINABLE AND GREEN CONSTRUCTION MATERIALS IN INDIA: A COMPREHENSIVE REVIEW

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Abstract

The quick development of the construction industry in India has escalated the environmental issues in the country including depletion of resources, energy excessive use, emission of greenhouse gases, and construction wastes that are piling up. Sustainable and green building materials have become an option to the traditional building materials in response to these worries. This review paper explores the notion, necessity, and importance of sustainable construction materials in Indian context under discussion on the following materials fly ash-based products, green concrete, bamboo and recycled construction and demolition waste. The paper points out the environmental, economic, and social advantages of such materials, such as a low level of carbon emission, preservation of natural resources, energy efficiency, better indoor environmental quality, and decreased life-cycle costs. Although they are beneficial, the paper also reveals several critical issues that prevent their wide implementation in India, including the absence of awareness and technical skills, increased initial implementation costs, lack of standardization, adherence to traditional beliefs, and supply chain. The review highlights that these barriers need to be overcome through appropriate policy support, research and development, capacity building and industry collaboration. Altogether the sustainable and green construction materials provide an important avenue in the context of the attainment of environmental friendly, resource efficient and climate resilient infrastructural development in India.

Keywords: Sustainable construction materials; Green building; Eco-friendly materials; Indian construction industry; Low-carbon construction; Circular economy

1. Introduction

The construction sector is a very important sector of the Indian economy and it has an important role in terms of creating employment and expansion of the infrastructure in India [1]. Nevertheless, it is also considered to be the most resource-consuming industry that occupy vast amounts of raw materials, including limestone, sand, gravel, and water, and consumes a lot of energy and produces greenhouse gases. Ordinary Portland Cement (OPC) is manufactured alone, and this fact is enough to cause global carbon dioxide emissions which is a major environmental concern [2].

Figure 1: Sustainable construction material

As the issue of climate change, environmental degradation and sustainable development has gained more and more awareness, the paradigm shift in dealing with sustainable and green construction has been adopted [3]. Sustainable construction materials are also constructed to have the minimal environmental impact in the entire life cycle of the materials- including the extraction and manufacturing of the raw material, their use, recycling and disposal. In India, industrial by-products, agricultural residues and traditional low-energy materials are available in large quantities and offer a special chance to facilitate green construction [4].

The scope of this review paper is to critically discuss the concept, types, applications, and importance of sustainable and green construction materials in India and the challenges and future implication of their usage in the country [5].

Table 1: Review of Literature on Sustainable and Green Construction Materials in India

Author(s) & Year	Title of the Study	Objectives of the Study	Methodology / Approach	Key Findings
Sharma (2018) [6]	Development of a 'Green building sustainability model' for green buildings in India	The study aimed to develop a sustainability assessment model for green buildings in the Indian context.	A conceptual and analytical model was developed based on sustainability indicators and existing green building frameworks.	The study revealed that an integrated sustainability model helped evaluate environmental, economic, and social performance of green buildings and supported decision-making for sustainable construction in India.
Kothari and Pathak (2021) [7]	Green building construction in India and benefits of sustainable building materials	The study focused on analyzing the benefits of green building construction and sustainable materials in India.	A descriptive review approach was adopted using secondary data and case-based analysis.	The findings showed that sustainable building materials reduced energy consumption, operational costs, and environmental impact while improving occupant comfort and building performance.
Tathagat and Dod (2015) [8]	Role of green buildings in sustainable construction: Need, challenges, and scope in the Indian scenario	The study examined the necessity, challenges, and future scope of green buildings in India.	The research employed a qualitative review of policies, practices, and industry trends.	The study identified lack of awareness, high initial costs, and limited technical expertise as major barriers but highlighted strong future potential for green construction in India.
Sheth (2016) [9]	Sustainable building materials used in green buildings	The paper aimed to discuss various sustainable building materials used in green buildings.	The study used a review-based approach supported by examples of green materials.	The results indicated that materials such as fly ash bricks, recycled materials, and renewable resources significantly reduced environmental impact and supported sustainable construction practices.
Sharma, Nigrawal, and Baredar (2021) [10]	Sustainable development by constructing green buildings in India: A review	The study reviewed the role of green buildings in achieving sustainable development in India.	A systematic review of existing literature and green building practices was conducted.	The study concluded that green buildings contributed to energy efficiency, reduced carbon emissions, and long-term economic benefits, aligning with sustainable development goals.

