(REVIEW ARTICLE)

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Assessing the state of Artificial Intelligence in the construction industry: A review towards safety and sustainable environment

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Abstract

The construction sector is a crucial component of the U.S. economy, valued at approximately $2 trillion in 2024. The study highlights the industry's role in infrastructure development and economic growth, employing over 7 million people and contributing around 4% to the GDP. Despite its significance, the construction industry faces challenges such as labor shortages, rising material costs, and stringent regulations, which necessitate the adoption of advanced technologies like AI to enhance operational efficiency and reduce costs. This review examined the current applications, benefits, challenges, and prospects of AI in construction, emphasizing its potential to improve safety, streamline project management, and automate processes. However, it also addresses the technological challenges of integrating AI with existing systems, the high costs of implementation, and the skill gaps that hinder effective adoption. Successful case studies, such as collaborations between construction firms and technology providers, illustrate the potential for significant time and cost savings through AI. This study elaborated the need for investment in training programs, collaboration among stakeholders, and the establishment of clear regulations to ensure responsible AI use, ultimately aiming for a more efficient, sustainable, and innovative future in the construction industry, especially in the United States. As the industry embraces digital transformation, this research supports innovation, efficiency, and sustainability in construction practices globally.

Keywords: Artificial Intelligence; Construction; United States; Safety; Sustainability; Smart Cites

1.   Introduction

The U.S. construction industry is a cornerstone of the country's economy, valued at around $2 trillion in 2024, with projections suggesting continued growth over time (8). It plays a major role in shaping the country's infrastructure and supporting economic development, employing more than 7 million people and contributing about 4% of the GDP (20). This industry isn't just about building structures but also about boosting economic growth and enabling other industries to operate effectively. According to the report by Building Radar, the construction industry can be divided into several key sectors: residential construction (focused on homes and housing complexes), commercial construction (including office buildings, retail spaces, and warehouses), industrial construction (covering facilities like factories and power plants), and infrastructure construction (which includes highways, bridges, airports, and public utilities) (8). Other sectors include energy and utilities construction (such as electricity and power, oil and gas, telecommunications, sewage infrastructure, and water infrastructure), as well as institutional construction (which involves educational buildings, healthcare facilities, research centers, and religious buildings) (23). Despite its significant contributions, the construction industry faces notable challenges, similar to those of other sectors. Labor shortages, rising material costs, and stringent regulatory requirements are significant issues that affect the industry's efficiency (20). These challenges have heightened the need for technological solutions that can optimize operations, minimize errors, and effectively

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manage costs. As a result, interest in emerging technologies like Artificial Intelligence (AI) has grown, especially because the industry remains one of the least digitized industries in the world (1). AI is a sophisticated digital technology transforming multiple sectors, from retail and telecommunications to manufacturing (12). While other technologies focus on basic mathematical functions, AI allows computers to think by analyzing data, predicting outcomes, and suggesting solutions (21). This has led to improvements in business processes, service delivery, and industrial productivity beyond what conventional methods could achieve (1; 10). Several subsets of AI, such as machine learning, natural language processing, robotics, computer vision, optimization, automated planning, and scheduling, are used to address complex problems and generate insights into real-world issues (41; 55). Past studies have documented the use of AI and its subsets in the construction industry, including machine learning (9; 30), robotics (43; 11), and knowledge database optimization (44; 3). Despite these advances, the full potential of AI remains underused in construction (25; 1). This study examines current applications, benefits, challenges, and prospects of AI within the U.S. construction sector. It aims to provide an overview of how AI is already influencing these areas and what the future might hold for this transformative technology in construction.

2.   Current Applications of AI in Construction

The construction sector is evolving due to automation, especially AI-powered robotics and self-driving equipment (43). Robotics is an interdisciplinary engineering field that focuses on designing, building, operating, and maintaining robots and other computer systems to mimic human actions in the real world (14). These technologies address labor shortages and improve efficiency in repetitive tasks (19). Robotics systems for construction have been developed since the 1960s and can be categorized into four groups: off-site prefabrication systems, on-site automated and robotic systems, drones and autonomous vehicles, and exoskeletons (14). In the United States, robotic arms and autonomous machines are increasingly used for tasks like bricklaying, concrete pouring, and site inspections (24). Large-scale project operations are further enhanced by autonomous concrete pouring machines, which use AI-driven precision to ensure accuracy and reduce waste (6). Additionally, AI-enabled drones perform routine site inspections by capturing high-resolution photos and videos that project managers can use to monitor progress and ensure safety regulations are followed without needing to physically inspect locations (8).

