Key Environmental Construction Technologies and Innovations Revolutionising the Construction Industry: A Systematic Review

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Abstract

The Construction Industry faces immense criticism for the lack of change in the traditional methods of construction and is required to adopt sustainable practices because the industry consumes over 40% of global energy yearly and generates 20% of fossil fuel gas emissions. This literature review explores key environmental technologies shaping the industry's future. The study uses databases like Web of Science and Google Scholar to identify 76 articles on construction environmental innovations that address consumer, governmental, and organisational needs. The paper examines ten themes under technologies and innovations driving sustainability in construction, including specifics such as robotics, green building materials, big data, the Internet of Things (IoT), 3D printing, energy-efficient buildings, Renewable energy technologies Energy-efficient, LED lighting, solar panels, Water conservation technologies, Air monitoring and purification technologies, Virtual and augmented reality, Artificial intelligence (AI) chatbots, and smart building management systems. The study suggests that adopting these technologies and innovations enhances efficiency and safety and reduces environmental footprints. As technology evolves, more ground-breaking solutions are expected to emerge, compelling sustainable development in the construction industry further. Therefore, the industry must embrace technological advances and invest in a more sustainable built environment.

Keywords: Construction materials, Environmental innovations, Environmental technologies, Sustainable construction

1. Introduction

In any vocation, excellence and innovation are critical for sustainable growth and success, but the contrary is true in the building construction industry about building sustainably. The World Economic Forum's (2018) report on "Environmental Sustainability Principles for the Construction Industry" declares that the industry consumes over 40% of global energy yearly and approximately 40% of the world's raw materials and generates 20% of global greenhouse gas emissions. Technology plays a critical role in driving construction sustainability through various innovative solutions. These technologies, which are energy-efficient, smart construction applications and technologies, are critical in the creation of sustainable development. Smart construction technologies engender effective energy usage and operational costs and minimise the environmental impact of construction activities. Thus, as technology advances, more innovative solutions can foster sustainable construction development. Innovations specifically related to the environment, or eco-innovations, may be defined as (1) the development of new ideas, behaviour, products and processes, application or introduce them, and (2) a contribution to a reduction of environmental burdens or to ecologically sustainability targets" (Reenings, 2000: 322 cited in Torre Ruiz, 2012). Further, eco-innovations are those innovations that attempt to lower the negative environmental impact of some business activity. Therefore, environmental innovation aims to improve environmental and economic performance within the construction industry, which is a seemingly win-win situation (Hall and Vredenburg, 2003, cited in Torre Ruiz, 2012). The Construction Industry has been tagged as one of the late adopters of technological advances as it still relies on traditional construction delivery methods. Recently, technology has been at its cusp and provides construction development opportunities for timely deliveries, optimising the construction cost and contributing to its sustainability.

2. Research Methodology

The analysis highlighted the primary and secondary needs of four key construction stakeholders. These include consumers, agents and associations, complementary industries, and government and regulatory authorities. The search methods used in this study were keyword searches, screenings, and categorisation. The search terms used included "Construction Industry environmental technologies," "Construction

Technologies," "Smart Construction," "Construction Technology," "Environmental Technology in Construction," and "Environmental Management technologies." The search tool engines consist of Google Scholar and Web of Science databases. The articles selected were all written in English, and the articles excluded were those in editorials, notes, errata, letters, or comments.

3. Results and Discussion

Technology is an important driver of innovation, but not all technological advances necessarily result in innovation (Freeman & Soete, 1997). According to the OECD (2005), innovation can take various forms, including product, process, organisational, and marketing. Product innovation involves the development of new or improved products that meet customers' needs. Process innovation refers to improving existing production processes to increase efficiency and reduce costs. Organisational innovation involves the development of new management practices, organisational structures, or business models that enhance the organisation's performance. Key construction environmental technologies and innovations for the construction sector

The construction environmental technologies and innovations identified address the needs of four key stakeholders: consumers, agents and associations, government and regulatory authorities and complementary industries (Sivunen et al., 2013). These Technology and Innovation themes identified in construction are listed in Table 1 and discussed.

