A State-Of-Art Of The Alternative Sustainable Building Materials For Green Construction

Nitu Balhara, Rajesh Kumar, Vanita Aggarwal and Surinder Gupta

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Nitu[1], Rajesh kumar[2], Vanita Aggarwal[3] and S.M. Gupta4

[1]Ph.D Research Scholar, M.M. Engineering College, M.M. (Deemed to be University), Mullana, Ambala, Haryana -133207, India
[2]Ph.D Research Scholar, M.M. Engineering College, M.M. (Deemed to be University), Mullana, Ambala, Haryana -133207, India

[3]Professor & Head, Civil Engineering Department., M.M. Engineering College, M.M. (Deemed to be University), Mullana, Ambala, Haryana -133207, India
[4]Professor, Department of Civil Engineering., NIT Kurukshetra, Haryana – 136119, India.

ABSTRACT. In recent years, the green concept is being encouraged expansively by ecologists. Construction materials play an indispensable part in establishing the built environment's vision at the core of the built environment. This permits the construction of a building capable of making appropriate physical and psychological well-being conditions and fading the effect of construction activities on human health and the ecosystem. It is seen that various alternative sustainable building materials can replace the conventional building materials like cement, wood, aggregates, etc. This work brings out a technology outline of the products and linked occupational prospects concentrating on sustainable development. It also brings out the different materials that could improve processing technologies and product innovation with the scientific and engineering skills application. Alternative materials are well-defined and detailed in various environments, making the design and construction community reluctant to utilize them. This work assesses the different parameters affecting the selection of sustainable construction materials and subsequently explores the world of eco-friendly and sustainable green construction materials. The study also reveals the advantages of using sustainable building materials over conventional materials.

Keywords: Sustainable construction, alternate materials, green, green materials, sustainability

1. INTRODUCTION

Since the safety of an individual from natural disasters and atmospheric aspects has become an indispensable necessity, some efforts have been made to offer housing and generate a safe environment for a more contented life with well-being. For this reason, utilizing prevailing assets in nature and taking advantage of them distinctively have been considered. The speed of activities towards reasonable advancement relies on choices considered by many in the designing cycle: owners, experts, designers, engineers, industries, etc. A significant choice is selecting sustainable and eco-friendly building materials to be utilized in the construction industry (Akadiri et al., 2013). Construction materials play an important role in defining the built environment's vision at the core of the built environment. This permits the construction of a building capable of producing appropriate physical and psychological well-being conditions and diminishing the effect of construction activities on both human health and the ecosystem.

The 'Green Buildings' target is accomplished early in the design process and on the working plan. Materials selection is a sensitive and complex task that depends on the tremendous quantity of building material options. Similarly, numerous factors tend to be well-thought-out by the architects and designers when assessing different building materials. The collections of parameters or factors often present trade-offs that make ones' choice process even more technical (Ogunkah and Yang, 2012). There is no definite criterion for selecting building materials always, which means designers or architects have to consider many materials selection factors. Therefore, the available statistics on building materials and product choices must be continuously assessed to consider justifiable material choices correctly. As the design process, awareness of appropriate prerequisites is vital in selecting suitable building products or materials.

It should be noted that achieving sustainable building is not about confining the quantity of construction. It concerns how to consider how the design and selection of green building materials can balance the environment to boost the quality of living and the health and comfort of the end-users (Ding, 2014 To be considered genuinely biological, appraisal strategies will be re-evaluated under the umbrella of maintainability natural, social and financial. Expanding the extent of conversation past ecological obligation and accepting the more extensive maintainability plan are expanding prerequisites (Zhao et al., 2019; Cole, 2019). Alternative materials are well-defined and detailed in various environments, making the design and construction community reluctant to encourage their utilization; other work has found this a significant obstacle to widespread use. By collecting definitions, obstacles, and design strategies, while analysing and exploring the benefits of definite conditions, this work lays the basis for an improved understanding and consideration of where new and more sustainable materials can be efficaciously utilized (Krueger et al., 2018; Streimikiene et al., 2020).

2. METHODOLOGY

This work results from bibliographic examination through virtual library chronicles like Scopus and Research Gate, and others, going from 2010 to 2021. The primary articles/research papers considered were taken from worldwide diaries that uncovered imaginative components in building materials. Subsequently, all through this paper, the most creative, later, and state-of-the-art sustainable materials will be broken down—those most probable bound to track down a practical future for development. Specifically, the review gathered information on new practical arrangements and innovative materials, like concrete, wood, glass and pottery that are fundamental to limit the natural effect of structures on the environment and to lessen the utilization of regular assets. Also, the parameters affecting the selection of sustainable building materials were identified and brainstormed with the practitioners. A questionnaire-based study was carried out for the same. The questionnaire was distributed through the Google form to 250 respondents, out of which 104 were completed in all aspects.

