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Construction Materials and Technologies: A Review of New Trends in Sustainable Development

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Abstract

The construction industry is currently experiencing a substantial transformation as a result of the growing focus on sustainability. Using traditional building methods and materials typically harms the environment immensely. This assessment looks at new developments in environmentally friendly building materials and technology. The main aims are to find low-carbon alternatives, smart materials, new ways to recycle, and building technologies that use less energy and are good for the environment. A comparative review of the essential parts of international law and initiatives makes it possible to define the responsiveness of policies that protect the environment in the sector and find ways to make things better. The current laws encourage the construction industry to become more sustainable by looking at the whole life cycle of a project. This includes finding ways to save energy and money, using natural resources more efficiently, and reducing waste. These include policymakers and scientists may use this study as a guide for making the building business genuinely green and sustainable. The results of this study show that the built environment can be made more sustainable by using more alternative, recycled, natural, and unconventional construction materials and thermal insulation materials, making use of prefabricated building elements, and using multi-objective optimization methods.

Keywords: Environmental policy, Construction Material, Sustainable Development, Technology Advancement, Modern Construction.

INTRODUCTION

A large part of the world's carbon emissions and resource use come from construction work. As cities get bigger and their infrastructure demands rise, the building industry must adopt sustainable practices (Zuo & Zhao, 2014). The new building materials and technologies are being developed to reduce their impact on the environment while yet being strong and cost-effective. The construction industry has a big impact on how buildings are built, but it also hurts the environment a lot. It is responsible for about 39% of global carbon dioxide emissions, most of which come from building materials and construction activities (UNEP, 2020). The world's population is growing and cities are becoming more crowded, which means that the need for structures and infrastructure is also growing. This puts a lot of stress on natural resources. As a result, there has been a movement in thinking toward building approaches that are more environmentally friendly, use resources more efficiently, and are more likely to last for a long time. The implementation of innovative construction methods, energy-efficient technologies, and eco-friendly materials in the construction industry is a critical component of sustainable development. These methods not only improve performance and affordability, but also reduce environmental impact (Zuo & Zhao,

2014). Concrete, steel and bricks are all traditional building materials that are structurally robust but have a lot of embodied energy and greenhouse gas emissions. Researchers and professionals are looking at other materials such as recycled aggregates, geopolymer concrete, bamboo and cross-laminated lumber, which have less of an effect on the environment (Habert et al., 2020; Sharma et al., 2015). The construction process is being transformed by emergent technologies such as Building Information Modeling (BIM), 3D printing, and modular construction, which are concurrent with material innovations. These technologies make planning more accurate, cut down on material waste, and speed up construction (Azhar, 2011; Ngo et al., 2018). Also, using passive design methods, smart materials, and renewable energy systems together makes building practices more in line with climate resilience and sustainability aims (Cabeza et al., 2011).

This assessment looks at new developments in materials and technology that are good for the environment. It seeks to give a full picture of how the building sector may help with global sustainable development initiatives by talking about the pros and downsides of these new technologies and what the future holds for them. Finally, research on how to assess productivity in the construction business stresses how important it is to use resources wisely. These studies show that increasing productivity is very important for improving the economy. The construction companies may be more productive and save money by making the best use of their resources and using cutting-edge technologies (Ye et al., 2019). The construction industry is becoming more and more focused on sustainability which is why there is a demand for greener and more energy-efficient solutions. As more and more people want eco-friendly structures, construction companies are utilizing more sustainable methods, like using renewable materials, designing buildings that use less energy, and making less waste. This change is not merely a response to regulatory pressure but it also deals with the bigger issues of being environmentally responsible and managing resources. The goal of these trends is to make building faster and better, lower costs and have less of an effect on the environment. The digital technologies in combination with environmentally friendly methods change the building business, encouraging new ideas and making sure the industry can survive global problems in the long term. The building industry can make a big difference in promoting sustainable development and upgrading infrastructure around the world by accepting modern and technology base reforms (Abasova et al., 2023).

