# A Review of Artificial Intelligence In The Construction Industry

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***Abstract***- *The construction industry is facing various complex challenges, including cost and time overruns, health and safety concerns, labor shortages, and low productivity. Moreover, the industry has been slow to adopt digital technologies, making it even more challenging to overcome these issues. In contrast, industries such as manufacturing, retail, and telecommunications have embraced Artificial Intelligence (AI) and its subfields, including machine learning, knowledge-based systems, computer vision, robotics, and optimization, to increase efficiency, safety, and profitability. However, the construction industry still faces several obstacles to implementing AI effectively. This research seeks to explore the potential of AI in the construction industry by reviewing existing literature on AI applications, including activity monitoring, risk management, resource and waste optimization, and identifying opportunities and challenges. The study aims to shed light on the benefits of AI in construction and how it can address industry-specific challenges while also highlighting the pathway to achieving these benefits.*

***Keywords***- Artificial intelligence Machine learning AI challenges AI opportunities Construction industry Robotics

## I. INTRODUCTION

TThe construction industry has been facing several challenges that have impeded its growth and resulted in low productivity compared to other industries like manufacturing. Despite being one of the least digitized industries globally, most industry stakeholders are reluctant to change . As a consequence, managing projects within the industry is needlessly cumbersome and complex. The absence of adequate digital expertise and technology adoption in the construction industry has been linked to cost inefficiencies, project delays, poor quality performance, uninformed decision-making, and low productivity levels in health and safety. With the current labor shortages, COVID-19 pandemic, and the increasing demand for sustainable infrastructures, it has become apparent that the construction industry must embrace digitization and improve its technological capacity rapidly.In recent years, Artificial Intelligence (AI) has emerged as a leading digital technology that has contributed significantly to improving business operations, service processes, and industry productivity. The application of AI techniques has enabled businesses to achieve better automation and gain a competitive advantage compared to traditional approaches. AI subfields such as machine learning, natural language processing, robotics, computer vision, optimization, automated planning, and scheduling have been utilized to address complex problems and aid decision-making for real-world scenarios. For example, the manufacturing industry has embraced Industry 4.0, the fourth industrial revolution, which focuses on automation, data-driven technologies, and the application of advanced AI techniques.

It is clear that the emergence of Artificial Intelligence (AI) has had a significant impact on the improvement of business operations, service processes and industry productivity, leading to process improvements, cost-efficiency, reduced production times, improved safety, and the achievement of sustainability goals in various industries. However, despite its potential benefits, the construction industry has been slow to adopt AI technologies due to various challenges, such as cultural barriers, high initial costs, talent shortages, security, and computing power. Nevertheless, some researchers have investigated the potential applications of AI and its subfields, such as machine learning, natural language processing, robotics, and knowledge-based systems, to tackle construction-specific challenges, including health and safety monitoring, cost estimation, supply chain and logistics process improvements, risk prediction, site monitoring and performance evaluation, offsite assembly, and waste management.

To address this gap in knowledge and understand the trends, opportunities, and barriers related to AI adoption in the construction industry, this study aims to answer three research questions:

(1) what are the areas of AI application in the construction industry,
(2) what are the future opportunities for AI application in the construction industry, and
(3) what are the challenges to adoption of AI in the construction industry.

The objectives of this study are to critically review existing AI applications and their subfields in the construction industry, identify opportunities for increased AI applications, and identify challenges affecting AI adoption. This study is a vital contribution to knowledge as it seeks to fill the gap in information about AI in the construction industry. The study provides background information on AI, its types, components, and subfields, followed by an in-depth discussion of its existing implementations in the construction industry.

## II. RESEARCH METHODOLOGY

The aim of this study was to conduct a comprehensive review of literature on the use of artificial intelligence (AI) in the construction industry. The study covered a period of six decades from 1960 to 2020, during which time AI has been adopted in various fields including construction. The study employed an extensive search using multiple databases, including SCOPUS, IEEE, ACM, and Science Direct, which were chosen due to their high impact publications in construction, engineering, and computer science. SCOPUS was the main data source while the others were used for full article download and data validation.

The search used 29 free-text keywords to narrow down the results to articles on specific AI techniques that were relevant to the construction industry. The search was limited to articles in English, and conference papers were excluded if they produced over 100 articles, as most conference publications are already written as journal articles.

