



## Review paper

# Trends and features in sustainable construction materials; a global review

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**Abstract:** Building construction projects are one of the major consumers of natural resources, causing resource depletion and the emission of environmental pollution. The sustainability parameters in construction are shifting the paradigm of traditional construction towards a more sustainable construction. Sustainable construction materials are designed and aligned to enhance structural durability, prevent exhaustion of natural resources, improve energy efficiency, lower harmful emissions, and enrich indoor air quality. The objective of this study is to explore the core features which drive sustainable construction materials in the building construction industry; to analyze current trends and preferences being made, and the advancement and challenges encountered in different regions worldwide. A comprehensive literature review approach is utilized to collect and synthesize data from a wide range of resources. The study includes research articles from 2014 till 2024 published in USA, Europe, and Asian countries, using search engine scopus, web of science, and google scholar, which discuss the environmental, social, and economic parameters of sustainable construction materials while excluding articles focusing exclusively on the non-construction industry. The literature review compares trends in sustainable construction materials, featuring different regions of the world. The review has identified several key features and trends shaping the construction industry towards a more sustainable construction world. It also provides a road map for industry players interested in incorporating green materials in construction works.

**Keywords:** building construction, construction materials, sustainable construction, sustainability, sustainable material

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# 1. Introduction

## 1.1. Overview of the sustainability

Sustainability is defined as the ability to meet the present requirement without over exploiting the resources in such a way that future generations cannot meet their needs. It focuses on the economic, environmental and social aspects with the view of attaining sustainable development [1].

The concept of sustainability has become popular in the last 20 years. Its main purpose is to help all individuals to fulfill their needs and enhance their well-being and the well-being of the environment, its resources, and the variety of life on earth now and in the future. It has been noted that the construction industry is slowly integrating sustainability into all its operations; this creates a good chance to minimize the negative effects of construction on the environment while simultaneously improving the lives of its clients [2].

In light of the increasing concerns on the environment and depletion of resources, sustainability in construction has become imperative. Sustainable construction materials ensure that the building design and construction reduces environmental pollution and greenhouse gases, improves indoor air quality, promotes economic development, conserves the environment, and improves the overall health of the inhabitants. This articulates with international standards on environmental conservation, climate change and community development. They also help in reducing carbon footprints and increase energy efficiency which makes them cost effective in the long run as far as building construction is concerned [3].

Sustainable construction materials are produced and utilized in order to preserve the environment and the natural resources during the construction process. Such materials are pragmatic in decreasing the negative effects of buildings on the environment since they are energy-efficient, durable, renewable, and recyclable thus fostering sustainability in the construction sector in the long run [4].

Sustainable construction materials exhibit environmental friendly features and address the challenges of greenhouse gas emissions, pollution, and help balance the ecosystems, which is a core issue with conventional materials. They are either reusable or recyclable and do not pose any harm to the environment and for this reason are referred to as “friends of the environment”.

The UN’s 17 sustainable development goals (SDGs) and 169 targets have been achieved through inter-disciplinary approaches all over the world through the UN 2030 agenda. The link between building materials and the SDGs is thus a knowledge-based decision-making framework for policy makers, designers, and construction industry actors in the implementation of the 2030 Agenda. The products related to building materials can also be seen contributing to the sustainable development goals especially SDG 3, SDG 7, SDG 9, SDG 11, SDG 12, SDG 13 and SDG 15 [5].

## 1.2. Importance of sustainable construction materials

Construction is one of the most important aspects of the world today, but there is an over dependence on synthetic materials. The manufacture of these artificial materials generate a lot of CO<sub>2</sub>, CO, NO<sub>2</sub>, and other pollutants that are hazardous to the health of human beings and the environment. Therefore, the construction industry is one of the lead contributors to world environmental problems. Due to the growing population and the ever-increasing use of

these materials there is a need to search for environmentally friendly options. The sustainable building materials should have characteristics such as energy efficiency, easy availability and should have a low risk of harming the environment. This is to minimize the adverse impacts of construction works upon the well-being of human beings and the ecosystem [6].

As construction activities are acknowledged to have environmental effects and the need for environmental friendliness in construction is realized, there has yet only been slight change in the choice and application of construction materials with sustainability features. Conventional materials are still in use both in the developed and the developing countries. There are several barriers that prevent the usage of sustainable materials; these include: higher cost for the materials, the possibility of increased costs for a project, lack of incentives and policies from the government and finally, lack of willingness from the construction industry. Other challenges include supply chain and logistics problems, limited knowledge and skills on the part of the construction personnel, and a lack of a well-coordinated database of possible sustainable building material alternatives [7].

Due to the fact that the construction industry is a rather diverse and decentralized one, as well as the fact that numerous parties are involved in the decision-making process, it is difficult to provide clear guidelines regarding the choice of sustainable building materials. A wrong choice of materials will lead to failure in the set goals of the project and its effectiveness [8].