Sustainable Construction Materials

In modern building methods, sustainable construction materials are becoming more and more important. The goal is to lessen the impact on the environment while promoting energy efficiency and resource conservation. These materials are made to have as little impact on the environment as possible from the time they are mined until they are thrown away, which supports the idea of a circular economy in the construction sector (Dixit, 2019). The recycle process is depicted in figure 1. The recycled concrete, bamboo, fly ash-based cement, and low-emission insulation are all common examples of these types of materials. They last longer and have less of an impact on the environment than traditional materials (Habert et al., 2020). The usage sustainable materials not only make buildings greener but it also helps the world reach its goals for climate resilience and sustainable urban development (United Nations Environment Program [UNEP], 2021).

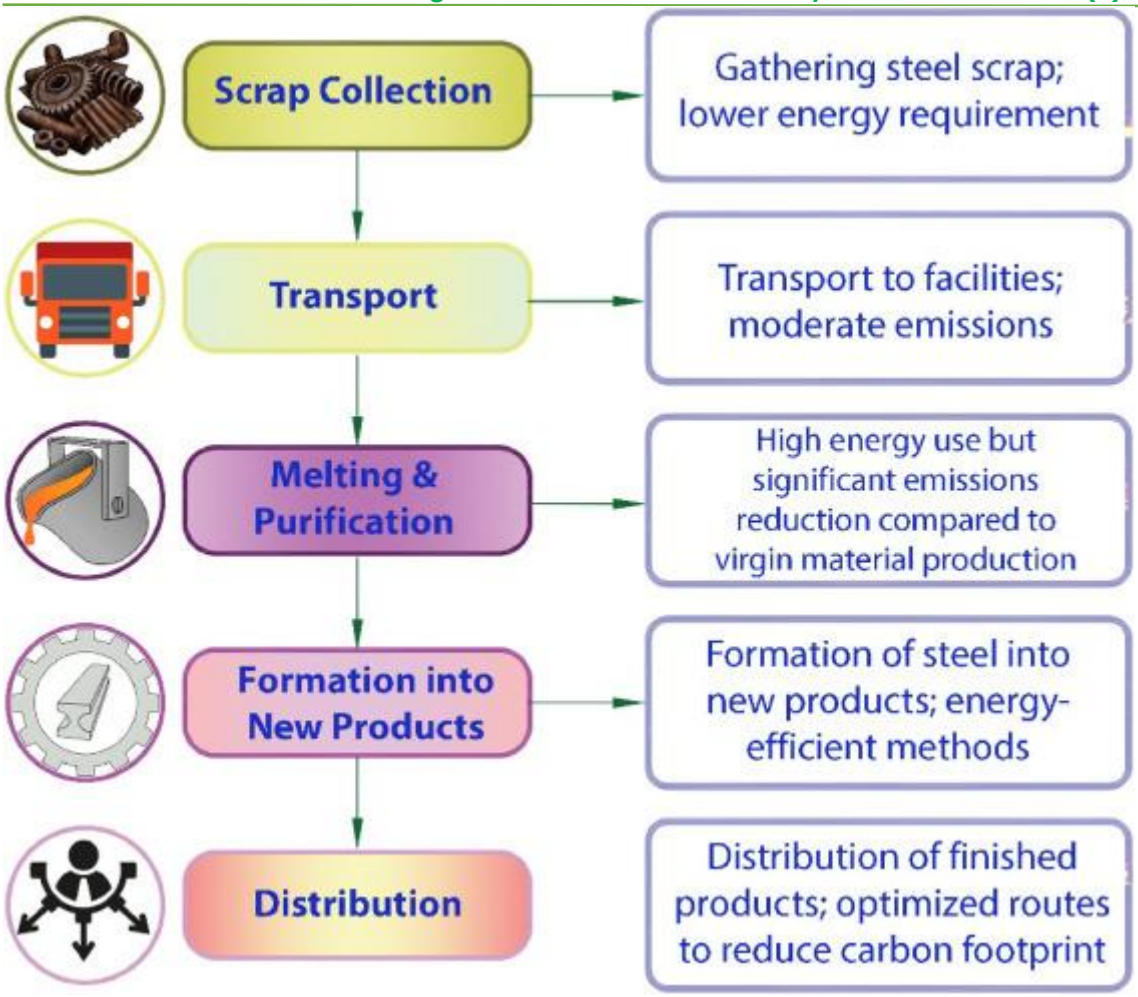

Figure 1:
Sustainable building materials and processing

a) Recycled and Waste-Derived Materials

Recycling garbage from building and tearing down buildings lowers the need for new resources. The concrete and asphalt have been successfully made from recycled concrete aggregate (RCA), fly ash, slag, and plastic waste (Tam et al., 2009). These materials usually make things last longer and lower the amount of carbon that is already in them.

b) Green Concrete

Green concrete uses fly ash, silica fume, and ground granulated blast furnace slag (GGBFS) from factories to cut down on the amount of Portland cement used, which is a big source of CO_2 emissions (Habert et al., 2020). Also, new carbon capture concrete methods are being developed that add CO_2 during the curing phase.

c) Bio-Based Materials

The materials such as bamboo, hempcrete, mycelium-based composites, and cross-laminated timber (CLT) offer renewable and biodegradable alternatives to conventional building products. These bio-based materials provide good thermal performance and lower environmental footprints (Sharma et al., 2015).

The role of mobile technology and applications in modern construction:

Mobile technology and apps have changed the construction sector in a big way by making things more efficient, encouraging teamwork, and making it easier to talk to each other in real time (Bilal et al., 2016). The integration of smartphones and tablets into construction projects provides immediate access to project information, resulting in improved project management and the acceleration of decision-making processes (Perera et al., 2020). The mobile devices make it easy for those who are on-site, Project Managers, and stakeholders to talk to each other right away. The use of video conferencing and instant messaging programs can facilitate discussions and reduce project delays (Azhar, 2017). The cloud-based applications provide access to