Green Materials, Applications and Sustainability

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Abstract: The growing environmental challenges posed by conventional materials have driven significant interest in green materials, which offer sustainable alternatives with minimal ecological impact. Green materials, derived from renewable, biodegradable, or recycled sources, are increasingly being utilized across industries such as construction, packaging, automotive, and energy. This paper explores the latest advancements in green materials, including biopolymers, natural fiber composites, and eco-friendly ceramics, highlighting their unique properties and applications. Additionally, the study examines innovative manufacturing techniques that enhance material performance while reducing energy consumption and waste generation. A key focus of this research is the sustainability assessment of green materials through life cycle analysis, evaluating their environmental footprint from production to disposal. The findings suggest that these materials significantly lower carbon emissions, reduce dependence on non-renewable resources, and promote circular economy principles. However, challenges such as scalability, cost competitiveness, and performance limitations under extreme conditions remain critical barriers to widespread adoption. The paper also discusses policy frameworks and industry initiatives that support the transition toward sustainable material use, emphasizing the role of government regulations, corporate responsibility, and consumer awareness in driving market adoption. By integrating technological innovation with ecological considerations, green materials present a viable pathway to achieving sustainable development goals. This study concludes with recommendations for future research directions, including the development of high-performance bio-based materials and advanced recycling technologies to further enhance sustainability in material science. This research article summarizes recent developments regarding green materials, their application areas, and sustainability, while highlighting their potential to advance technologies across various fields. The insights gained from this research article will undoubtedly assist researchers in designing innovative green materials with specific properties tailored to particular applications.

Keywords: Green materials, Applications, Sustainability, Recycling, Eco-friendly, Future.

1. INTRODUCTION

Green materials are also called sustainable materials or eco-friendly materials. Green materials are materials that have minimal environmental impact throughout their life cycle, from extraction and production to use and disposal. These materials are generally renewable, biodegradable, recyclable, non-toxic, and efficient. For example, bamboo and hemp are renewable materials. PLA plastics and mycelium are also biodegradable materials. Additionally, materials such as natural dyes and low-VOC paints are also non-toxic. Finally, the production of materials such as compressed earth and straw bales is also energy efficient. The goals of these materials can be summarized as reducing pollution, conserving resources, and supporting a circular economy [1-3] (Table **1**).

The concept of green materials has evolved alongside environmental awareness. These developments can be summarized as follows between the pre-industrial era and the present time: In the pre-industrial era, natural materials such as wood, clay, natural fibers, and stone dominated. During the Industrial Revolution, which took place between the 18th and 19th centuries, synthetic materials such as plastics and concrete emerged, raising pollution concerns. Later, between the 1970s and 1980s, societal environmental awareness grew. The emerging environmental movement encouraged various research projects on paper and plastic recycling. Subsequently, regulations such as LEED certification, enacted between the 1990s and 2000s, encouraged sustainable green construction and production. Finally, between the 2010s and the present, various research and development efforts have been underway on nanotechnology, bio-based polymers, and carbon-neutral materials such as graphene and hemp concrete [4, 5].

This article examines the latest developments in green materials, including biopolymers, natural fiber composites, and environmentally friendly ceramics, highlighting their unique properties and applications. The study also examines innovative manufacturing techniques that improve material performance while reducing energy consumption and waste generation. The study concludes with recommendations for future research directions, including the development of high-performance biobased materials and advanced recycling technologies, to further enhance sustainability

