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AI-Driven Transformation of the Construction Industry: A State-of-the-Art Review

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Abstract:

The construction industry has been dealing with constant challenges of cost overruns, schedule delays, low productivity, and safety risks mainly due to the environmental factors of project complexity, dynamic site conditions, and high rate of uncertainty. Recent progress in artificial intelligence (AI) has opened up new opportunities for data-driven, predictive and adaptive decision making in construction management. This paper discusses a comprehensive review of applications of AI technologies, including machine learning, deep learning, computer vision and natural language processing, in the major construction management functions. The article examines how the use of AI is helping in project planning by better cost estimation and design optimization, scheduling through delay prediction and productivity forecasting, and project control through monitoring progress in real-time, risk and performance identification, and project performance evaluation. Key implementation barriers are also analyzed, including data availability and quality, lack of model transparency, integration issues with existing platforms such as Building Information Modeling (BIM) and organizational readiness. Taking a lifecycle-oriented perspective, this study shows how AI systems can help informed decision-making during planning, execution and control phases. The paper has added a value to the literature on construction engineering and construction management by providing a structured synthesis of existing applications with the identification of future research directions for the explainable, scalable, and industry-ready AI solutions.

Keywords: Construction, Application of AI, Review

1. Introduction

The construction industry is a major contributor to economic development and infrastructure provision, yet it continues to face the challenges of cost overruns, delays in timelines, safety incidents, low productivity growth and haphazard decision making. These challenges are due to the nature of construction projects as they are temporary, complex and context-dependent, comprise multiple stakeholders, site conditions are uncertain, and there are continual interactions among technical, managerial and contractual factors. As such, the processes of planning, scheduling, and control are often based on judgment based on experience, rather than being based on systematic, data-based analysis.

Persistent digitalization has brought the availability of construction data to a whole new level during the project lifecycle. Contemporary projects produce enormous amounts of heterogeneous data from various sources such as Building Information Modeling (BIM), project schedules, cost records, sensors, site images and videos, contracts and procurement documents. While these data have great potential to aid decision-making, traditional methods of analytical and rule-based approaches have trouble processing high-dimensionality, uncertain and unstructured data and are limited in producing actionable and timely insights.

Artificial intelligence (AI) is a promising data-driven paradigm that can overcome these limitations. AI methods allow to learn from past and current data, recognize complex non-linear relationships, and adjust to changing conditions of projects. Techniques such as machine learning (ML), deep learning (DL), computer vision (CV), natural language processing (NLP) and reinforcement learning (RL) have been found to have a good applicability in various construction management tasks such as cost estimation, design optimization, delay prediction, productivity analysis, automated progress tracking, safety monitoring, quality assessment and risk management. These capabilities are conducive for a shift from a reactive project management to predictive and adaptive decision-making.

Despite the expanding body of research on artificial intelligence in the context of construction, current research is fragmented. Many work on isolated tasks or single phases of a project, and others focus on the algorithmic development, without enough thinking on lifecycle integration, not considering the established management workflow and the digital platforms like BIM. In addition, adoption in the industry is still limited by barriers such as data quality and standardization problems, lack of model transparency, workforce skill gaps, and organizational resistance to change. These challenges suggest there is need for a structured and holistic synthesis of applications of AI in construction management.

Accordingly, this paper presents a review of applications of A.I. in construction planning, scheduling, and control by using the lifecycle-oriented framework. Combining synthesis of academic literature and emerging industry practices, the study classifies major AI techniques, explores applications in key management functions, assesses benefits and limitations, and identifies important research gaps. The goal is to help researchers and practitioners to create practical, explainable, and scalable artificial intelligence-based solutions for improving the performance of construction projects.

2. Review Scope and Objectives

This study adopts a structured literature review methodology to systematically analyze and synthesize existing research on AI applications in construction planning, scheduling, and control. The review framework was designed to ensure transparency, reproducibility, and comprehensive coverage of relevant academic contributions, while remaining flexible enough to capture emerging and interdisciplinary research trends within construction engineering and management, as shown in Figure 1.

