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Research Article

Contribution of artificial intelligence (AI) to construction project management processes: State of the art with scoping review method

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ABSTRACT

The Artificial Intelligence (AI) is being considered as a new way to tackle the challenges frequently faced by the Architecture, Engineering and Construction (AEC) industry in terms of its ability to leverage advanced technologies, data analysis techniques, and automation to address specific challenges and improve efficiency, productivity, safety, decision-making, and overall project outcomes. Thus, it is imperative to know the future of AI in construction project management processes. With this background, this study aims to detect application areas of AI in construction project management processes by using scoping review method and create a base for the development of theories that can support future studies. According to the findings of studies, application areas of AI in project management domain are generally clustered under eight main topics: cost, time, quality, contract, dispute, risk, safety, and sustainability. In line with the findings, this study contributes in two-folds. As the theoretical contribution researchers can benefit from this study, which addresses the research trends and current applications of this ground-breaking technology in project management processes, by mapping the current interest in AI studies. The future studies can be directed in line with identified gaps and justifications. As the practical contributions, construction companies that want to be the early movers can benefit from the findings of this study as they reveal crucial areas where they can focus their investment on areas where AI can make the most significant difference to address their company's specific requirements.

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INTRODUCTION

Construction 4.0 that involves the use of new technologies [1], has changed the collaborative communication in AEC industry by enabling real-time communication. For example, Wang et al. noted that the adoption and use of new technologies have led to reduced revisions [2], more accurate decisions, and improved quality of work. Beier et al. highlighted the production of systems that facilitate

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real-time communication among company personnel using Internet connections [3]. At this point, as a component of Construction 4.0, Artificial intelligence (AI) has also emerged as a new solution to tackle common challenges faced by the industry [4, 5] such as design problems, delays, and contract disputes. Project management processes and approaches will also change as AI applications become widespread [6]. Considering the possible contributions that AI promises for more efficient project management, practitioners need to better understand the potential benefits of AI in construction project management processes.

Within this background, this study aims to investigate existing practices and acquire basic information on artificial intelligence in the construction industry to better understand the relationship between the two. In line with this aim, this study reveals the potentials of using AI in the AEC industry through a scoping review, identifies the application areas of AI in construction project management processes, and provides preliminary information for future studies.

In literature, many authors have conducted literature reviews to determine the future potential of AI [7-11]. For example, Pan and Zhang conducted a bibliometric review to explore the use of AI in modeling, predicting, and optimizing problems throughout the lifecycle of construction projects [9]. This study covers all processes of construction projects from a broader perspective. In a different research endeavor examining the application of artificial neural networks in the field of construction management, Xu and colleagues offered a comprehensive overview and categorized the research articles based on different criteria [12]. Although these studies seem to have overlaps in classification, this study differentiates from prior studies within its scope since it scans all the methods of artificial intelligence, addresses both the positive and negative results of these technologies, and provides a guide to the potential of future studies based on this information, as well as scanning the latest literature on the subject in a holistic way. Contrast to existing literature reviews on AI use in project management domain, this study aims to detect application areas of AI in construction project management processes by using scoping review method and create a base for the development of theories that can support future studies.

In line with the scope of the study, after the introduction section, section 2 presents the importance of using artificial intelligence (AI) in project management. In section 3, the methodology of the study and its steps are then elaborated upon. In this section, research questions and the boundaries of the publications are determined. General information obtained from the scoping review is processed. Findings derived from scoping review analysis are addressed in Section 4. This section consists of the presentation of key application areas of AI in construction project management, research trends and identified gaps and justifications based on the scoping review findings. Finally, Section 5 concludes the study by stating practical and theoretical implications, and Limitations and Directions for Future Research for further studies.

Importance of Artificial Intelligence (AI) Use in Project Management

The history of AI dates to 1950, when the British mathematician Alan Turing posed the question of whether machines could think. After experiencing ups and downs over the course of 60 years, AI has regained technological importance due to rapid developments in computing, big data, artificial neural networks, deep learning, and other new technologies [13, 14]. AI is a computer system that perceives visual perception, recognizes speech, and can translate between languages. It is used to solve complex decision-making processes that cannot be solved directly with mathematics by understanding project information and the project environment [15]. Machine learning is a subset of AI, using algorithms and statistical models to learn from data and make decisions [16, 17]. With the advancements in machine learning and big data technologies, AI has become a major technological opportunity in the world. The potential of this technological advancement also triggers the need for AI use in AEC industry. On a limited scope, the need for AI use in construction arises from the desire to improve cost management, enhance quality control, increase efficiency and productivity, and address complex issues in project management. The potential areas that AEC industry can benefit from AI use explained in detail in below:

