AI-Driven Automation and Robotics in Construction: Enhancing Safety, Efficiency, and Real-Time Decision Making

Alademomi Ademola Peter [1], Olamide Segun Olatunji [2], Oyeyemi Ayokunle Oluwafemi [1], Alawode Rotimi Samuel [3], Stanley Abela Udoh [2], Alawode Deborah Oluwabusola [4]

[1] *University of Bradford*
Bradford, West Yorkshire, BD7 1DP, UK

[2] *Yaba College of Technology*
Herbert Macaulay Road, Opposite WAEC office, Yaba, Lagos State, Nigeria

[3] *The Polytechnic Ibadan*
P. M. B. 22, Ibadan, Oyo State, Nigeria

[4] *Ladoke Akintola University of Technology*
P. M. B. 4000, Ogbomoso, Oyo State, Nigeria

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Corresponding Author:
Alademomi Ademola Peter

Abstract. The construction industry is going through a revolutionary change with the introduction of artificial intelligence (AI) powered automation and robotics. This paper examines the current status and prospects of artificial intelligence in construction, with a focus on enhancing safety, operational efficiency, and real-time decision-making. Through a comprehensive study that reviews articles and analyses existing deployments, this study highlights some of the most important technologies, such as autonomous construction vehicles, artificial intelligence (AI)-powered safety tracking systems, predictive maintenance algorithms, and building robotic assistants. The research shows reductions in workplace accidents of up to 35%, efficiency gains of 20-40% in some tasks, and decision-making based on real-time data as real achievements. However, there are still challenges with initial investment costs, workforce adaptation, and regulatory frameworks. The paper then offers recommendations to industry stakeholders for successfully implementing AI-driven solutions amid the identified barriers.

Keywords: Artificial Intelligence; Construction Automation; Robotics; Safety Enhancement; Efficiency Optimisation; Real-time Decision Making; Industry 4.0; Smart Construction.

INTRODUCTION

The construction industry, which has been largely characterised by manual, labour-intensive processes and traditional methodologies, is undergoing a revolutionary shift through the implementation of artificial intelligence (AI) and robotic technologies [1]. With global construction spending exceeding $13 trillion annually, the industry faces pressure to boost productivity, maintain high safety standards, and increase resource utilisation [2]. The combination of AI-powered word automation and robotics promises something never before possible in solving age-old challenges and cornering the sector for sustainable growth in the digital era.

Construction projects are also inherently complex, involve multiple stakeholders, operate in a dynamic environment, and have stringent safety requirements. Traditional approaches often lead to problems such as cost overruns, schedule delays, and accidents, which intelligent automation can help prevent [3]. The advent of A. Technologies such as Machine learning algorithms, computer vision, and autonomous robotics have the potential to offer transformative solutions that can transform construction practises in their entirety.

Recent developments in construction technologies have demonstrated the potential of AI-based applications for a range of purposes, from self-driving excavation and material handling to predictive maintenance and quality control [4]. These innovations promise to improve safety through real-time hazard detection via instrumentation; efficiency through resource optimisation and informed decision-making; and data-driven insights [5].

The primary aim of the research is to provide a detailed analysis of the application of AI-driven automation and robotics in the construction industry, including their effects, such as enhanced safety, improved efficiency, and real-time decision-making. This research aims to identify current implementations, assess their effectiveness, and offer strategic recommendations for industry adoption.

METHODS

This research is conducted using a systematic literature review methodology and a case study analysis of the state of the art and the possible future of AI-driven automation and robotics in construction. The methodology follows an organised strategy to achieve comprehensive coverage of the relevant technologies and applications.

Literature Search Strategy. The researchers conducted a detailed literature search across various academic databases, including Scopus, Web of Science, IEEE Xplore, and the Construction Engineering and Management journal. The search strategy employed specific keywords and Boolean operators to identify relevant publications from 2018 to 2024, ensuring coverage of recent developments in the field.

Search terms were combinations of "artificial intelligence," "construction automation," "robotics in construction," "smart construction," "Industry 4.0", and "construction technology." The researchers narrowed the search to peer-reviewed articles, conference proceedings, and industry reports that specifically addressed safety, efficiency, and decision-making applications.