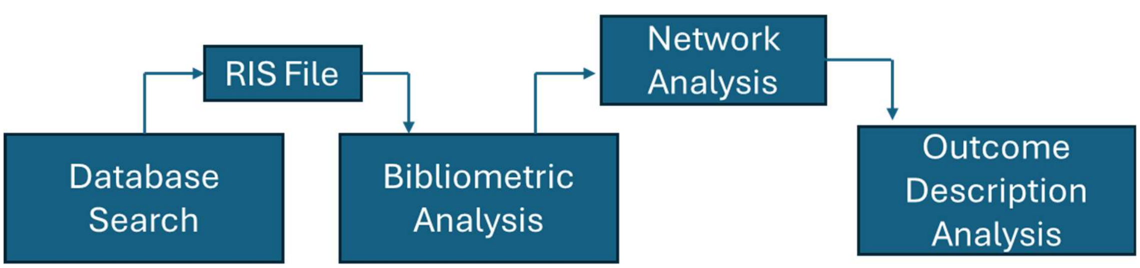

Figure 1: Research methodology adopted for the outcomes of this review paper

The primary objective of this review is to systematically identify, classify, and critically analyze existing research on the application of AI across major construction management functions. Adopting a holistic perspective, the review examines how AI techniques support decision-making throughout the construction project lifecycle. Specifically, the study analyzes AI applications across key functional domains, including project planning and design, scheduling and progress monitoring, project control and performance management, safety and quality management, procurement and contract administration, and operation and maintenance. In addition, the review critically assesses the technical, organizational, and socio-technical challenges associated with AI adoption in construction. Through this structured analysis, the study aims to provide a comprehensive understanding of the current state of AI research in construction and identify promising directions for future investigation.

The review focuses on peer-reviewed journal articles and reputable conference proceedings that explicitly apply or discuss AI-based methods in construction-related contexts. The reviewed studies span a wide range of construction management functions, including planning, scheduling, project control, safety, quality assurance, procurement, contract administration, and facility operations.

A systematic literature search was conducted using Google Scholar to ensure broad coverage of publications across construction engineering, project management, computer science, and interdisciplinary AI research. The search employed combinations of AI-related and construction-related keywords, as summarized in Table 1.

Table 1: The search Strategy adopted to write this review paper

Component	Search Expression
AI Keywords	"artificial intelligence" OR "machine learning" OR "deep learning" OR "computer vision" OR "natural language processing"
Construction Keywords	"Planning" OR "scheduling" OR "project control" OR "safety" OR "quality" OR "procurement"

To enhance completeness, backward snowballing was applied by examining reference lists of highly cited and seminal papers identified in the initial search. This process enabled the identification of additional relevant studies, including foundational and interdisciplinary works published under alternative terminology.

The publications retrieved through the database search were screened using a two-stage filtering process. In the first stage, titles and abstracts were reviewed to eliminate clearly irrelevant studies, such as those unrelated to construction or infrastructure contexts or those not involving AI-based methods. A total of 280 publications were initially retrieved.

In the second stage, full-text screening was conducted based on predefined inclusion and exclusion criteria. Studies were included if they (i) focused on construction engineering, construction management, or infrastructure projects; (ii) applied or evaluated AI-based techniques such as ML, DL, CV, or NLP; (iii) addressed one or more construction management functions (e.g., planning, scheduling, project control, safety, quality, procurement, or operations); and (iv) were published in peer-reviewed journals or reputable conference proceedings in English. Studies were excluded if they relied solely on traditional statistical or rule-based methods without AI components, or if they were editorials, opinion pieces, short abstracts, or non-peer-reviewed reports.

For each selected study, key information was systematically extracted, including publication year, application domain, AI technique employed, data sources, performance evaluation metrics, and reported outcomes. The extracted data were synthesized using thematic analysis to identify dominant research trends, commonly adopted methodologies, and recurring technical and practical challenges. This approach enabled comparative analysis of AI techniques across lifecycle stages and supported assessment of reported performance improvements, data requirements, validation practices, and implementation contexts.

3. Results and Discussion

Figure 2 shows the author's bibliographic coupling network of AI research in construction management generated by using VOSviewer. The network does show a distinctly clustered structure suggesting that the development of AI research in construction has not followed one single trajectory, but a number of themed streams. Several influential clusters are centered around influential authors reflecting established research centers concerning the developments of methodology and focus of applications.