3. RESULTS AND DISCUSSION

The present work testifies to the development in bio-building and highlights the utmost important sustainable developments applied to construction industry. First, the various research papers and articles were assessed to list all the parameters affecting sustainable building materials. Some of the parameters were dropped upon further brainstorming with the contractors, construction engineers, site managers, and other practitioners in the construction field. Finally, the reduced list was created, assessed by the questionnaire-based survey distributed to the various practitioners. The respondents were requested to govern the importance of the parameters on a 5-point Likert scale: where 1 is 'least important', 2' fairly important', 3 'important', 4 'very important', and 5' extremely important'. A confidence level of 95% was presumed with a significance level of 0.05, and the standardized variable was taken as (Z) 1.96. Depending on these confidence level values and Z, the sample size was calculated as 95 samples. However, according to the literature, the sample size must be at least 100; therefore, a minimum of 100 responses was required. The results are presented in terms of the questionnaire survey and different materials used in green building construction. Each material shall be described in detail according to the researchers.

4. PARAMETERS INFLUENCING THE SELECTION OF SUSTAINABLE BUILDING MATERIALS

The selection of building materials is a multifaceted job assessed by many parameters impacting the sustainability of buildings. The congregation of such parameters is done by studying previous studies' benchmarking and experts' opinions (Lou and Poodineh, 2016; Rahla et al., 2021; Sahlol et al., 2021). After much brainstorming, 36 parameters were found, and then a questionnaire survey was made to understand the need of such parameters among the stakeholders. The parameters were divided into three categories, namely technical, environmental and socio-economic. The results presented that the Kaiser– Meyer–Olkin (KMO) measure of sampling adequacy is 0.657, which is more than 0.5. This shows that the sample is appropriate for even factor analysis. Also, this proves that the questionnaire respondents are aware of sustainable construction techniques and materials.

Table: Selection of sustainable building materials

Category	**Parameter**	**Importance index**
Technical	Availability of materials (locally available or not)	0.881
	Maintainability	0.772
	Affluence of construction	0.886
	Thermal insulation properties	0.851
	Resistance to fire	0.789
	Durability	0.876
	Resistance to decay	0.612
	Sustainable sites i.e., heat island effect	0.655
	Deconstruction	0.765

	Disassembly and Reassembly	0.814
Environmental	Extraction of raw materials	0.801
	Reuse of building and its components	0.743
	Fabrication of Materials on site	0.421
	Swiftly renewable materials	0.469
	Embodied energy within material	0.893
	Reuse of resources or salvage materials	0.712
	Recycled materials	0.706
	Storage of recyclable waste	0.728
	Material waste management	0.945
	Removal of hazardous and toxic material	0.919
	Utilization of prefabricated items	0.559
	Low influence material	0.807
	Certified Wood	0.497
	Diminish pollution	0.794
	Probability of ozone layer depletion	0.491
	Influence of material on air quality	0.687
	Reused materials	0.773
	Recycled aggregates	0.558
	Carbon emission	0.789
Socio-economic	Aesthetics	0.567
	Interior fittings, finishing and furnishings	0.532
	Utilization of local material	0.904
	Health and safety	0.809
	Availability of labour	0.771
	Life cycle cost (LCC)	0.917
	Saving of energy	0.699

The formula for the importance index was given by Hair et al. in 1998, which is given below:

Importance index = $\frac{\sum_{i=1}^{N} w_i x_i}{A \, X \, N}$ X100

Here,

wi: five-point Likert scale ranging from 1 to 5,

xi: frequency of the scale used,

A: highest value i.e.,

N: no. of respondents in the questionnaire survey

From the above analysis, all the parameters are found to be significant. Considering the parameters, many construction materials are sustainable and can be a replacement for conventional building materials. On studying further about the sustainable construction materials from various literature, a detailed study yielded the results as in the subsequent sections.

