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

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Abstract

Artificial Intelligence (AI) technology is increasingly being adopted in the construction industry in the current era. AI can be integrated with digital technologies such as Building Information Modeling (BIM), Internet of Things (IoT), and Smart Vision (SV). The integration of AI with digital technology has the potential to enhance efficiency, productivity, accuracy, and safety in construction project. This systematic literature review focuses on studying the implementation of AI in construction management, aiming to assess the current role of AI and anticipate future trends in the field. The findings of systematic literature review reveal that AI has been employed in construction projects for tasks such as estimation, resource management, improvement of workplace safety, material selection, structural analysis, and more. The advancements in digital technology, including the influence of 5G connectivity, have further augmented the sophistication of AI applications in the current era. The systematic literature review also delves into the study of machine learning and deep learning, both of which are pivotal in AI technology for executing predictive tasks, analyses, and automated decision-making. Despite the vast potential of AI, this review identifies various challenges associated with the technology, particularly concerning data security. Most existing studies focus on the limited application of AI in specific domains within the construction industry. To address this gap, this systematic literature review provides a comprehensive literature review on the broader perspective of AI application in construction management.

Keywords: AI Technology, Automation, Optimization, Machine Learning, Construction.

1. Introduction

Construction projects have unique characteristics; moreover, the construction process involves significant resources and stakeholders, making construction management often challenging and almost insurmountable for the human mind. Generally, projects worldwide consistently face issues related to delays, cost overruns, rework, and low customer satisfaction. To address these challenges, the construction industry in the current era is increasingly leaning towards the use of industry 4.0 technology [1]. Innovations such as Digital Twin (DT), Building Information Modelling (BIM), Artificial Intelligence (AI), Internet of Things (IoT), and Smart Vision (SV) are rapidly advancing in the present era. These technologies are created to enhance efficiency, productivity, accuracy, and workplace safety. Industry 4.0 technology is believed to drive the construction industry towards transforming from traditional and manufacturing industries into autonomous smart systems [2].

Industry 4.0 in the construction sector is defined as the integration of modern industrial production systems, cyber-physical systems, digital technology, and computing. Production systems 4.0 encompass 3D printing and assembly, prefabrication, as well as offsite manufacture. Cyber-physical systems include the Internet of Things (IoT), robots, collaborative robots (COBOT), actuators, and other digital technologies. Construction Industry 4.0 has also given rise to computational technologies such as Building Information Modelling (BIM), Artificial Intelligence (AI), deep learning, machine learning, cloud computing, big data, data analytics, blockchain, augmented reality (AR), and digital twin [2].

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Technological advancements are influencing the emergence of construction projects on a larger and more complex scale, while the set deadlines and costs are becoming increasingly stringent [3].

AI is created to learn, reason, and solve complex and undefined problems through intelligent and adaptive means according to the conditions faced. AI has significant potential in terms of worker efficiency up to 40%, but the construction industry currently lags behind other industries in the utilization of AI [4]. Simply put, AI technology enables machines to think intelligently like humans and can solve problems that may even be beyond human capabilities [5]. In the current era, AI is developing significantly with the emergence of technologies such as computer vision, robotics, autonomous vehicles, language translation, speech recognition, and generative designs [2]. AI can be applied from the planning phase, construction process, to the operation and maintenance stages, aiming for automation to improve significant productivity and better reliability in construction execution [4]. This systematic literature review explores the application of AI technology in construction management tasks. In the 21st century, AI has seen advancements due to sophisticated algorithm development, the emergence of various modern devices, and the collection of more data for processing through machine learning [5]. Analyzing large amounts of data and complex conditions manually can be challenging, and AI technology can assist in addressing such issues.