It is important to implement sustainability in our everyday lives, as this will improve our health and the general well-being of the economy, society, and the environment. It is therefore important to select the building materials carefully to reduce the negative environmental impacts while simultaneously minimizing the project life cycle cost [9].

Sustainable construction is a philosophy which embraces the environmental, social as well as the economic aspect in the construction process. Some of the main goals include improvement of the quality of life, work productivity, and provision of health in the workplace. The sustainable construction practices try to enhance the technological and innovative capacities in the construction process, and improve strategies from the beginning of the construction up to the disposal of wastes at the end of the construction [10].

### **1.3. Development in sustainable construction materials**

The construction industry is moving towards sustainable construction as global awareness and legal mandates for sustainable construction are increasing [11]. Technological developments have enhanced the possibility of incorporating sustainable products in the construction of buildings and other structures. Some current products are made from industrial waste, which reduce the amount of embodied energy and encourage the use of sustainable resources. Technologies are quite indispensable in the advancement of projects that define next generation green building [12].

Sustainable building materials (SBM) are products which can be recycled or can be reused and are not a source of pollution when used in construction. SBM are in fact, recyclable materials and can contribute to a decrease of the consumption of primary resources SBM contributes to the well-being of the environment through the improvement of building performance and quality of indoor air [13].

Sustainability in the construction industry has an immense and a far reaching impact on the environment. Sustainable construction deals with the provision of structures that uphold the conservation of the environment and prevent depletion of natural resources and energy. This

approach results in a decrease of greenhouse gases and the overall carbon footprint related to buildings. Also, green construction methods assist in efficient and proper water and waste management [14].

Sustainable construction is gaining momentum worldwide and calls for more studies on how to overcome the challenges of sustainable construction during the different phases of a project. Despite the fact that a significant number of papers have been published on the topic, only a small number of these papers have aimed at providing a systematic literature review of the area, in order to evaluate the current state of research or suggest further directions [15].

The innovation of eco-friendly and low cost concrete mix using fly ash and marble powder waste as substitute to the fine aggregate, has helped in reducing carbon footprint [16]. The use of supplementary cementitious materials like metakaolin and limestone powder, as partial substitute to the cement, is an achievement in sustainable structural concrete and engineering environment sustainability [17]. The sustainable alternatives to traditional materials, like geopolymers, with enhanced mechanical and eco-friendliness properties, GGBS as replacement to fly ash, are the realm of advancement in sustainable construction practices [18].

## **2. Material and methods**

### **2.1. Literature review approach**

The purpose of a literature review is to provide the reader with a global idea of the state of knowledge on a particular subject for the purpose of research proposals, and to identify the expected contribution of the proposed research. In this case, the term ‘knowledge’ is not synonymous with the ultimate truth, or theorem. Instead, it refers to convictions which people have to some extent and which stem from study or practice. In the social sciences and policy research, very few hypotheses can be stated as fact. As such, literature reviews tend to centre on the claims or arguments advanced by different works or paradigms. A meta-synthesis of the findings of the existing literature would categorise these claims and assess the degree of evidence for each [19].

### **2.2. Description of the review process**

A comprehensive literature review approach is utilized to collect and synthesize data from a wide range of resources. The review is focused on the most relevant research articles to sustainable construction materials using Scopus, web of science and google scholar database published considering 2014 to 2024. The combination of search keywords used are sustainable construction materials, green building materials, eco-friendly construction materials.

### **2.3. Selection criteria**

The extent to which qualitative studies should be critically assessed in systematic reviews is still a great area of discussion. Of particular concern in this regard is the question of whether quality assessment should be employed to deliberately exclude some studies from the analysis [20].

The study included research articles that discussed the environmental, social and economic parameters of sustainable construction materials; and excluded articles focusing exclusively on the non-construction industry. The literature review compares trends and features in sustainable construction materials across different regions of the world, such as north America; Asian countries particularly Malaysia, Singapore, South Korea, Japan, India; middle east countries and the United Arab Emirates.

## **2.4. Data extraction and analysis**

Method for extracting and analyzing trends and features:

A total of 184 research articles have been selected globally which meet the search criteria that includes 52 articles from North America, Canada, EU countries; 52 research articles from Malaysia, Japan, South Korea, Singapore, China, and India; 45 research articles from the middle east region, and 35 research articles from the United Arab Emirates. The selected articles are reviewed critically and the features of sustainable construction materials are extracted. Most related, repeated and pronounced features include sustainability awareness, recycle/reused materials, alternative/ substitute materials, embodied energy, carbon footprint, indoor air quality, water efficiency, and regional materials.