After assessing 1800 publications, 1272 were deemed relevant for further investigation based on inclusion criteria that required a practical application of an AI subfield and its techniques in the construction industry. The study extracted data from each article on the application area in construction, the methodology/techniques used, and the findings.

The review found that most of the studies focused on using specific AI techniques to achieve stated goals. The subfields of AI that were most commonly used in the construction industry included machine learning, knowledge-based systems, and optimization. The study identified research gaps, opportunities, and challenges in the use of AI in the construction industry.

Overall, the review provides valuable insights into the existing applications of AI in the construction industry, highlighting the areas where AI has been most successful and the challenges that still need to be addressed. The study also serves as a resource for researchers and practitioners interested in exploring the potential of AI in the construction industry.

## III. OVERVIEW OF ARTIFICIAL INTELLIGENCE AND ITS SUBFIELDS

The development of machines that exhibit intelligence like humans can be traced back to several fields such as philosophy, fiction, imagination, computer science, electronics, and engineering inventions. A turning point in the field of AI was Alan Turing's test for intelligence, which exceeded traditional theological positions and mathematical conclusions about the possibility of intelligent machines. Today, intelligent machines outperform humans in many domains, such as learning, by leveraging rapid advances in other technologies such as big data and computer processing power. Ref. [26] defines AI as the study of how to make machines do things that people currently do better.

Fig. 1 provides an overview of the types, components, and subfields of AI. There are three types of AI: Artificial Narrow Intelligence (ANI), Artificial General Intelligence (AGI), and Artificial Super Intelligence (ASI). ANI refers to a form of AI where machines exhibit intelligence in a particular domain such as chess playing, sales prediction, movie suggestions, language translation, and weather forecasts. AGI is concerned with making machines operate at the same level as humans. It refers to making machines that can solve a range of complex problems in different domains, control itself autonomously, with its own thoughts, worries, feelings, strengths, weaknesses, and disposition. Artificial super intelligence (ASI) is concerned with building machines that exceed human capabilities across several domains.

The major components of AI, as shown in Fig. 1, are: learning, knowledge representation, perception, planning, action, and communication. Some studies have also classified some of these components as tasks that can be carried out by AI as compared to human senses.

To understand the current state of AI in the construction industry, it is important to identify the major subfields of AI, such as machine learning, computer vision, natural language processing, knowledge-based systems, optimization, robotics, automated planning, and scheduling. Each of these subfields is presented below.

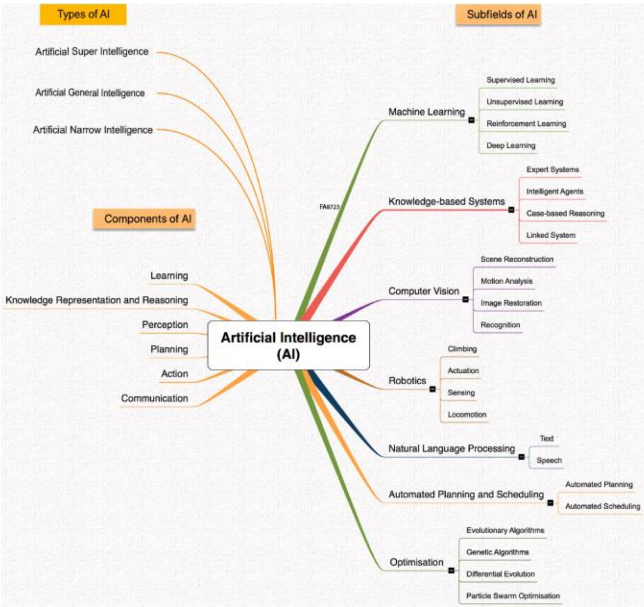


Fig. 1. Components, types and subfields of AI

### 3.1. A. Machine learning

Machine Learning refers to the development and application of computer programs that can learn from previous data or experiences. These programs use statistical techniques to model, control, or predict outcomes without being explicitly programmed. There are several types of Machine Learning methods, including Supervised Machine Learning, which involves the use of labelled datasets to make decisions, and is divided into classification and regression. Unsupervised Machine Learning, on the other hand, focuses on learning the essential structure of unlabelled data, and is categorized into clustering and dimension reduction techniques. Reinforcement Learning involves learning from interactions with the environment to maximize a reward or reinforcement signal, and Deep Learning is the current state-of-the-art in machine learning, which is known for its ability to provide more accurate predictions compared to conventional machine learning techniques.

