Building Tomorrow: Sustainable Construction Innovations towards a Zero-Carbon Footprint

Vishwa B T[1*], Shwetha Patil[2], Dr. Shivarajappa[3]
[1,2] *Department of Civil Engineering, Navodaya Institute of Technology, Raichur, India*
[3] *Department of Civil Engineering, Navodaya Institute of Technology, Raichur, India*

Abstract - Technology is an important factor in the evolution of the construction industry. The use of new trends, modern tools, software and technology can help overcome the usual difficulties in the construction industry and increase the efficiency of projects. This paper discusses the opportunities, challenges, limitations and strategies involved in the use of technology in the construction industry. It will be beneficial for contractors, planners, designers, engineers, architects and academicians to enhance their performance and productivity. In addition, it will promote the use of new technologies to increase efficiency and the results of construction projects.

Building construction projects are usually unique in structure, configuration and design. This variety makes reconfiguration and network optimization difficult, especially in automated construction manufacturing systems. Artificial Intelligence (AI) has become a key solution. It enables smart planning, optimization and data-driven decision-making. This study reviews AI methods and their uses in the construction industry. It also examines digital technologies that help implement circular economy (CE) practices in the built environment. However, adopting CE principles in construction faces challenges due to the sector's fragmented and project-based nature. A systematic literature review identifies ten essential digital technologies that promote circularity throughout a building's lifecycle. These technologies are Building Information Modeling (BIM), spatial data acquisition, artificial intelligence and machine learning (AI/ML), Internet of Things (IoT), block chain, digital twin, augmented and virtual reality (AR/VR), digital platforms or marketplaces, material passports and additive manufacturing with digital fabrication. Among these, BIM acts as the main integrative platform. Block chain and material passports show strong potential across the entire lifecycle, but their use in the industry is still limited. The study also points out the need for more research to evaluate how well technological integrations support CE policies, standards and assessment frameworks. It raises concerns about privacy and cyber security risks that come with digitalization. The paper also discusses these advancements in the context of India's rapidly growing construction and real estate sectors. To achieve these ambitious goals, the industry needs to increase the use of modern construction technologies such as precast systems, BIM, 3D visualization and virtual tours. Backed by construction-focused start-ups, technological innovation is speeding up India's shift toward a more efficient, sustainable and digitally integrated construction ecosystem.

Keywords: Technological innovation, Artificial Intelligence (AI), Machine Learning (ML), Building Information Modeling (BIM), Internet of Things (IoT), Blockchain, Digital twin, Augmented reality and virtual reality (AR/VR), Spatial Data Acquisition, Circular Economy (CE), Lifecycle Management, Virtual tours.

1. INTRODUCTION

The introduction chapter has five sections. The first section presents the background of the study. The second section includes the problem statement. The third section outlines the study's objectives. The fourth section gives a brief description of the research methodology. The final section discusses the significance of the study.

1.1 Background

Advances in science during the 17th and 18th centuries allowed engineers to experiment with new materials. This experimentation brought significant changes in construction during the 19th-century Industrial Revolution. Today, industrialization and digitization are quickly changing the construction industry. By 2035, it is estimated that most buildings worldwide will be built using industrialized methods as manufacturing and construction combine. However, construction is still one of the least digitized industries. Its processes are repetitive and labor-intensive and each project is

unique. Projects also face limits related to time, cost, quality and safety. A McKinsey study revealed that large construction projects generally take 20% longer than planned and go over budget by as much as 80%. To tackle these issues, stakeholders need to adopt new technologies, skills and processes. The International Data Corporation (IDC) reports that 66% of Indian construction companies view digitization and industrialization as important priorities. Still, 72% are in the early stages of digital adoption and only 3% have successfully completed their digital transformation.

Engineers using virtual reality goggles and deploying robots to monitor construction progress may soon become possible. These robots can track site activities, while software helps plan electrical and plumbing systems. Artificial Intelligence (AI) can also improve worker safety by monitoring how workers interact with machinery and objects. It alerts supervisors to potential risks, errors or productivity problems. Although the construction industry has often been slow to embrace new technologies, recent years have shown a significant shift toward digitalization. Companies are increasingly using innovative tools to boost efficiency, productivity and sustainability. This report looks at the role of digital technologies in the construction industry, how stakeholders currently adopt them and what the future holds.