The use and development of AI have the potential for violations of regulations and laws, the EGE (European Group on Ethics in Science and New Technologies) proposes principles and prerequisites for AI in forming regulations that are considered to pose risks to social conditions, the environment, ethics, safety, privacy, human rights, and environmental sustainability. In Europe, AI regulation is based on basic principles and prerequisites set out in the treaties of the European Union and the Charter of Fundamental Rights of the European Union, AI regulation in construction management may consider the following aspects [6]:

1. Data protection and privacy: Concerns data protection to respect privacy and refrain from collecting or disseminating data without owner consent.
2. Security, safety: Relates to reliability against hacking resilience and fieldwork safety.
3. Human dignity: Relates to human involvement in setting specific parameters, such as determining humane working hours or worker welfare, establishing legal boundaries regarding when and if someone interacts with AI or other humans, and respecting the existence of humans themselves.
4. Rule of law and accountability: Involves a clear and detailed legal framework so that individuals who feel violated can file lawsuits and receive protection against risks related to human rights such as safety in AI use and privacy rights.
5. Autonomy: Concerns human responsibility and control over AI, ensuring that decisions and actions generated by AI do not affect human standards, values, and norms in the construction industry.
6. Responsibility: Relates to the development and use of AI to create social welfare and mitigate environmental impacts.
7. Justice, equality, and solidarity: Pertains to fair access to AI benefits and ensuring that AI does not create inequality or discrimination, particularly in construction management regarding project opportunities or selection processes involving AI technology.
8. Democracy: Concerns the development and use of AI that considers the participation of various stakeholders and the public in decision-making.
9. Sustainability: Relates to AI responsibility for the sustainable prosperity of humanity and environmental preservation for future generations.

Most literature review on AI technology in the construction industry tend to focus on its application in specific areas, such as implementing AI in Building Information Modeling (BIM) or in automatic construction manufacture technologies. This systematic literature review thoroughly examines the role of AI in construction projects and investigates sustainability aspects, along with the future trajectory of AI in the construction industry, particularly in tasks related to project management, efficiency, safety, and risk analysis. The systematic literature review consolidates the latest findings to demonstrate practices and challenges faced by the construction industry in adopting AI technology in the current era and the future. It provides a comprehensive overview of AI involvement in construction project management, efficiency enhancement, safety measures, and risk analysis. By unifying recent discoveries, this review aims to present a holistic understanding of the practices and challenges encountered by the construction industry while embracing AI technology in both the present and future periods. This study presents a literature review from the perspective of AI application in construction

management through (1) searching for accredited and relevant scholarly journals on the topic, (2) highlighting the use and benefits of AI in construction management, (3) summarizing AI technology research in the construction industry, and (4) identifying the sustainability of AI technology in the future of the construction industry.

2. Research Methods

2.1 Planning

Systematic Literature Review (SLR) method is used in this research study, through the collection and identification of relevant research, as well as the data analysis process from those studies. By systematically reviewing available literature, this method can reduce subjective judgments and produce reliable findings from which conclusions are drawn and decisions are made. This literature review is conducted systematically, and the flowchart of this research process is depicted in Figure 1. The three stages in SLR research are identification, screening, and assessment [7]. The purpose of this SLR review is to investigate the extent of implementation and trends of artificial intelligence technology in construction management tasks. Five keywords used in this SLR review are Artificial Intelligence (AI) technology, automation, optimization, machine learning, and construction management.