### 3.2. Computer vision

Computer vision is a cross-disciplinary area that focuses on the replication of the human visual system through artificial means. The main objective of computer vision is to enable machines to emulate human intelligence by facilitating comprehensive comprehension of digital and multidimensional images. This is accomplished by acquiring images via suitable devices, utilizing cutting-edge algorithms to process them, and analyzing the images to facilitate decision-making.

### 3.3. Automated planning and scheduling

Planning, a subfield of AI, focuses on achieving desired goals or objectives by selecting and sequencing actions based on their expected outcomes. Meanwhile, scheduling involves the allocation of time and resources necessary to achieve the desired goals based on the total available resources. These techniques are being applied to provide solutions for complex applications that better fit problem constraints and user needs. Planning is commonly used in situations where its benefits outweigh the cost due to its complexity, cost, and time-consumption. The heuristics and algorithms typically used for planning and scheduling include search techniques, optimization techniques, and genetic algorithms.

### 3.4. Robotics

Robots are advanced devices that can perform physical tasks in the real world. Robotics is a field of engineering that involves designing, building, operating, and maintaining robots and other computer-controlled devices that can mimic human physical actions. Robots are designed for specific tasks and may take various shapes, not necessarily humanoid, that are best suited for their functions, and they interact with their surroundings using sensors and actuators. As stated by [39], the majority of the learning problems in robotics involve reinforcement machine learning.

### 3.5. Knowledge-based systems

The branch of AI known as Knowledge-based Systems (KBS) focuses on machine decision-making based on existing knowledge. It is composed of a knowledge base, an inference engine, and a user interface. The knowledge base stores domain expert knowledge, past cases or experiences, or other relevant sources, and is used to make inferences and arrive at conclusions that are heuristic, flexible, and transparent. The KBS has the advantage of easy access and interactions with large requisite domain knowledge, leading to increased productivity and efficiency.

KBS is classified into four types: (A) Expert Systems, which imitate human decision-making in solving specific problems by using task-specific knowledge from an expert in a particular domain; (B) Case-based Reasoning (CBR) Systems, which use past experiences or old cases to explain, interpret, or critique new situations; (C) Intelligent Tutoring Systems, which use AI techniques to provide tutors with what they teach, who they teach, and how they teach it; and (D) DBMS with intelligent user interfaces and linked systems, which are database systems with intelligent user interfaces driven by AI. The linked or hypertext manipulation systems (HMS) in this category allow easy traversal of complex information networks, enabling writers and authors to easily link passages and references.

### 3.6. Natural language processing

Natural Language Processing (NLP) is a branch of AI that aims to develop computational models that emulate the linguistic abilities of humans . NLP has diverse applications, such as machine translation, text processing and summarization, user interfaces, cross-lingual information retrieval, speech recognition, and expert systems . The tasks involved in NLP encompass part-of-speech tagging, chunking, named entity recognition, and semantic role labeling .

### 3.7. Optimisation

The field of optimization is focused on making decisions that lead to the best possible outcomes while adhering to certain constraints. According to Boyd and Vandenberghe, an optimization problem involves selecting the best choice from a set of available choices. Originally a mathematical discipline aimed at finding the optimal solution for any given problem, optimization has evolved to include a range of metaheuristic algorithms, known as evolutionary algorithms (EA), which were introduced with the advent of AI in the 1950s. Examples of modern EA algorithms include evolutionary strategies (ES), evolutionary programming (EP), genetic algorithms (GA), differential evolution (DE), and particle swarm optimization (PSO)

## IV. STATE-OF-THE-ART AND FUTURE OPPORTUNITIES OF AI APPLICATIONS IN THE CONSTRUCTION INDUSTRY

### 4.1. Trends of AI application in the construction industry

The use of artificial intelligence (AI) in the construction industry has been increasing since the 1960s, with optimization techniques being the foremost area of research. Machine learning has surpassed knowledge-based systems as a subfield of interest in the last decade, likely due to labor and skill shortages. Robotics has also come to the fore in the industry, with the introduction of 3D printing, exoskeletons, and UAV technologies for construction processes. However, natural language processing has been the least researched subfield. In the last decade, over 60% of AI application research in construction has emerged, giving rise to advanced technologies such as quantum computing, the Internet of Things (IoT), cybersecurity, and blockchain. Quantum computing can help AI accelerate problem-solving and optimize its solutions, while IoT has been integrated with AI in various ways, such as energy-saving on demand, IoT-enabled building information modeling (BIM) platforms, and hazard energy warnings on underground construction sites. However, an ever-evolving cyber threat is a challenge to the advantages of increased access to the internet and interconnected systems. Cyber threats common in the construction industry include malware, social engineering, and phishing. The introduction of level 3 BIM and an increasing reliance on virtuality increase exposure to cybercrime, making any digital technology used in the construction industry at risk of cyber-attacks without proper network security and response plans. Finally, blockchain has seen rapid growth in adoption in various areas, including the construction industry.