## **2.5. Data extraction and analysis**

The research articles include the articles published in united state of America, European countries, Asian countries, but excludes the articles published in Africa countries. The paper also includes only articles addressing sustainable construction and excluded articles, that addresses non-construction domain.

## **2.6. Research methodology**

The research methodology follows exploratory research technique. The research articles are studied by the researcher in depth to get insights of the sustainable construction features worldwide. The features are then recorded, highlighted, emphasized and ranked.

# **3. Results and discussion**

## **3.1. Global trends in sustainable construction materials**

Summary of emerging trends worldwide:

Sustainability awareness: the level of understanding about sustainability by the project stakeholder is emphasized in the design, materials, and execution of projects as well as operations of the buildings, with the knowledge of cost and benefit analysis, social and environment outcomes. The gaps in sustainability awareness require identification, evaluation and analysis in terms of how, why and to what degree the sustainability concept takes dimension. The awareness campaigns in society, learning subjects in the education institutes and offered courses at organizational levels help fill the gaps in sustainability awareness [21].

**Material recycle/re-use:** the construction sector is the major source of natural resource consumption generating construction demolition waste and increasing landfills. Various policies and frameworks have been introduced at the government level across the globe to mitigate this problem. The waste materials are recycled and used as an alternative construction material in order to save natural resources, reduce landfills and protect the environment. There is an urgent need to focus on this area of study and explore ways to address these problems [22].

**Alternative/substitute material:** utilization of alternative materials is needed in order to address the depletion of traditional materials and to address the impact of greenhouse gas emissions, taking into account economical and methodological issues. The amount of greenhouse gases released can be avoided by substitution with alternative materials. Energy consumption and emissions by building materials are being navigated with alternative materials while adhering to the project specifications and performance criteria.

Several alternative construction materials are being introduced and used in the construction industry in order to mitigate the environmental, social and economic issues. The use of GGBS, fly ash, recycled materials, plasticizers, wooden alternatives to steel and concrete are among the list [23].

### **3.2. Features of sustainable materials**

Key characteristics and attributes of the materials identified:

The following are the key sustainable and project management factors:

**Embodied energy:** the amount of energy spent in the extraction of raw materials, manufacturing and transportation of various construction materials and considering the greenhouse gas emission into the atmosphere is a matter of concern. Studies showed that the amount of embodied energy can be reduced at construction projects by considering various alternative and energy efficient materials as smart choices. The construction materials having higher embodied energy can result in more CO<sub>2</sub> emission as compared to the materials with less embodied energy [24].

**Carbon footprint:** the construction industry is a major source of carbon emissions from the construction materials, activities and operations directly or indirectly linked to the carbon footprint; a threat to global climate change and increased greenhouse gas concentrations in the environment. Over the last few decades, due to an increased understanding of global climate, carbon emissions and their regulations, efforts are being made globally, regionally and at individual enterprise level to pursue carbon and environmental emission mitigation projects [25].

**Indoor air quality:** the specification and selection of building construction materials greatly influence the health and wellbeing of humans mostly in terms of indoor air quality. It is essential to consider the effect of hazardous materials in building construction projects. Construction materials containing volatile organic compounds contaminate the indoor air quality and increase the risk of the chronic respiratory disease for the inhabitants. Improvement in the building design and construction materials may improve energy efficiency and indoor air quality.

The construction products regulation (CPR) provides comprehensive solutions for the performance assessment of construction materials. The energy performance buildings directive

(EPBD) provides energy performance standards, zero emission, supports better air quality, digitalization of energy systems and roll out of infrastructure for sustainable mobility [26].

**Energy efficiency:** building construction projects take a significant part in terms of energy at every step of the life cycle. In building construction materials, energy is consumed during the extraction and manufacturing processes, transportation from the source to the construction facility site, during the construction process itself, and ultimately in the demolition phase at the end-of-life cycle. Hence considering the energy consumed by the construction materials is a key parameter in evaluating the energy efficiency of the building. Energy efficient materials contribute both economically and environmentally by consuming less energy, reducing hazardous emissions and pollution. Energy efficient designs distinguish from the other designs by reducing the amount of energy and cost, keeping individual and social benefits by selection of suitable materials, design parameters, construction techniques, operational procedures and ultimately end of the structure life [27].

**Regional materials:** utilization of regional materials is a common technique in green practices in architecture, construction and material production. Regional materials are extracted and manufactured in the local or neighboring areas of the construction site projects. The ecological benefits of regional materials are reduced transport cost and emissions, and support of the local economy by using local materials. Due to inherent characteristics of regional materials, they tend to adopt local climate conditions and harmonize with the existing environment. The key advantage of regional materials is that they require less lead time if the requirements in scope of the project fluctuates [28].