One big cluster focuses on applications of computer vision in construction safety, progress monitoring and activities recognition, including dense interconnections and shared deep learning background. A closely related cluster is on safety management and worker behavior analysis which illustrate the interdisciplinary nature of safety research and its connection to productivity and real-time safety control. Additional clusters reflect applications of AI in planning, scheduling and performance prediction, such as cost and delay prediction, indicating quite the overlap is found with safety-oriented research. Smaller clusters on the periphery are indicative of less mature emerging applications of procurement analytics, risk management, and decision-support systems, suggesting these fields of AI research are less mature than safety and scheduling-oriented AI research.

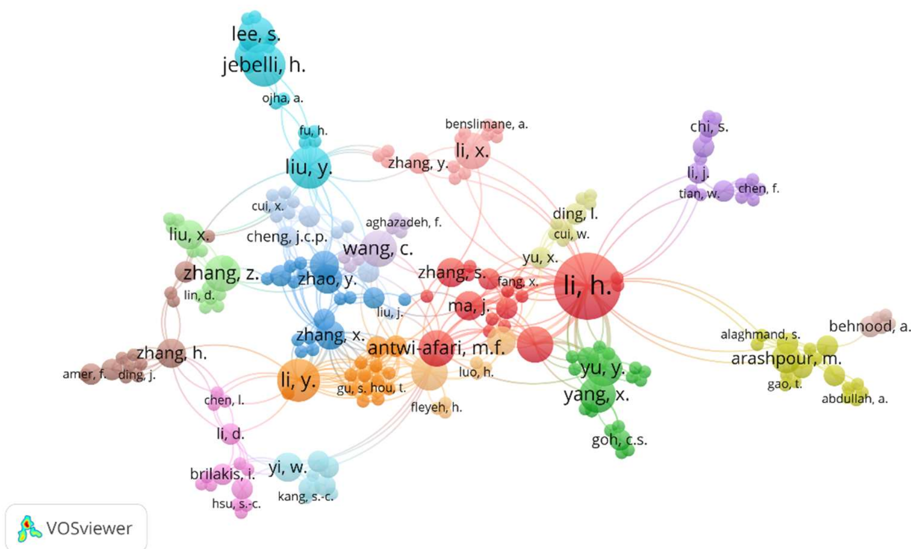

Figure 2: Author-Cocitation Network

Figure 3 is keyword co-occurrence network of AI-enabled construction management research which is produced by using VOSviewer. The network is centered around "machine learning" and "construction industry" and this confirms machine learning as the dominant AI paradigm and emphasizes the inter-disciplinary nature of AI applications in various technical, managerial, and operative spheres.

Distinct clusters represent significant areas of research such as in AI-driven planning and digital transformation (e.g. BIM, automation), predictive modeling and optimization (e.g. forecasting, neural networks, sustainability), and safety and human-oriented applications (e.g. occupational health, accident analysis). Smaller peripheral clusters point to the new AI applications in risk management and procurement which are less developed than safety, forecasting and project management research. Overall, the network reflects a transition from individual applications of EI towards integrated EI with a lifecycle approach, while uncovering unexplored possibilities in the purchase, contract risk, and post-construction phases.