The use of blockchain technology employs cryptography and a consensus mechanism to verify transactions, prevent double-spending and ensure the legitimacy of high-value transactions in an untrustworthy environment. In the construction industry, blockchain technology has been applied to manage building lifecycle data by integrating with IoT and BIM , improve logistics of construction materials , and enhance supply chains in the composite materials industry . The potential benefits of blockchain technology in addressing issues of trust, communication, and transparency in the construction industry are significant. By integrating AI and blockchain technology, secure, transparent and decentralized CDE solutions can be developed.

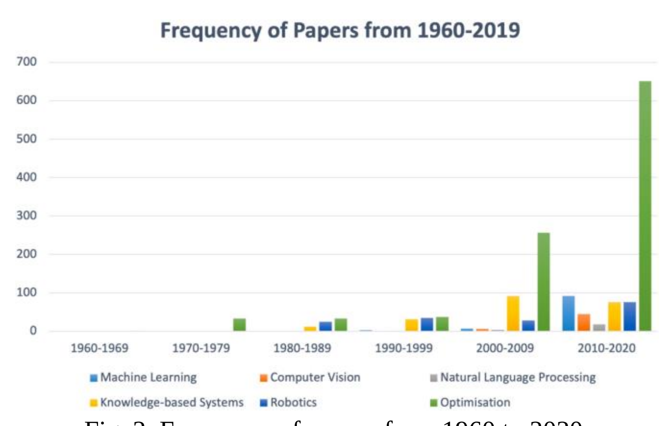


Fig. 2. Frequency of papers from 1960 to 2020.

### 4.2.Application of AI subfields in the construction industry

Table 1: outlines the different ways that AI subfields have been utilized in the construction industry, along with their benefits and drawbacks.

Table 2: presents an overview of the advantages and limitations specific to each AI subfield in the construction industry. While several benefits are common to all subfields, such as cost and time savings, improved safety, and increased accuracy, limitations such as incomplete data, high initial

deployment costs, and data and knowledge acquisition difficulties are also prevalent.

### 4.3. Common application areas and future opportunities of AI in construction

Table 3 illustrates the various domains where AI can be implemented in the construction industry, along with the latest trends and potential opportunities for increased adoption of AI. The table identifies fourteen (14) subdomains with their respective state-of-the-art applications and opportunities to address construction-specific issues. Some of the subdomains identified are waste and resource optimization, value-driven services, supply chain management, health and safety, AI-based construction contract analytics, voice user interfaces, and an AI-based audit system for construction finances. Value-driven services subdomain includes estimation and scheduling, construction site analytics, job creation, and AI and BIM integration with other industry tools such as the internet of things (IoT).

**Table 1**
Application of AI subfields in Construction.

| AI Subfields | Construction Application Areas | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Health and Safety | Scheduling | Cost Estimation | Legal (Contracts & Conflict Management) | Supply chain & Logistics | Site Monitoring & Performance Evaluation | Material Management | Offsite Assembly | Plant and Equipment Management | Project Planning | Knowledge Management | Design | Risk Management | Temporary Structures | Bids/ Tenders | Energy Management | Sustainability |
| Machine Learning | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| Computer Vision | ✓ | | | ✓ | | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | | | | | |
| Automated Planning & Scheduling | | ✓ | | | | | | | | ✓ | | | | | | | |
| Robotics | | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | | | ✓ | |
| Knowledge-based Systems | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | | ✓ |
| Natural Language Processing | ✓ | | | ✓ | | ✓ | ✓ | | | ✓ | ✓ | | ✓ | | | | |
| Optimisation | | ✓ | ✓ | ✓ | ✓ | | ✓ | | ✓ | ✓ | | ✓ | ✓ | ✓ | | | |