Construction project management is complex and involves multiple tasks that could be made more efficient with AI (51). AI is transforming how teams handle scheduling, budgeting, and resource allocation in construction management. Advanced AI tools (like Procore and Autodesk Construction Cloud) are streamlining project timelines by analyzing large datasets from previous projects, weather patterns, and material availability to generate accurate scheduling predictions. These platforms assist in developing solutions for complex applications that better address user needs and project constraints (13). Resource allocation also benefits from AI platforms; these tools enable managers to distribute labor and materials more effectively, reducing waste and increasing productivity (21).

AI is transforming design and planning in construction by enhancing Building Information Modeling (BIM), architectural design, and urban planning. AI-powered BIM tools, such as Revit and Autodesk Construction Cloud, leverage machine learning to automate clash detection, predict structural weaknesses, and optimize design layouts based on spatial data (36). These programs create design alternatives by utilizing machine learning techniques to investigate every possible solution variation. Following user-specified requirements, the generative design program generates 3D models that are optimized for the limitations, learning from each iteration until the ideal model is produced (40). Also, AI-assisted models assist in simulating city layouts and predicting infrastructure needs based on demographic trends and environmental data. This helps planners create efficient, resilient urban spaces that anticipate future growth and environmental challenges (17). Furthermore, by leveraging vast datasets, generative AI can produce innovative design solutions beyond traditional methods, which rely heavily on manual input and intuition (33). Generative AI enables architects and engineers to quickly explore a multitude of design alternatives by anticipating potential clashes and issues and optimizing for factors such as cost, space, and sustainability (46; 29).

The construction industry is regarded as one of the most dangerous industries in the world (39). To address safety concerns, AI enhances real-time monitoring of construction environments and personnel, leading to early identification of potential hazards and prompting preventive measures (25). AI-powered hazard detection tools, like Smartvid.io and OpenSpace, use machine learning to analyze site images and videos, identifying unsafe practices or hazardous conditions, such as improper PPE use or fall risks (32). AI tools analyze past incident records, project schedules, and environmental data to predict when and where risks are most likely to occur. These analytics target high-risk zones, allowing for proactive safety measures and reducing incident likelihood (2). In the construction sector, safety is not only a legal necessity but also a top priority that guarantees both the success of projects and the welfare of employees (5). By utilizing these AI advancements, the construction sector is moving toward a future in which safety is constantly observed, possible hazards are recognized and proactively reduced, and construction sites are overly safe (32).

The impact of AI is not limited to pre- and during-construction activities; it also spans the post-construction activities involving the maintenance of the project (34). Generative AI can analyze data from historical trends, drones, security systems, etc., to monitor the condition of building infrastructure, which allows early detection of issues related to cracks and leakages, leading to prompt repairs and maintenance (2; 3; 24). Also, AI continues to ensure a project complies with dynamic codes and safety regulations by ensuring deviations from the original design requirements are reported timely manner, facilitating structural integrity and compliance over time (38). Generative AI simplifies post-construction documentation through automation. This could be compliance paperwork, report generation, etc., reducing manual errors and enhancing administrative tasks to save time and provide efficiency to the construction team (47).

3. Benefits of AI in Construction

AI significantly boosts efficiency and productivity by reducing the time and resources required to complete a project (12). By automating repetitive tasks and enhancing real-time decision-making, AI helps teams streamline workflows and tackle complex projects more effectively (37). AI's ability to manage resource allocation and reduce waste plays a huge role in maintaining productivity. With smarter allocation, such as automated delivery schedules and predictive labor assignments, teams use their resources to the fullest without overextension. Tools like Buildots and Doxel use computer vision and machine learning to track project progress daily, flagging potential issues before they cause delays. This predictive insight allows project managers to make timely adjustments to staffing, materials, or workflows, reducing the likelihood of bottlenecks (15).