- Empowering project managers in decision-making processes by leveraging data processing and utilization: In AEC industry, as the construction projects become more complex and large-scaled, the number of participants and the volumes of construction data including project plans, schedules, and performance metrics start to increase. In this regard, AI stands out as one of the digital technologies with significant potential to leverage the vast amount of available big data for problem-solving and enhancing decision-making within the field of construction management [18-20]. By applying machine learning algorithms, AI can identify patterns, trends, and insights that can inform decision-making, optimize resource allocation, and improve project outcomes. As it can be seen, artificial intelligence has the capability to offer continuous real-time monitoring and analysis of construction operations, enabling project managers to make well-informed decisions promptly based on data. This improves not only project control, reduces risks, and enhances overall project performance but also prevents poor decision-making through the project management processes.
- Increasing productivity and efficiency: Considering that AEC industry is already criticized because of efficiency and productivity issues [21], incompetency in data analytics might imbricate these efficiency and productivity issues. AI technology can improve work

efficiency and standards by changing the required human resources for construction-related jobs [14]. AI can automate repetitive and time-consuming tasks, such as data entry, document management, and project scheduling. This allows construction professionals to focus on more complex and value-added activities and result as increase in overall efficiency and productivity. AI can also enable the use of autonomous equipment and robotics in construction, reducing the need for manual labor in repetitive or dangerous tasks. This can lead to increased productivity along with improved safety, and cost savings.

- Sustaining project success: The use of AI in AEC industry also has a vast number of potentials in sustaining project success. Project success is mainly defined by the project management triangle, consisting of time, cost, and quality pillars [22]. Planning a project is one of the most important processes in project management, but the importance of planning software needs to be investigated [23]. Construction cost control is crucial, as delays in any stage of the project can cause cost overruns due to increased workmanship, working time, or material usage [24]. AI has the potential to forecast cost overruns by considering project scale, contract type, and the competence of the project manager [25]. AI can also support investment decisions by accurately estimating the cost of construction projects, which can help reduce project implementation costs [26]. Predictive models that utilize historical data, such as planned start and end dates, can be used to create realistic timelines for future construction projects [22]. By implementing AI in construction scheduling, managers can monitor schedules more efficiently by estimating the completion and delay times of construction projects [27]. AI can be applied in real-time, enabling project managers to swiftly and knowledgeably decide how to allocate resources as the project unfolds [28]. This can help prevent project delays and lead to more realistic timelines for future projects. Furthermore, AI can provide a clear and realistic view of construction site activities to top-level management and engineers, which can lead to improvements in construction efficiency and quality [14]. AI can also analyze data from various sources, such as sensors and cameras, to monitor construction quality in real-time. It can identify defects, deviations from specifications, and potential issues, enabling early intervention and improving overall quality control.
- Anticipating occupational accidents and equipment-related safety issues: Safety represents a paramount and indispensable aspect of the construction industry. AI can be used to anticipate occupational accidents and equipment-related safety issues that may arise during construction projects [25]. AI-powered technologies (such as drones, robots, and wearable technologies) can be used for site inspections, monitoring hazardous areas, identifying potential safety risks, and monitoring workers' behavior. AI algorithms can analyze real-time data on-site from sensors to detect unsafe conditions, helping to prevent accidents and improve safety on construction sites [20]. Additionally, pattern recognition-based AI technologies are being used for data and system integration for enhancing safety management. When paired with virtual reality, these technologies become even more potent as they assure real-time personnel safety.
- Providing insights for project managers to quickly prioritize potential risks and identify proactive actions: As the main field of construction management, AI can monitor, recognize, evaluate, and predict potential risks in terms of safety, quality, efficiency, and cost across teams and work areas even under high uncertainty [29, 30]. AI-based risk analysis can provide insights to help project managers quickly prioritize potential risks and identify proactive actions rather than risk mitigation responses [9]. Machine learning and natural language processing are being applied in construction for risk detection and assessment to issue early warnings [20]. Consequently, AI is expected to play a significant role for project managers in risk assessment, generating decision support, automation of risk monitoring, and simulation and scenario analysis. Additionally, AI technologies, such as Building Information Modeling (BIM) and virtual reality allow for better visualization, clash detection, and coordination among different disciplines, reducing errors and rework during construction.

In brief, the novelty of AI systems in the construction industry lies in their ability to leverage advanced technologies, data analysis techniques, and automation to address specific challenges and improve efficiency, productivity, safety, decision-making, and overall project outcomes. AI systems bring new capabilities, insights, and efficiencies to the construction industry, enabling practitioners to leverage data-driven intelligence for better project execution. By embracing AI technologies, the AEC industry can drive innovation, increase productivity, supports decision-makings arise from complex project management challenges, and achieve better project outcomes.

Along with these contributions that artificial intelligence will provide to project management, there has been a notable rise in research on the application of artificial intelligence in the construction industry. It is evident from the literature that the use of AI techniques in the construction industry has become a trending topic. The researchers also discussed many different AI methods for construction project management. The practical implementation of AI applications has led to positive outcomes in project management processes, indicating that the technology will continue to evolve. As the amount of data in the construction industry grows, the use of AI is expected to become more prevalent, given its reliance on data processing and utilization.

Consequently, AI is expected to play a significant role in the industry's future.

Research methodology

The use of AI in the industry has vast potentials. Thus, it is imperative to know the future of artificial intelligence in construction project management processes. With this background, this study aims to identify research trends in this area while determining the role of artificial intelligence in the construction industry. In line with this aim, the scoping review method was adopted.

