ICCEPM 2024 https://dx.doi.org/10.6106/ICCEPM.2024.0293
The 10th International Conference on Construction Engineering and Project Management
Jul. 29-Aug.1, 2024, Sapporo

Applications of Artificial Intelligence (AI) in Construction Project Management: A Systematic Literature Review

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Abstract: The rapid emergence of Artificial Intelligence (AI) across diverse sectors has also made its presence felt in the construction sector, where its adoption is gaining momentum at a remarkable pace. The anticipated impact of AI on decision-making processes pertinent to construction project management is considerable, necessitating a holistic understanding of AI's potential applications. As a first step towards that goal, this paper conducts a systematic literature review and in-depth content analysis of existing literature related to the applications of AI in the context of construction project management. The authors selected journal papers, technical papers, and conference proceedings published between 2010 and 2023 on the topic of Artificial Intelligence for construction project management applications. Additionally, the authors also reviewed several industry and trade publications in the same topic area. The search resulted in more than 200 relevant articles, after which the authors conducted a thorough content analysis. The results categorized applications of AI in construction project management across categories: construction productivity, construction safety, construction quality, construction document management, and construction site planning. Additionally, the review identified the current trends of AI applications in construction project management, advantages, and challenges to implementation. Understanding AI applications, advantages, and challenges to implementation helps contractors gain new insights into the efficient implementation of AI for various project management purposes.

Keywords: Artificial Intelligence, Construction Project Management, Construction Productivity, Construction Safety, Construction Quality

1. INTRODUCTION AND BACKGROUND

The construction industry faces numerous challenges that have constrained its growth and resulted in significantly lower productivity levels than other sectors, such as retail, health care, or manufacturing. The industry allocates approximately 1% of its total budget to technology investments, a fraction of what is seen in sectors like financial services and manufacturing [8]. This underinvestment indicates that the construction sector is one of the least digitized globally, with a widespread recognition among

stakeholders of a longstanding culture resistant to change [52]. The prevailing lack of digitization and the industry's reliance on manual processes complicate project management and cause unnecessary challenges [6,18]. Furthermore, insufficient digital expertise and slow adoption of new technologies have been linked to cost overruns, delays, subpar quality, uninformed decision-making, and generally poor productivity, health, and safety outcomes [37]. Considering recent challenges, such as labor shortages, the COVID-19 pandemic, and the pressing need for sustainable infrastructure, it has become evident that the construction industry must accelerate its digital transformation [18,22].

Stakeholders across the construction project lifecycle, including contractors, operators, owners, and service providers, increasingly recognize the importance of artificial intelligence (AI) not just as a tool for other industries but as a critical component for improving construction engineering and management [8]. The application of AI in construction has grown significantly, driven by its potential to enhance performance and efficiency [40]. While AI's use in construction is still emerging, a select group of construction technology startups is gaining recognition and market presence for their AI-driven solutions [8]. This momentum is expected to profoundly impact decision-making processes in construction project management, underscoring the need for a comprehensive understanding of AI's potential applications.

Despite the industry's vast potential, the path to enhanced safety, productivity, quality, efficacy, and project management lies in embracing digitalization, adopting new construction techniques, and fostering innovation by implementing AI based technologies [21]. Research by [8] suggests that construction firms with a robust digitalization strategy are 50% more likely to profit from AI integration. This evidence highlights the critical importance of digital transformation in unlocking the construction industry's full potential, making it imperative for stakeholders to overcome resistance to change and invest in technology and digital capabilities. Therefore, this paper aims to identify potential applications, benefits, and implementation challenges of Artificial Intelligence in Construction Project Management.

1.1. Artificial Intelligence

Artificial Intelligence, a branch of computer science focused on creating systems that learn, reason, and adapt like humans, has emerged as a cornerstone technology in driving this transformation. AI's ability to handle complex and ambiguous problems has made it invaluable in addressing the unique challenges faced by the construction industry [27]. AI's role in construction project management has become increasingly significant, from enhancing decision-making processes to improving project outcomes.