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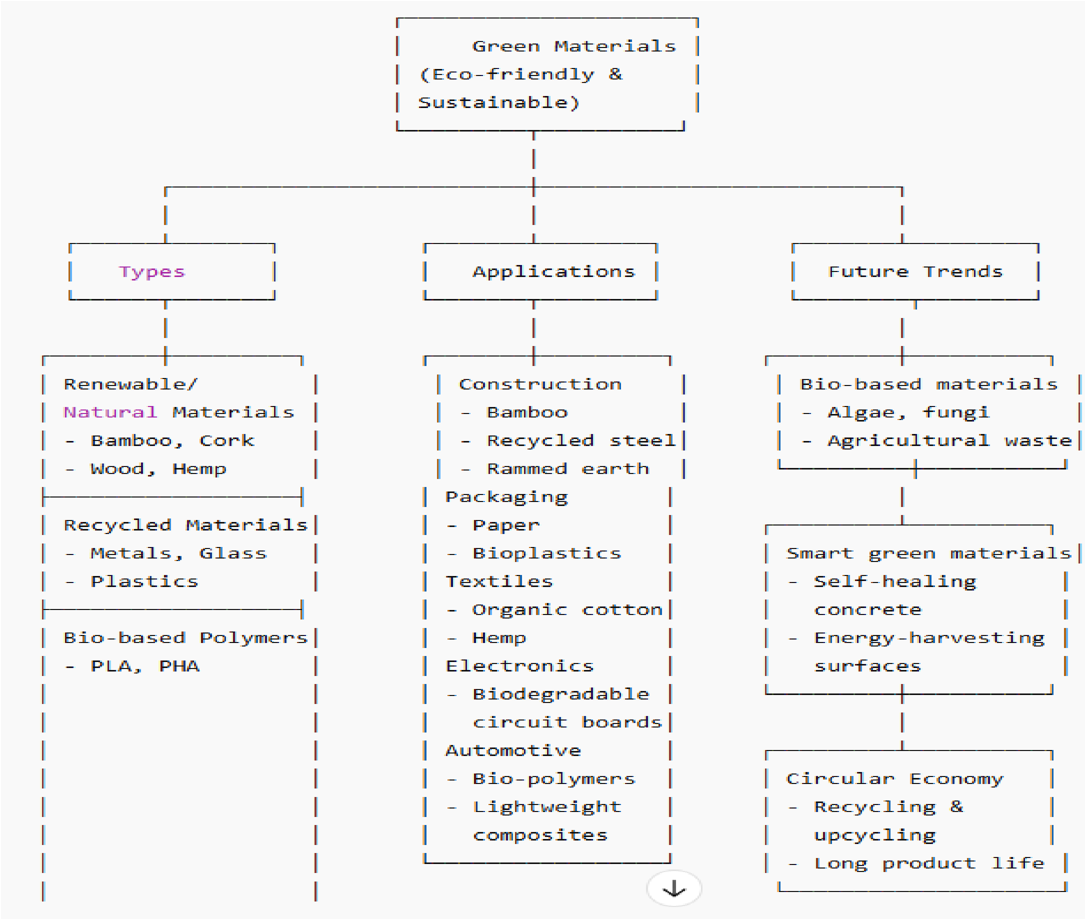
Received on 02-08-2026 Accepted on 18-09-2026 Published on 22-09-2026

E-ISSN: 2819-828X/26

Table 1: Types of Green Materials



in materials science. This research article also summarizes recent developments regarding green materials, their application areas, and sustainability, while highlighting their potential to advance technologies across various fields.

2. APPLICATIONS

Green materials are revolutionizing industries by offering environmentally friendly alternatives to traditional, resource-intensive materials. Due to their environmental and functional advantages, green materials are being adopted in many sectors. Applications of green materials include construction, packaging, textiles, automotive, electronics, and energy (Figs. **1**, **2** and **3**) [6, 7]. These include bamboo, hemp concrete, laminated timber, recycled steel and glass, and compressed earth and straw bales in construction and architecture. Bamboo is stronger than steel by weight and is used in flooring, scaffolding, and structural elements. Hemp concrete, on the other hand, is a carbon-negative insulation material that absorbs CO_2. Cross-laminated timber is a sustainable alternative to steel/concrete in high-rise buildings. Recycled steel and glass materials reduce mining waste and energy consumption. Compressed earth and straw bales are low-energy, natural insulation materials.

In packaging applications, bioplastics, mycelium, renewable packaging, and recyclable cardboard and paper are used. Bioplastics such as PLA and PHA are derived from corn starch or sugar cane and are compostable. Mushroom packaging, or mycelium, is grown from agricultural waste and is fully biodegradable. Seaweed-based films are used for food packaging as edible packaging. Recycled cardboard and paper reduce deforestation and landfills. In the textile and fashion sector, organic cotton, bamboo, and hemp fabric, recycled polyester, and bio-fabricated leather are used. Organic cotton is grown without pesticides and uses less water. Bamboo and hemp fabric are green materials and are naturally antibacterial and durable. Recycled polyester is produced from plastic bottles, reducing petroleum use. Bio-fabricated leather, or lab-grown leather, is cultured from yeast or fungal mycelium.

In the automotive and transportation sector, natural fibers, recycled rubber, and bio-based polymers are used (Fig. **4**). Linen and hemp are natural fiber composites. These materials are lightweight and used in vehicle interiors. Recycled rubber tires can be turned into road surfaces or new tires. Bio-based polymers are used for dashboards and insulation [9].

Figure 1: Types and applications of green materials.

Figure 2: View of several green kitchen utensils [8].

Figure 3: View of a green lawnmower [8].