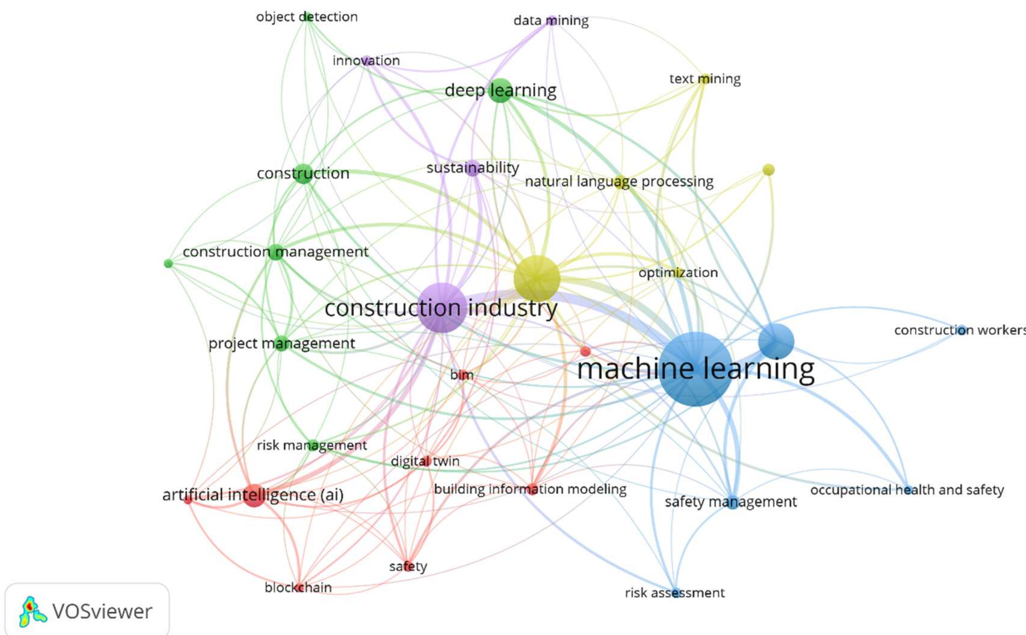

Figure 3: Keywork Network

4. Application of AI in Planning and Design

AI has been increasingly used to improve construction planning and design processes through enabling data-driven estimation, early-stage optimization and better decision-making in the face of uncertainty. Machine learning and natural language processing techniques have been demonstrated to significantly enhance the costs of conceptual and design stage cost estimation by clustering historical projects by semantic and quantitative attributes, reducing the use of subjective judgment and incomplete bid-price information at the early planning stages [[1], [2]]. Other than the cost estimation, AI-implemented analytical frameworks are supporting better planning accuracy by allowing for evaluating scenarios, forecasting resources, and competency development among the project stakeholders, demonstrating the role of AI in bolstering the preconstruction and design coordination processes [1]. Recent researches have gone further to show that the integration of AI and Building Information Modeling (BIM) has a significant impact on the development of design workflows, which can be automated by matching building elements with environmental and performance data sets, and thus a building's sustainability impacts can be evaluated earlier during the design phase, when decision flexibility is at its peak [2]). Such BIM-enabled AI tools use to address the longstanding challenges relating to the interoperability of data, manual handling of data, and the final stage evaluation of sustainability. Complementary research concentrates on the fact that adoption of AI in planning and design is not technical but deeply socio-technical and human factors such as perceived usefulness and digital competences as well as organizational readiness determine effective adoption of AI [3]. There is also empirical evidence suggesting that planning-related competencies are affected in different ways depending on how much experience an individual has with AI-driven digital transformation, in order to promote responsible AI use in design decision-making, which requires the design of specific training and governance schemes for this purpose [4]. In addition, emerging planning-oriented AI research underscores the increasing importance of integrating AI with much broader forms of digital ecosystems (such as those enabled by blockchain - i.e., procurement; and by IoT - i.e., informed planning; and sustainability-oriented decision frameworks - i.e. to support more resilient and transparent project planning).

5. Application of AI in Construction Scheduling

The introduction of AI in construction scheduling has attracted much attention at academic level due to the need for more sophisticated project management methodology [5]. This technological development provides huge potential for automizing complex processes and complementing the ability to make decisions in the construction sector [6]. Specifically, as AI applications such as neural networks transform the method of budget forecasting by moving away from the old heuristic methods, it can make your cost management more accurate. Specifically, budget forecasting applications like neural networks have set the standard of budget forecasting by changing the method that has been followed by substituting over the old heuristic approach. Furthermore, machine learning algorithms and predictive analytics are becoming more common to improve scheduling accuracy, reduce delays, and optimize overall effectiveness in construction projects [7]. These AI-driven models are part of the proactive risk mitigation and dynamic resource allocation, in adapting to inherent variability of the construction environment [7]. The use of AI in scheduling of construction also provides a boost for stakeholder collaboration in construction, reduces human error, and ultimately enhances project success [7]. Despite these advancements, the implementation of AI in the construction sector is currently an emerging area and the adoption practices are fragmented and ongoing research is under [1]. Typically, the traditional approaches to scheduling in the construction activities involve the creation, monitoring, and updating of the schedule and activities are primarily manual forms and time-consuming, which are detached from the real-time field work, which is why there is a need for integrated approaches in the field [6]. Research shows that AI applications are especially common in the early phases of design and implementation, with AI techniques like genetic algorithms, deep learning neural network and reinforcement learning being employed to optimize and aid decision-making based on collected data [1]. For example, neural networks can be used to predict the outcome of a project with high accuracy, while genetic algorithms can be used to optimize the project schedules to minimize the duration or cost [8].