2. Concept of Sustainable and Green Construction Materials

Sustainable or green construction materials are also building materials which are produced, designed and utilized in a manner that drastically minimizes the negative effect of the material on the environment in comparison to the conventional construction materials [11]. As opposed to the usual materials, which usually undergo energy and resource-intensive manufacturing cycles and the massive exploitation of the non-renewable materials, the green materials are concerned with and aimed at reducing environmental damages over the entire life cycle, including sourcing and manufacturing of the raw materials, and their use, maintenance, and subsequent disposal [12].

The low embodied energy of construction materials can be considered one of the major features of sustainable construction materials as it indicates that they use less energy in the course of extracting, processing, transportation, and manufacturing. This has a direct effect in the form of less carbon emission thus contributing to climatic change and the reduction of carbon footprint of construction activities. These materials also encourage the effective utilization of the natural resources by using industrial by-products, recycled materials or natural material, which will reduce the reliance on virgin raw materials as well as environmental degradation.

Recyclability and reusability of the construction materials is also another aspect that is important to green buildings as it aids in reducing wastes and promoting the use of circular economy. Reusable or recyclable materials that could be used at the end of their service life can assist in reducing construction and demolition wastes, which is becoming an issue in the fast-paced urban areas [13]. Also, environmentally friendly materials are appreciated due to their longevity and better life cycle and functionality because more durable materials minimize the necessity of replacement or frequent repairs, thus saving on resources and minimizing long-term expenditures.

The idea of green construction materials in the Indian context also goes beyond the environmental factors to consider the availability, affordability, and the suitability of the material to the climate. The variety of climate zones and the abundance of natural and industrial by-products in India make the necessity of using region-specific materials that will be cost-effective. The products of local sourcing in the form of fly ash, bamboo, lime-based binders, agro-waste compounds not only help to decrease transportation-related emissions but also promote the economies of the area and jobs [14].

3. Need for Sustainable Construction Materials in India

India is experiencing a high rate of urbanization and a high population growth rate with an increased rate of infrastructure and housing demand [15]. As much as this growth would be imperative to economic development, it has escalated a number of structural issues such as acute housing shortages, over exploitation of natural resources, and creation of huge amounts of construction and demolition wastes [16]. The conventional methods of construction based on high consumption of energy seeming materials and non renewable resources are becoming less and less environmentally as well as economically viable. In this respect, the introduction of sustainable construction materials is not only desirable but also the key to the long-term development of India.

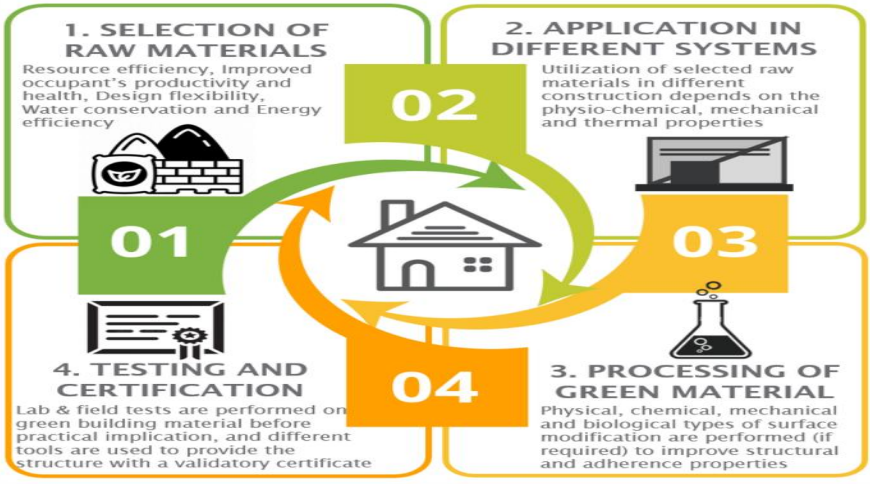

Figure 2: Application of green material in Construction system

A major motive of the promotion of sustainable materials is the increasing rate of environmental pollution of the construction activities. The air, soil and water pollution are caused by dust emissions, improper waste disposal and high emission of green house gases by cement and steel production [17]. Sustainable materials especially by-products of industries and recycled waste minimise pollution since they consume less landfill and they also emit less pollution in the manufacturing process.

The other crucial issue is the increase in the energy requirement and the carbon emission associated with traditional construction products [18]. The construction sector has been highly significant in creating carbon emissions because of the increasing energy demand in India, and the reliance on fossil fuels. The construction materials that are sustainable normally consume less energy to be made and transported thus reducing the embodied energy in buildings and also helping to reduce the infrastructure that is made which is energy efficient.