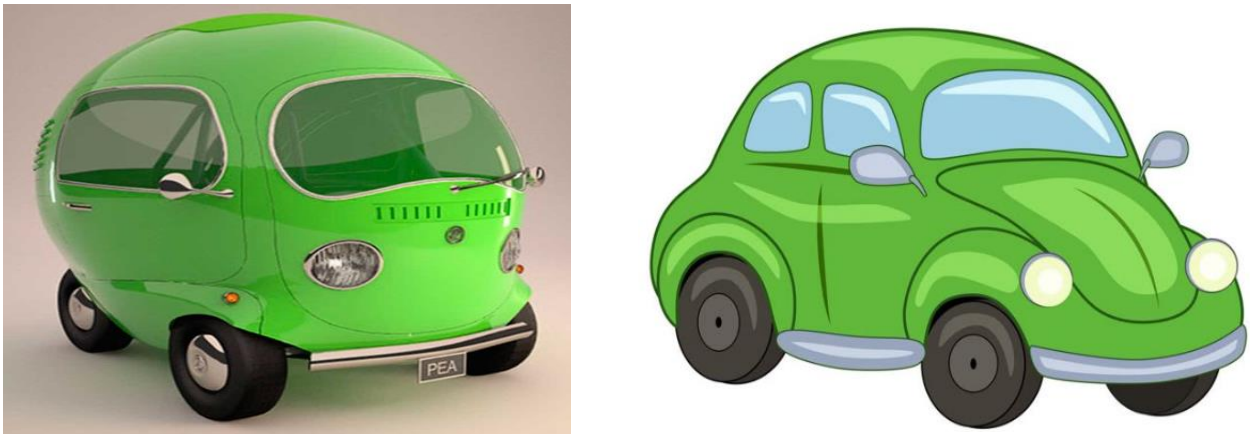


Figure 4: Electrical cars.

In the electronics sector, biodegradable circuit boards, lead-free solder, and solar cells are used. Biodegradable circuit boards are made from cellulose or flax fibers. Lead-free solder also reduces toxic electronic waste. Organic photovoltaics, or solar cells, are flexible and require low energy to manufacture.

In the energy sector, perovskite solar cells, recyclable wind turbine blades, and graphene cells are used. Perovskite solar cells are more efficient than silicon and have lower production costs. Similarly, recyclable wind turbine blades used in the energy sector are manufactured using thermoplastic resins. Additionally, graphene cells used in this sector have higher energy density and fast charging capabilities (Tables **2** and **3**).

3. SUSTAINABILITY

Sustainability refers to the ability to meet present needs without compromising the ability of future generations to meet their own needs. Green materials contribute to sustainability from environmental, economic, and social perspectives:

From an environmental sustainability perspective, green materials minimize environmental impacts such as resource efficiency, pollution, and waste throughout their life cycles. Regarding resource conservation, the use of renewable materials such as bamboo, hemp, and biopolymers reduces reliance on limited resources [11, 12]. Furthermore, regarding energy efficiency, the production and processing of green materials generally requires less energy compared to traditional materials. Regarding pollution reduction, biodegradable and non-toxic materials reduce air, soil, and water pollution.

Waste reduction is also crucial for the environment. Recycled and recyclable materials help divert waste from landfills. For example, replacing Ordinary Portland Cement (OPC) with 50% Ground Granulated Blast-furnace Slag (GGBS) reduces the embodied carbon of

Table 2: Summary Table of Applications

Sector	Examples	Benefits
Construction	Bamboo, recycled steel, fly ash concrete	Energy efficiency, low carbon footprint
Packaging	Bioplastics, recycled paper, plant-based	Reduces waste, eco-friendly disposal
Textiles & Fashion	Organic cotton, hemp, recycled polyester	Less water & chemical use, biodegradable
Electronics	Biodegradable circuit boards, lead-free solder	Reduced e-waste, safer disposal
Automotive & Transport	Bio-polymers, natural fiber composites	Fuel efficiency, lower emissions
Miscellaneous	Eco-friendly household & medical products	Sustainable everyday use

Table 3: Embodied Carbon and Energy, Service Life and Recyclability for Different Materials [10]

Material Type	Embodied Carbon (kg CO2 eq/kg)	Embodied Energy (MJ/kg)	Service Life (Years)	Recyclability Rate (%)
Traditional OPC Concrete	~0.13 – 0.15	~1.0 – 1.3	50 – 100	Low (Downcycled)
Geopolymer / Alkali-Activated Concrete	~0.03 – 0.06 (~60-80% reduction)	~0.4 – 0.7	75 – 100+	Moderate
Structural Steel (Virgin)	~1.8 – 2.2	~25 – 35	100+	High (~85-90%)
Cross-Laminated Timber (CLT)	-0.4 – 0.2 (Net negative with sequestration)	~8 – 12	50 – 80	High (Reusable/Energy)

concrete from roughly 0.14 kg CO2 eq/kg to 0.07 kg CO2 eq/kg, representing a 50% reduction in Global Warming Potential (GWP) over a 100-year cradle-to-gate lifecycle assessment."