Artificial Intelligence is a technological innovation that allows manufacturing systems to learn from past experiences, eventually realizing linked, intelligent, and ubiquitous business practices [55]. The application of AI in construction encompasses a wide range of areas, including productivity enhancement, safety improvements, quality assurance, document management, preconstruction planning, claims and litigation, and site planning. These applications testify to AI's versatility and potential to revolutionize construction.

AI applied in construction is a pragmatic instrument for examining and managing the sourcing of construction materials and skilled resources. Other applications include logic-controlled tools for recording the logistics and waste produced in construction [23]. AI is also used in distributing and transporting construction materials and products and combating counterfeit construction products and materials [23].

This study attempts to identify various current and future potential applications of Artificial Intelligence in construction project management.

2. RESEARCH METHODOLOGY

This study employed a systematic approach to investigate the applications of artificial intelligence (AI) in construction project management, encompassing both literature review and content analysis.

The initial phase involved a comprehensive keyword search across prominent academic databases, including Google Scholar, Web of Science, IEEExplore, and ResearchGate, utilizing terms such as "Artificial Intelligence," "Construction Project Management," and related terms like "Construction

Quality," "Construction Safety," "Construction Productivity," "Construction Claims," and "Preconstruction." This search yielded a pool of 2253 articles.

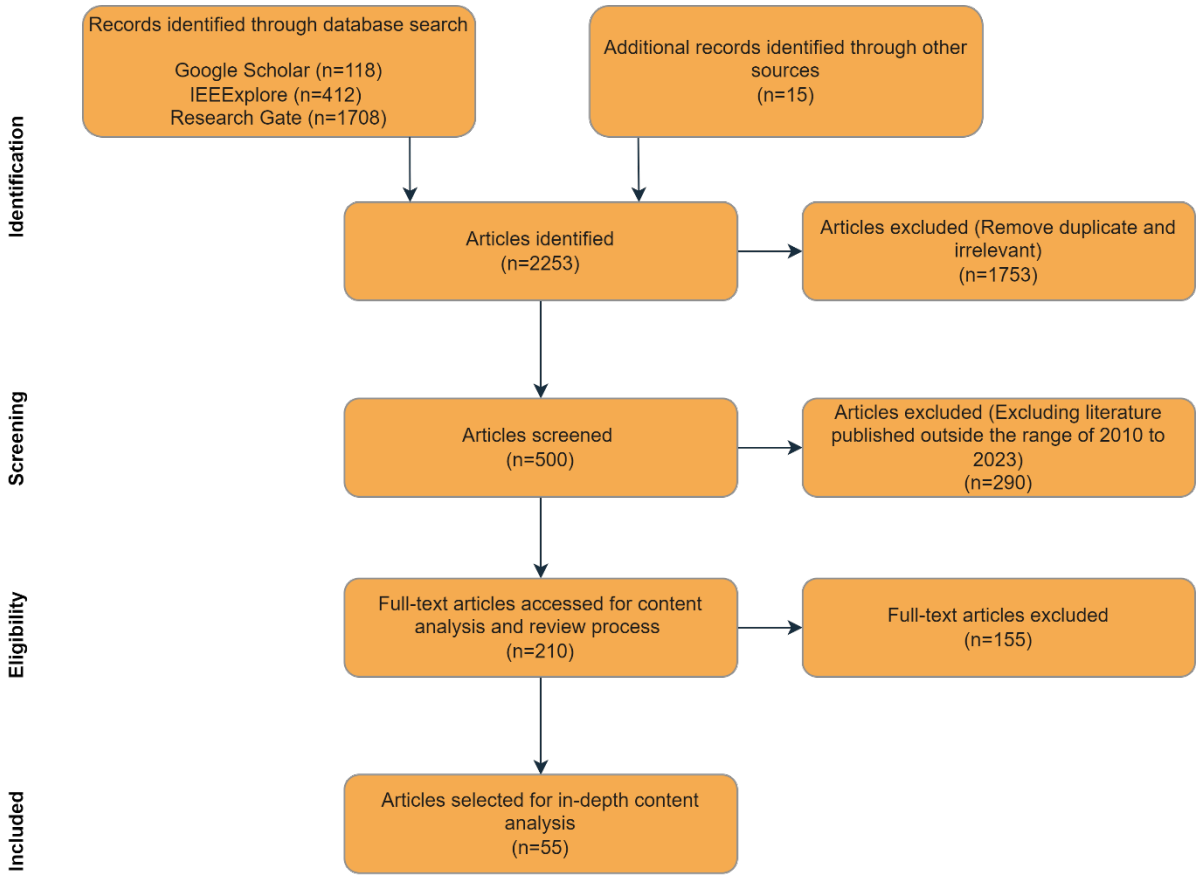
Following this, a meticulous screening was conducted to ensure relevance and quality. Duplicates and articles not directly relevant to the construction industry or lacking AI applications were eliminated, resulting in a refined selection of 510 articles.