#### 4.3.1. Resource and waste optimization

the focus is on resource and waste optimization in the construction industry. Due to rapid development, there is a growing amount of construction and demolition waste (C&DW) produced each year, which has negative impacts on the environment, natural resources, and human resources globally. In the past, waste management strategies were reactive and focused on reducing waste after it happens. However, there has been a paradigm shift towards proactive data-driven approaches like waste analytics (WA), which aim to minimize waste through design. BIM has been increasingly used as a virtual and less expensive environment to facilitate construction design that minimizes waste generation. Advanced data analytics techniques are essential to turn the diverse data from different sources such as building design, material properties, and construction strategies into relevant information for waste minimization. This is where artificial intelligence techniques come in, especially with the integration of AI and BIM to optimize design for offsite construction, material selection, reuse and recovery, waste-efficient procurement, deconstruction, and flexibility. The state-of-the-art and potential opportunities for this subdomain are summarized in Table 3.

#### 4.3.2. Value-driven services

The following section examines various auxiliary services in the construction industry that can profit from the growing utilization of AI technology.

#### 4.3.2.1. Estimation and scheduling

The use of AI-based prediction models for estimating construction costs and duration is discussed in this section. Integration of BIM with time and cost allows better planning for project scheduling and estimation. However, BIM automation ignores external factors, leading to additional work for estimators. To take advantage of better accuracy, advanced AI techniques such as deep learning can be integrated with BIM for cost and time prediction. Additionally, deep learning techniques can predict other relevant factors. Table 3 summarizes the current state-of-the-art and future opportunities for this subdomain.

**Table 2**
Advantages and limitations of AI subfields in construction.

| Subfield | Advantages in construction | Limitations in construction |
|---|---|---|
| ***Machine Learning*** | - Relevant predictive and prescriptive insights<br>- Increased efficiency<br>- Cost savings<br>- Improved safety<br>- Efficient utilisation of resources<br>- Reduced mistakes and omissions | - Incomplete data<br>- Learning from streaming data, dealing with high-dimensional data, scalability of models and distributed computing |
| ***Computer Vision*** | - Faster inspection and monitoring<br>- Better accuracy, reliability and transparency<br>- Cost effective<br>- Increased productivity<br>- Increased safety | - Total scene understanding<br>- Action recognition of equipment and/or workers<br>- Improvement of tracking accuracy and effective visualisation of tracking results. |
| ***Automated Planning and Scheduling*** | - Cost savings due to improved processes e.g. logistics<br>- Increased productivity<br>- Reduced planning effort<br>- Simplified monitoring and control<br>- Optimal plan and schedules | - Mostly expensive to implement<br>- Could be Complex<br>- Knowledge representations for needed models, monitoring issues, integration issues, synthesis techniques, etc. |
| ***Robotics*** | - Increased safety<br>- Increased productivity<br>- Improved quality<br>- Better reliability and accuracy<br>- Faster and more consistent than humans | - High initial costs<br>- Potential job loss due to automation - Maintenance and repair costs<br>- Unstructured work environment |
| ***Knowledge-based systems*** | - Easy access to relevant information<br>- Easy to update<br>- Ability to explain reasoning behind solution<br>- Consistency and availability<br>- Can work with incomplete information<br>- Clear logic | - Intellectual property protection and security issues<br>- Knowledge acquisition issues<br>- Knowledge validation issues |
| ***Natural Language processing*** | - Increased productivity<br>- Cost effectiveness<br>- Time efficiency<br>- Improve communication among stakeholders | - Appropriate representation of fragmented, extended and errorful language<br>- Speech recognition issues such as construction site noise, homonyms, accent variability, etc.<br>- Data privacy and security issues |
| ***Optimisation*** | - Increased productivity due to optimised processes<br>- Increased efficiency<br>- Cost and time savings | - Requires significant computing power<br>- Scalability issues |

#### 4.3.2.2. Construction site analytics

The increasing use of digital technologies such as IoT sensors has transformed construction sites into smart working environments. Construction site analytics involves collecting and analyzing data generated on construction sites to optimize performance in key areas such as planning, design, safety, quality, schedule, and cost. Advanced AI techniques can be used to analyze unstructured data such as images and videos, and integrated with BIM for better insights. Developing a holistic site analytics tool using AI for real-time, cloud-powered analytics could improve productivity and quality control. A construction site AI chatbot could provide real-time updates for project managers and stakeholders.