Secondly, economic sustainability comes into play. Green materials can be economically beneficial in the long term in terms of cost savings, added value, and market growth: Energy-efficient materials reduce operating costs in buildings, electronics, and transportation. The use of recycled and bio-based materials can reduce raw material costs, resulting in added value.

The increasing demand for sustainable products creates new business opportunities, which in turn drives market growth. For example, lightweight composites used in vehicles increase fuel efficiency and reduce costs over time.

Thirdly, social sustainability is key. As is well known, green materials also improve health, living conditions, and human well-being: Non-toxic, low-VOC materials improve indoor air quality and reduce exposure to harmful chemicals. Sustainable housing materials increase thermal comfort and lower energy bills, leading to better living conditions. Finally, growing green industries create jobs in the production and recycling of renewable materials.

4. FUTURE PERSPECTIVES

The future of green materials is being shaped by technological innovations, policy support, and global environmental needs. This topic can be examined under six groups: biobased and smart green materials, the circular economy, advanced technologies, policy support, and industry trends.

Biobased and renewable materials include topics such as the increased use of algae, fungi, and agricultural waste for polymers, textiles, and packaging. This involves the development of fully biodegradable and compostable materials.

Self-healing concrete and coatings, among smart green materials, reduce maintenance and extend product life. Energy-harvesting materials, such as solar-powered windows or surfaces, convert energy from the environment.

Within the circular economy integration, material and product design encompasses reuse, recycling, and upcycling. The goal is to minimize waste generation and reduce reliance on virgin resources.

Nanotechnology, which increases material durability and functionality while using fewer resources, is among the advanced technologies. Here, artificial intelligence (AI) is used to optimize material design and lifecycle performance.

Policy and regulatory support are crucial for the development of green materials. Governments worldwide are encouraging the use of sustainable materials through eco-standards, green production incentives, and regulations.

In terms of industry trends, there is increasing adoption in the construction, automotive, electronics, and packaging sectors. Furthermore, there has been a shift from a "linear economy" (make-use-dispose) to sustainable and regenerative systems. The global focus on carbon neutrality and climate change mitigation is spurring innovation.

In summary, green materials are critical to environmental, economic, and social sustainability. Future trends emphasize bio-based, smart, and circular materials (Figs. **5** and **6**). Policy support, technological innovation, and consumer awareness will accelerate adoption. Sustainable materials are essential for achieving global goals such as carbon reduction, waste minimization, and green development [13-15].

5. DISCUSSION

5.1. Sustainable Building Materials and Green Construction Practices

Sustainable building materials are central to reducing the environmental impact of construction while enhancing the health, comfort, and energy efficiency of buildings. These materials are sourced from renewable resources, incorporate recycled content, and promote circular economy principles by minimizing waste and pollution throughout their life cycle.

5.2. Green Concrete and Recycled Construction Materials

Green concrete represents a major advancement in sustainable construction. By substituting traditional Portland cement with industrial byproducts such as fly ash, slag, and recycled aggregates, green concrete significantly reduces carbon emissions associated with cement production. Fly ash concrete, for example, can cut CO_2 emissions by up to 30% compared to conventional concrete while maintaining comparable strength and durability. Recycled aggregates derived from crushed concrete and glass further reduce raw material consumption and landfill waste.

However, challenges including variability in performance under freeze-thaw cycles or high-strength applications are being addressed through ongoing

Figure 5: Future green car.

Figure 6: Interior space fit-up [14].

research aimed at optimizing mix designs and additives, ensuring wider applicability.

5.3. Energy-Efficient Construction and Material Benefits

Incorporating green materials such as bamboo, cross-laminated timber (CLT), hempcrete, and compressed earth into building design improves thermal insulation and reduces embodied energy. Bamboo is an excellent structural material due to its high strength-to-weight ratio—stronger than steel by weight—and rapid renewability. CLT offers a sustainable alternative to steel and concrete in mid- and high-rise buildings, providing excellent carbon sequestration and energy savings. Hempcrete functions as a carbon-negative insulation material, sequestering CO_2 while enhancing building breathability and thermal regulation.

These materials contribute to lowering operational energy demands by improving the building envelope's insulating properties, which translates into reduced heating and cooling costs. Designs combining these materials with passive solar techniques and modern HVAC systems create highly energy-efficient buildings that meet or exceed standards such as LEED and BREEAM.