Particular emphasis was placed on articles published between 2010 and 2023 to capture the latest trends and advancements. This focused timeframe included 210 journal papers, technical papers, conference proceedings, and industry publications.

The study then transitioned to a detailed content analysis phase to elucidate AI applications' current status, limitations, and future trends in construction project management. Within this scope, 55 articles were identified for in-depth examination, focusing on their associated applications and implications.

This systematic research methodology is represented in Figure 1.

Figure 1. Research Methodology



3. RESULTS AND DISCUSSION

Current Applications

Construction Productivity

Construction productivity is a critical factor in determining the success or failure of any construction project, as it involves efficiently utilizing resources to produce the desired output. It is commonly measured in terms of the man-hours required to complete a project compared to the planned man-hours [24]. The construction industry heavily relies on labor, making labor productivity a key aspect [33]. AI-powered robots are revolutionizing construction sites by automating routine tasks such as bricklaying and welding, enhancing efficiency, productivity, and profitability [27,39].

Optimization techniques are crucial for decision-making in construction projects, enabling effective task prioritization, resource allocation, and management of time-cost-quality trade-offs, thus fostering improved productivity and collaboration. Developing dynamic layout models through tracking on-site resources and demands enhances safety, productivity, and cost-efficiency in real-time construction processes. Virtual and augmented reality technologies integrated with AI techniques are being adopted for simulating hazardous environments and training workers, improving safety awareness, cognitive learning, and overall productivity. Lastly, AI-powered analytics leverage machine learning for predictive tasks in construction, offering strategic insights into project performance and risk management, thereby guiding proactive project management toward achieving project goals [39]. As a result, Artificial intelligence (AI) is seen as a transformative force in improving construction productivity by optimizing processes, automating repetitive tasks through AI-powered robots, and facilitating decision-making through intelligent optimization techniques [8,27,38,39].

Construction Safety

The construction industry plays a vital role in global economic development, yet it carries inherent risks that pose safety threats to workers and the public. Artificial Intelligence (AI) is a powerful technology that can transform construction safety management [7,17,20,29,46].

AI's capability to perform tasks that require human-like intelligence, such as learning, analysis, and problem-solving, is revolutionizing safety protocols [19,54]. Analyzing historical data allows AI algorithms to predict safety risks, enabling proactive risk management. This technology optimizes resource allocation, ensuring efficient safety equipment and personnel deployment. During emergencies, intelligent systems that combine AI with other technology guide workers to safety with geolocation technology. Predictive maintenance identifies potential equipment failures before they occur, minimizing accident risks. Automated documentation processes record safety protocols and compliance data accurately, while AI-powered cameras analyze worker behavior to provide real-time feedback on unsafe actions, enhancing safety awareness. AI also plays a crucial role in monitoring construction activities for adherence to safety regulations, ensuring real-time compliance. Furthermore, data analytics identify safety trends, enabling proactive safety management based on insights. Remote inspections by AI-assisted drones reduce the need for human presence in hazardous areas [42]. AI's impact extends beyond safety to include project control, where it classifies, quantifies, and forecasts potential risks, thereby guiding proactive management to ensure project reliability and effectiveness. AI's data-driven insights assist in optimizing work site safety, marking a significant advancement in construction quality and safety management [12,39].