the most recent project data, plans, and schedules from any location (Zhou et al., 2022). The employees may access and amend project documents in real time, which helps make sure the data is correct and cuts down on mistakes (Ghosh et al., 2021). The smartphone software has checklists for security, options for reporting incidents, and notifications for hazards that make the workplace safer (Davies & Harty, 2013). Real-time updates on security protocols lower the chance of mishaps happening on the job (Zhao et al., 2019).

The task management software makes it easier to keep track of schedules, allocate resources, and check on progress. Project managers can use full reporting capabilities to make decisions based on facts to keep projects on schedule (Shafiq et al., 2021). For example, PROCORE has tools for managing projects, keeping records, and working together. It has a user-friendly interface that lets you get updates and track performance in real time. PlanGrid makes it easy to manage plans by letting team members look at, share, and comment on plans on their phones. It syncs updates so that they are always easy to get to (Procore, 2023; PlanGrid, 2023). A primary concentration of Fieldwire is on on-site collaboration and task management. It has configurable task lists, trouble tracking, and document storage, all of which help make workflow more smoothly (Fieldwire, 2023).Table 1 is showing several technologies with their role in sustainable construction.

Table 1.
Emerging Technologies and their role in Sustainable Construction

Technologies	Role in Construction Sector	References
3D Printing in Construction	Additive fabrication or 3D printing, enables the precise positioning of materials and reduces wasteful practices. This technique makes it possible to employ eco-friendly concrete mixtures which cuts down on the time and money needed for building by a large amount.	(Ngo et al., 2018).
Prefabrication and Modular Construction	Off-site building procedures cut down on waste on the job site and speed up project timeframes. Modular modules made under regulated settings frequently have greater quality and energy efficiency.	(Lawson et al., 2012).
Energy-Efficient and Passive Design Strategies	There are several new design ideas that use less energy are passive solar design, better insulation, natural airflow, and daylighting. The addition of renewable energy systems like	(Cabeza et al., 2011). (Zhang et al., 2019)

	photovoltaics to building envelopes has also become more popular. The Phase change materials (PCMs) and other smart materials are utilized to control the temperature within buildings and make them more energy efficient.	
Building Information Modeling (BIM)	BIM makes it easier to design buildings, manage resources, and make sure they last a long time. Sustainable decisions can be made at an early stage by modeling energy consumption and material usage during the design phase.	(Azhar, 2011).