Literature review methods encompass a range of tools available to researchers, and there isn't a single universally "perfect" type of literature review. Scoping is one type of literature review method. However, there are some differences with a systematic literature review. While a systematic literature review focuses on well-designed questions, there is no need to specify a clear question, as the different topics covered in scoping studies will create broader issues. A systematic literature review provides clear answers and seeks answers to specific research questions. For this reason, answers to questions are sought rather than evaluating the included studies [31]. At this point, it should be noted that the scoping review technique differs from the systematic review technique. Scoping reviews provide a broad view of the evidence on issues. In this way, emerging areas are examined, and basic concepts are explained. It also enables the identification of gaps in the literature [32]. Since scoping studies do not provide detailed information about the method of analysis consistent with their own logic, there is not enough information about the way scoping studies are conducted [33]. The reliability of the findings has increased as the study contains details that can be replicated by someone else and refutes the judgment that the study lacks methodological rigor since it did not perform a "systematic" review [34].

When utilizing the scoping review method, it's essential to follow a series of stages, including determining the research question, identifying relevant studies, selecting the studies, creating data visualizations, and summarizing and reporting the results in a concise manner respectively [31]. On the other hand, literature searches are accelerated by keyword searches created by research questions [7]. The research questions of this study are expressed in the next section.

Determining the Research Questions

The research questions addressed by this study are as follows:

- What are the key application areas of AI in construction project management?
- What are the research trends in AI technology usage in the AEC industry?
- What are the literature gaps and justifications related to AI use in AEC industry?
- What are the potential future applications of AI use in the AEC industry?

Identification of Related Studies

The selections are limited to studies between 2012 and 2023 in terms of containing the current literature. Databases used for searching are the American Society of Civil Engineers (ASCE), IEEE Xplore Digital Library, Web of Science (WOS), and Scopus. The keywords used for searches are "deep learning" "machine learning" or "artificial intelligence" and "construction management". Since most of the literature in the selected databases is in English, searches were also made with English keywords.

Selection of Studies

The inclusion or exclusion criteria of the studies were carried out to determine the effects of machine learning from artificial intelligence applications on construction projects were selected in relation to the nature and quality of the studies. Since the subject of artificial intelligence is based on a technological development that has been focused on in recent years, the time frame has been limited to between 2012 and 2023 to keep up with current studies. Older studies were excluded, assuming that before these dates the subject was studied with old, incomplete, or insufficient equipment.

It is envisaged that the latest developments in the literature, including the subject, will be discussed with a selection of current studies. The exclusion criteria are limited to excluding other studies that are not closely related to the subject in question. Since machine learning is known to serve interdisciplinary issues, the studies discussed were directly or indirectly related to the architecture, engineering, and construction industries. Studies that do not meet these conditions are excluded. Figure 1 shows the literature search strategy.

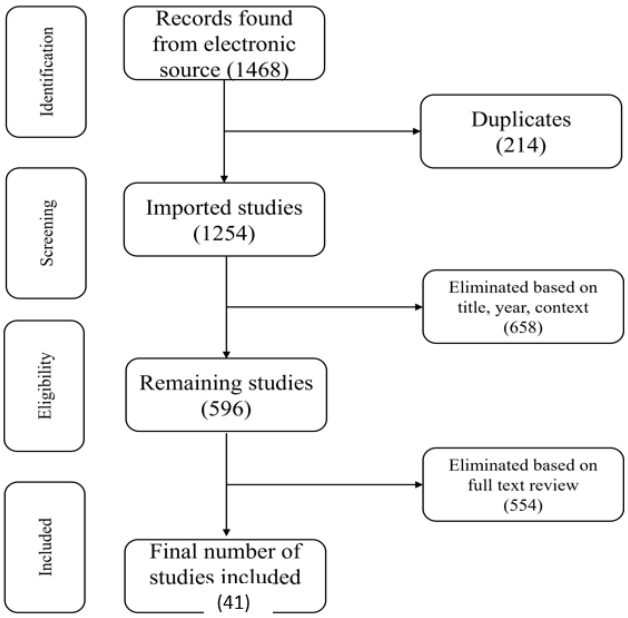

Figure 1. Literature search strategy.

Graphing the Data

In this section, a total number of 41 studies obtained through literature review were analyzed. "Table A1. Summary findings of selected articles" in "Appendix" presents the 41 studies with their key findings whereas "Table A2" in "Appendix" presents the classified application areas of artificial intelligence technologies in reviewed articles.

Compilation of Results

According to the findings of studies, application areas of artificial intelligence technologies in project management processes are classified under eight main topics: cost management, time management, quality management, safety management, risk management, contract management, dispute management, and sustainability. The compilation of results shows that the majority of the studies deal with the subject of "time management" (a total number of 18 studies out of 41), whereas "cost management" comes in second place with 16 studies. The least directly addressed issue was "sustainability," with a total number of 3 studies.

Evaluation of Findings

In line with the aim of detecting application areas of AI and creating a base for future studies on AI applications in construction project management processes, results gathered from the scoping review method were presented in three main sections: "Key application areas of AI in construction project management", "Research trends", and "Identified gaps and justifications".