Construction Quality

Integrating Artificial Intelligence (AI) in construction project management has marked a revolutionary shift towards achieving unparalleled construction quality. Utilizing AI's capabilities in image recognition and sensor technology, construction quality management has evolved from traditional methods to AI-driven automated quality assurance. This transformation is significantly bolstered by the synergy of AI and other emerging technologies like Building Information Modeling (BIM), which leverages data, automation, and intelligent algorithms to refine quality management processes [11,42,47].

This innovative approach ensures superior construction results and streamlines operational efficiencies, as highlighted by [42] in the context of intelligent construction management. According to [5], AI holds the potential to revolutionize building construction by facilitating machine and deep learning applications. Moreover, AI's role in refining the accuracy of construction contracts and documents further contributes to reducing disputes and elevating the overall project quality, showcasing its comprehensive impact on improving construction quality management [48].

Construction Document Management

Artificial Intelligence (AI) transforms construction document management, enhancing the speed and precision of project planning and execution. By leveraging machine learning and natural language processing (NLP), AI technologies can identify patterns, predict outcomes, and interpret complex documentation, such as contracts, with remarkable accuracy. Machine learning algorithms facilitate modeling project parameters, including scheduling, cost estimation, and resource allocation, by

analyzing vast datasets to uncover insights. Meanwhile, NLP aids in the detailed understanding and management of legal documents and specifications, ensuring clarity and reducing the potential for disputes [48].

Furthermore, AI significantly automates the documentation process, from generating reports to managing safety protocols and compliance data, making information retrieval from previous projects more efficient [4,32]. This capability supports enhanced decision-making and knowledge management, which is crucial for the dynamic environment of construction projects.

Integrating AI into construction document management is not just about automating routine tasks; it's about providing a foundation for smarter, more efficient project planning and execution. This advanced approach ensures that construction projects can be delivered with higher quality, on time, and within budget, highlighting the significant benefits of AI in modernizing the construction industry.

Construction Site Planning

Construction site layout and logistics planning are essential components and could incomparably affect the project's progress. The construction site layout planning task is dynamic, multi-objective, and uncertain as the project proceeds [50]. This planning involves strategically arranging facilities and logistic operations to ensure safety, efficiency, and cost-effectiveness, addressing the challenges of an ever-changing construction environment. Recent advancements in Artificial Intelligence (AI) have significantly contributed to optimizing these complex planning tasks. Notably, researchers like Xu and Li [50] have developed mathematical models using fuzzy random variables for multi-objective optimization, focusing on cost minimization and safety enhancement by strategically distancing high-risk and hazard-prone facilities. Similarly, Yahya and Saka [51] employed the Artificial Bee Colony algorithm to refine site layout planning, achieving robust and efficient results in real-world construction projects. Lien and Cheng's [30] integration of Bee Algorithm and Particle Swarm Optimization showcased superior performance in crane location optimization, though it faced challenges in operational cost optimization for multiple cranes [49].

Beyond site layout, AI techniques have broadened their utility in construction to encompass resource localization, material transportation, and machinery path planning, showcasing a transformative impact on construction logistics and planning [28,44,53]. The advent of intelligent construction sites, powered by IoT and cloud-based analytics, leverages AI for real-time data analysis, enhancing productivity, safety, and decision-making through comprehensive site analytics tools [31].

AI's predictive analytics and real-time monitoring, marks a new era of efficiency and innovation in construction site planning and management, promising significant strides in meeting project objectives and sustainability goals [1].

Advantages

Efficiency and Productivity Enhancements

AI significantly boosts project efficiency and productivity by automating routine tasks and optimizing project planning, scheduling, and budgeting. This automation speeds up the construction process and reduces operational costs, ensuring projects are delivered on time and within budget. By leveraging predictive analytics and historical data, AI aids in precise decision-making, minimizing delays and avoiding cost overruns, enhancing overall project efficiency [1,35,36].

Safety Improvements and Quality Assurance

Safety is paramount in construction, and AI contributes by predicting and identifying potential hazards, leading to proactive safety measures, and reducing the likelihood of accidents. Additionally, AI's ability to analyze complex datasets ensures higher accuracy in project execution. It detects discrepancies and potential issues early, facilitating timely corrections that improve the quality of construction and reduce the need for rework [13,41].