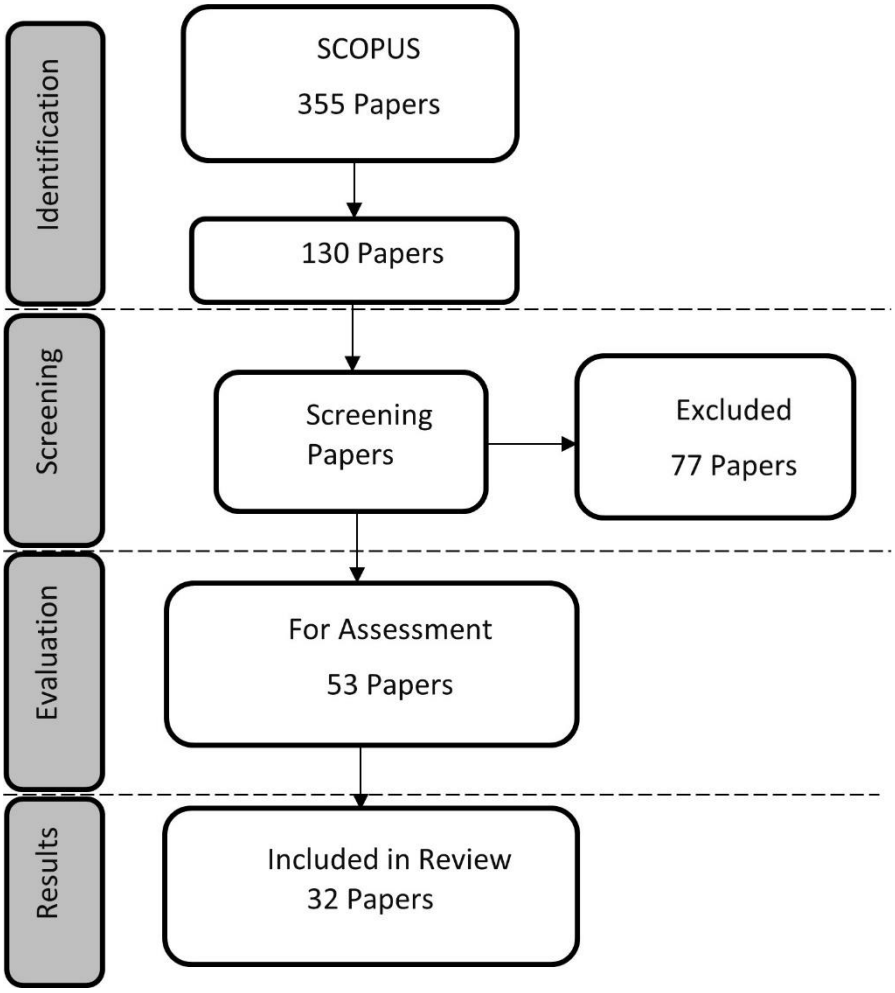

Figure 1. Systematic Literature Review Research Methodology

2.2 Data Collection

Research literature was obtained from the Scopus journal database with the assistance of the Publish or Perish 8 software. Keyword searches were conducted through article titles, keywords, and abstracts, restricted to journals published in the last 10 years. Literature was also restricted by excluding publication types other than scholarly journals such as book chapters or conference proceedings. The initial literature dates back to 2017, and over time, there has been an increase in literature, especially in

2020, in the field of artificial intelligence in construction. After the data collection stage, all selected articles were imported into the VOSviewer software to generate a visual keyword network showing the influence and impact of AI on the construction management context. This software visually analysis and creates a research direction network map consisting of interconnected nodes and links as seen in Figure 2.