AI tools are vital to projects as they forecast cost overruns based on factors like project size, contract type, and the skills of project managers (40). They lead to significant savings by reducing material waste and optimizing resources. By predicting peak periods and efficiently allocating resources, AI minimizes idle time and boosts productivity. This real-time flexibility prevents resource overuse, helping to cut costs substantially (52). The combination of Generative AI with BIM (5D BIM) improves cost insight, alerts, and automates cost estimation (50). Generative AI platforms like the BIM-enabled Generative AI Platform for Productivity and Accuracy Enhancement of Construction Cost Planning (BIM-GA cost) can automatically produce initial cost plans and related documents. This automation increases productivity by saving time on these tasks, which is key for finishing projects on schedule and making the best use of resources (7; 42).

AI significantly enhances the quality and precision of construction work by providing tools that reduce human error and improve task execution (16). Self-driving construction equipment undertakes repetitive tasks more efficiently than humans, while some of them, with little human interaction, can perform tasks to exact specifications (40). For example, Doel employs AI-powered robots equipped with 3D laser scanners to capture site data, compare it with digital models, and identify any deviations. This real-time feedback enables construction teams to make adjustments swiftly, improving both quality control and accuracy (54).

AI has significantly improved safety in the construction industry by reducing risks and enhancing hazard detection. Through the use of AI-powered monitoring systems, construction sites are now equipped with real-time hazard detection, proactive risk mitigation, and alert systems (25; 5). Furthermore, AI enhances safety by predicting potential risks based on historical project data. AI can forecast risk hotspots on a construction site by analyzing previous incidents, environmental conditions, and worksite activities (2).

4. Challenges and Limitations

Implementing AI in the construction industry faces several technological challenges, particularly concerning integrating existing systems and data management (52). Also, many construction companies still rely on outdated legacy systems that are not designed to interact with AI tools, and this incompatibility may result in cost increases, delays, and significant adjustments to the project cycle (49). Overcoming this challenge will require substantial investment in technology and more industry-wide collaborations.

Adoption of AI, like any other advanced technology, is cost-intensive. This cost is associated with data collection and management, building and maintaining infrastructure, and hiring skilled personnel (49; 1). Consequently, this may be unaffordable for many construction companies, especially small firms. It is now the responsibility of construction companies to evaluate the cost of adopting this technology and the return on investment before making investment decisions (52; 49; 1). However, as the adoption of AI in construction becomes prevalent, it is expected that the cost of implementation will reduce over time (1).

No matter how advanced a technology may be, it still requires some human interaction to operate effectively. A major challenge in incorporating AI into the construction industry is the skill gap within the workforce (18). This lack of specialized training is a significant obstacle, as workers might not know how to integrate AI into their daily tasks, from project management to resource allocation. Moving from traditional methods to AI-driven processes demands upskilling or reskilling the workforce, which can be costly and time-consuming (49). Addressing these challenges involves construction professionals working alongside researchers and AI industry experts to develop innovations that will support the industry's adoption of new technology (1).

Ethical concerns have been a major issue in the adoption of AI in any industry. AI has the potential to introduce ethical and legal risks, such as bias, discrimination, accountability, and transparency in any establishment, including construction (56). As AI continues to evolve, regulators struggle to keep pace with the rapid advancements, resulting in a gray area when it comes to standards for AI systems, data usage, and safety protocols. Furthermore, construction projects often involve sensitive personal information, such as employee data or client details, which raises privacy concerns when AI tools process this data (1). To mitigate these, several governments and agencies are working towards providing adequate regulations that govern the use of AI in all industries (49).