Over-extraction and environmental regulations have high-ranked the scarcity of conventional raw materials particularly the river sand that has become a serious problem in India. Sustainable sand mining is the cause of riverbank erosion, depletion of the groundwater and ecological disequilibrium. Manufactured sand, recycled aggregates and industrial by-products are some of the sustainable alternatives that would offer viable alternatives that would not strain the natural ecosystems and would still meet the construction demands [19].

Besides, there is an urgent requirement in India of affordable housing solutions especially in the affordable housing and rural development programs. The sustainable construction materials usually use locally produced materials and wastes, which are likely to reduce the cost of construction and affordability of housing. They also have better life-cycle performance, and this increases their durability, which lowers the maintenance and operational costs in the long run thus making them economically viable in large scale housing projects [20].

4. Types of Sustainable and Green Construction Materials in India

The increasing construction industry in India has boosted the pace of demand of construction materials, which are not only structurally sound, but environmentally friendly. Green and sustainable construction materials are important in minimizing environmental foot print of any building as they reduce the amount of energy used, waste materials produced and also save on the available natural resources. These materials in the Indian context often use industrial by-products, recycled wastes, and renewable materials, available locally and at an economically viable rate. This paper presents the discussion on some of the most popular and potential sustainable construction materials in India in the following sections.

4.1 Fly Ash-Based Materials

Fly ash is a fine particulate matter that is created when coal is burnt in thermal power plants and India does not lack in the industrial by-product produced annually. Rather than discarding fly ash in landfills or ash ponds, there is increased use of fly ash in making fly ash bricks, blocks and blended cement. Materials made using fly ash have a number of environmental and technical benefits over the traditional fired clay bricks. They minimize the excavation of topsoil, hence the conservation of agricultural land, and also the carbon emissions are kept at a very low level because they do not have to be heated in high temperatures with the use of kiln. Also, fly ash bricks have homogeneous size, enhanced compressiveness, and reduced water absorption as well as enhanced thermal insulation. Their extensive application promotes the use of waste, reduction of expenses, and sustainable urbanization.

4.2 Green Concrete

Green concrete is a concrete that is environmentally friendly, as a substitute to ordinary Portland cement by the means of partially or completely substituting the latter with other cementitious products like fly ash, ground granulated blast furnace slag GGBS, silica fume and other industrial by-products. As cement production generates many carbon dioxide emissions, the direct effect of shrinking cement content in concrete leads to a decrease in the environmental implication of construction. The green concrete does not only reduce the carbon emissions and energy consumption but also increases the longevity, resistance to chemical attacks and long-term performance. The sustainability profile is further enhanced by the use of recycled aggregates to ensure its reliance on natural stone is minimized as well as the amount of construction waste is minimized. Green concrete is used in the infrastructure projects in India, commercial buildings and environmentally friendly housing projects.

4.3 Bamboo as a Construction Material

Bamboo is one of the most sustainable and renewable construction materials available in India, particularly in rural and northeastern regions. It grows rapidly, requires minimal energy for processing, and has a high strength-to-weight ratio, making it a viable alternative to traditional materials such as timber and steel in certain applications. When properly treated against pests, moisture, and decay, bamboo demonstrates excellent durability and structural performance. It is commonly used in housing, scaffolding, roofing, flooring, and temporary structures. Engineered bamboo products such as laminated bamboo boards and bamboo composites further expand its applicability in modern construction. The use of bamboo not only reduces carbon emissions but also supports rural livelihoods and promotes environmentally responsible building practices.

4.4 Recycled Construction and Demolition Waste

The C&D waste is a fast-emerging environmental issue in India because of the volume of construction and demolition activities related to the development of infrastructure and urban renewal works. The alternative solution to this waste is to recycle it into useful construction materials so that waste management and resources conservation can be successfully achieved. Recycles of aggregates in the form of crushed concrete, bricks and masonry waste are also becoming popular in construction of roads, paving blocks, embankments, and non-structural concrete work. This will lessen the pressure on landfills, save on natural aggregates, and decrease transportation-based emissions. Recycled construction materials could be processed properly and can be used as quality control to achieve performance standards and play an important role in sustainable and circular construction in India.

5. Advantages of Sustainable Construction Materials

These advantages are numerous and may be summed up as environmental, economic, and social in nature, and therefore, green construction materials used are very appropriate to satisfy the numerous construction needs in India. The reduction of the greenhouse gas emissions is one of the most drastic benefits. Through substitution of old products that consume large amounts of energy with low-carbon products like fly ash products, green concrete, and other binders, the carbon footprint of buildings can be significantly reduced. This is a direct contribution to the initiatives of India to fight climate change and cut the emissions of the building industry.