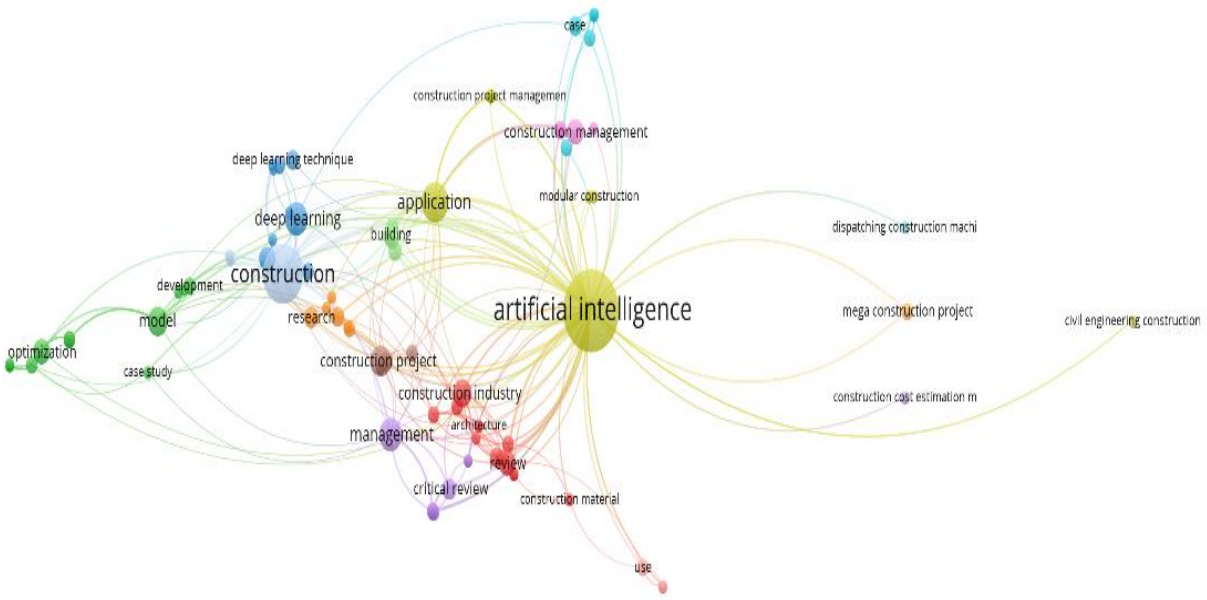

Figure 2. Keyword Search Using VOSviewer

2.3 Filtering

In the initial stage, a literature search related to artificial intelligence in the construction industry was conducted, resulting in a total of 355 articles. Then, the relevance of each article to the construction work context was assessed, articles mentioning AI but focusing on sectors other than construction work were not selected, resulting in 130 articles. Further filtering was done by examining the abstracts of each article, resulting in 53 articles; articles discussing AI unrelated to construction management were not chosen. In the final stage, a comprehensive assessment of the content of the selected articles regarding the SLR topic, namely the use, development, and trends of AI in construction management, was conducted. This process retained 32 selected articles for further literature analysis. This filtering process is illustrated in Figure 1.

2.4 Assessment

There were 32 articles retained after evaluating the literature material against the objectives of the SLR. These articles were analyzed, and the AI developments found in the literature were discussed in the future trends section. Each selected article has met the assessment criteria used, which include (1) type of AI technology used, (2) current implementation of AI in construction management and trends in the future, (3) limitations and potential improvements that can be made, (4) sustainability regarding economic, environmental, or social goal considerations, (5) tasks related to construction management, (6) stage of construction that can be implemented throughout the lifecycle stage of operation.

2.5 Descriptive Analysis

The last five years have seen an increase in the number of publications discussing specific applications of AI in construction management, indicating that AI technology has become one of the prominent research topics in the construction industry. Particularly since 2020, publications have experienced a significant increase, with growing awareness and the rapid development of technology making AI adoption in construction management increasingly feasible. The selected articles were published as accredited journal papers, with the majority originating from two main regions in succession Asia (45%) and Europe (34%), which together accounted for 79% of the total publications

on the specific topic of AI application in construction management, while the rest were distributed among countries in America, Africa, and Australia. Based on the classification mentioned in Table 1, research is divided into five categories. Research on the use of AI in construction management focuses sequentially on the potential implementation and benefits of AI (44%), Project Improvement (31%), Estimation (16%), Smart Planning (6%), and Autonomous (3%).

3. Result and Discussion

In this section, the findings of the application of AI in construction management will be discussed. To illustrate this analysis, a thematic division is conducted into three categories relevant to this SLR topic, namely (1) AI technology in construction management, (2) Application of AI in construction management, and (3) Machine learning in construction management. Table 1 indicates that current AI research is geared towards performance enhancement and various AI implementations. From 2017 to 2023, research on AI in the construction industry has shown an increase.

Table 1. AI Research Table from 2017 to 2023

Construction AI Research	2017-2018	2019-2020	2021-2022	2023-2024
Estimation	1	2	2	
Autonomous		1		
Smart planning			1	1
Project Improvement	2	1	3	4
Implementation & Benefit		1	7	6

3.1 AI Technology in Construction Management

Artificial Intelligence (AI) technology uses algorithms to solve complex problems. This technology trains machines to think, plan, process, perceive, move, and manipulate things as humans do, aiming to address complex issues. AI consists of both structured and unstructured data systems to learn and mimic human behavior, enabling it to make decisions. In this context, AI has the potential to handle various problems beyond human thinking capabilities, which can positively impact productivity improvement [1].

AI in the construction industry is considered to enhance efficiency, safety, and construction management performance. The following are some AI technologies in the construction industry.

1. Autonomous Vehicles: Integration of AI with autonomous construction vehicles, such as bulldozers and excavators, enables heavy machinery to operate autonomously [8]. In addition to heavy equipment, autonomous systems can also be applied to hoist systems. This autonomous hoist is considered efficient and practical for moving workers around the project area without requiring operator manpower [9]. Autonomous construction equipment, in general, is seen to improve safety and project productivity [10].
2. Computer Vision System: This technology allows real-time monitoring at construction sites to enhance safety by detecting potential hazards and ensuring compliance with safety protocols and workplace safety in the project area [8].
3. Natural Language Processing and Chatbots: This technology serves as an efficient communication and collaboration system, reducing the potential for misunderstandings among project teams [8].
4. Machine Learning and Internet of Things (IoT): Integration of these technologies can enhance efficiency and reduce errors in tasks such as automatic data collection at project sites, resource management, and improve decision-making accuracy [8].
5. Machine Learning and Building Information Modeling (BIM): Integrating this technology can simplify complex planning tasks. This technology can also perform real-time project analysis, including energy efficiency analysis [8].
6. Offsite Manufacture: This technology is closely related to automation through robotic technology trained using AI algorithms. Offsite manufacturing products in the construction industry include prefabricated and modular buildings. Robots are divided into ground robots that automate some manual and repetitive processes, and aerial robots that automate land surveying, scanning, and site monitoring [2].