5.   Case Studies

5.1.   Mortenson Construction: AI-Driven safety and efficiency in wind energy construction

Mortenson Construction, a major player in the U.S. construction industry based in Minneapolis, Minnesota, is known for adopting innovative technologies to optimize project delivery. They are industrial leaders in markets like sports facilities, renewable energy, data centers, and healthcare. The company undertook several large-scale infrastructure projects and sought AI to improve scheduling and risk analysis. Mortenson implemented Itasca's AI-powered Bearing Capacity Prediction Tool [35]. The web-based software rapidly predicts the ground-bearing capacity via automation and an artificial neural network and scaling techniques based on FLAC3D computer simulations. It produces an accurate assessment of soil conditions and crane stability calculations in minutes. The collaboration between Itasca Consulting Group and Mortenson Construction using machine learning to advance safety and efficiency in wind energy construction bagged them a 2021 Tekna Award (Artificial Intelligence/Machine Learning category) from the Minnesota Technology Association [27]. The AI tool produces results in minutes compared to traditional means that take weeks and cost more resources and time. Mortenson Construction and Itasca Consulting Group's prediction project is advancing the implementation of AI in the wind energy construction industry and championing the initiative to achieve real-time efficiency, safety, and timeliness.

5.2.   Skanska USA and Dusty Robotics: Revolutionizing on-site operations

Skanska USA, a branch of the global construction giant, is one of the largest, most financially sound construction and development companies in the U.S. They are focused on prioritizing on-site safety through predictive technology [45]. They have a large client base, such as transportation, power, industrial, water/wastewater, healthcare, education, sports, data centers, government, aviation, and commercial [26]. Skanska's goal is to reduce safety incidents and improve hazard detection on U.S.-based sites. Skanska partnered with Dusty Robotics' Multi-Trade Layout Robot at Sutter Health's Samaritan Court Ambulatory Care and Surgery Center project. This partnership saw the use of the Dusty Field Printer, which automated the printing of mechanical, electrical, plumbing, framing, and drywall layouts for the three-story, 70,000-square-foot mixed-use medical facility. It eliminated bottlenecks while increasing layout speed and reducing change orders. The team used an integrated form of agreement (IFOA), which, throughout the pandemic, helped stimulate creative ideas and planning remotely. As a result, Skanska delivered the project nearly three months ahead of schedule and $3 million under budget [48]. Despite the COVID pandemic and supply chain challenges, Skanka leveraged innovative construction technology that accurately printed BIM models from different construction professionals on-site. This project shows AI's transformative potential in on-site efficiency, even with less interaction from the team. According to the team, over three hundred issues were resolved in two months, excluding those that could have been repeated multiple times [45]. This shows the effectiveness of AI in teamwork planning. With further development, similar AI tools could become standard, ensuring efficient construction sites industry-wide.

5.3.   Akita Box and Buckeye Elementary School partnership on facility management

Akita Box, a Midwest-born and raised company founded in 2015, is a software platform designed to optimize building operations, particularly in the Architecture, Engineering, and Construction (AEC) industry [5]. Buckeye Elementary School District is a Pre-K-8 school district located across the vast desert region of Buckeye, Arizona. With over 5000 students and 600 staff, the district was transitioning from paper paper-based system to a technology-based system in managing large-scale facilities [49]. At Buckeye Elementary School, the Akita box was leveraged to digitize asset tracking

and automate maintenance management. AI algorithms identified patterns in equipment wear and tear, enabling predictive maintenance. The Akita Box software offers a modern, minimal interface that works seamlessly with iPads in the field. Due to their simplicity of use, which aided rather than hindered his technicians and facilities managers, these tablets were the preferred choice [4]. The implementation of the Akita box resulted in measurable improvements in efficiency, cost savings, and safety. The school saved about 30% of the time in locating asset information through its centralized digital database. It was also recorded that the predictive maintenance cost was reduced by 15% annually. The success at Buckeye Elementary School with Akita box highlights the importance of proactive maintenance strategies facilitated by AI in the post-construction stage [53]. Looking forward, integrating Akita box with IoT-enabled devices could provide real-time data on asset performance, further enhancing efficiency and cost-effectiveness [49]. Additionally, its scalability makes it an ideal solution for other schools and public facilities aiming to streamline post-construction operations

6.   Future Prospects and Trends

As AI develops further, several new technologies could affect the building sector, improving the sustainability, safety, and efficiency of projects (40). Robotics powered by AI has promise for automating repetitive jobs like welding and bricklaying. By carrying out high-precision operations independently, even in dangerous circumstances, robotics under AI guidance has the potential to greatly increase productivity and alleviate employment shortages (14). Another transformative trend is digital twin technology, which blends 3D representations of building sites with real-time data from artificial intelligence (54). Digital twins assist project managers in seeing results and identifying problems before they arise by modeling many scenarios.