Table 1: Technology and Innovation Themes

S/No	Technology Themes
A	Technology (waste, conservation)
B	Building management technology
C	Renewable Energy
	Innovative Themes
D	Radical construction innovations
E	Sustainable design
F	Construction method - prefabrication

3.1. Technology (waste, conservation)

3.1.1. Robotics and drones

Drones afford a birds-eye view of a construction site, allowing surveyors to map out inaccessible areas (AlRushood et al., 2023). Drones are used to detect deviations from plans, allowing rectification by crews to correct problems that may result in stoppages of construction activities. Further, Drones improve safety by allowing construction managers to monitor sites without being physically on-site. In addition, drones are used to deliver construction materials, thereby reducing the amount of vehicle traffic at the construction site. This lowers carbon emissions, reduces fuel use, and improves efficiency. Surprisingly, most companies and sites still conduct visual inspections, not automatically. Visual inspection is labour-intensive, consumes much time, and can put employees at risk (Patrick et al., 2020). Drones eliminate climbing high structures, reaching difficult areas or putting people in potentially dangerous positions. Visual inspection is a time-consuming and tedious task. Monitoring work in real-time helps minimise overall downtime (Shehhi & Maflahi, 2021).

Robots contribute immensely towards improving construction sustainability through the variability of tasks and full environmental control. However, recently, the Construction Industry has become much more technologically advanced. Some companies use robots for repetitive tasks on their sites, like painting, masonry and bricklaying. This can improve both the speed and quality of the work, leading to a safer environment while conserving energy. VR and AR, SaaS, 3D scanning, drones, AI and robotics, and wearable techs can help with referrals, networking, and reputational enhancements for construction professionals and stakeholders (Ullah et al., 2018).

3.1.2. Big data

Big data can be used to predict weather patterns, business activity, traffic, and more. Construction managers often use big data to determine optimal timing for construction activities (Kassem et al., 2017). This minimises downtime, reduces waste, and improves construction efficiency. Big data can evaluate vast amounts of data and uncover behavioural patterns, unknown correlations, and hidden trends (Khosravi & Ahmed, 2018; Jeong et al., 2019).

The Internet of Things (IoT)

Integrating sensors and smart devices, collectively known as the Internet of Things (IoT), is increasingly becoming a crucial aspect of the construction industry (Benachio et al., 2020). Even minor upgrades can significantly reduce the industry's carbon footprint. Installing sensors in vehicles and machinery that can shut them off when idle is one example of how IoT can reduce fuel waste.

3.1.3. 3D printing

The construction industry increasingly relies on 3D printing, which uses computer-aided design to produce three-dimensional objects (Lim et al., 2012). This technology is invaluable because it creates precise samples and full objects, ensuring that every detail is appropriately designed (Khoshnevis, 2004). By doing so, it significantly reduces material waste and saves time. Additionally, 3D printing makes it possible to prefabricate materials in advance, either offsite or directly at the construction site, for immediate use (Vries & Geraedts, 2015). When integrated into the pre-construction process, 3D printing can help reduce labour costs, increase energy savings, and promote overall sustainability (Belém & Sousa, 2016).

3.1.4. Renewable energy technologies

Solar panels can be installed on buildings to generate renewable energy and reduce reliance on fossil fuels. These technologies can generate clean energy on-site and reduce reliance on fossil fuels. Wind turbines are a great way to reduce energy costs and reduce the environmental impact of a building. Wind turbines can generate electricity, heat water, and provide hot water for buildings. They can also provide cost savings over the long term, particularly as the cost of renewable energy technologies continues to decline. Geothermal systems use the earth's constant temperature to heat and cool buildings, reducing energy consumption and greenhouse gas emissions (Dadzie et al., 2018).