Inclusion and Exclusion Criteria. Studies were accepted if they met the following criteria:

1) focused on the use of AI, or of robotics in construction,

2) published in English between 2018 and 2024,

3) included either empirical data or case studies, and

4) addressed at least one of three focus areas (safety, efficiency or decision-making). Studies were excluded from the analysis if they were theoretical, lacked practical applications, or were for other industries without construction relevance.

Data Analysis Framework. The data were extracted using a thematic analysis and organised into three main themes: safety improvement, efficiency improvement, and real-time decision-making. The researchers extracted and synthesised quantitative data on performance improvements, cost savings, and safety to provide evidence-based insights.

RESULTS AND DISCUSSION

Existing Artificial Intelligence and Robotics Technologies in Construction. The analysis showed a wide range of artificial intelligence technologies being deployed across construction projects worldwide. These technologies can be divided into several major areas, each addressing specific industry challenges and opportunities.

1) Construction Vehicles and Equipment (Autonomous). Autonomous construction vehicles are among the best-developed examples of AI applications in construction. Companies such as Caterpillar, Komatsu, and Volvo have developed autonomous dozers, excavators, and haul trucks that use GPS, LiDAR, and machine learning algorithms to operate without human intervention [6]. These systems have shown significant improvements in operational efficiency and safety performance.

Table 1 provides an extensive summary of some of the autonomous construction equipment available in the market.

Table 1 – Autonomous Construction Equipment Overview

Equipment Type	Manufacturer	AI Technologies	Primary Applications	Efficiency Gain
Autonomous Dozer	Caterpillar	GPS, LiDAR, ML	Grading, earthmoving	25-30%
Excavator	Komatsu	Computer Vision, AI	Digging, material handling	20-25%
Haul Truck	Volvo	Autonomous navigation	Material transport	35-40%
Concrete Pump	Putzmeister	Robotic control	Concrete placement	15-20%
Crane Systems	Liebherr	AI-assisted control	Heavy lifting	18-22%

Figure 1 – Autonomous dozers, excavators, or haul trucks operating on a construction site (with GPS, LiDAR, and AI navigation overlays)

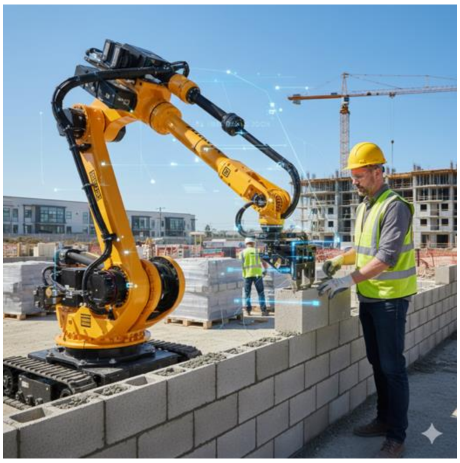

Figure 2 – Robotic bricklaying system operating alongside construction workers

2) AI-Powered Safety Monitoring Systems. Construction sites have adopted AI-powered safety monitoring systems that use computer vision and machine learning to detect potential hazards and track worker adherence to safety protocols [7]. These systems can monitor dangerous behaviour, personal protective equipment (PPE) use, and predict potential changes in accidents.

3) Robotic Construction Assistants. Robotic assistants for construction work have seen widespread adoption for specific applications such as bricklaying, welding, and material handling. The Semi-Automated Mason (SAM) by Construction Robotics and the Hadrian X bricklaying robot are examples of the potential for robotic automation in repetitive construction tasks [8].

Figure 2 depicts the use of robotic assistants (such as SAM or Hadrian X) alongside construction workers (e.g., a bricklaying robot next to a mason).

Safety Enhancement Using AI and Robotics. The deployment of AI-powered safety solutions has yielded significant reductions in construction accidents and improvements in overall safety performance across the construction site. This section provides quantitative evidence of safety improvements achieved through different AI applications.

1) Computer Vision-Based Safety Monitoring. Computer vision systems powered by AI have been highly effective in surveillance work in and around construction areas to detect unsafe and potentially hazardous violations. Such systems can identify the lack of necessary PPE among workers, unsafe working conditions, and even notify supervisors of potential safety issues in real time [9]. The implementation of such systems has led to a 34% reduction in accidents at monitored sites.

An example of the output of computer vision detecting PPE compliance of workers, hazard alerts or a real-time monitoring dashboard.