1.2 Evolution of the construction industry from the Stone Age to 2026

Period / Era	Approx. Time	Major Construction Materials	Key Technologies / Methods	Notable Developments
Stone Age	Pre-3000 BCE	Stone, wood, mud, animal skins	Manual tools made of stone	Simple shelters, caves, huts
Ancient Civilizations	3000 BCE – 500 CE	Stone, mud bricks, timber	Masonry techniques, ramps, primitive cranes	Pyramids, temples, aqueducts, early urban planning
Medieval Period	500 – 1500 CE	Stone, timber, lime mortar	Gothic architecture, scaffolding	Castles, cathedrals, fortified cities
Renaissance & Early Modern	1500 – 1800	Stone, brick, timber	Architectural design principles, early engineering methods	Domes, bridges, planned cities
Industrial Revolution	1800 – 1900	Iron, steel, concrete	Steam-powered machines, prefabrication beginnings	Railways, large bridges, factories
Early Modern Construction	1900 – 1950	Reinforced concrete, steel	Structural engineering theories, cranes, elevators	Skyscrapers, dams, large infrastructure
Post-War Construction Boom	1950 – 1980	Reinforced concrete, steel, glass	Heavy construction equipment, prefabrication	Mass housing, highways, urban expansion
Digital Introduction Era	1980 – 2000	Advanced concrete, composites	Computer-Aided Design (CAD), project management software	Faster design processes, improved structural analysis
Early Digital Construction	2000 – 2015	High-performance materials	Building Information Modeling (BIM), automation tools	Integrated project planning and visualization
Smart Construction Era	2015 – 2023	Sustainable materials, prefabricated components	Internet of Things (IoT), drones, AI, 3D printing	Smart buildings, real-time monitoring
Digital & Sustainable Era	2023 – 2026	Green materials, recycled materials	AI, digital twins, robotics, block chain, AR/VR	Smart cities, circular economy practices, fully digital project management

1.3 Overview of the Construction Sector in India

Construction in India is witnessing a gradual change with the incorporation of innovative technologies that promise to reduce construction costs and completion times and increase construction quality. Such a trend is also being driven by the rapid growth of India's construction and real estate sectors. India's real estate sector is currently valued at about 0.52 trillion USD in 2024 and is expected to reach 0.86 trillion USD in 2029, growing at a CAGR of 8.71%. With a projected population of 675 million to live in urban areas in 2035, there is a projected demand of over 25 million housing units. To meet this demand, the government's Pradhan Mantri Awas Yojana (PMAY) aims to construct 1.12 crore urban and 2 crore rural housing units in the coming years. An increase in government capital expenditure of 11.11 trillion INR (3.4% of GDP) in FY 2024-25 is also expected to contribute to the development of India's infrastructure, especially in tier-II and tier-III cities. Tier-I cities like Delhi NCR, Mumbai, Bangalore, Hyderabad, Chennai, Pune and Kolkata are still seeing high growth rates, with over 300,000 residential units being sold annually. The demand for office space is also increasing. In 2023, over 55 million sq. ft. of new office space has become operational. Other markets like retail, warehousing, hospitality and data centers are also seeing high growth rates in tier-I and tier-II cities.

With increasing construction demands, it is important to implement innovative ideas that not only reduce construction time and costs but also ensure quality construction. In India, precast construction is still in a very small percentage compared to conventional construction methods. Although aluminium formwork is widely used in construction, there are a number of limitations to this method, such as a high capital investment and suitability only for modular construction. Nevertheless, there are many construction developers investing in construction infrastructure to implement precast construction methods and government agencies are also promoting this method to increase construction speeds. At the same time, investments in technology are increasing to increase construction speeds. For instance, tools such as Building Information Modeling (BIM) are being implemented to increase construction management and collaboration. Virtual tours and 3D visualizations are also being implemented to increase property decision-making speeds. Such tools are also being implemented to increase energy efficiency, although there are still many gaps to be filled. Moreover, India is also witnessing a growing start-up ecosystem, with over 880 start-ups focused on construction challenges.

1.4 Problem statement

Economic growth, competitive advantage and successful project completions are all dependent on innovation and advancements in products, technology and management. However, the construction industry is often seen to be less inclined towards adopting and using technology compared to other industries. Despite major technological advancements, the construction industry has been slow to fully utilize these developments and is still behind in terms of digitization and technological progress. Many construction companies are still reluctant to embrace these advanced technologies due to several challenges and obstacles, such as technological, financial, psychological and process-related challenges. Digitalization and industrialization are associated with many advantages; therefore, these challenges must be overcome for the organization to achieve competitiveness and complete the project on time, within budget and with good quality and safety.