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7. Integration of AI Technology with Extended Reality (XR), Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR), Laser Scanners, and Drones, in the construction planning and material selection processes [11].
8. Doxel AI: This technology combines robots and drones equipped with cameras and LiDAR sensors to monitor and scan construction project locations. Visual data is then processed using deep learning algorithms to measure the amount of work completed and assess production progress based on the planning and design parameters desired by the owner. Doxel AI can also detect construction errors by comparing visual data from daily scans at the project site with the created design [12].

AI technology has significant potential in automating tasks, where robotic machines can perform roles similar to humans without exhibiting human characteristics such as fatigue or illness. Additionally, AI in the current era possesses greater computer memory capacity and more sophisticated programs to enhance its functionality [13]. Despite being viewed as an innovative solution that can address productivity and project efficiency issues in the construction industry, increased automation in AI technology still requires considerations regarding safety and ethical aspects related to privacy and accountability [8].

3.2 Application of AI in Construction Management

The application of AI in construction management, in general, can aid in optimizing [14], [15] and automating [4] various construction management tasks. This includes project scheduling, delay analysis, Work Breakdown Structure (WBS) creation, project budgeting, updating project progress and schedules, identifying deviations, creating risk maps, and team member allocation [16]–[18].

AI is classified by scientists into two levels, namely weak AI and strong AI. Weak AI is known as limited intelligence in solving specific problems using software. AI at this level functions as a problem solver in a particular field. Strong AI is associated with Artificial General Intelligence (AGI) and Superintelligence; strong AI can exhibit cognitive functions similar to humans and even surpass human capabilities [13]. Here are some applications of AI in the field of construction management:

1. The selection of construction materials is a crucial aspect of construction projects as it can impact project duration, building durability, strength, energy usage, emissions, and even the aesthetic aspects of a structure. In this regard, material optimization can benefit from AI technology. Current material optimization is commonly performed on concrete materials due to their composite nature involving multiple components [2].
2. In project management, AI offers various algorithms, such as Support Vector Machine (SVM), which can assist in resource management, cost optimization, predicting task durations, and minimizing project waste. AI algorithms can also estimate worker productivity, rank and select contractors most suitable for a project [2].
3. In terms of safety, AI can detect objects and enhance safety in construction environments [12]. AI can also estimate safety factors such as slope stabilization during construction and analyze data from sensors used by workers. These processes utilize big data, which is then analyzed to predict potential incidents and provide mitigation in Occupational Health and Safety (OHS) systems [2].
4. Commercial applications like BuildAI are commonly implemented in the construction industry to monitor project progress, combined with sensors installed at project sites [2].
5. AI systems adopting Lean techniques [19] and Enterprise Resource Planning (ERP) can improve productivity and minimize resources in construction projects. This technology can be applied to project monitoring by analyzing work location data through computer vision technology to predict the continuity of construction activities, such as Doxel AI using robots, drones, and sensors to scan work locations [16].
6. AI can also be applied in Artificial Emotional Intelligence (EI) to select project managers. AI can accurately measure an individual's attitude and emotional intelligence [20].
7. AI can accelerate processes and improve design outcomes [21] through machine learning algorithms, enabling effective management of construction project waste and components. This process involves robot systems for collecting and classifying Building Construction and Demolition Waste (BCDW) at construction project sites [22],[23].
8. Neural Networks (NN) and sensors installed on smartphones can automatically recognize worker data. This data is extracted and used to identify worker behavior patterns for enhanced project supervision and control [10], [24].