#### 4.3.2.3. Job creation.

According to a report, construction jobs are at risk of being automated in the next decade due to the increasing prevalence of automation technologies such as AI and IoT. However, the adoption of such technologies could also create new job roles to assimilate and reskill displaced workers. For example, the advent of BIM has led to the creation of new roles such as BIM project manager, director, coordinator, and designer. The adoption of digital technologies like AI will give rise to new types of jobs such as construction AI researcher, trainers, and engineers. These jobs will be responsible for continually carrying out research, bringing innovation, developing and deploying state-of-the-art AI solutions suited to the construction industry, and ensuring these solutions carry out designated goals effectively and efficiently.

#### 4.3.2.4. AI and BIM with industry tools

The architecture, engineering, and construction (AEC) industry worldwide has adopted BIM as the current state-of-the-art . In the UK, the government mandated BIM level 2 for all publicly procured projects. However, despite efforts to make BIM a global standard, its adoption rate remains low . As a result, it is important to conduct relevant research to improve the adoption of BIM. For example, some studies have combined BIM applications with AI subfields like NLP to enhance the navigation of BIM interfaces. A study conducted by Styhre et al. (2006) on construction project work revealed that the nature of construction practice is heavily reliant on direct verbal and symbolic communication for sharing expertise and information. This may be because speech is one of the oldest and most natural forms of communication (Dutoit, 1997; Furui et al., 2004; Taylor, 2009). Integrating voice interaction with BIM will make it feel more natural and authentic to the construction industry. Other studies have also combined AI and BIM with other Industry 4.0 tools such as IoT, smart cities, augmented reality, blockchain, and quantum computing.

#### 4.3.3. Supply chain management (SCM)

A recent study conducted by Luo et al. aimed to investigate the factors that impact supply chain excellence and outcomes. The study found that issues such as lack of supply chain management (SCM) knowledge education and supply chain culture were significant barriers to supply chain excellence. Other hindering factors included lack of top-level buy-in and general understanding of supply chain, high cost of advanced IT for SCM, lack of unique and regional-specific performance measurement frameworks, lack of organizational trust, and ineffective communication channels between partners . AI techniques can be used to overcome these barriers to achieve excellence in the supply chain.

Tsang et al.  developed an IoT-based real-time risk monitoring system for controlling product quality and occupational safety risks in cold chains using wireless sensors network, cloud database services, and fuzzy logic. Barata et al. [90] indicated that real-time integration of decentralized supply chains is a top priority for European institutions, industries, and multinational consulting firms. Xiong et al.Sdeveloped a process specification language to improve supply chain communication for offsite construction.

To address the organizational trust and communication issues in construction supply chain, this study proposes the development of a decentralized supply chain knowledge management and monitoring system. Blockchain technology can be used to ensure the transparency and legitimacy of transactions, combined with the advanced analytics powered by AI. For instance, Mondragon et al. explored the applicability of blockchain to enhance manufacturing supply chain and found that it provides a tamper-proof history of product manufacturing and storage. AI can be used to manage the entire supply chain process, detect potential issues, and ensure timely and quality project delivery. Additionally, AI chatbots can be created for supply chain management systems to provide users with relevant information in a simple manner.

#### 4.3.4. Health and safety analytics

Health and Safety analytics (HSA) uses advanced data analytics techniques to predict and prevent occupational accidents in the workplace. Unfortunately, the construction industry has a higher rate of occupational injuries and deaths compared to other industries. This is due to the numerous on-site dangers such as working from heights, getting trapped, falling objects, equipment and tool hazards, exposure to dust and toxic materials, and hearing loss caused by noise. These risks could lead to long-term health problems, disability, or even death for workers. Employers may also face negative consequences such as loss of reputation, reduced productivity, increased insurance premiums, litigation, and claim costs. Therefore, it's essential to adopt a proactive approach using digital technologies like AI to anticipate and prevent accidents or health risks before they happen.

Some recent applications of AI in health and safety include BIM-based fall hazard identification and prevention, integration of sensor-based technologies with BIM to enhance construction safety, and wearable technology for construction safety monitoring. These technologies generate data that can be used in various construction stages with BIM to prevent and mitigate safety risks. However, to make relevant use of this data for predictive and proactive safety management, it is necessary to apply advanced AI techniques such as deep learning.