5.4. Practical Applications and Innovation

Practical use cases demonstrate the viability of green materials in construction. Bamboo is utilized in scaffolding, flooring, and load-bearing structures.

Hempcrete and straw bales serve as natural, low-energy insulation alternatives in walls. Recycled steel and glass are incorporated into framing and decorative elements, reducing both environmental impact and material costs. Finishes using low-VOC paints and natural dyes improve indoor air quality and occupant health.

Innovations such as self-healing concrete extend the lifespan of infrastructure by repairing micro-cracks autonomously, decreasing maintenance needs and resource consumption over time. Emerging energy-harvesting materials like solar-embedded windows contribute to buildings generating their own renewable energy.

5.5. Life-cycle and Sustainability Assessment

Goal and scope: To enable meaningful comparison with previous studies, this assessment adopts a cradle-to-gate system boundary and a functional unit of [1 kg of product / 1 functional unit], consistent with recent LCA studies on comparable textile and bio-based systems.

Previous LCA findings: Several studies have quantified the environmental performance of textile and related supply chains. Iqbal *et al*. [16] found that textile products from virgin cotton fiber exhibit approximately 60% higher global warming potential than products from post-consumer textile waste fibers, demonstrating the environmental advantage of closed-loop recycling strategies. Şimşek Yeşil *et al*. [17] reported that the total water footprint of cotton textile production in Türkiye ranges from 4,573 to 7,583 m³/ton, with 93–97% attributable to cotton cultivation alone. A systematic review by indicated that polyester textiles have a cradle-to-grave GWP of approximately 40.28 kg CO_2-eq/kg, with the consumer use phase contributing more than half of total emissions. In a more recent integrated assessment, wool's climate impact was reported as 52.0 kg CO_2-eq/kg (direct) but rising to 182 kg CO_2-eq/kg when indirect land-use change is included, while hemp performed best among the compared options on combined sustainability indicators.

Environmental indicators: We report the following indicators, consistent with ISO 14040/14044 and widely used in textile LCA literature: Global Warming Potential (GWP100), expressed in kg CO_2-eq per functional unit, using IPCC characterization factors. Cumulative Energy Demand (CED), in MJ per functional unit. Water Scarcity Footprint, in m³-eq per functional unit, using AWARE or equivalent method. Acidification and Eutrophication potentials, in kg SO_2-eq and kg PO_4-eq respectively, where data permit.

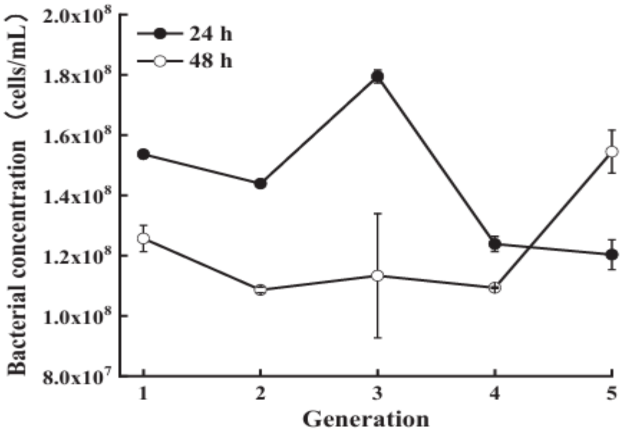
Economic indicators: Economic sustainability is assessed through: Levelized cost per functional unit (USD/FU), where cost data are available. Capital and operational expenditure structure. Payback period, for systems involving investment. Where primary economic data are unavailable, we report qualitative discussion grounded in sector-level cost analyses.

Social indicators: Following UNEP/SETAC guidelines for Social LCA and recent integrated frameworks, we evaluate: Employment generation, expressed as job-years or direct/indirect employment per functional unit. Occupational health and safety risk, using sector- and country-level risk screening (e.g., SHDB-based). Supply-chain social risk context, including country-level indicators for labor conditions in raw material sourcing.