Key Application Areas of AI in Construction Project Management

Detailed evaluations regarding the eight main application areas of AI technologies on construction project management processes can be found below:

i) AI use in cost management

Artificial intelligence helps many researchers make the necessary decisions for the control of budget overruns in construction projects considering controlling project expenses is important in cost management [35]. The use of artificial intelligence reduces costs by providing savings, so it can be argued that the integration of artificial intelligence is beneficial to project construction processes. For example, computer vision [36], reducing chaos is possible [29]. The reviewed literature shows that the success of AI-powered tools in determining cost trends is clear. In this way, benefits such as joint budget tracking, resource optimization, and quality control can be achieved in projects. When the studies on the application of AI to the efficiency of cost management were examined, Boosting and Adaptive Boosting (AdaBoost), Extreme Gradient Boosting (XGBoost), Stochastic Gradient Boosting and Decision-making systems are amongst the most preferred AI tools for the development of cost estimation models in construction.

ii) AI use in time management

Since time management is one of the three main pillars of project success [37, 38], the importance of providing time management based on artificial intelligence applications is increasing. Project managers' work can be facilitated by estimating potential delays in projects by making predictive scheduling with the algorithms to be developed. The allocation process of resources can be managed, and automatic progress can be tracked. For example, pre-construction projects should contain reliable projections of project duration [39]. The problems created by the data collection method used in traditional methods consisting of grueling actions such as field visits are facilitated through systems established with analytical platforms [40, 41]. For example, with systems using GPUs, computations are improved, and the adoption of new technologies is increased [42]. On the other hand, the problem of reducing competitiveness is caused by the unpredictability of the project duration at the tender stage, disagreements between the contractors and the property owners [43], the length of the problem-solving period of the projects, and the length of the time required for data processing [44]. When the studies on the application of AI to the efficiency of resource allocation, and planning were examined, the following AI tools come to forefront: Machine Learning algorithms, and Convolutional Neural Network (CNN) for planning and scheduling of construction projects, Artificial Neural Networks (ANN) for estimating durations and for establishing a link between logistic resources allocated to a construction project and program success, Discrete-event simulation (DES) for improving foresight method in the optimization of planning and scheduling.

iii) AI use in quality management

The use of AI is a promising tool for quality management in AEC industry. Because what is desired in quality management is quality management systems that document and monitor quality information [45]. However, experts have associated the lack of adoption of new technologies in the construction industry with poor quality performance [46]. Within this perspective, studies reveal that AI can be a helpful tool in identifying potential quality problems in projects [18], providing effective data management [47], automating scheduling in project processes [48, 49], making quality and efficiency calculations in projects [7], improving the skills and expertise of project stakeholders [9], obtaining fast and accurate results by automating tasks, increasing quality and productivity [49, 50], and obtaining the necessary information to meet the quality and safety objectives of projects with object detection [51]. AI can also be used to improve construction project delivery quality by integrating technologies such as BIM and 4D CAD [52].

iv) AI use in contract management

The rights of construction stakeholders and the determination of these rights depend on the contracting stages

of the projects. For this reason, processes are facilitated with a platform where contract management can be facilitated [53]. There are researchers who have developed this and similar platforms in the literature. Choi et al. have developed an artificial intelligence algorithm module that performs automatic risk extraction to identify risk items and detect and manage risky statements while preparing construction contract documents [54]. Authors used AI and text mining to develop a risk analysis tool for analyzing contractor's risk in invitation to bid in EPC projects.

v) AI use in dispute management

Conflicts in construction projects affect the quality of construction and the interests of the parties [53]. Various technologies supported by artificial intelligence have been used to prevent these problems. For example, Chou et al. used artificial intelligence technology for the early detection of conflicts in public-private partnerships and proposed a model that provides a warning by detecting possible conflicts [55]. An efficient model has been developed using Fast messy generic algorithm (FPGA)-based SVM for the estimation of possible conflicts in public-private partnership projects. According to the study of Gao and Sun, conflicts in construction projects arise from different understandings of the rights and obligations of the project parties in the process [53]. Weak legal awareness of the parties, unclear rights and responsibilities in the contract, uncertain terms, and even the absence of the contract in some cases create various project conflicts. The artificial intelligence-supported platform they have developed takes part in the resolution of disputes as a "fourth party" in the resolution of contractual disputes in construction processes [53].

vi) AI use in risk management (uncertainty/forecast)

Construction project stakeholders face many risks due to contracts [18]. Studies in the literature show that these risks can be managed with a digital risk analysis tool based on artificial intelligence and data mining [54]. Construction cost estimation, building energy system behavior estimation, short-term building cooling load estimation, building design energy estimation, compressive strength and crack estimation of recycled concrete, long-term electrical and heating load estimation, and heavy equipment parameters estimation can be made with artificial intelligence [5]. Artificial intelligence applications can be used to prevent risks by prioritizing risks at the project site, which helps the project team focus their resources on the biggest risk factors. Prevention of conflicts between stakeholders by identifying them before the project and estimations of the resolution of these conflicts in cases where there are disagreements can be realized by machine learning methods. When the studies on the application of AI to the efficiency of risk management were examined, the following AI tools come to forefront: machine learning algorithms capturing complexity-risk interdependencies, CBR to evaluate the cyclical risk management of construction projects that have inherent risks, decision tree and Naïve Bayesian classifiers for facilitating accurate project delay risk analysis and estimation.