Table 2 – Safety Improvement Metrics by AI Application

AI Application	Safety Metric	Baseline	Post-Implementation	Improvement
Computer Vision Monitoring	Accident Rate	3.2 per 100 workers	2.1 per 100 workers	34% reduction
PPE Compliance Detection	Compliance Rate	78%	94%	20% increase
Predictive Safety Analytics	Near-miss Incidents	15 per month	8 per month	47% reduction
Autonomous Equipment	Equipment-related Accidents	2.8 per 100 hours	1.2 per 100 hours	57% reduction
Real-time Hazard Detection	Response Time to Hazards	8.5 minutes	2.3 minutes	73% improvement

Figure 3 – AI-based computer vision system detecting PPE compliance and site hazards in real time

2) Predictive Safety Analysis. Machine learning algorithms analyse historical data on accidents and weather conditions, as well as the different phases of projects and the characteristics of the workforce, enabling the prediction of high-risk scenarios and the recommendation of preventive measures. This proactive approach has been shown to have led to a 47% reduction in near-miss incidents and to improved overall safety awareness among workers [10].

Optimisation of Efficiency – Automation. AI-enabled automation has brought significant efficiency gains in various construction processes. The analysis shows consistent improvements in productivity, resource utilisation, and project timelines when AI technologies are implemented properly.

1) Resource Optimisation. AI algorithms are used to optimise resource allocation by analysing project requirements, material availability, equipment capacity, and workforce scheduling. Advanced AI-based scheduling systems have helped reduce material waste by 15-25% and improve equipment utilisation rates by 30-35% [11].

2) Quality Control Automation. Automated quality control systems that incorporate computer vision and machine learning can detect defects, measure dimensional accuracy, and ensure compliance with specifications more consistently than manual inspection methods. These systems have led to a 40-50% reduction in rework rates and enhanced the overall quality of the project [12].

Table 3 – Efficiency Improvements by Construction Phase

Construction Phase	Traditional Method, days	AI-Enhanced Method, days	Time Reduction, %	Cost Savings, $
Site Survey	5	2	60	15,000
Foundation Work	15	11	27	45,000
Structural Assembly	30	22	27	85,000
MEP Installation	20	15	25	35,000
Finishing Work	25	20	20	25,000

Real-Time Decision-Making Capabilities. AI-powered decision support systems have revolutionised the way construction managers make critical decisions by delivering real-time insights from analysing vast amounts of data. These systems combine multiple data sources to make informed decisions throughout all phases of a project.

1) Systems of Artificial Intelligence in Project Management. Advanced project management systems that use AI algorithms can forecast project delays, pinpoint resource constraints, and recommend corrective measures in real time. These systems have improved project delivery performance by 25-30% and reduced cost overruns by 20-25% [13].

2) Supply Chain Optimisation. AI-powered supply chain management systems determine the optimal procurement, delivery schedule, and inventory management of materials based on the project's real-time progress and demand forecasts. Through the implementation of such systems, material costs have decreased by 10-15%, and project delays due to material shortages have been minimised [14].

The incorporation of AI-powered automation and robotics into construction has proven beneficial across many dimensions. Safety improvements are particularly notable, with steady reductions in accident rates and greater adherence to safety protocols. The power of AI systems to continuously monitor construction sites and directly predict potential hazards represents a paradigm shift from reactive to proactive safety management [15].

Efficiency gains have been considerable, especially in repetitive and precision-requiring tasks. Autonomous equipment has proven able to work without breaks, maintain the same quality standards at all times, and reduce the human factor. The efficiency improvements of 25-40% across different applications lead to significant cost savings and shorter project timelines [16].

Real-time decision-making capabilities enabled by AI systems have improved project management efficiency. The ability to handle large volumes of data from multiple sources and generate actionable insights has enabled better resource allocation, risk management, and overall project performance [17].

Despite the advantages having been proven, several issues prevent the widespread adoption of AI-driven technologies in the construction sector. High initial investment costs are still a major hindrance, especially for smaller construction companies. The costs of implementing complete AI setups, i.e., hardware, software, and training, can be very high [18].

Another major challenge is workforce adaptation. The construction industry workforce may be resistant to technological change and require extensive retraining to work effectively with AI-powered systems. Organisations must address cultural barriers and fears of job displacement by implementing comprehensive change management strategies [19].