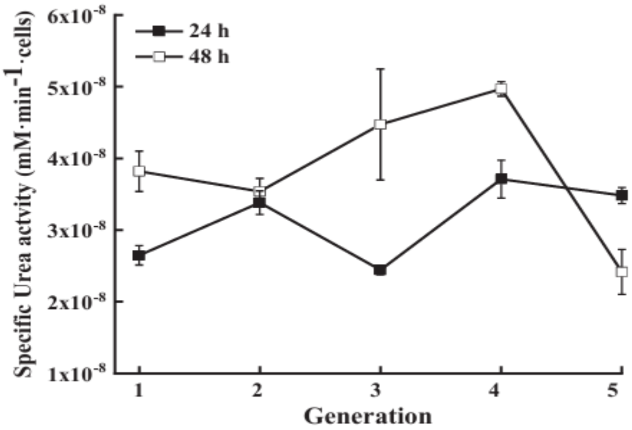
6. RECENT STUDIES

Recently, there are so many studies have been done in the specific topics. However, few of them will be reported here for the sake of global information. In 2022, Wang *et al*. [18] published a paper titled "Use of recycled concrete aggregates as carriers for the self-healing of concrete cracks via bacteria with high urease activity." In this study, microbial urease activity was first examined across different propagation generations in a selected culture medium; subsequently, the potential of recycled concrete aggregates (RCAs) to serve as microbial carriers was investigated, taking into account their porous structure. Even after propagation through five generations in the selected culture medium, the specific urease activity of the bacteria at 48 hours remained high, at 2.4×10^8 mM·min^{-1}·cell^{-1}. The RCAs did not cause a loss of ureolytic activity following immobilization and were able to maintain bacterial viability during the concrete mixing process (Fig. **7**). Compared to concrete containing no repair agents or only the substrate and calcium source, concrete containing biological agents loaded onto RCAs completed the majority of crack repair within the first week. For initial crack widths of less than 0.6 mm, the microbial self-healing method achieved an average crack repair rate of 71% and a crack area repair rate of 84%. As evidenced by microbial precipitation on the crack walls, the crack repair depth reached 17.8 mm. Following the microbial self-healing process, the recovery rate for compressive strength reached 99.7%, and the recovery rate for water impermeability reached 99.2%; The fractures are filled with tightly packed, irregularly shaped rhombohedral crystals composed of calcite and minor amounts of vaterite.

In 2023, Li and colleagues [19] published an article titled "Construction of pure nucleic acid nanostructures



(**a**)



(**b**)

Figure 7: Effects of CSU medium on (**a**) bacteria concentration and (**b**) specific urease activity [18].

based on rolling circle amplification products for biomedical applications." Nucleic acid nanomaterials, characterized by good biocompatibility, biodegradability, and programmability, hold significant promise for biomedical applications. They are often combined with inorganic nanomaterials to enhance their biological stability; however, the undefined toxic side effects of such composite nanocarriers hinder their *in vivo* use. As a potential solution to avoid biotoxicity, nanostructures composed entirely of DNA oligonucleotides have seen rapid development in the biomedical field in recent years. Rolling circle amplification (RCA) is an isothermal enzymatic nucleic acid amplification technology used for the large-scale production of periodic DNA or RNA sequences with pre-designed structures and functions. By altering the sequence of the circular template, RCA products can be customized with specific functional segments, enabling the creation of complex, multifunctional DNA nanostructures such as nanowires, nanoflowers, origami, nanotubes, and nanoribbons. Crucially, as nick-free building blocks, RCA products can enhance the biostability of DNA nanostructures, particularly in *in vivo* environments. Nucleic acid nanostructures derived from RCA products can serve as scaffolds or nanocarriers to interact with or encapsulate various agents, including metal nanoparticles, proteins, lipids, cationic polymers, therapeutic nucleic acids, and drugs. This article examines the assembly strategies for RCA-based DNA nanostructures of various shapes and their applications in the fields of biosensing, bioimaging, and biomedicine. Finally, the development of nucleic acid nanomaterials for the clinical diagnosis and treatment of diseases is discussed.

In 2024, Chen and colleagues [20] conducted a review study titled "Biomaterial technology and policies in the construction sector." This study examined construction biomaterials, associated policies, and life-cycle assessments through case studies. Bio-based materials have the potential to reduce carbon dioxide emissions by over 320,000 tons by 2050. Furthermore, these materials offer advantages such as improved mechanical properties, alongside enhancements in water absorption (by 40%), energy consumption (by 8.7%), and acoustic absorption (by 6.7%). Recent developments in the fields of mycelium-based materials, bio-concrete, natural fibers, and fiber-reinforced composites were summarized. Additionally, the contributions of nanotechnology and microalgae technology to enhancing the thermal insulation and eco-friendly characteristics of biomaterials were discussed.