3.1.5. Water conservation technologies

This can also be adopted for the housing units. Low-flow fixtures like toilets and faucets can significantly reduce water usage without sacrificing performance. Water recycling systems, which capture and treat wastewater for reuse in non-potable applications, can also reduce water usage and costs. Water-saving technologies, such as low-flow fixtures, rainwater harvesting systems, and greywater reuse systems, can be installed to reduce water usage and promote sustainability. Rainwater harvesting systems can collect and store rainwater for non-potable uses such as irrigation, toilet flushing, and cleaning (Hofman-Caris et al., 2019).

3.2. Building management technology

3.2.1. Smart Building Management Systems/ Smart Homes

According to Lee et al. (2015), smart homes are key technology drivers for sustainability in construction infrastructure development and operation. Thus, smart homes are embedded with advanced technologies such as smart thermostats, lighting systems, and energy-efficient appliances that can be conveniently controlled remotely via smart devices. The integration of advanced technologies in smart homes enables the end-users to effectively control energy consumption according to their needs, preferences, and occupancy levels; as a result, waste is minimised, and energy is optimally utilised (Lee et al., 2015).

3.2.2. Building information modelling (BIM)

Kaming and Olawumi (2019) claimed that the adoption of Building Information Modeling (BIM) is gaining attraction as one of the innovative technologies with the potential towards revolutionising the processes and methods of building design, construction, operation and management. Eastman et al. (2011) encouraged the Built environment sectors to leverage BIM as advanced software to create digital models of structures, enabling architects, engineers, and contractors to collaborate and seamlessly partner for optimal project delivery and maintenance. Thus, BIM application can be utilised for simulating building performance and to detect potential inefficiencies and opportunities for improvement, which will ensure less environmental impact of construction development on society (Wang et al., 2013). With additional technologies such as augmented reality, robotics, and artificial intelligence, BIM can fully digitise real estate and enhance industry productivity (Giel et al., 2014).

3.3. Renewable energy

Renewable energy involves developing and deploying technologies that harness renewable energy sources (Khan & Pareek, 2017). Renewable energy technologies, such as solar, wind, geothermal, hydropower, and biomass, harness natural resources to generate electricity, heat, and fuel with lower carbon emissions and environmental impact than fossil fuels and are essential to the transition to a low-carbon, sustainable energy system, with the potential to reduce greenhouse gas emissions, enhance energy security, and support economic development." (Rao et al., 2015; IPCC, 2011).

3.4. Radical innovations

These involve radical shifts in construction practices, such as adopting entirely new technologies or introducing disruptive business models. Using blockchain for transparent property transactions could be an example of radical innovation in the construction industry.

3.4.1. Smart locks:

According to a study by Bae and Kim (2015), smart locks can improve security and convenience for property owners and tenants. The study notes that smart locks can be integrated with other smart home technologies, such as thermostats and lighting, to create a more connected and efficient living environment.

3.4.2. Energy-efficient windows:

Research by Gou and Prakash (2013) suggests that energy-efficient windows can significantly reduce energy consumption in buildings, particularly in colder climates. The study notes that advances in window technology have made it possible to achieve high insulation levels without sacrificing natural light or visibility.

3.5. Sustainable design

3.5.1. Green building materials

Environmentally friendly building materials, such as recycled materials, sustainably sourced wood, and non-toxic paints and finishes, can be used to reduce the environmental impact of building holistic management. These materials, like recycled steel, bamboo, and reclaimed wood, have lower embodied energy and carbon emissions than traditional building materials (Dadzie et al., 2018). Mass timber is a renewable building material that has a low carbon footprint. It is made from sustainably harvested wood and can be used for various construction applications, including structural framing, wall panels, and floor systems. Green Insulation or environmentally friendly insulation materials such as cellulose, wool, and cotton are made from recycled materials and are free of harmful chemicals. Smart glass is a dynamic glazing system that can change its tint to control the heat and light entering a building. This technology can reduce energy consumption and improve occupant comfort (Dadzie et al., 2018).