6. Application of AI in Safety Management

Recent research has shown that AI has become a central enabler of proactive and data-driven safety management in construction; moving safety practices from reaction (inspection) to continuous monitoring and predictive intervention. Deep learning-based computer vision methods, especially object detection algorithms from the YOLO-family, have found broad use in the automated detection of unsafe conditions including missing personal protective equipment, worker falls, and dangerous interactions between workers and machinery with both real-time performance and complex site conditions [9], [10]. Beyond isolated detection of hazards, complete artificial AI systems safe now give perception, event logging, alerting and platform interoperability which allow deployable occupational health and safety (OHS) solutions even for small and mainstream contractors limited in computing resources [9]. Machine learning also has been applied to the modeling of worker's level risk heterogeneity, with probabilistic and clustering methods being used to identify age-based and behavior-based risk groups which were used to justify targeted safety interventions and policy design [11]. Advances in temporal recognition of vision and action, lead to further improvements in safety, by image recognition and capturing dynamic behavior of machinery and worker--equipment interactions that is not detected in static image analysis, making the analysis more robust in cluttered and occluded environments [10] AI enabled robotics and human-robots interaction models provide an additional level of safety, tackling trust calibration and unsafe behavior from autonomous or semi-autonomous construction robots, pointing out as the socio-technical nature of AI driven safety systems [14].

7. Application of AI in Procurement, Contracts, and Risk Management

AI has been slowly revolutionizing the construction procurement field thanks to its capabilities of data-driven assessment of bids, contractor competitiveness, contractual risks and decision transparency at the tendering and award stage. Early AI-enabled procurement systems were aimed at eliminating subjectivity in best value selection by creating an architecture for formalizing performance information and minimizing human bias in contractor evaluation and resulted in measured increases in cost, schedule, and quality results in public-sector projects [12]. Building on this foundation, there is a recent series of studies using advanced machine learning techniques, network theory, and pattern mining techniques to understand more complex competitive dynamics that are not reflected by traditional metrics such as the number of bidders. Network-based models will make use of historical winning and losing records in order to measure the competitiveness of individual bidders and infer about the nature of the market more precisely during the letting phase, to support the decision of owners towards the acceptance, rejection, or re-letting of a bid [13], [14]. Complementary research uses data mining and pattern recognition to identify abnormal or collusive bidding behaviours in low-bid procurement, to provide early warnings of red-flag patterns which may be indicative of bid rotation or market manipulation [15]. In parallel, natural language processing (NLP) techniques have been applied more and more broadly to documents relevant to procurement processes, such as contracts, schedules or the texts of tenders, aiming to cluster semantically similar items, standardise the text of unstructured information and facilitate downstream analytics for procurement risk assessment and decision support [16]. AI based contract analytics can provide further reinforcement to procurement activities by automating the process of identifying and classifying of risky contractual clauses at the tender stage, thereby enabling the contractor and the owner to better account for legal and financial exposure before submission of the bid [17]. From a governance perspective and dispute avoidance perspective, AI models with both machine learning and interpretable models (for example, fuzzy logic) have been demonstrated to be reasonable in predicting litigation outcomes in construction contract dispute, which highlights the possibility of AI in helping with procurement practices that reduce conflict after post-award dispute [18] are adaptive.

8. Conclusion

This review shows that artificial intelligence is significantly transforming construction management by allowing predictive and data-driven and adaptive decision-making processes related to planning, scheduling, control, safety, and procurement processes. The synthesis shows that though the AI applications, especially the machine learning ones, used in safety monitoring, forecasting, and project management, have been developed to a reasonably mature stage, other areas like procurement analytics, contractual risk management, and the post-construction operations remain poorly explored. Bibliometric and keyword network analyses further show a definite trend from isolated technical applications towards integrated decision support systems for the whole life cycle. However, there remains a constraint of widespread industry adoption due to data quality, interoperability, model transparency, and organization readiness. Addressing these limitations will require future research to take a more emphasize into explainable and scalable AI models, more a tight integration with digital platform like BIM and digital twins and governance frameworks which can support a responsible deployment of AI which is human centered. Collectively, these efforts are needed to bridge efforts between AI research and research-based industry-ready and practical solutions that can enhance the performance and resilience of construction projects.

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