### **3.3. Regional variations**

The papers compiled in the review are related to sustainable construction and cover several topics, including the barriers, successes, and advanced materials and techniques. Global challenges about climate change and environmental issues have created a lot of interest and research in sustainable construction materials and techniques. It is possible to note that these researches present different effective methods and products that help minimize the negative impact of the construction sector on the environment and improve the efficiency of buildings. Altogether, the above- mentioned works reveal that sustainability should be incorporated into construction projects by means of utilizing new materials, technologies, rules and management systems.

**Barriers to sustainable construction:** the theme can be defined as an identification and evaluation of factors that hinder the implementation of sustainable construction. These barriers include; pre-construction constraints, managerial constraints, legislative constraints, financial and planning constraints.

**Comparative analysis of green building standards:** some of the papers review green building standards across different countries. They reveal disparities in the assessment approaches and standards, which may assist in the creation of new policies and the enhancement of green building certification systems. Areas that are compared include energy and atmosphere, water efficiency, materials and resources, site selection, and indoor air quality and outdoor spaces.

Environmental impact of materials: special attention is paid to the ecological issue of the construction materials used. For instance, the environmental aspects of wooden structures were studied and it was established that among the different factors, insulation, plastics, and composites have more dire effects on the environment than wood. Other papers discussed the opportunities for application of recycled materials; for instance, using demolition waste in production of concrete, recycled masonry aggregates, and plastic waste in order to minimize negative effects.

### 3.4. Global trends in sustainable construction materials

The features of sustainable construction materials are extracted from research articles and analyzed for global priorities in the below Table 1.

Table 1. Global overview of sustainable construction material priorities as per literature review

Sustainable construction materials features	USA, EU, Canada region		Japan, China, Korea, Malaysia, Indian region		Middle east region		United Arab Emirates region		Global overview	
	Feature weightage	Rank	Feature weightage	Rank	Feature weightage	Rank	Feature weightage	Rank	Feature weightage	Rank
Sustainability awareness	4%	7	15%	3	13%	3	5%	5*	9%	5
Recycle / re-use materials	21%	2	21%	1	21%	2	20%	2	21%	2
Alternative / substitute material	12%	4	18%	2*	9%	5	12%	4*	13%	4
Embodied energy	7%	5	5%	5	5%	7*	0%	6*	5%	6*
Carbon footprint	18%	3	13%	4	11%	4	17%	3	15%	3
Indoor air quality	5%	6*	3%	7	5%	7*	5%	5*	4%	7*
Energy efficiency	24%	1	18%	2*	27%	1	29%	1	23%	1
Water efficiency	5%	6*	4%	6	2%	8	12%	4*	5%	6*
Regional materials	5%	6*	2%	8	7%	6	0%	6*	4%	7*

The table presents the global overview of sustainable construction material features which include: sustainability awareness, recycle/ Re-use materials, Alternative/ Substitute materials, embodied energy, carbon footprint, indoor air quality, energy efficiency, water efficiency, and regional materials.

The features are then weighted in percentage from the total number of articles from the literature review. It is found that energy efficiency, with a rank-1 in trend prevalence, is most considered globally in research articles that have been ranked globally as number-1. recycle/re-use material found to be the second most prominent feature in the research articles, carbon footprint found to be third in rank. Alternative/ substitute materials at rank-4, sustainability awareness rank-5, embodied energy and water efficiency are both at rank-6, and regional material priorities and indoor air quality both found to be at rank-7.

## 4. Conclusions

The article has identified several key features and trends in shaping the construction industry towards a more sustainable construction world. It has highlighted growing trends in recycled materials; preferences to regional materials in order to avoid and minimize the carbon footprint and CO<sub>2</sub> emissions; low carbon concrete, incorporating industrial biproduct of slag and fly ash in order to reduce emissions; as compared to ordinary portland cement. Also highlighted is the growing focus on the use of low VOC materials in order to enhance the indoor environmental quality. The results also stress the importance of supportive policies, financial incentives, and harmonization of the regulation framework as key factors for an increased use of sustainable materials. It also provides a road map for industry players interested in incorporating green materials in construction works.

Thus, we have been led to a realization that sustainable construction material is the much needed solution to curb the effects of environmental degradation in construction. Through this global trends and features review, it has been possible to illustrate the rising interest in materials with low ecological effects, energy efficiency, durability and circular economical strategies.

There is a further need to investigate region-specific materials, refine current LCAs, and cooperate with policy-makers and industrial partners, as well as academic institutions on a global level in order to enhance a sustainable approach. With construction being one of the most thriving industries in the current world, it has therefore become mandatory to have sustainability integrated into the construction processes, as it remains key in preventing the depletion of resources and high carbon emission. Better more integrated regulations with improved material technology will be the driving force behind a more sustainable future for the built environment.

Recommendations for the future research: the research gaps are identified to pave the way for further studies and overcome challenges in enhancing the durability of bio-based materials, decreasing the cost of sustainable options, and enhancing the existing legislation.

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