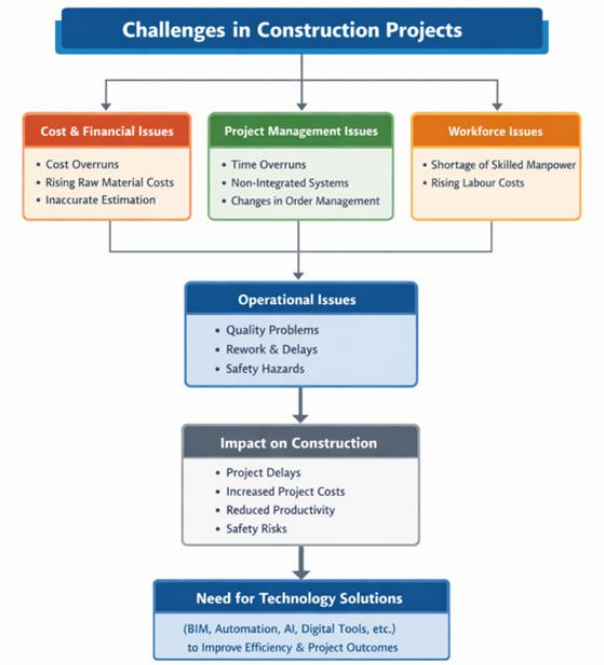
1.5 Objectives

- The study aims to determine the obstacles to adopting technology developments in the construction sector.
- The need for automation in the construction sector was studied through a questionnaire survey conducted to understand the technology used in the construction industry.
- The advantages and disadvantages of technology used in the construction sector were studied.
- The study results can be used for further research to formulate detailed ideas on technology adoption.

1.6 Significance of the study

Due to many factors like pandemics, inflation and the complexity of the project, etc., the construction industry has been more concerned with the sustainable method of project execution. Every industry has experienced the advantages of technology and the construction business is no exception. To sustain the market with the use of technology, it is imperative for the construction businesses to be aware of technology and the advantages of using technology, like reducing the stress on the workers, financial advantages and quality construction with the required time.

II. CURRENT CHALLENGES IN CONSTRUCTION PROJECTS



Sl. No.	Government Initiative	Role in Technology Adoption in Construction
1	Pradhan Mantri Awas Yojana (PMAY)	Promotes rapid and cost-effective affordable housing using technologies such as modular construction, precast components and composite structures. Budget 2023–24 allocated INR 79,000 crore for implementation.
2	Make in India & PLI Scheme	Provides financial incentives for domestic manufacturing, encouraging adoption of automation, digitalization and advanced construction technologies.
3	Green & Sustainable Construction Incentives	Government incentives at national and state levels promote energy-efficient, sustainable and environmentally friendly construction practices.
4	Smart Cities Mission	Large-scale urban infrastructure projects (7,804 projects worth INR 181,322 crore) encourage adoption of technology-driven and smart construction solutions.

III. GOVERNMENT'S ROLE IN FOSTERING A TECH-ENABLED CONSTRUCTION INDUSTRY

Although there are no specific government policies requiring the use of technology in the construction industry, there are certain government policies related to the use of technology in the industry, which encourage companies to use technology to enhance their efficiency. As mentioned on the official website of the Government of India, investments in the construction industry impact more than 250 associated industries, which include building materials, components and machinery. The government initiatives undertaken to ensure the timely completion of large-scale real estate and infrastructure development projects are expected to enhance the use of technology in the industry.

IV. KEY TECHNOLOGIES REVOLUTIONIZING THE CONSTRUCTION INDUSTRY

Many different and innovative technologies have been developed to accomplish these two major objectives: minimizing project duration and enhancing construction quality. The emphasis on efficiency and performance is changing all aspects of construction, such as design, planning and execution. The following are some of the major technologies changing the construction industry.

a. Building Information Modeling (BIM) and Digital Twins

Building Information Modeling (BIM) is a tool that helps architects, engineers and contractors work together in a collaborative environment to share information about a construction project. BIM is useful in improving coordination and reducing errors in a construction project. Digital twins are also useful in construction as they provide a virtual copy of a physical object or a construction project.

b. Drones

Drones are now sophisticated tools in the construction sector and their applications include land surveying, mapping, structural inspection and monitoring of construction progress. Drones help in acquiring precise information in a quick and efficient manner.

c. Data Analytics

Data analytics helps construction professionals analyze the data generated on the project, which aids in decision-making. Using data analysis, the organization can optimize the allocation of resources, scheduling and budgeting, which helps in the efficient management of the project.

d. Artificial Intelligence (AI)