Augmented and Virtual Reality (AR and VR) are changing the construction industry by changing how people learn and how they create things (Wang et al., 2018). The overlapping of digital data AR enhances the real-world environment, enabling employees to directly observe intricate designs and schemes (Chi et al., 2013). The VR on the other hand, makes computer-generated worlds that are so real that users can explore and change 3D models without being limited by actual space (Whyte, 2018). In the construction industry both AR and VR make training methods much better. The practitioners may train in bright and safe environments which helps them get better without putting anyone in danger (Zaker & Coloma, 2018).

The interactive modules and feedback in real time help people grasp and remember difficult ideas. The standardized training programs make it easier for employees in different parts of the world to take part, which cuts down on logistical challenges (Sampaio et al., 2020). The stakeholders may see design changes which helps them make decisions more quickly. The teams can work together in a virtual space no matter where they are in the world by looking at and changing the same model at the same time (Li et al., 2018). These mobile and AR/VR technologies can both help make the workplace safer and more productive.

Augmented and virtual reality are not just cool tech gimmicks, they are real tools that may greatly improve productivity, safety and creativity in the construction sector. The construction industry can address complicated design challenges, improve training programs and create a collaborative work atmosphere by properly combining various technologies (Bottarelli et al., 2021).

Waste Reduction and Management in Sustainable Construction:

In order to promote sustainability in the construction sector it is imperative to implement effective waste reduction and management strategies. The waste reduction includes methods like prefabrication and modular construction. These technologies make the best use of materials and cut down on waste on site by letting parts be made off-site in controlled settings (Tam et al., 2021). Furthermore, the design of a building for deconstruction facilitates the effortless disassembly and repurposing of materials at the conclusion of its life cycle, thereby reducing landfill dependency and promoting circular material use (Crowther, 2005). The use of digital technology, especially Building Information Modeling (BIM), makes it easier to accurately estimate materials and cuts down on ordering too much and throwing away too much (Chong et al., 2017). Another important method is to recycle and reuse building resources such reclaimed concrete, steel, glass and wood. This reduces the demand for new materials and has less of an effect on the environment (Zhao et al., 2010). The waste-

to-energy technologies are also becoming more popular as a way to turn waste that can't be recycled into useable energy or products (Arena, 2012). The implementation of lean construction principles enhances process efficiency and reduces the use of unnecessary materials (Ballard & Howell, 2003). Additionally, resource-efficient technologies such as 3D printing and robotics enable precise material deployment (Ghaffar et al., 2018). The site waste management plans (SWMPs) can promote a strong waste management system by keeping track of materials and disposing of them properly at all stages of construction (Osmani et al., 2008).

The following of environmental rules and getting green certifications makes these practices even stronger by requiring that trash be handled in a way that is good for the environment. The working together and teaching people are also very important. For example, working with eco-friendly suppliers and teaching workers how to separate and throw away trash properly helps create a culture of environmental responsibility (Lu & Yuan, 2011). Finally, using tools for measuring and monitoring such performance measurements and waste tracking analytics makes it possible to keep track of and enhance waste reduction activities (Ajayi et al., 2017). These tactics usage at every stage of a project in the construction industry can greatly lessen its impact on the environment and move toward more sustainable ways of doing business.