Subsequently, in 2025, another review study titled "On green building construction strategies: The role of nanomaterials in green buildings for a sustainable future" was published by Humadian *et al.* [21]. This study employed a systematic review to provide an overview of sustainable construction strategies focusing on energy efficiency, resource conservation, waste minimization, and indoor environmental quality. A total of 231 documents were examined, including publications from Elsevier, Springer, MDPI, Taylor & Francis, and Wiley, as well as government documents from the World Green Building Council and the UN. The review focused on nanomaterials as emerging solutions to enhance green building performance—specifically improving thermal insulation, structural reinforcement, air purification, self-cleaning capabilities, and corrosion resistance—while also addressing associated challenges. Accordingly, the study characterized green buildings as eco-friendly structures that utilize fewer resources, reduce waste, and improve indoor air quality (Fig. **8**). Furthermore, research limitations and geographical implications regarding sustainable buildings were discussed, and recommendations were offered. The study's contribution lies in demonstrating how nanomaterials can be consciously integrated into

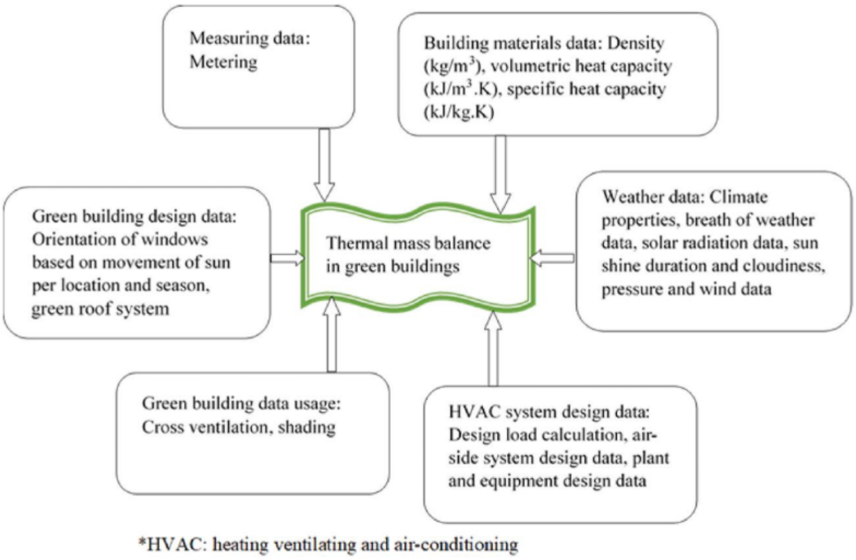


Figure 8: Thermal mass for green buildings; the higher the volumetric hear capacity, the high the mass balance [21].

Table 4: Mix Proportion for Bacterial and Non-bacterial Rubberized Mortars [22]

Mix	Cement in kg/m^3	Crushed sand in kg/m^3	Rubber fibre			Mixing water		SP in kg/m^3
			(in %)	BIRF in kg/m^3	RF in kg/m^3	BS in kg/m^3	NW in kg/m^3	
BM-0	760.72	1342.66	0.0	0.00	–	293.60	–	3.80
BM-1	755.55	1333.52	1.0	7.62	–	291.60	–	3.78
BM-2	750.44	1324.51	2.0	15.14	–	289.63	–	3.75
BM-3	745.40	1315.61	3.0	22.56	–	287.68	–	3.73
BM-4	740.43	1306.84	4.0	29.88	–	285.76	–	3.70
NM-0	758.51	1338.75	0.0	–	0.00	–	292.74	3.79
NM-1	753.36	1329.67	1.0	–	7.60	–	290.76	3.77
NM-2	748.28	1320.70	2.0	–	15.10	–	288.80	3.74
NM-3	743.27	1311.86	3.0	–	22.50	–	286.86	3.72
NM-4	738.33	1303.13	4.0	–	29.80	–	284.95	3.69
(weight ratio)	1.000	1.765	0.000–0.040			0.386		0.005

BIRF bacteria immobilized rubber fibre; *BS* bacterial solution; *NW* normal water; *RF* normal rubber fibre; *SP* Superplasticizer; *BM* Bacteria innoculated mortar; *NM* Non-bacterial morta

every stage of a building's lifecycle—ranging from design choices aimed at reducing operational energy to the systematic use of water and other resources, construction techniques that prioritize waste reduction, reassembly strategies that extend service life, and demolition plans that facilitate value recovery—thereby serving as an integrative tool for the adoption of green building practices.

Later, Gupta *et al*. published their article titled "Evaluation of Food Waste in Bacterial Rubber Mortar as a Cost-Effective Medium for Carbon Sequestration" in 2025 [22]. This study aims to evaluate food waste as a cost-effective medium for carbon sequestration and biocementation processes in bacterial slurries. In this study, food waste was recycled with two different strategies in order to develop powder and pulp-based media. Powder based medium, *E. coli* showed higher bacterial growth for DH5 and was used in the preparation of bacterial solution. The bacterial solution prepared using food waste was used together with waste tire rubber fibers to develop different bacterial slurries. Bacterial mortars were compared experimentally with non-bacterial mortars. Bacterial mortar prepared with food waste; It exhibits an improved microstructure, doubles the compressive strength (105.94% increase), shows self-healing ability, reduces carbon emissions per unit strength (42.89%–43.38% decrease) and reduces the cost per unit strength (26.80% decrease) (Table **4**). This study reveals that food waste can be considered as a value-added raw material for both carbon sequestration and biocementation processes. The use of food waste as a medium in bacterial slurries can contribute to sustainability through food waste management and carbon sequestration processes.