5. SUSTAINABLE CONSTRUCTION MATERIALS

5.1 Energy harvesting concrete

This concrete is also known as energy-scavenging concrete. Concrete with intelligent and functional properties such as self-sensing, self-healing, and energy harvesting concrete signifies a transformative path in the field of construction materials. Energy harvesting concrete can store or convert the ambient energy for practicable utilization, lessening the global energy and pollution levels and also reducing the carbon footprint. It has the ability to capture and accumulate the wasting energy resulting from external sources for reuse. The external sources may be mechanical energy, solar power and thermal energy. Energy-harvesting concrete is created by consolidating piezoelectric, pyro electric, thermoelectric, and photovoltaic materials into conventional concrete. Attributable to special changing over or putting away the accessible energy from the climate, the energy-reaping concrete permits an independent energy supply for foundations, particularly streets, rail routes, carrier runways, and city walkways with circulated nature which make composite stock problems for conventional energy. The captured energy can be controlled by electrical frameworks such as lighting systems), structural health monitoring systems of infrastructures, wireless data communication systems that provides data, electric vehicle charge, etc. This type of concrete is a hopeful material for moving toward the worldwide energy issue without exhausting regular assets. However, some specialized hardships such as low-power, low conversion rate, and poor stability should be defeated before acknowledging wide applications of energy-harvesting concrete (Bhattacharjee et al., 2010; Qiao et al., 2011; Sudevalayam and Kulkarni, 2011; Park et al., 2012; Hosseini et al., 2013).

5.2 Martian Concrete

A group of researchers at North-western University, Illinois was talented to produce a novel and pioneering eco-cement, a construction material that could endure the specific states of the red planet. Moderately easy to create and 100% recyclable, this substantial need not bother with water and associates sulphur with raw materials available in the Mars's crust. The major obstacle was that water is a rare source and mainly exists in the form of ice on Mars. As explicated in a report briefing their study, the capability to shape cement lies in sulphur. The developed martin concrete was found to be highly practicable for the construction purpose on Mars planet and was found to be mechanically simulated by a discrete particle model. When utilized as paste and warmed up to 240 degrees, it moves from solid state to fluid. It is then joined with components and minerals on Mars' surface and passed on to cool (Wan et al., 2016). The outcomes, notwithstanding, are not explicit. Researchers and designers have been testing sulphur in concrete on earth with unsuitable outcomes for quite a long time. What's more, the specific conditions of Mars make the test much more complicated. For instance, at low temperatures, sulphur can break and it turns into a gas in a vacuum. Also, during the cooling system, sulphur particles psychologist and will, in general, make pits that undermine the nature of the material. The analysts tracked down that the ideal blend for Martian design is half made out of half sulphur and half of the dirt in the world. The mix ensures a compressive strength of something like 50 MPa. The figured Martian Concrete is mimicked by the Lattice Discrete Particle Model (LDPM), showing tremendous capacity in displaying the material reaction under different stacking situations. There are exceptional possibilities for reusing materials like the eco-concrete; which is 100% recyclable as the sulphur can be again taken to the softening point for giving the compound another form (Wan et al., 2016; Troemner et al., 2021).

5.3 Bacterial concrete

Nevertheless, mechanically concrete is relatively durable, it experiences a few downsides such as low tensile strength, low permeability, reinforcement corrosion, vulnerability to chemical attack and low durability. Notwithstanding the misery in solidified concrete, the plastic concrete may suffer damage due to plastic shrinkage and settlement cracking. Over time, adjustments have been produced to defeat the troubles of cement; however, those loads of cycles are challenging and acceptable. As of late microbial remediation of cement has been begun to tackle a portion of these hardships. Concrete has a genuine defect: it can undoubtedly break when under strain. On the off chance that these breaks become excessively huge, they will prompt consumption of the steel support, which brings about an ugly appearance and endangers the construction's mechanical characteristics (Gupta, 2015). Scientists from the Technology University of Delft (Jonkers and Schlangen, 2016) from Holland have fostered a genuinely resourceful and natural resolution to the brittleness of cement, which will permit this material to have a significantly lengthier life expectancy. Bacterial concrete can be defined as the concrete in which bacteria have been added or included as live cells or spores during concrete mixing. The calcite precipitated by bacteria will plug the microcracks and pores in concrete. This results in automatic (self) healing of cracks. Hence in this type of concrete, the bacteria play the role of self-healing agents. In self-healing concrete, the concrete material can heal the cracks generated on its own, aided by microbial action. The elementary principle of this concrete is the development of $CaCO_3$ precipitate by microbial action, which leads to the formation of more robust, sustainable, eco-friendly, crack-free and additional effective concrete.

Various studies have also found that this concrete leads to less pollution and, above all, is economical. The instrument of break mending in bacterial cement probably happens through the metabolic transformation of calcium lactate to calcium carbonate what brings about break fixing. This bio-synthetically interceded measure brought about proficient fixing of sub-millimetre estimated (0.15 mm width) breaks. (Jonkers, 2021; Jena et al., 2021; Shashank & Nagaraja, 2021; Girish et al., 2021). More development of this new self-healing concrete will likely result in a more durable, effective, efficient and sustainable concrete that will be principally suitable for the utilization in wet conditions where the durability of conventional concrete constructions is hampered due to reinforcement corrosion.