Cybersecurity in the construction sector:

Cybersecurity is of paramount importance in the construction industry as a result of the increasing reliance on information technology (Almohsen & Almulhim, 2022). The cyber assaults can happen to construction companies, and they can put sensitive information including project blueprints, financial information, and personal information at risk (Eadie et al., 2013). These are people or groups who want to deceive employees, get sensitive information, or accidentally download malware (Amin et al., 2021). The data is encrypted by malware, and the keys necessary for decryption are demanded by assailants in exchange for a ransom. This can cause big problems with the working (Rehak et al., 2020). The access to essential systems by employees or contractors may result in security breaches whether intentionally or unintentionally (ENISA, 2020). If someone gets into private information without permission, it can cost a lot of money and hurt your reputation (Zhou et al., 2022). Construction companies need to put in place full cybersecurity plans to lower these risks (NCSC, 2023). Using multi-factor authentication (MFA) can make it much less likely that someone will get into your account without permission (Cheng et al., 2021).

This means using two or more separate credentials, like passwords, security badges, or biometric authentication, together. It is highly important that all employees know the best ways to protect themselves online. The training should teach people how to spot phishing efforts, handle their passwords correctly, and report any questionable activity (Hadlington, 2017). The backing up data process often to safe places away from the computer might help lessen the damage caused by ransomware attacks. The data integrity and operational recovery capabilities of these backups should be periodically verified (Cisco, 2023). You can safeguard sensitive data from being accessed and hacked by using encryption for data that is at rest and in transit (NIST, 2020). These devices keep an eye on network traffic for strange behavior and can let administrators know about any threats. The firewalls that are set up correctly can keep those who shouldn't be able to access the network from doing so, which protects it against attacks from outside (Singh et al., 2020).

In construction, technology systems often have trouble working together. There are a lot of stakeholders involved in the construction process, and they all use different software and tools (Zhou et al., 2022). These systems not being standardized and compliant might cause problems with efficiency and communication, which makes it hard to employ just one IT framework (Perera et al., 2020). The Internet of Things (IoT) helps with site management by keeping an eye on equipment, resources, and the environment in real time and making sure that connected devices talk to each other quickly (Bilal et al., 2016). This network of interconnected devices helps with preventive maintenance and cuts down on downtime which saves a lot of money (Alaloul et al., 2020). The self-regenerating concrete, nanomaterials and smart sensors are examples of advanced materials that are stronger and last longer (Azimi et al., 2021). These materials are made to adapt to changes in the climate which makes buildings last longer and makes construction projects less harmful to the environment (Nasir et al., 2022). The augmented reality (AR) and virtual reality (VR) add to the design and planning process by giving users interactive and immersive project models (Li et al., 2018). The blockchain technology is becoming a safe and open way to handle payments and contracts, which builds confidence and accountability in the supply chain (Turk & Klinc, 2017).

Use of Technology and their expected outcomes:

The use of new technology in the construction industry is changing the way buildings are built by making them more productive, efficient, and environmentally friendly. These new technologies, such Building Information Modeling (BIM), the Internet of Things (IoT), artificial intelligence (AI), drones, and robotics, are changing the way construction projects are planned, run, and carried out (Perera et al., 2020). The projected results are better project coordination, fewer mistakes and delays, better use of resources, and safer construction sites (Bilal et al., 2016). Also, technologies like augmented and virtual reality (AR/VR) help people see projects in a more realistic way, which helps with stakeholder participation and design correctness (Wang et al., 2018). Overall, using technology strategically is not only making operations more efficient, but it is also pushing the construction industry toward smarter and more sustainable growth. Table 2 is giving idea about the technology advancement and their results in construction.

Table 2.
The use of Technology and their expected outcomes in Sustainable Construction.

Technologies	Outcomes
Energy Efficiency	Optimize energy use through efficient insulation, passive design, and renewable sources like solar panels.
Smart Technology Integration	Use sensors and IoT for real-time monitoring of heating, cooling, and lighting systems.
Sustainable Materials	Increase use of eco-friendly and recycled materials to reduce environmental impact.
Water Conservation	Implement strategies like rainwater harvesting and efficient plumbing fixtures.
Green Roofing and Living Walls	Integrate vegetation for insulation, rainwater absorption, and biodiversity promotion.
Waste Reduction	Minimize construction waste through better design and recycling.
Certifications	Emphasize green building certifications like LEED and BREEAM.
Health Considerations	Design for improved indoor air quality, natural lighting, and physical activity promotion.
Resilient Design	Consider climate change impacts for structures resilient to disasters.