Most recently, in 2026, Ezeh [23] conducted a review study titled "Advances in the Development of Polyester Resin Composites." This study aimed to provide an overview of recent developments in the field of polyester resin composites. The review introduces the properties of polyester resins and the manufacturing techniques used to produce polyester resin composites (Fig. **9**). It offers an overview of reinforcement materials—such as fibers and nanoparticles—commonly used to enhance composite properties. Additionally, recent advancements regarding the use of fillers like nanocellulose, graphene, and carbon nanotubes are discussed. The study highlights the latest developments in the functionalization of polyester resin composites, aiming to improve material properties for specialized applications in sectors such as aerospace, biomedicine, and energy. It also illustrates how industry and academia collaborate globally to advance polyester resin composite technologies. This review article summarizes recent progress in the development of polyester resin composites and emphasizes their potential to advance technologies across various fields.

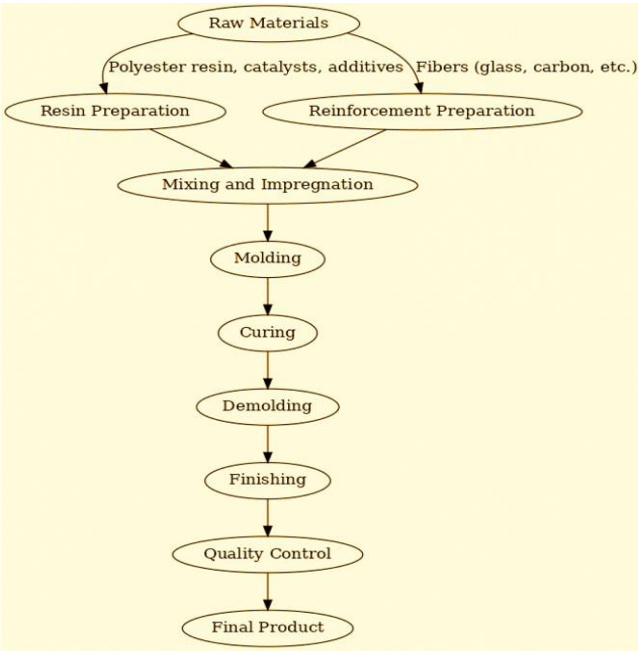


Figure 9: Process flow chart of polyester resin composite manufacture [23].

7. CONCLUSIONS

Green materials are no longer a niche trend, but a necessity for a sustainable future. While challenges such as cost and scalability remain, technological advances, policy support, and consumer demand are driving rapid innovation. The following conclusions can be drawn from the current study:

- Green materials are also called sustainable materials or eco-friendly materials. Green materials are materials that have minimal environmental impact throughout their life cycle. These materials are generally renewable, biodegradable, recyclable, non-toxic, and efficient. The goals of these materials can be summarized as reducing pollution, conserving resources, and supporting a circular economy. The concept of green materials has evolved alongside environmental awareness.
- Green materials are being adopted in many sectors due to their environmental and functional advantages. Applications of green materials include construction, packaging, textiles, automotive, electronics, and energy. Packaging applications include bioplastics, mycelium, renewable packaging, and recyclable cardboard and paper. Natural fibers, recycled rubber, and bio-based polymers are used in the automotive and transportation sectors. The electronics sector uses biodegradable circuit boards, lead-free solder, and solar cells. The energy sector uses perovskite solar cells, recyclable wind turbine blades, and graphene cells.
- Sustainability refers to the ability to meet current needs without compromising the ability of future generations to meet their own needs. Green materials contribute to environmental, economic, and social sustainability: From an environmental sustainability perspective, green materials minimize environmental impacts such as resource efficiency and pollution and waste throughout their life cycle. Recycled and recyclable materials help prevent waste from being sent to landfills. Green materials can be economically beneficial in the long term, resulting in cost savings, added value, and market growth. Sustainable housing materials improve thermal comfort and reduce energy bills, leading to better living conditions.
- Green materials are critical to environmental, economic, and social sustainability. Future trends emphasize bio-based, smart, and circular materials. Policy support, technological innovation, and consumer awareness will accelerate adoption. Sustainable materials are essential to achieving global goals such as carbon reduction, waste minimization, and green development.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest to disclose.

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