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9. AI algorithms assist in structural analysis and design. Structural design is commonly conducted through computer simulations based on numerical simulations, while AI performs it through statistical and probability analysis. Examples of AI usage in structural optimization include seismic design, load capacity analysis and calculations, and predicting the level of damage to existing structures [2].
10. Optical Character Recognition (OCR) is an AI application for finding required images and converting them into editable documents, images, and data [12].
11. Integration of live video and image detection through machine learning. This technology can be used to learn and identify construction risks in real-time, such as workers not wearing proper PPE according to safety protocols at the project site [13].
12. Vision machine is an AI application on a machine to replace human eyes in measurements and assessments. Captured visuals are sent to a specialized image processing system to receive information from the captured visuals [25], [26].

For a better understanding of AI, Figure 3 illustrates several AI categories that can be applied in the construction industry, ranging from machine learning, natural language processing, expert systems, vision, speech, robotics, to planning functions.

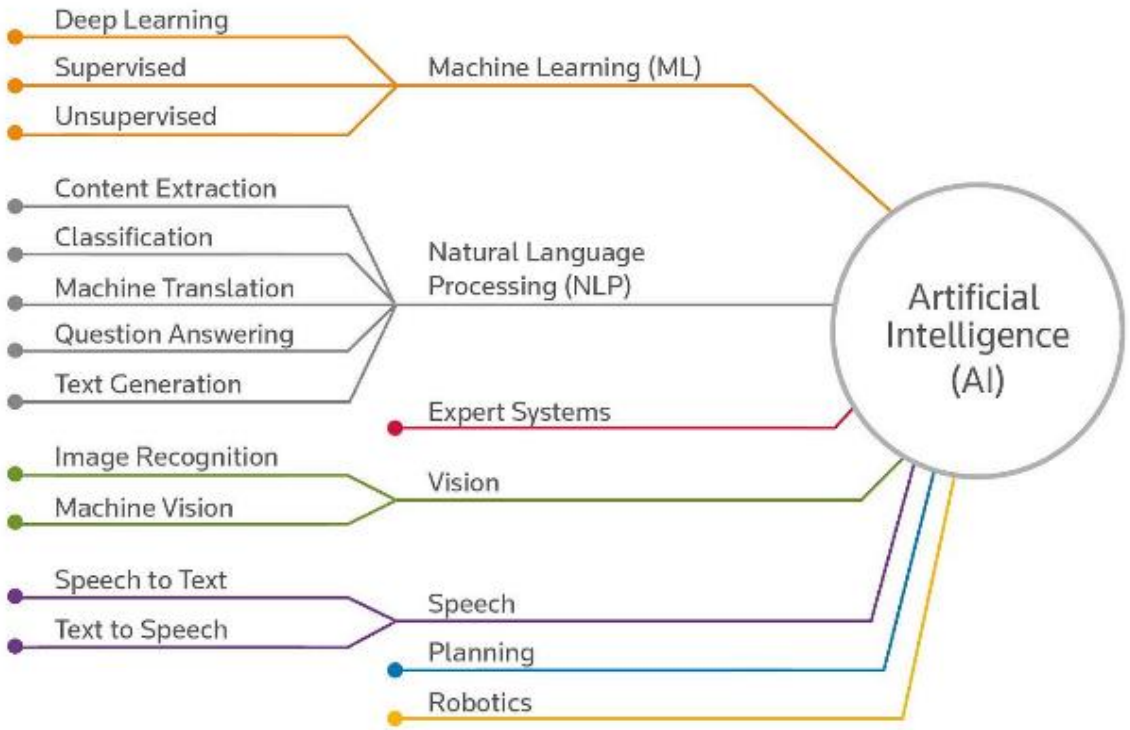

Figure 3. Categories of Artificial Intelligence (AI) [13]

3.3 Machine Learning in Construction Management

Predictive analysis in AI technology can be conducted by leveraging historical data and algorithms through machine learning. This application can predict the likelihood of delays, material shortages, and potential cost overruns [8]. The key technologies behind AI are machine learning and deep learning. Machine learning is a subset of AI where computers observe a given set of data and generate a model based on the received data to solve problems. Machine learning differs from traditional programming, as traditional programming still relies on manual commands to process information, while machine learning can process information automatically [2].