Circular Economy Practices	Encourage reducing, reusing, and recycling materials for a closed-loop system

Resilient and Adaptive Design for Climate Change in Construction:

As climate change makes the weather more unpredictable, building design that is strong and flexible has become an important part of sustainable construction. When designing for extreme weather, you need to include hurricane-resistant buildings in areas where high winds are common. These structures are made with strong materials and structural reinforcements so they can stand up to storms and flying debris (Kibert, 2016). The flood-resistant design features including raised foundations, flood barriers, and water-resistant building materials are utilized in locations that are likely to flood to reduce damage and make structures more likely to survive (Li et al., 2020). Also, using structures that are flexible and may change over time makes them useful for a long time. The modular building makes it easier for structures to adapt since it uses prefabricated parts that can be quickly changed or added to meet the needs of users or the environment (Kamali & Hewage, 2016). The convertible spaces also offer flexibility because they can be used for different purposes depending on how many people are using them (Wilkinson et al., 2016).

Green roofs, rain gardens and bioswales are examples of nature-based solutions that make cities more resilient by managing stormwater, lowering urban heat and increasing the ecological value of built environments (Geneletti & Zardo, 2016). These green constructions protect against flooding and severe rain while also helping to protect biodiversity. The usage of climate-responsive building envelopes such high-performance windows and enhanced insulation makes it easier to control the temperature inside and lessens the need for mechanical systems (Attia et al., 2013). The buildings that can run off the grid and use renewable energy, storage systems, and water-saving fixtures are better prepared for emergencies and times when resources are scarce (Ameen et al., 2015).

Resilient urban planning is very important at the community level. The combine building design with urban infrastructure makes sure that utilities and public spaces work together to make the community more resilient, especially when climate-related problems happen (Meerow et al., 2016). The working with the authorities on disaster preparedness plans makes ensuring that localized dangers and vulnerabilities are dealt with quickly and effectively. The advanced technologies make buildings even more resilient. For example, climate monitoring systems let buildings respond in real time to changes in the environment, and smart infrastructure optimizes energy use and resource allocation on the fly (Arup, 2019). These strategies show a proactive and integrated approach to building that can withstand climate change and protect both people and the environment.

CONCLUSION

The use of innovative building materials and technology is a step toward making buildings that last longer and are better for the environment. New ideas like green concrete, bio-based materials, 3D printing, and BIM are changing the way buildings are made. Sustainable building may become the norm instead of the exception if more research is done, rules are put in place to encourage it, and businesses work together. Modern developments in green construction take a big-picture view of building methods that are good for the environment and the people who live in them. The utilization of renewable energy sources, smart technologies, and energy-efficient design concepts all show a dedication to using less energy and releasing less carbon.

At the same time, using eco-friendly materials, saving water and new ideas like green roofing and living walls all help to lower the impact on the environment. The industry's devotion to strict environmental standards is shown by its efforts to reduce waste through better design and construction processes, as well as its concentration on getting certifications and following green building standards. Also, designs that put a lot of attention on indoor air quality, natural light and places that encourage physical activity show that the health and well-being of the people who live there is very important. The principles of resilient and adaptive design are indicative of a forward-thinking approach, which recognizes and prepares for the effects of climate change. The circular economy methods make the commitment to making a closed-loop system even stronger. They stress the importance of reducing, reusing, and recycling materials during construction. In short, these changes in green building show a shift in thinking toward making not only buildings that last, but also homes that are healthier, more efficient, and better for the environment. The building industry is continuing to adopt and improve on these ideas, which will help make both built and natural ecosystems more sustainable and resilient in the future.

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