vii) AI use in safety management

Construction safety is a necessity in terms of people and money. Artificial intelligence techniques provide a safer environment by removing construction personnel from dangerous and poorly constructed environments [56]. Worker deaths and injuries caused by inadequate safety measures in construction processes can be resolved with the new occupational safety system, an online monitoring technology based on the approach of detecting the falling probability of workers working in high-rise buildings [57]. With artificial intelligence, the detection of the security guard, the detection of the protective equipment of the worker, and the postural evaluation of the employees can be done [5]. Liu et al. reviewed articles using computer vision technologies to ensure construction safety and supported the use of this integration [51]. Reviewed papers using computer vision technologies to ensure construction safety generally focus on the implementation of AI tools such as machine learning algorithms, CNN, SVM, ANN, k-Nearest Neighbors (k-NN), Regions with Convolutional Neural Network (R-CNN) and Region-based fully Convolutional network (R-FCN) to support the use of AI in this application area.

viii) AI use in sustainability

To prevent the damage caused by construction waste to the environment, artificial intelligence applications that helps post-construction waste management by determining the technique to be applied to construction waste can be used [58]. But the number of studies in which artificial intelligence has been applied in construction waste management has been found to be limited. This may be because AI focuses more on off-site applications of project management processes and deals with contracting processes. On the other hand, sustainability is not just about waste management. Ending a process with less expense, less time and more effectiveness than before also contributes to sustainability. In addition, thanks to the integration of artificial intelligence applications into projects, reducing the number of employees and the use of labor and carbon consumption will also support sustainability. In this respect, almost all AI use cases indirectly support sustainability. The exception here is that the high-capacity computers and power usage required by AI will be viewed negatively in terms of sustainability alongside all their technological and economic benefits.

Research Trends

While there is evidence of resistance to technological innovations in the AEC industry, the benefits of digitalization should also be acknowledged. Current studies indicate the need for further work on key plans that will facilitate the adoption of technology and address sustainability

and quality management aspects in project management. Additionally, evaluations of the applications of artificial intelligence technologies in construction project management processes suggest that research trends will increasingly embrace the use of AI. Furthermore, despite extensive research on cost and time management, ongoing efforts are being made to explore these processes using advanced machine learning methods.

The researchers discussed many different AI methods for construction project management. Researchers have discussed proposals for the use of artificial intelligence for construction project management using many AI tools such as Artificial Neural Networks (ANN), Deep Neural Network (DNN), Convolutional Neural Network (CNN), and Recurrent Neural Network (RNN). One commonly used artificial intelligence technique in the context of construction project management is supervised learning, which is a machine learning method. In supervised learning, the classes of data used for training the AI are predetermined. Examples of this method include KNN, SVM, ANN, DT, and NB. Another machine learning method is deep learning, which has gained prominence with the advancement of technology and the utilization of powerful machines. In the field of construction project management, the use of deep learning is observed through methods such as CNN and RNN. The selection of these methods is aimed at continuously updating the systems and considering past information to achieve better evaluation and results.

Identified Gaps and Justifications

The AEC industry is considered as an industry that resists the acceptance of technological innovations. Although the studies examined re-expressed the existence of this resistance and listed the benefits of digitalization to the sector, the amount of work on key plans that will ensure the adoption of technology is limited. On the other hand, the fact that most of the work focuses on cost and time management can show that the most important issue in construction work is time and financial income. However, when the project management triangle (time, cost, and quality) is considered, it is seen that the quality features of the projects are also very important. For this reason, it is expected to increase the number of studies on the use of artificial intelligence applications in quality improvement initiatives related to construction project management.

In general, it is seen that the *use* of "dataset", which artificial intelligence technology requires by its nature, is rare. Datasets are difficult to obtain, especially in construction project management, because project stakeholders tend to keep their information confidential. However, when the project stakeholders do not provide a data set for researchers, studies on the transition to the digitalization process will not be developed. For this reason, it is necessary to increase the amount of publicly available datasets that will enable the use of artificial intelligence in the construction industry.

Furthermore, decisions made in the AEC industry are related to experience gained based on past experiences. However, artificial intelligence applications used today cannot cope with the accumulation of knowledge based on human experience [57]. Thus, more attention should be put based on AI use in a broader range of project management contexts especially by using specific case studies and historical data with real-world scenarios.

CONCLUSION

This study was conducted to identify AI application areas in the project management process. A scoping review method was adopted to analyze 41 papers published between 2012 and 2023, which were classified under eight main application areas: cost management, time management, quality management, contract management, dispute management, risk management, safety management, and sustainability. The findings indicated that there are limited studies on quality management compared to time and cost management in terms of project success triangle. It is notable that "sustainability" and "dispute management" are the least researched areas of artificial intelligence applications in project management.

Implications For Researchers

The study presents how AI's role in construction has been addressed by researchers and highlights the research trends by showing ongoing efforts in using advanced machine learning methods. Within this respect, this study that addresses the research trends and current applications of ground-breaking technology in project management processes provides theoretical contribution researchers by mapping the current interest related to artificial intelligence studies.

Implications for Construction Industry

Construction practitioners should identify their company's pain points and areas where AI can have the most significant impact. Once pain points are identified, practitioners should explore available AI solutions that address those specific needs. There are numerous AI technologies and tools tailored for the construction industry, including project management software, predictive analytics, computer vision, natural language processing, and robotic automation. Evaluating and selecting the right AI solutions is crucial for successful implementation. The findings of this study might shed light to crucial areas where they can prioritize their investment where AI can have the most impact on their company's unique needs.