Construction is utilizing Artificial Intelligence to forecast cost overruns, recognize possible risks and facilitate project planning and safety management. Artificial Intelligence is also being applied to off-site construction processes and is improving productivity through automated analysis and intelligent decision-making.

e. Prefabrication

Prefabrication is a construction technique whereby building components are produced in a factory and then transported to the building site for assembly. This technique has the advantage of saving construction time and minimizing disruption to the building site.

f. Green Technology and Innovative Products and Materials

Green construction technologies and materials in construction work towards minimizing the ecological footprint of construction activities. Sustainable construction practices not only improve the performance of buildings but also offer energy efficiency and cost savings.

g. 3D Printing

The technology of 3D printing makes it possible to produce building components with the layer-by-layer method. This technology helps to produce complex architectural forms and customized structural components with minimal wastage of materials.

h. Real-time Monitoring and Internet of Things (IoT)

Internet of Things-enabled devices and monitoring systems can track construction activities and equipment in real-time. These technologies can help identify safety hazards and track project status to ensure timely completion of construction activities.

i. Virtual Reality (VR) and Augmented Reality (AR)

Design visualization, employee training and giving clients immersive project experiences are all made possible by VR and AR technologies. They enhance communication throughout the planning and execution phases and aid stakeholders in comprehending project layouts.

j. Autonomous Heavy Equipment and Construction Robots

Bulldozers, excavators and load carriers are examples of autonomous construction equipment that can complete tasks with little assistance from humans. Bricklaying, material handling, demolition and even printing entire building structures using cutting-edge automation technologies are all tasks performed by construction robots.

k. Wearable Technology

The use of wearable technology, such as exoskeletons, safety vests and smart helmets, is growing in order to improve worker productivity and safety. Construction sites can be made safer and more productive by using these gadgets to track workers' health, levels of fatigue and environmental conditions.

These technologies greatly enhance the quality of project outcomes in a number of ways in addition to expediting construction processes.

i. Improved Design and Planning

By improving coordination among project stakeholders, cutting-edge technologies like Building Information Modeling (BIM) enhance design and planning. Effective clash detection and improved project component integration are made possible by BIM, which dramatically lowers design errors and the likelihood of rework during construction.

ii. Data-Driven Decision Making

Real-time data that facilitates well-informed decision-making is provided by the use of sensors and digital monitoring systems. By identifying possible issues early on and acting quickly to address them, this data helps construction professionals increase project efficiency and minimize delays.

iii. Enhanced Quality Control

Prefabrication and off-site manufacturing allow building components to be manufactured in a controlled environment. This would allow for a higher level of quality inspection and standardization, thus reducing the chances of defects in construction.

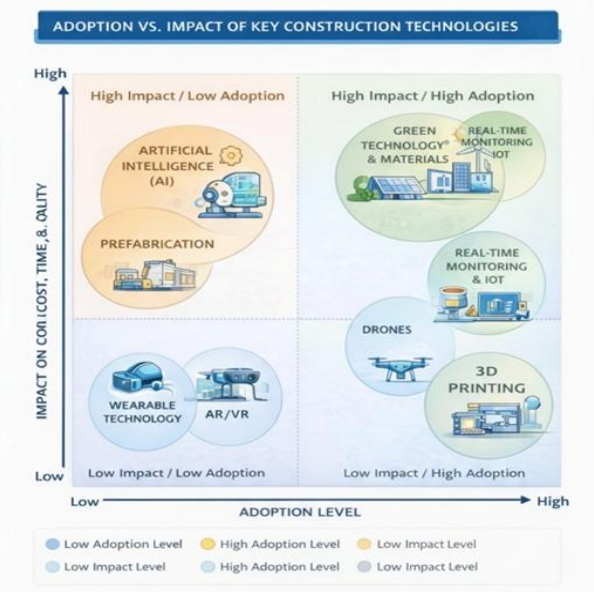
iv. Automation Reduces Human Error

Automation and robotic technologies have the capability to perform tasks with precision and accuracy. These technologies minimize human errors in crucial construction activities by reducing human intervention.

V. CONSTRUCTION AND THE RELEVANT TECHNOLOGIES

VI. INFLUENCE OF STAKEHOLDER PARTICIPATION ON COST, TIME AND QUALITY OUTCOMES

Based on the questionnaire survey carried out in the previous study, discussions were made with major property developers and construction companies to understand the extent of technology usage adopted by major companies in this industry. The major findings of this survey and discussions are presented in the table below.



VII. CONCLUSIONS

In conclusion, while the use of advanced construction technology remains low, the impact such technology will have on the industry cannot be overemphasized. As technology, digitalization and automation in the industry continue to grow; they will be instrumental in transforming the way the industry operates, thereby improving the efficiency and productivity of the industry, the cost savings and returns on investment and the emphasis on sustainability.