5.4 Light-emitting cement

A group of investigators in Mexico designed a superior cement that can absorb the sun's energy and emits the same energy at night. This was designed at Michoacan University of San Nicolás de

Hidalgo and was published in a book by Han et al. in 2017, and a related article by Carreño (2016) was initiated through sitographic research. The objective of the examination was to lessen energy utilization, and contamination brought about by conventional concrete. This glowing concrete could be utilized to illuminate streets, interstates, cycleway or structures. Traditionally, concrete is a murky body that does not permit the section of light through its inside. It is, indeed, a combination of powder when further added to water, breaks down as a bubbly pill and begins to turn into a hearty and safe gel. Simultaneously, this cycle likewise makes gem pieces in the gel that block approaching daylight. Along these lines, scientists zeroed in on changing the small design of the concrete to take out gems and make it ultimately a gel by adding blended polymers in with glowing properties, fit for engrossing sun-based energy and recurring it to the climate as light during the night for about 12 hours. There are many advantages of this concrete. Most fluorescent material presently accessible is made out of plastic and has a short life expectancy of about three years since they rot under openness to UV light. This new sort of concrete is sun-safe and can endure as long as 100 years. It has many advantages like environmental-friendly, can be manufactured inexpensively, saves on electricity and has a low environmental effect (Wang, 2013; Wiese et al., 2015; Wang et al., 2021).

5.5 Wood foam

The necessity to decrease pollution produced by the construction industry to make it more environment-friendly, sustainable and effective has led to the discovery of wood foam (Thongcharoen et al., 2021; Beluns et al., 2021). An investigation was carried out to advance and study the properties of a new type of structural insulated panel (SIP). SIP prototypes comprised of insulated foam mass-produced from natural rubber. The core layer was made up of natural rubber filled with wood particles. Three types of commercial wood-composite boards such as plywood, cement particleboard, and fibre-cement board and many others were used for the surface layer (Holcroft et al., 2021). Subsequently, the physical and mechanical properties of the SIP prototypes were assessed. The results revealed that the kind of surface layer materials is very important as they play a substantial role in the SIP properties. SIP enclosed with cement particleboard, and the fibre-cement board exhibited high mechanical properties and high-water resistance. The SIP prototype roofed with plywood displayed low density, high resistance of screw withdrawal, and low thermal transmittance properties. Though, high water absorption and low fire resistance were disadvantages of the SIP enclosed with plywood and hence required an improvement in the properties. It was also revealed that SIPs manufactured from wood-composite boards and natural rubber foam core would be an alternative and eco-efficient resource utilized in the construction industry.

There were many studies carried out in the past few years for the alternative to wood. Another researcher technologically advanced a pioneering wood-insulating foam with noteworthy acts (Fraunhofer, 2014). This wood foam can supplant superior high-sway plastic foams from petrochemicals since it is a light, proficient and regular item produced using economical crude materials. Researchers generate the froth by pounding wood finely till the minute wood particles convert into a disgusting material. Unexpectedly, they add gas to this suspension to grow it into a foamy froth that is solidified. The solidifying system is helped by normal substances confined in the actual wood. In an elective strategy, explicit compound cycles are utilized to deliver the eventual outcome. The subsequent wood froth has excellent protection from mugginess and pressure and excellent protection like ordinary plastic froths. It is an optimal substance for home protection, to keep the warmth inside and establish a comfortable climate for the structure's inhabitants.

5.6 Thermally insulating gypsum composites incorporating aerosol

The construction industry offers critical potential for further developing energy effectiveness through proficient protection. The quest for new structure materials with significant protection limits has turned into a compelling answer for lessening energy needs (Pedroso et al., 2020; Westgate et al., 2018). Aerosol is presented as an option for utilization in building materials. In the study, the thermo physical and mechanical properties were figured out for including aerosol to mortar. There was a shift of the substance of aerosol in the mortar from 0% to 15%. The addition of aerosol improves thermal properties of plaster, lightens the plaster by reducing its density, reveals remarkable thermal performance, and low density affirmed decent items for the thermal insulation and protection marketplace. For mechanical properties, the upsurge in aerosol content contrarily influences the flexural strength.