Deep learning is a subfield of machine learning and can be interpreted as a technique in machine learning to teach computers to process data. Convolution Neural Networks (CNN) is a widely used technique in deep learning processes today to recognize visual and auditory objects, then generate images, sounds, and translation machines. Machine learning and deep learning are also related to data collection tools. In construction projects, data collection tools are found in strain gauge sensors, load

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cell sensors, accelerometer sensors, laser sensors, Linear Variable Differential Transformer (LVDT) sensors, draw-wire sensors, thermal sensors, infrared (IR) sensors, ultraviolet (UV) sensors, air quality sensors, sound sensors, and various other sensors. Most of these sensors are connected to the cloud through the Internet of Things (IoT) network for information exchange in performing analysis, monitoring, and smart management [2]. One implementation of deep learning is carried out to automatically calculate the use of steel with a YOLOv3 detector. This process produces accurate and fast steel calculations [27].

Rema and Nalanth [28] conducted a study on the application of deep learning technology through Convolutional Neural Network-Long Short-Term Memory (CNN-LSTM), which is a computer program to estimate the amount of construction material generated from the demolition process [28]. The results achieved an average accuracy of 98% in predicting the amount of building materials produced after the demolition process. Accuracy in predicting construction waste is crucial in planning the reuse of materials [28]. Deep learning is a subset of machine learning that enhances AI functions. Machine learning has limitations in processing data. To overcome these limitations, deep learning is tasked with learning existing data representations, thereby improving the performance of machine learning in analytical tasks such as image recognition and natural language processing [5]. In 1991 and 1992, Moselhi introduced Neural Networks (NN) as a tool that could automate current construction management [5]. NN can be used for various tasks such as cost estimation for various construction types [29], estimating the duration of construction projects, and estimating material consumption for construction work [30].

In general, AI is the ability of computer systems to mimic human intelligence. This artificial intelligence does not need to be pre-programmed but utilizes algorithms that can work with their own intelligence. Machine learning enables computer systems to make predictions or decisions using previously existing data. Deep learning is an algorithm that can analyze data with a logical structure similar to how humans draw conclusions. Deep learning algorithms are typically useful with higher-dimensional data such as images, videos, and audio due to the presence of long computation paths [2]. The relationship between AI, machine learning, and deep learning is illustrated in Figure 4.