3.5.2. Energy-efficient buildings

One of the significant contributions of technology to sustainability in the construction industry is the emergence of energy-efficient and sustainable buildings (Asif et al., 2007). Such buildings utilise advanced insulation materials, energy-efficient and intelligent windows, and heating, ventilation, and air conditioning (HVAC) systems (Sharma & Pareek, 2020). These systems are designed to adapt to the changing temperature and occupancy levels, effectively reducing energy waste, resource consumption, operational costs, and carbon emissions. Moreover, green buildings can benefit from green bonds and climate-linked funds (Wang et al., 2020). For instance, LED lighting systems can significantly reduce excessive energy consumption and substantially save on costs. According to Dadzie et al. (2018), intelligent lighting systems allow for occupancy to enjoy natural light levels, which further increase energy efficiency, thereby reducing the amount of energy needed to heat and cool a building.

3.5.3. Green roofs

Green roofs are vegetated roof systems that provide a range of environmental, social, and economic benefits, such as urban heat island mitigation, biodiversity conservation, and energy efficiency (Oberndorfer et al., 2007). Integrating green roof technology into the construction sector enhances green building sustainability (Getter & Rowe, 2006). Studies estimate that green roofs can hold up to 60 -100 per cent of the rainwater, and when adorned with vegetation, they aid in the absorption of carbon dioxide and diminish heat absorption green roofs (Oberndorfer et al., 2007; Getter & Rowe, 2006). It can be installed on buildings to reduce the amount of heat absorbed by the building, improve air quality, and provide habitat for wildlife. Green roofs are an effective way to reduce energy consumption and improve the environmental performance of a building. Green roofs can reduce the amount of heat absorbed by a building, reduce stormwater runoff, and improve air quality (Oberndorfer et al., 2007; Getter & Rowe, 2006).

3.5.4. Sustainable Resource Sourcing

Sustainable resource sourcing involves the responsible extraction, production, and disposal of natural resources, such as wood, minerals, and metals, to minimise environmental impact and support social and economic development." (UNEP, 2011).

3.5.5. Low-Energy House and Zero-Energy Building Design

Low-energy house and zero-energy building design aim to create buildings that use little or no energy from external sources through design strategies and technologies such as passive solar heating, high-performance insulation, energy-efficient lighting and appliances, and on-site renewable energy generation." (Lomas et al., 2007).

3.5.6. Low-Emitting Materials

Low-emitting materials emit low levels of volatile organic compounds (VOCs) and other harmful pollutants, improving air quality and occupant health." (Green Seal, 2015).

3.5.7. Green Innovation

Green innovations focus on environmentally sustainable practices. In the construction sector, this may involve adopting energy-efficient building materials or implementing eco-friendly construction techniques (Vigren et al., 2022).

3.5.8. Sustainable Resource Sourcing

Sustainable resource sourcing is a key pillar of sustainable construction technology. It ensures the use of building materials created from recycled, remanufactured, recyclable products and obtained from sustainable and environmentally friendly sources (Martin & Perry, 2019). For example, agricultural wastes or by-products may be used to produce building materials (Danso, 2018).

3.5.9. Low-Energy House and Zero-Energy Building Design

This refers to mechanisms to lessen energy consumption. For instance, the construction of buildings with wood is a sustainable construction technology as it has a lower embodied energy than those built of steel or concrete. Also, the strategic placement of windows makes daylighting available, thereby minimising the need for electric lighting during the day (Hossain et al., 2020).

3.5.10. Low-Emitting Materials

Selecting low-emitting materials and products is essential in today's design and construction world. It helps building projects achieve green building credits from agencies like LEED, IGBC, and GRIHA and improves human health. (Bisegna et al., 2016).