Additionally, AI is a rapidly evolving field, and practitioners should stay updated on the latest advancements and innovations. Another contribution of this study for practitioners is enabling practitioners updated on AI advancements by reveal important insights on AI use in project management processes.

Limitations and Directions for Future Studies

While this study presents potential benefits of AI use into project management domain and the state-of-the-art of AI-based studies with scoping review method, it is essential to recognize its limitations. Since this study is a review paper, it has the limitations based on the selection of studies within scoping review. Since machine learning is known to serve interdisciplinary issues, the studies that were not directly or indirectly related to the architecture, engineering, and construction industries were excluded. Another limitation involves language selection. The studies that were subject to our analysis were selected only from the studies in English.

According to the results obtained from the findings, the usage areas of artificial intelligence in project management are increasing day by day in academic terms. However, a limited study on AI use in sustainability and dispute management were detected. Thus, this study recommends further emphasis on sustainability and dispute management, as these areas have been covered by relatively few publications. Future research can focus on exploring the use of AI in dispute management and addressing sustainability issues in construction project management.

On the other hand, traditionalism and not following technological developments, which are two of the dominant features of the AEC industry, prevent the use of artificial intelligence tools in the field of project management in the sector. In addition, the number of samples to be studied by researchers who want to conduct research on this subject is limited. Therefore, future studies can focus on developing key plans that facilitate the adoption of AI technologies in the construction industry. These plans can address the challenges and resistance to technological innovations, promoting the integration of AI tools in project management processes. Additionally, for facilitating the use of AI in the construction industry, future efforts should focus on increasing the availability of publicly accessible datasets. This will enable researchers to develop and test AI algorithms and models for construction project management.

In brief, future research should aim exploring AI use sustainability and dispute management domains, overcoming resistance to technology adoption, and expanding the availability of datasets for AI applications in construction project management.

NOMENCLATURE

AdaBoost	Adaptive Boosting
AEC	Architecture, Engineering, and Construction
AI	Artificial Intelligence
ANN	Artificial Neural Networks
ASCE	The American Society of Civil Engineers
CBR	Case-Based Reasoning
CNN	Convolutional Neural Network
DNN	Deep Neural Network
DT	Decision Tree
EPC	Engineering, Procurement and Construction
FPGA	Fast Messy Generic Algorithm
IEEE	The Institute of Electrical and Electronics Engineers
WOS	Web of Science
KNN	K-Nearest Neighbors
NB	Naive Bayes
R-CNN	Regions with Convolutional Neural Network
R-FCN	Region-based Fully Convolutional Network
RNN	Recurrent Neural Network
SVM	Support Vector Machines
XGBoost	Extreme Gradient Boosting

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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Table A1. Summary findings of selected articles

Paper ID	Title of the Study	Author(s)	Key Findings	AI Tool(s) Mentioned in the study
2	Research on system construction and application of Enterprise intelligent finance from the perspective of Artificial intelligence.	Wang et al. [3]	Digital technologies that can be used in the construction industry are discussed.	· Decision-making system in general
4	Deep learning in the construction industry: A review of present status and future innovations	Akinosho et al. [4]	It explores the solutions that image processing, computer vision, deep learning and natural language processing techniques find to challenges in the production industry. Deep learning is not an automatic algorithm, so as with any other machine learning technique, many procedures need to be processed for best results.	· Deep neural network (DNN) · Convolutional neural network (CNN) · Recurrent neural network (RNN) · Auto-encoder (AE) · Restricted Boltzmann machine (RBM) · Deep Belief Network (DBN) · Generative Adversarial Networks (GAN)
7	Bibliometric Review of Artificial Intelligence (AI) in Construction Engineering and Management	Xiao et al. [7]	It analyzes current trends in the application of artificial intelligence in construction and selected literature research areas in the field of construction.	· Decision-making system in general
8	Using Deep Learning Artificial Intelligence to Improve Foresight Method in the Optimization of Planning and Scheduling of Construction Processes	Hatami et al. [8]	It is recommended to plan complex construction projects with deep learning and artificial intelligence methods.	· Discrete-event simulation (DES)
9	Roles of artificial intelligence in construction engineering and management: A critical review and future trends	Pan and Zhang [9]	With a bibliometric review, the use of artificial intelligence to solve the problems in the entire life cycle of construction projects has been examined.	· D-S evident theory · Ensemble model · Support Vector Machine (SVM) · Artificial Neural Network (ANN) · Reinforcement learning
10	Digital Technology in Architecture, Engineering, and Construction (AEC) Industry: Research Trends and Practical Status toward Construction 4. 0	Wang et al. [10]	The article proposes a smart financial system that can optimize the decision-making level of enterprises and increase the competitive advantage of the enterprise.	· Decision Support Systems in general
11	Critical Project Management Knowledge and Skills for Managing Projects with Smart Technologies	Ngo and Hwang [11]	It addresses the impact of the use of smart technologies in project management.	· Decision-making system in general
12	Application of Artificial Neural Networks in Construction Management: A Scientometric Review	Xu et al. [12]	The use of artificial neural networks, one of the artificial intelligence techniques, in construction management has been examined.	· Artificial Neural Network (ANN)
14	Application of Artificial Intelligence in Water Conservancy Project Management	Shi and Wu [14]	The contribution of artificial intelligence applications to construction costs in terms of water saving has been expressed.	· Decision Support Systems in general