By 2030, experts anticipate that digital twins could become essential for managing complex projects, particularly in urban infrastructure. A notable trend is the use of AI in construction robotics, particularly in automating labor-intensive tasks like bricklaying, concrete pouring, and even welding (31). Also, it is anticipated that construction robotics, with AI-powered precision, could ease labor shortages, lower prices, and expedite project schedules, thus strengthening the industry's resilience and sustainability in the face of skilled labor shortages (52; 49). Furthermore, AI algorithms can optimize energy use, minimize waste, and evaluate and recommend eco-friendly goods. The growing interest in AI solutions that facilitate green building certifications and carbon footprint reductions is a result of the environmental impact of the construction sector (35; 3).

Future developments in AI in construction could lead to even more sophisticated and integrated systems, influencing everything from design to on-site implementation. The emergence of self-governing machinery is one encouraging trend. AI-powered tools, such as cranes and bulldozers, might be used to safely and precisely complete dangerous or repetitive jobs, reducing labor costs and minimizing human error (31; 15; 54). Cutting-edge AI systems can predict problems based on materials, weather, and past project data, enabling teams to plan for potential delays and allocate resources efficiently (1). Predictive insights are likely to lead to less financial risk and stronger project planning (16; 10; 30). GIS (Geographic Information Systems) plays a key role in the future of AI in construction by providing spatial intelligence that improves decision-making. As smart cities and digital twins develop, GIS will remain vital in mapping, modeling, and managing built environments [28]. By combining GIS with AI, construction professionals can analyze site suitability, environmental impact, and infrastructure planning more accurately. AI models trained on GIS data enable predictive analytics for land use, risk assessment, and urban planning [30]. This partnership supports smarter, location-aware construction that lowers costs and boosts sustainability.

Additionally, AIs enable real-time simulations of construction processes through the use of 4D modeling and enhanced digital twins. Better project monitoring and flexible scheduling are made possible by digital twins, which are especially helpful for intricate, large-scale construction projects where timeliness and precision are essential. Virtual project simulation has the potential to revolutionize the way engineers and architects work together, guaranteeing more efficient project execution from beginning to end (31; 11; 40).

7.   Conclusion

The construction industry is an integral element of our environment. It serves as the cornerstone to the infrastructure development of all other industrial establishments for mankind. This study highlighted the transformative potential of AI in enhancing operational efficiency, improving safety, and streamlining project management. Successful case studies, such as Skanska's collaboration with Dusty Robotics, demonstrate how AI can automate processes, leading to significant time and cost savings. However, the industry also grapples with workforce issues, requiring upskilling and reskilling to adapt to new technologies, which can be costly and time-consuming. This trend is not just for developed countries like

the US; it also cuts across to the construction industry all around the world. Furthermore, ethical and regulatory concerns, such as bias and data privacy, also pose significant hurdles to AI adoption across the board. This report emphasizes the necessity for clear regulations to ensure responsible AI use in construction. The overall impact of AI on the construction industry is profound, offering opportunities for increased productivity and innovation. To effectively leverage AI, stakeholders are encouraged to invest in training programs that equip workers with the necessary skills to work alongside AI technologies. Collaboration between construction firms, technology providers, and academic institutions is vital to drive innovation and develop tailored AI solutions. Policymakers should establish comprehensive regulations that address ethical concerns and promote transparency in AI applications. Additionally, as technology continues to evolve, raising awareness about the benefits of AI and leveraging data analytics for informed decision-making can further enhance project outcomes. By adopting these strategies, the construction industry can navigate challenges and embrace the transformative power of AI, leading to a more efficient, sustainable, and innovative future.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest.

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