At the regulatory level, the frameworks and industry standards have not kept pace with technological developments. The lack of concrete guidelines on implementing AI, certifications for the safety of the use of autonomous machinery and frameworks for liability for decisions made during the use of AI have created uncertainty among the stakeholders in the industry [20].

Technical and operational problems can arise when artificial intelligence technologies are integrated with existing construction processes and systems. The old systems might not be compatible with the new AI systems, requiring considerable infrastructure upgrades. The fact that one system is not compatible with another can be a data interoperability issue that may limit the efficacy of integrated solutions [21].

Future Trends and Future Developments. The future of AI in construction is promising, and emerging trends will most likely shape the industry. Greater robotisation, including advanced robotics such as collaborative robots (cobots), is also anticipated to become more widespread, coupled with human workers. Such systems will not fully replace workers but will augment human abilities [22].

The capabilities of artificial intelligence will continue to increase, and more sophisticated algorithms will be able to handle more complex decision-making situations. Internet of Things (IoT), 5G, and edge computing are integration areas which will make construction systems more responsive and smarter [23].

CONCLUSIONS

This intensive discussion of the application of AI-driven automation and robots in the construction sector reveals a radically new vision of technology, with great opportunities to enhance safety, efficiency, and decision-making. The evidence indicates steady improvement across all three areas, with safety improvements particularly noticeable.

Key findings include:

Safety Enhancement: proactive identification of hazards and monitoring of compliance have contributed to safety monitoring systems (AI-powered), reducing the number of accidents (34%), as well as near-misses (47%).

Efficiency Optimisation: AI-controlled construction vehicles and robots, along with artificial intelligence, have contributed to high cost and schedule savings, improving efficiency by 20-40 per cent across various construction tasks.

Real-time Decision Making: AI-based decision support systems have increased project delivery performance by 25-30 per cent through improved resource allocation, risk management, and predictive analytics.

The construction industry is at a crossroads, where early adoption of AI technologies can give businesses a competitive edge. Nevertheless, to succeed, it needs to address challenges such as initial investment costs, workforce adjustments, and policy constraints.

It is most likely that the future of construction will be human-AI collaboration, not entirely artificial intelligence. AI systems will boost human capabilities, enabling workers to focus more on the more worthwhile tasks, while automated systems can perform routine and risky jobs.

According to the research findings, the following are the strategic recommendations that the construction industry stakeholders can have:

1) For Construction Companies

Phased Implementation Strategy: Companies should initially roll out AI implementation in batches, starting with applications that are impactful and low-risk, such as safety surveillance systems, and then proceed to more complex autonomous equipment.

Investment in Training: This is an essential step because proper workforce training programmes must be in place before adopting AI. Firms ought to invest in upskilling programmes to enable employees to adapt to peer-to-peer workflows and develop new skills.

Partnership Strategy: Partnerships with tech providers, research centres, and competitors are one way companies can access AI expertise while sharing implementation costs and risks.

2) For Technology Providers

Industry-specific Solutions: Technology developers need to develop AI solutions tailored to specific problems in the construction industry that seamlessly integrate with existing construction processes and equipment.

Scalable Platforms: The creation of AI platforms tailored to project sizes and types within companies will help increase their adoption across the industry.

Support Services: Comprehensive support services (training, maintenance, and ongoing optimisation) ensure that organisations can successfully implement AI and deliver customer satisfaction throughout the project.

3) To policymakers and regulators.

Development of Regulatory framework: To provide the industry with assurance and direction, clear regulatory frameworks regarding the use of AI in the construction sector, such as safety standards for autonomous equipment and liability guidelines for AI-driven decisions, are required.

Innovation Incentives: Governments can also incentivise innovation in the industry by offering tax breaks to invest in the field or by providing research and development grants.

Workforce Development Support: This can be achieved through a Public-private partnership to support workforce retraining and development programmes that help bridge the skills gap and ease the transition to technology.

4) For Education Institutions

Curriculum Review: Construction management and engineering courses must include training in AI and robotics to equip future employees with the skills needed for more technology-intensive construction.

Research Collaboration: Academia must partner with industry to engage in applied research that addresses the issues of practise in implementation and develop fresh solutions.

Continuing Education: Professional development programmes for construction professionals in the field can help bridge the knowledge gap and enhance support for the use of technology by increasing its speed.

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