Innovation and Competitive Advantage

Adopting AI in construction project management drives innovation, offering companies a competitive edge. AI technologies enable the development of novel construction methods and the optimization of designs to meet specific client requirements, making projects more sustainable and

resource-efficient. Furthermore, AI-enhanced collaboration tools streamline stakeholder communication, ensuring project execution aligns closely with planned outcomes [26,42].

Comprehensive Project Insights

Integrating data analysis and machine learning, AI provides deep insights into every aspect of project management, from logistics and supply chain optimization to design and execution. These insights allow for more informed decision-making and strategic planning, further contributing to the project's success [42].

Challenges

Technical and Data Challenges

One of the primary hurdles is the issue of incomplete and non-standardized data. AI algorithms require vast amounts of consistent and high-quality data to function optimally. However, the construction industry often grapples with fragmented data and the absence of uniform data formats, making it challenging for AI systems to process and learn from existing project data accurately. Additionally, AI's technological limitations may not fully capture the complexities and dynamics of construction projects, potentially leading to errors or inefficiencies in project planning and execution [1].

Financial and Economic Barriers

Implementing AI in construction management involves significant upfront costs, including investment in technology, infrastructure, and training, which may be prohibitive for smaller firms. Moreover, the need for robust cybersecurity measures to protect AI systems from potential cyber-attacks adds to the financial burden, raising concerns over the security and reliability of deploying AI solutions in construction projects [9,45,48].

Workforce and Expertise Shortages

The construction industry faces a shortage of professionals who possess both AI expertise and an understanding of the sector's specific needs. This gap in skilled labor is a significant impediment to the effective implementation of AI technologies. Furthermore, workers are apprehensive about the potential for job losses due to automation, which can create resistance to adopting AI solutions [9,10].

Cultural and Organizational Obstacles

A significant cultural resistance to adopting new technologies within the construction industry, compounded by a perceived high risk of errors, hinders the integration of AI. Many construction firms lack organizational flexibility, an open mindset, and digital infrastructure to embrace AI effectively. This resistance to change can be attributed to traditional practices and the industry's late adoption of technological innovations [10,18].

Legal, Ethical, and Regulatory Concerns

The deployment of AI raises several ethical, legal, and regulatory questions, including issues related to data privacy, intellectual property rights, and the moral implications of replacing human jobs with machines. Navigating these concerns requires careful consideration and the development of appropriate legal frameworks to ensure that the use of AI aligns with societal values and norms [25,43].

Infrastructure and Environmental Constraints

The unique and varied nature of construction sites presents additional challenges. Many sites are located in remote areas with limited access to essential infrastructure such as power and internet connectivity, which are critical for the operation of AI technologies. Moreover, each construction project has specific conditions and environmental factors, requiring AI solutions to be highly adaptable and capable of quickly learning from new environments [10,18,25].

4. CONCLUSION

Based on the comprehensive analysis conducted in this research paper, it is evident that Artificial Intelligence (AI) holds immense potential to revolutionize construction project management across various domains. Through a systematic literature review and content analysis, the paper identified categories of AI applications in construction project management: construction productivity, construction safety, construction quality, construction document management, and construction site planning.

The current applications of AI in construction project management demonstrate significant advancements in enhancing efficiency, safety, and quality throughout the project lifecycle. From automating routine tasks to predictive analytics for risk management, AI technologies offer unprecedented opportunities to optimize decision-making processes and improve project outcomes.

Despite the undeniable advantages of AI integration, several challenges must be addressed to realize its full potential in the construction industry. These challenges include technical and data limitations, financial barriers, workforce shortages, cultural resistance, legal and ethical concerns, and infrastructure constraints. Overcoming these obstacles requires concerted efforts from stakeholders to invest in technology, address skill gaps, foster a culture of innovation, and develop appropriate regulatory frameworks.

In conclusion, while AI presents promising opportunities for transforming construction project management, its successful implementation requires collaboration, innovation, and a commitment to overcoming the challenges inherent in adopting new technologies. By embracing AI and leveraging its capabilities effectively, the construction industry can drive efficiency, safety, and sustainability, ultimately delivering projects that meet the evolving needs of society.

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