3.6. Construction methods: prefabrication

This involves assembling building components in a factory and transporting them to the construction site. This process reduces waste, improves quality control, minimises construction time and can incorporate sustainable design features into prefabricated components. Modular construction enables flexible and adaptable building designs (Li et al., 2018). Prefabrication falls under the construction theme because it involves assembling building components offsite in a factory setting, using standardisation and automation to improve quality, reduce waste, and increase efficiency (Gibb & Isack, 2003).

3.7. Conceptual framework: key environmental technologies and innovative drivers and enablers

Figure 1 presents a conceptual framework for drivers and enablers of key environmental technologies and innovation for sustainable infrastructure development. These drivers, namely radical construction innovation, sustainable design, and renewable energy, are the factors that precipitate technology application, building management technology application and construction methods, which ultimately result in sustainable infrastructure development. This implies using new technology and innovative processes to sustain industry growth.

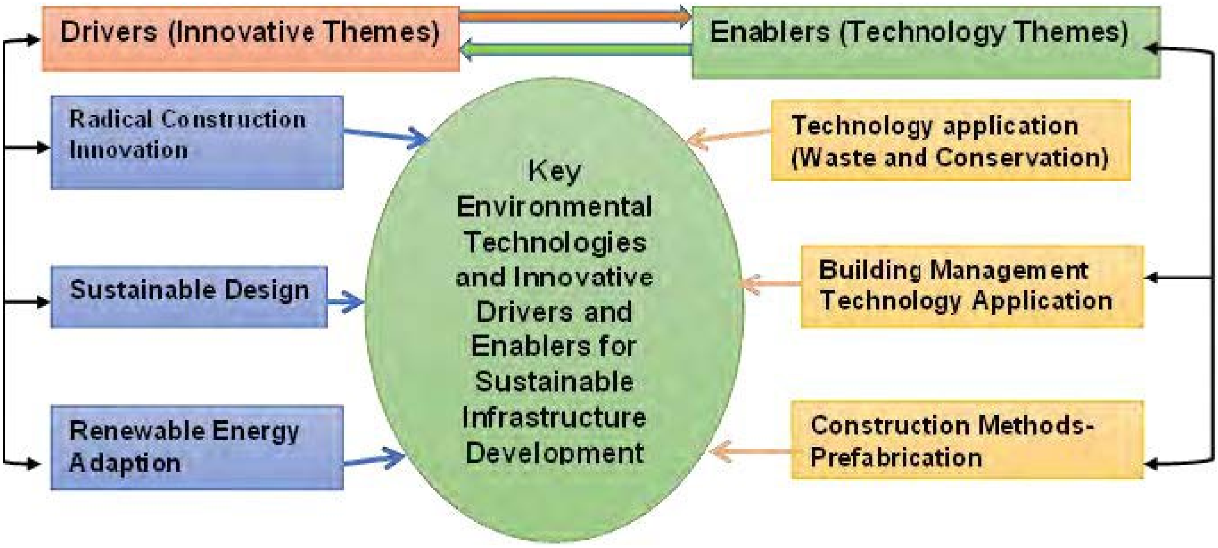

Figure 1: Innovation

Source: (Researchers' Construct: 2024)

4.Conclusion and Further Research

In conclusion, the construction industry is critical in creating a safer, more innovative, and more sustainable environment. By embracing the technologies identified in this literature review, including robotics, green building materials, big data, the Internet of Things (IoT), 3D printing, energy-efficient buildings, and smart building management systems, the industry can enhance efficiency and safety and reduce environmental footprints. However, to realise these benefits, all industry stakeholders must invest in these technologies and embrace sustainability and climate considerations in the building process. By doing so, industry leaders can future-proof their buildings, yield higher returns, and become more responsible stewards of our planet. The area recommended for further research is concerning building materials. Much has yet to be discovered of materials widely accepted for replacing traditional building materials.

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