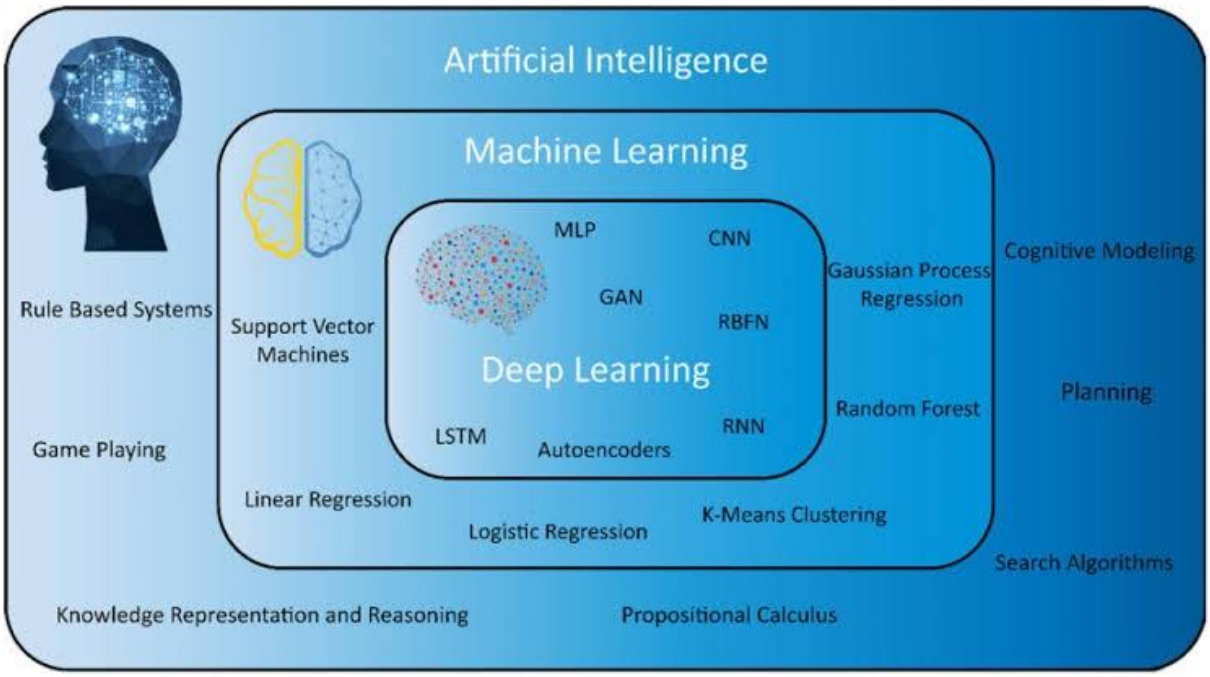

Figure 4. Relationship of AI, Machine Learning, and Deep Learning [2]

Another AI technique currently available is Fuzzy. Fuzzy is divided into Fuzzy Logic and Hybrid Fuzzy Techniques. These techniques have been applied to support construction decision-making processes in four categories [31]:

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1. Contractor selection, residential building assessment, site plan planning, optimization, resource allocation [5], [31],
2. Measuring and simulating project performance in terms of cost, risk, and duration [5],
3. Risk assessment, contractor or business partner qualification, working capital needs, project value, productivity, new construction technology [5],
4. Creating a framework for subcontractor selection, selection of company resource planning, forming a multifunctional team. Fuzzy techniques are considered suitable for analyzing construction problems facing uncertainty [5].

3.4 Future Trends

Currently, AI technology, both in terms of tools and implementations, is predominantly used in the realms of design and project monitoring. However, future trends in AI are heading towards various applications such as Smart robotics capable of modular building fabrication, Virtual Reality (VR) and Augmented Reality (AR) for tasks like clash detection or worker training media, Cloud and Artificial Intelligence of Things (AIoT) aiding in automation and remote control, Digital Twins to generate a digital replica of a building, 4D printing involving the creation of 4D-printed structures using materials like concrete, geopolymers, and mortar, blockchain integrated with payment processing, supply chain, and BIM in the application of smart contracts [2].

These findings indicate that project cost management, project schedule management, and project risk management are likely to be significantly influenced by AI in the future, particularly in the planning phase involving cost estimation, risk, and schedule. AI functions as a predictive and decision-making tool, enabling the delegation of project management-related issues requiring human capabilities to AI functions [16]. Automation in the construction industry is not limited to repetitive tasks, as there is a trend towards automating construction activities that require complex skills [10].

The future implementation of AI is supported by 5G connectivity, which can enhance the operation of construction machinery from thousands of kilometers away and enable the operation of machinery underground without being hindered by network availability issues as is the case today. This process speeds up work and avoids construction workers from health and safety hazards [13]. Despite the significant potential of AI across various industries, this technology also faces various challenges that need to be addressed, such as [32], [33]:

1. Machine learning in AI requires a large amount of data collection to obtain meaningful analysis.
2. Periodic transfer learning is required to ensure the processed machine learning data remains relevant.
3. Machine learning in AI necessitates high-quality data that is accurate, complete, and representative.

Combining data from various sources and technologies, such as IoT and the cloud, can pose cybersecurity risks and privacy concerns.

4. Conclusion

Based on the literature review regarding the implementation of AI technology in construction management, it can be concluded that the application of AI in construction management has a significant impact on various aspects of work, ranging from planning and project execution to risk management. The main findings in this SLR indicate a rapidly growing implementation of AI in the construction industry, especially from 2017 to 2024. This trend primarily focuses on using AI to enhance project performance and optimization. The application of AI in construction management extends to safety aspects, resource management, project administration, contractor selection, and construction material optimization. Implementations of AI through technologies like Doxel AI, BuildAI, and automatic recognition of worker data demonstrate significant progress in project monitoring and productivity improvement.

Machine learning and deep learning have become techniques that significantly influence the AI predictive analysis process in predicting potential delays, material shortages, and potential cost overruns. One example is the application of deep learning techniques through Convolutional Neural Network-Long Short-Term Memory (CNN-LSTM) to accurately estimate the amount of construction material produced from the demolition process. AI in the future will continue to evolve, encompassing Smart Robotics, VR, AR, Cloud, AIoT, Digital Twins, 4D printing, and Blockchain systems. However,

challenges such as the need for large amounts of data, periodic transfer learning, and cybersecurity should be a concern for AI users in the construction industry.

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