Nonetheless, the plaster does not give a heap bearing job regarding the construction. Notwithstanding, at least opposition and inflexibility should be ensured to this material. In everyday exercise, composites comprehending 10% aerosol have an astounding property contrasted with 15% aerosol dependent on water receptiveness, making them cutthroat with building materials utilized in development areas. The materials examined' remarkable warm execution and low thickness affirmed great items for the warm protection market, prompting an increment in the energy-saving capacities of such materials and broadening their extent of utilization to new development and recovery (Tiza 2021; Ouhaibi et al., 2021).

5.7 Metal roofing

Eco-friendly building materials are often much easier to come by than many people realize, and they can make the interior and the exterior of the home far more energy-efficient and sustainable. Metal roofing is one such material that has become increasingly popular in many residential homes. Metal roofing offers many eco-friendly benefits that can help one live a more sustainable life. Metal roofs last far longer than other roofing materials, including wood, tile, or asphalt shingles, and they are entirely recyclable at the end of their long lives. This significantly reduces the amount of waste that goes into landfills each year. Metal roofing also lowers the house's energy consumption, reducing the carbon footprint and environmental impact (Miller et al., 2004; Harimi et al., 2005; Kosny et al., 2011; Balaji et al., 2021; Mano & Thongtha, 2021)

5.8 Bamboo

Bamboo is a trendy alternative to traditional hardwood floors for several reasons. Contrary to popular belief, bamboo is not technically wood—it is part of the grass family. It is well-thought-out as one of the novel emergent materials which holds tremendous commercial potential. Structural bamboo has been conventionally utilized in nations like China, India, the Philippines and Latin America for more than ten decades. It has been used as a structural member in short-span footbridges, low-rise housings, long-span roofs and construction stages. In addition, it is also utilized in erection of signage, ornamentation, civil works and demolition. As such, it grows far faster than most wood, and it is much more sustainable (Patil & Mutkekar,2014). Some bamboo species can even grow up to three feet in 24 hours. The high productivity rate and the short harvest cycle enable bamboo to be an excellent construction material in comparison to other naturally growing resources. Bamboo is also extremely lightweight. This means that not as much energy is needed to manufacture, transport, or install bamboo (Goh et al., 2019). Excessive energy consumption is a major contributing factor to climate change, but using bamboo as an alternate building material limits this consumption. One can use bamboo as an alternate flooring option or in cabinetry and furniture.

Furthermore, the bamboo possesses high tensile strength to density ratio and is found to be six times higher than steel. Because of its high strength-weight ratio, bamboo is often utilized as a extremely resilient substance against earthquake loads and forces from high-velocity winds (Gupta & Kumar, 2008; Goh et al., 2019). In pursuing sustainable construction, regionally found natural substances can be utilized as a base for geopolymer processing, and one such material is bamboo. In a study steered by Riberiro et al. in 2016, the composite geopolymer reinforced with bamboo fibres was utilized as a binder for the bamboo strips. On carrying out the experimental study, it was found that Amazonian metakaolin geopolymer reinforced with bamboo is a latent green sustainable construction material. It possessed good compressive and flexural strength, and the bamboo strips could be used as reinforcements.

6. CONCLUSION

The selection of building materials is the most crucial task as it can impact the overall performance of the structure. Choosing the correct and most suitable material for construction plays an important role, and in the same various parameters are considered impacting the sustainability of buildings. In the present study, various parameters were assessed, and the results revealed that the parameters could be divided into three categories: technical, environmental, and socio-economic. The study revealed that the questionnaire respondents were well aware of sustainable construction techniques and materials. The results showed that availability of materials (locally available or not), affluence of construction, durability, Embodied energy within the material, material waste management, removal of hazardous and toxic material, life cycle cost and health & safety were the most critical parameters out of the 36 parameters that were assessed. All the parameters were found to be significant. Considering the parameters, many construction materials are sustainable and can be a replacement for conventional building materials.

Employing sustainability can improve human life quality by yielding a healthy and fruitful life and promoting social, economic, and environmental surroundings. The suitable utilization of building materials can assist in diminishing the negative environmental effect and life-cycle cost (LCC) of the structures. Thus, it is essential to utilize sustainable building materials compared to conventional/ traditional materials. To sum up, the following point must be considered for green construction:

- Reuse of waste materials in their original forms.
- Environmental impact of selecting green materials.
- The durability of materials in sustainable construction.
- Interaction between local economy and selecting local -green materials.
- Impact of energy consumption in choosing the right construction materials.
- Selecting materials and components with lower carbon emission and the application of the low carbon building technology.
- Using sustainable components for providing green concrete as a popular construction material.
- Use of in-site materials and recycled materials as a raw material for products.

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