The other important advantage is the preservation of natural resources. Sustainable construction material minimizes the use of finite resources like limestone, river sand and timber sources through the use of recycled material, industrial by-products and renewable resources. This assists in the conservation of ecosystems, forestation, and the balance of ecology which is of great essence in a country where urban growth and pressure to the environment are very high.

Green building materials also help in enhancing energy efficiency of the buildings. Most of the sustainable materials have a high thermal insulation and moisture-controlling factor that helps to ensure a comfortable temperature indoors and decreases the use of artificial heating or air conditioning. Subsequently, the buildings erected using these materials use less energy during their operation which help in saving energy in the long run and less electricity is needed.

Economically, sustainable materials are cheaper in terms of life-cycle expenses though in some cases, they may be a little expensive in terms of initial cost. They have high levels of durability, environmental degradation, and low maintenance needs, which result in a high level of cost savings throughout the life of the building. This renders green materials especially appealing to affordable housing and public infrastructure and long-term development projects.

Figure 3: Benefits of Sustainable Building Construction

Indoor environmental quality is also improved through the use of environmentally-friendly materials, which minimize the amount of toxic substances, volatile organic compounds (VOCs), and other pollution-causing elements known to be part of the traditional building material. Better indoor air quality helps to enhance the health, comfort and productivity of the occupants and has been identified as a key element to a sustainable building design.

Lastly, sustainable construction materials are highly active in promoting the use of waste and recycling where industrial and agricultural waste can be transformed into helpful construction materials. This method will minimize landfill congestion, help establish the principles of the circular economy, and promote responsible waste production and consumption. All these advantages render green construction materials very appropriate to the use in both urban and rural construction in India, as well as sustainable development of infrastructure, maintaining a balance between the environmental interests, economic efficiency and social well-being.

6. Challenges in Adoption of Green Construction Materials

Although sustainable and green construction materials are undoubtedly cost-effective and ecologically safe, their massive use in India is still insignificant because of a number of interrelated issues. The lack of awareness and technical knowledge of the most relevant stakeholders, such as builders, contractors, architects, and the end users is one of the leading barriers. Several professionals still use the traditional construction materials due to the familiarity and lack of experience using green materials. Poor training, lack of spreading the research results and use of sustainable materials in the academic and professional programs further impair making informed decisions.

The other major hurdle is the impression of the increased initial cost of the green building materials. Sustainable materials may lead to a reduced cost of operation and life cycle, but may have a higher initial cost because of small scale of production, specialized processing or because of certification. This early cost consideration usually puts off developers, especially in small and affordable housing projects, in a price sensitive country such as India, to use environmentally friendly solutions.

The scarcity of standardization, codes and guidelines is also a significant challenge. Some of the green materials are known in the current building standards but many of the new materials do not have in place a comprehensive standard, testing procedures and performance standards. This gives confusion on their dependability, long life and structural appropriateness and this makes them unwilling to accept their application in major construction by engineers and the regulating bodies.

Also, the traditional ways of construction are opposed to change to a large degree. In India, the construction sector is generally conservative and there is a tendency of the stakeholders to resort to the traditional material and methods

as opposed to the new and unknown ones. Such opposition is supported by fears of performance risks, the construction schedule, and lack of large-scale example projects in which green materials have proved successful over time.

There are also problems with supply chain constraints and quality control, which are further hindering adoption. Predominantly, the supply of sustainable materials is not uniform regionally and mixed quality of recycled or waste-based materials may compromise performance and receptiveness. The absence of well-structured supply chains, ineffective processing facilities, and proper quality assurance systems decreases the trust of both the users and regulators.

7. Conclusion

Economic, and social issues brought about by the high construction industry in India. Green materials including fly ash-based products, green concrete, bamboo, and recycled construction waste have a great potential in terms of greenhouse gas emission reduction, natural resource conservation, energy efficiency, lowering the cost of life cycle, improving the quality of indoor environment, and promoting the use of waste materials in accordance with the principles of the circular economy (as discussed in the review). These are the benefits that make sustainable materials applicable both in the urban and rural construction in various climatic regions of India. Their widespread application, however, is limited by such challenges as the low level of awareness and technical knowledge, the increased initial costs, absence of standardized codes, disposition to the traditional practices, and the problem of the supply chain and quality control. Such hurdles have been overcome by concerted action by way of enabling government policies, intensified research and development, uniform rules, capacity building and by ensuring active cooperation among the industry stakeholders. Sustainable and green construction materials with long-term dedication and planned execution can make a revolutionary impact on the realization of the environmentally responsible infrastructure development and promotion of long-term sustainability objectives in India.

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