Furthermore, technological advancements will enhance safety and risk management, data-driven decision-making and the ability of the organization to attract and retain the best human resource in the competitive environment. They will also offer new opportunities for collaboration among the stakeholders and enhance regulatory compliance.

Ultimately, as the industry continues to adopt and embrace these innovations, it is envisioned that the construction industry will be able to deliver faster construction projects with better quality and sustainability in its future.

REFERENCE

[1] Construction Technologies: Reducing Timelines & Increasing Quality Expectations CBRE Research. (2024, December).

[2] Jamiu A. Dauda, Ninad N. Chavan, Abdullahi B. Saka, Saheed O. Ajayi & Adekunle S. Oyegoke (2025) An appraisal of barriers to digitalisation of construction industry in developing countries: perspective from India, International Journal of Construction Management, 25:7, 770-782, DOI: 10.1080/15623599.2024.2362014

[3] Aiyetan, A. O., & Das, D. K. (2023). Use of drones for construction in developing countries: Barriers and strategic interventions. *International Journal of Construction Management*, 23 (16), 2888–2897. https://doi.org/10.1080/15623599.2022.2108026

[4] Alva L. 2022. Construction Industry: technology based innovation is sparking a revolution. Online. [accessed 2023 November 27]. https://etinsights.et-edge.com/construction-industry-technology-based-innovation-is-sparking- a-revolution/.

[5] Babaeian JM, Sutrisna M. 2022. Guest editorial: working smarter by applying advanced technologies in construction: enhancing capacity and capability in construction sector for infrastructure project delivery. JEDT. 20(4):861–865. DOI: 10.1108/JEDT-08-2022-744.

[6] Bajpai A, Misra SC. 2020. Assessment of success determinants for implementing digitalization in Indian construction industry. In 2020 IEEE International Conference on Engineering, Technologyand Innovation (ICE/ITMC); Cardiff, IEEE.

[7] Singh A, Kumar V, Verma P, Kandasamy J. 2023. Identification and severity assessment of challenges in the adoption of Industry 4.0 in Indian construction industry. Asia Pacific Manage Rev. 28(3):299–315. DOI: 10.1016/j. apmrv.2022.10.007.

[8] Ronaghi MH. 2023. The influence of artificial intelligence adoption on circular economy practices in manufacturing industries. Environ Dev Sustain. 25(12):14355–14380. DOI: 10.1007/s10668-022-02670-3.

[9] Parwal U. 2023. India construction industry: current status & trend analysis. [accessed 2024 March 6]. https://equipmenttimes.in/india-construction-industry-current-status-trend-analysis/.

[10] Maiti D, Castellacci F, Melchior A. 2020. Digitalisation and development: issues for India and beyond. 1st ed. Singapore: Springer.

[11] Hiray, A. C., Bhargav, S. U., Tallam, S., Krishna, V., Meghasyam, B., & Vidya Sagar, B. K. (2023). Exploration and analysis of new technology and its adoption in Indian construction industry. International Journal of Novel Research and Development (IJNRD), 8(5), e160–e187.

[12] Rangani, S., & Solanki, J. (2020). Automation in construction industry: Its application and barriers to implementation on construction site. International Research Journal of Engineering and Technology (IRJET), 7(6). e-ISSN: 2395-0056, p-ISSN: 2395-0072.

[13] Jadhav, O., Minde, P., Yadhav, A., & Gaidhankar, D. (2023). A review of emerging trends & advances in construction technology in the Indian scenario. *Materials Today: Proceedings*, 77(Part 3), 897–904. https://doi.org/10.1016/j.matpr.2022.12.041

[14] Kansal, A. (2022, May 9). *How technology is reshaping the Indian construction industry*. Construction Week India. https://www.constructionweekonline.in/people/how-technology-is-reshaping-the-indian-construction-industry

[15] Boyal, R. (2025, December 12). *Role of technology in building India's infrastructure and construction industry*. Construction Times. https://constructiontimes.co.in/Role-of-technology-in-building-India%E2%80%99s-infrastructure-and-construction-industry

[16] RS Builders. (2025, May 19). *The role of technology in modern-day construction projects*. RS Builder. https://rsbuilder.in/technology-in-modern-day-construction-projects/

[17] AMS India. (2024, November 14). *The impact of technology on construction consultancy*. AMS Construction Project Management Consultants. https://amsindia.co.in/the-impact-of-technology-on-construction-consultancy/