Winge et al. identified seven common factors causing construction accidents, including worker actions, risk management, immediate supervision, equipment and material usability, local hazards, worker capabilities, and project management. All of these factors can potentially be addressed using AI technologies such as robotics, computer vision, advanced data analytics, and optimization techniques when integrated with other digital technologies. Additionally, a more holistic system that integrates monitoring, visualization, notification, and action-taking would benefit the health and safety management process.

#### 4.3.5. AI-driven construction contract comprehension

Managing construction contracts can be complicated and involve multiple, extensive agreements that can lead to significant implications if errors are made, such as project delays, litigation costs, and loss of reputation. The challenge lies in the fact that current contract management is heavily dependent on humans, making it prone to errors, which is why automation is necessary to improve accuracy and speed up processes. AI can play a significant role in contract management by retrieving relevant information, drafting contracts, identifying potential disputes, and enforcing obligations. However, developing an AI-driven tool for contract management poses some challenges, such as implementing text summarization, which requires construction-specific training, and machine reading comprehension, which is a difficult task that researchers are working on. A holistic AI-driven contract management system can overcome these challenges by providing fast and accurate processing of construction contracts.

#### 4.3.6. AI-driven audit system for construction financials

Despite the construction industry generating huge economic outputs, firms within the industry still experience a high rate of insolvency. One reason for this could be that managing finances is particularly challenging for construction businesses due to the unique and lengthy nature of projects, which is crucial for project success. With multiple projects running simultaneously and employees and equipment moving between them, construction firms often have thin profit margins due to competitive bidding and overhead costs that are not accurately accounted for. Therefore, it is crucial to effectively track project and general overhead costs. The focus should not only be on delivering quality work but on proactive management of financial resources. Unfortunately, there are currently no AI-driven financial audit tools available to effectively track project costs and predict potential financial issues before they arise. To avoid bankruptcy, financial managers must proactively respond when a project is overspending or underspending and measure its overall impact on other projects and the entire business in real-time. This will guide the decisions of the firm's stakeholders and prevent financial problems from escalating.

## V. CHALLENGES

The study has highlighted the potential benefits and emerging developments of AI in construction processes. However, to enhance this field of expertise, it is crucial to recognize and address the major obstacles. Fig. 3 illustrates the opportunities, emerging trends, challenges, and unresolved research issues concerning the use of AI in the construction sector. The following six primary challenge areas impeding the implementation of AI in construction are identified.

### 5.1. Cultural issues and explainable AI

The construction industry is notorious for being slow to adopt new technologies and has a low level of digitization compared to other industries. This is largely due to the high risk and cost involved in construction processes, where even minor errors can have significant consequences. Traditional methods of construction are often preferred over newer, untested technologies that promise significant benefits [Babiˇc & Rebolj, 2016]. Consequently, the construction industry is slow to adopt innovative technologies, unlike the manufacturing sector. Moreover, construction sites are typically unique, requiring AI systems that can learn and adapt quickly to changing environments. AI technologies deployed in the construction industry must be adaptable to different construction projects or sites and thoroughly tested to convince contractors and businesses to use them. One approach to building trust and transparency in AI systems is to take advantage of other digital technologies such as blockchain. However, many machine learning systems use a black-box approach and do not explain how they reach conclusions. Therefore, to build trust, it is necessary to use explainable AI (XAI) to produce explainable models that allow humans to understand, trust and manage the systems. Some popular XAI approaches include local interpretable model-agnostic explanations (LIME) and layer-wise relevance propagation (LRP) [131]. Fig. 3 depicts the opportunities, emerging trends, challenges and open research issues of AI in the construction industry.

### 5.2. Security

Although AI has the potential to enhance security and identify intrusions, it is also highly vulnerable to exploitation by cybercriminals and poses a serious threat to privacy. This is a significant problem with substantial economic and financial consequences. Minor errors in construction processes can lead to significant repercussions, affecting the project's quality, cost, and duration, as well as its overall plan, such as supply chain and logistics. The safety of construction workers is also at risk, which could result in life-threatening accidents or fatalities. For instance, an AI system that recognizes automated construction equipment may be deceived into incorrectly labeling a construction worker working at height. The use of AI to control certain processes or augment construction workers' activities must be done with minimal security risks. This necessitates mitigation measures like adversarial machine learning, which involves developing machine learning techniques to resist attacks by an adversary. Additionally, further research is needed in this field, particularly in emerging technologies like computer vision and robotics that are being used in construction research.