Table A1. Summary findings of selected articles (Continued)

Paper ID	Title of the Study	Author(s)	Key Findings	AI Tool(s) Mentioned in the study
15	Artificial intelligence applications in earthquake resistant architectural design: Determination of irregular structural systems with deep learning and Image AI method	Bingöl et al. [15]	A system has been created to determine the conformity of the buildings to the earthquake regulations in the early stages of the design process.	· Machine Learning algorithms in general
17	Applying Artificial Intelligence within the AEC Industry: Collecting and Interpreting Data	Karan et al. [17]	It is discussed how decisions are made in construction projects with artificial intelligence.	· Decision-making system in general
18	Artificial intelligence in the construction industry: A review of present status, opportunities, and future challenges	Abioye et al. [18]	Artificial intelligence applications used in the construction industry are discussed in the context of applications such as activity monitoring, risk management, resource, and waste optimization.	· Machine Learning algorithms in general
27	Machine Learning and Artificial Intelligence Applications in Building Construction: Present Status and Future Trends	Ensafi et al. [27]	This article provides a literature review to explore the current know-how involving the application of machine learning and artificial intelligence in building construction.	· Machine Learning algorithms in general
29	A review of artificial intelligence-based risk assessment methods for capturing complexity-risk interdependencies: Cost overrun in construction projects	Afzal et al. [29]	Artificial intelligence methods related to cost-risk assessment in project management processes have been reviewed and the use of artificial intelligence methods in cost overrun management is supported in order to avoid chaos in projects.	· Machine Learning algorithms in general
35	Fusion of Computer Technology and Intelligent Logic Analysis Algorithm in Construction Engineering Cost Management	Xuan and Li [35]	Examines computer technology algorithms based on construction project cost management.	· Decision-making system in general
38	Machine Learning Algorithms for Construction Projects Delay Risk Prediction	Gondia et al. [38]	Using objective data sources in the study, machine learning models are identified and developed to facilitate accurate project delay risk analysis and estimation.	· Decision Tree and Naïve Bayesian Classifiers
41	Classification and analysis of deep learning applications in construction: A systematic literature review	Khallaf and Khallaf [41]	Analyzes were made by scanning 80 journal articles related to deep learning and the construction industry.	· Recurrent Neural Networks (RNNs) · Convolutional encoder-decoder networks · Fully convolutional networks (FCN) · Restricted Boltzmann Machines
47	The Role of Information Technologies to Address Data Handling in Construction Project Management	Martínez-Rojas et al. [47]	Examines information communication technologies for access to construction data and uses this information in project management.	· Machine Learning algorithms in general
50	Applications of Smart Technologies in Construction Project Management	Zhu et al. [50]	Determines the impact of smart technologies on project duration, cost and quality management.	· Machine Learning algorithms in general

Table A1. Summary findings of selected articles (Continued)

Paper ID	Title of the Study	Author(s)	Key Findings	AI Tool(s) Mentioned in the study
51	Computer Vision Technologies and Machine Learning Algorithms for Construction Safety Management: A Critical Review	Liu et al. [51]	Reviewed papers using computer vision technologies to ensure construction safety and supported the use of this application.	· Convolutional Neural Network (CNN) · Support Vector Machine (SVM) · Artificial Neural Network (ANN) · k-Nearest Neighbors (k-NN) · Regions with Convolutional Neural Network (R-CNN) · Region-based fully Convolutional network (R-FCN)
52	Current Trend in Planning and Scheduling of Construction Project Using Artificial Intelligence	Liu et al. [52]	It is aimed to determine the historical trend of augmented reality applications in the construction project planning process and to determine the trend in existing projects. In addition, this article identified gaps in the adoption of artificial intelligence technologies between the academic perspective and the real world in both construction planning and planning.	· Convolutional neural network (CNN)
54	AI and Text-Mining Applications for Analyzing Contractor's Risk in Invitation to Bid (ITB) and Contracts for Engineering Procurement and Construction (EPC) Projects	Choi et al. [54]	The modules developed as a risk analysis tool for construction stakeholders using artificial intelligence and text mining are described.	· The Critical Risk Check (CRC) · Terms Frequency Analysis (TFA)
55	Optimizing parameters of support vector machine using fast messy genetic algorithm for dispute classification	Chou et al. [55]	An efficient model has been developed using FPGA-based SVM for the estimation of possible conflicts in public-private partnership projects.	· Classification and regression tree (CART) · QUEST (Quick, Unbiased and Efficient Statistical Tree) · C5.0 · Exhaustive Chi-squared Automatic Interaction Detector (Exhaustive CHAID) · Fast messy generic algorithm (fmGA) · Support vector machine-based classification · Integration of fmGA and SVM
56	Applicability of Artificial Intelligence (AI) Methods to Construction Manufacturing: A Literature Review	Hatami et al. [56]	The latest technology in artificial intelligence techniques is reviewed in manufactured constructions and the future potentials of this technology are determined.	· Decision-making system in general

Table A1. Summary findings of selected articles (Continued)