### 5.3. Talent shortage

The construction industry faces a shortage of AI engineers who possess the necessary skills to lead meaningful advancements in the field . It is challenging to find AI engineers who have worked in construction and can develop customized solutions to address the industry's numerous challenges. To alleviate this issue, governments should invest more in STEM education. Additionally, construction professionals should collaborate with AI experts and researchers to exchange ideas and create novel solutions that effectively meet the demands of the construction industry.

### 5.4. High initial costs

The advantages of using AI-powered solutions in construction are undeniable. Nevertheless, the initial investment costs, such as robotics, are often exorbitant. Moreover, the maintenance requirements of these solutions need to be factored in. This could be unaffordable for most subcontractors and small companies that comprise the majority of the construction industry. Therefore, it is crucial for companies to evaluate the cost savings and ROI of these technologies to determine if they should invest or not. Furthermore, as these technologies become more commonplace and accepted in the construction industry, it is expected that prices will decrease, making them more affordable for smaller companies.

### 5.5. Ethics and governance

The construction industry can benefit greatly from AI-driven solutions, but it is crucial to establish a transparent and adaptable governance structure to gain public trust. Failure to regulate AI technologies properly can lead to dangerous consequences, such as a malfunctioning robot causing harm to workers on a busy construction site. Additionally, certain AI solutions could give an unfair advantage to some firms, making regulation imperative. Yu et al. identified four ethical areas of concern regarding the use of AI: exploring ethical dilemmas, individual ethical decision frameworks, collective ethical decision frameworks, and ethics in human-AI interactions. While some researchers advocate for building ethics into AI, others, such as Ref., propose a new field called "AI safety engineering." The development of AGI and ASI, which could surpass human thinking, is a major concern for accountability in AI governance. Governments, including the UK government, are taking steps to establish proper regulations for AI governance.

### 5.6. Computing power and internet connectivity

Construction sites are typically located in remote areas with limited access to power, telecommunications, and internet connectivity, which can cause significant challenges for the use of AI tools on these sites. This is especially true for robots and site monitoring systems that rely heavily on reliable internet connectivity and power supply. Interruptions in power and internet connectivity during construction activities exacerbate the problem, making it essential to find efficient and effective solutions. One way to address this challenge is through the use of 4G (LTE/max) communication technologies, which have been able to mitigate the issue to some extent. However, the emergence of 5G technology offers even greater reliability for construction sites, with advantages such as high data rates, reduced latency, energy savings, cost reductions, higher system capacity, and the ability to connect to massive devices.

## VI. CONCLUSION

AI is a promising solution to enhance productivity and overcome challenges in several industries, including construction. The construction industry faces significant challenges, and AI has the potential to harness data generated throughout the building lifecycle and utilize other digital technologies to enhance construction processes. To address research questions in this study, the authors conducted a comprehensive review of relevant research published over the past six decades in several construction application areas. The study adopted a qualitative approach through a database search using searches from the SCOPUS database, validated with data from three other digital journal databases, including Science Direct, IEEE, and ACM. The authors classified AI subfields into emerging, ripe, and mature fields in construction research, with computer vision, robotics, and NLP falling under emerging technologies, ML, automated planning, and scheduling as ripe technologies, and KBS and optimization as mature technologies. The study also designed a hype cycle to predict the duration to maturity of each subfield. Despite the several AI technologies applied in construction research, recent advances in those technologies have improved significantly, but the adoption of recent, more powerful AI technology has been relatively slow. For example, the use of deep learning has the potential to provide more accurate predictions than conventional ML techniques.

In addition, this research has identified and examined further opportunities and unresolved research issues for AI in the construction industry. Despite the gradual increase in the use of AI, its relevance is strengthened by the emergence of other trends such as BIM, IoT, quantum computing, augmented reality, cybersecurity, and blockchain. We have explored some of the challenges that hinder the adoption of AI in the industry and provided recommendations to address them. This study provides valuable information for researchers and practitioners regarding relevant AI applications and research in the construction industry. A clear understanding of the potential benefits and obstacles associated with the application of different subfields of AI has been presented in this study. Construction stakeholders, including regulatory bodies, decision-makers, high-skilled workers, and technology enthusiasts, can leverage the information presented in this study to define a clear path for AI implementation and mitigate potential risks.

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