Paper ID	Title of the Study	Author(s)	Key Findings	AI Tool(s) Mentioned in the study
57	A new labour safety in construction management based on artificial intelligence	Alheeti and Aldaiyat [57]	To ensure worker safety in construction processes, an artificial intelligence supported online monitoring technology has been proposed and its success has been experimentally proven.	· Machine Learning algorithms in general
58	Application of Artificial Intelligence in Construction Waste Management: A conceptual framework for effective waste management system	Ali et al. [58]	It proposes the use of artificial intelligence in the waste management created by the construction industry.	· Decision Support Systems in general
60	Application Possibilities of Artificial Neural Networks in the Construction Industry	Németh [60]	This article proposes a method to model the link between logistic resources allocated to a construction project and program success using neural networks.	· Artificial Neural Networks (ANN) · Bacterial Evolutionary Algorithm (BEA) · bacterial Memetic Algorithm (BMA)
61	Machine learning for the identification of competent project managers for construction projects in Nepal	Karki and Hadikusumo [61]	Machine learning methods were used to find the competency factors needed by competent project managers in developing countries.	· Machine Learning algorithms in general
62	Applications of object detection in modular construction based on a comparative evaluation of deep learning algorithms	Liu et al. [62]	It evaluates the performance of artificial intelligence object detection algorithms used in modular object detection.	· Faster region-based convolutional neural networks · Single shot multi-box detector
63	Construction of Enterprise Business Management Analysis Framework in the Development of Artificial Intelligence	Song and Chen [63]	It recommends the use of artificial intelligence to support corporate business management.	· Expert system · Knowledge base system · Decision-making system in general
64	Construction Project Cost Management Model Based on Big Data	Xu [64]	A method has been developed for the detection of abnormal data in construction projects containing large data.	· Decision-making system in general
65	Influence of the Development of VR Technology on Enterprise Human Resource Management in the Era of Artificial Intelligence	Xu and Xiao [65]	It analyzes the demand for artificial intelligence supported VR technology, establishes, and tests the corporate human resources management system.	· Polynomial Bayesian List Classification
66	Research on the new era of construction management mode of using the Internet of Things and big data	Yao and Hu [66]	With the view that quality and cost control of the project implementation process, project quality assurance and quality and cost control have a vital role; It aims to improve the level of quality and cost management by making use of the internet of things, big data, and mobile internet.	· Decision-making system in general
67	Artificial Intelligence and Parametric Construction Cost Estimate Modeling: State-of-the-Art Review	Elmousalami [67]	Examines different computational intelligence techniques for the development of cost estimation models in construction.	· Boosting and Adaptive Boosting (AdaBoost) · Extreme Gradient Boosting (XGBoost) · Stochastic Gradient Boosting

Table A1. Summary findings of selected articles (Continued)

Paper ID	Title of the Study	Author(s)	Key Findings	AI Tool(s) Mentioned in the study
68	Improvement in Estimating Durations for Building Projects Using Artificial Neural Network and Sensitivity Analysis	Fan et al. [68]	It proposes the use of neural networks for a more accurate estimation of construction time.	· Artificial neural network in general
69	Deep Learning in Construction: Review of Applications and Potential Avenues	Jacobsen Teizer [69]	The limitations of neural networks in construction are discussed and a way to exploit the potential of neural networks is proposed by examining real-time models and new architectures.	· Feed-forward neural network · Convolutional neural networks · Recurrent neural network
70	Deep Learning Image Captioning in Construction Management: A Feasibility Study	Xiao et al. [70]	This article explores the applicability of deep learning captioning methods in construction management.	· Convolutional neural networks · Recurrent neural network
71	Potentials of artificial intelligence in construction management	Eber [71]	The algorithmic and entropic scope of artificial intelligence has been evaluated in the context of construction management.	· Neural Networks in general
72	Artificial Intelligence in the Construction Industry: Main Development Trajectories and Future Outlook	Chen and Ying [72]	Statistical data on the latest developments in the field of artificial intelligence in the construction industry were obtained by using the main path analysis method.	· Decision-making system in general
73	Can Artificial Intelligence be a Critical Success Factor of Construction Projects	Kumar et al. [73]	It has been investigated whether artificial intelligence is a critical success factor in construction project success, and it has been stated that it takes years for artificial intelligence to recognize itself.	· Machine Learning algorithms in general
74	A knowledge-based risk management tool for construction projects using case-based reasoning	Okudan et al. [74]	A web-based tool has been developed to evaluate the cyclical risk management of construction projects that have inherent risks.	· Case-based reasoning (CBR)

Table A2. Classified application areas of artificial intelligence technologies

Application areas	Reference ID accessed from Table A1	Frequency
Cost management	[2], [15], [17], [27], [29], [35], [41], [50], [62], [63], [64], [65], [66], [67], [69], [70]	16/41
Time management	[2], [10], [17], [27], [29], [35], [38], [41], [50], [60], [62], [63], [64], [65], [68], [69], [70], [74]	18/41
Quality management	[8], [9], [12], [18], [35], [47], [50], [52], [62], [66]	10/41
Contract management	[10], [35], [47], [50], [54], [69], [71]	7/41
Disputes management	[27], [29] [47], [54], [55]	5/41
Safety management	[4], [8], [15], [51], [57], [62]	6/41
Risk management (Uncertainty/Forecast)	[4], [27], [41], [50], [60], [62], [69], [71], [74]	9/41
Sustainability	[15], [27], [59]	3/41