Challenges and Strategies of Artificial Intelligence Application in Iran's Construction Industry: A Combination of Fuzzy ANP and QFD

Abstract

The lack of studies focusing on improving strategies for the application of Artificial Intelligence (AI) in the construction industry underscores a critical gap in research and practice. While there is growing interest in AI's potential to revolutionize construction processes, there remains a dearth of empirical studies and evidence-based approaches to guide its effective implementation. Without comprehensive investigations into the specific challenges and opportunities within the construction context, stakeholders may struggle to develop targeted strategies that address industry-specific needs and constraints. This paper examined the challenges and strategies for the application of AI in Iran's construction industry. Through a comprehensive analysis of the current state of AI adoption in construction management, significant challenges hindering its widespread integration have been identified using fuzzy ANP and experts' opinions, including the complexity of construction projects, limited technological infrastructure, and insufficient AI awareness and education. Drawing upon methodologies such as Quality Function Deployment (QFD), tailored strategies have been developed to address these obstacles and enhance AI application in construction management. Recommendations for future directions include continued investment in research and development, promotion of knowledge sharing and skills development, and establishment of supportive regulatory frameworks. By embracing these recommendations, Iran's construction industry can leverage AI to drive innovation, enhance productivity, and improve project outcomes, positioning itself at the forefront of AI-driven construction innovation.

Keywords: Artificial Intelligence, Construction Industry, Fuzzy ANP, QFD model

Introduction

Artificial Intelligence (AI) holds immense significance in the construction industry due to its potential to revolutionize traditional processes and drive efficiency, productivity, and sustainability. With the complexity inherent in construction projects, AI offers valuable capabilities to analyze vast amounts of data, optimize resource allocation, and streamline decision-making. By leveraging machine learning algorithms, predictive analytics, and automation, construction professionals can gain valuable insights into project performance, identify potential risks and opportunities, and make informed decisions to enhance project outcomes.

Moreover, AI technologies such as computer vision and drones enable real-time monitoring of construction sites, allowing for proactive identification of safety hazards, progress tracking, and quality control. This capability not only improves job site safety but also facilitates better project management and coordination among stakeholders. Additionally, AI-driven design and planning tools enable architects and engineers to optimize building designs for energy efficiency, cost-effectiveness, and environmental sustainability. Overall, the integration of AI in construction not only enhances operational efficiency and project delivery but also contributes to the development of smarter, more resilient built environments.

Within the architecture, engineering, and construction (AEC) sector, the field of construction engineering and management (CEM) is rife with unique issues and complexities. CEM encompasses a range of construction-related activities and processes as well as human elements and interactions (Jin et al, 2019). Due to its size, the construction industry contributes significantly to both long-term national development and economic growth (Giang & Pheng, 2011). Due to its intrinsic complexity, construction is thought to be one of the riskiest sectors. It is highly sensitive to a wide range of unpredictable events, including players in various positions, the environment's volatility and high level of unpredictability, the risk of being struck by equipment, and others (Sacks et al, 2009; Wang & Razavi, 2018; Pan & Zhang, 2021).

AI appears to offer a viable solution for issues that are too difficult for the human mind to handle, whether it be because of the sheer amount of data, the intricacy of the problem, or some other factor. Task volume issues are perceived as predetermined for computer applications, but complexity is a distinct concept. There are definitions of complexity provided (e.g., Liening, 2017; Eber and Zimmermann, 2018). They are mostly talking about a system's behavior that is best defined by the interactions of the entire interactive system rather than by its local attributes or next-neighbor interactions. This conduct is in opposition to the notion of location as emerging. Formerly, this duty was manageable, although it required some effort and wasn't always effective, as long as the number of building projects was restricted and there was a pretty precise division of contractual labor into crafts. Concurrently, there is a noticeable increase in the volume of construction and real estate projects, together with a tightening of financial and timing constraints, as shown in the case of huge turn-key buildings. This development suggests that construction management on this scale may be beyond the capabilities of the human intellect, as seen by the growing number of publicly recognized catastrophic projects (Förster, 1993). Simply put, construction management is the effective coordination of many individual or group participants with an equivalent number of technical construction parts, or, to put it more abstractly, virtual units like activities, services, and cost, along with their extensive web of nonlinear interactions (Schelle et al., 2005). Construction management's job would be to guide a system "construction project" toward a very specific objective in terms of time and expense, even if it is evident that the behavior of such a project is emergent (Caldarelli & Vespignani, 2007). Will artificial intelligence be able to handle this if human skills are exceeded? (Eber, 2020).

Long-term changes in construction will result from the IoT and AI technology combinations, which will open up new business prospects and income streams as well as new business models and organizational structures that leverage these technologies. Business models in the construction sector are predicted to change as a result of artificial intelligence in the areas of logistics, customer relationship management, support, workflow, automation, and finance. More AI may be used to create training scenarios that are more realistic, minimizing accidents and expensive errors while increasing operational efficiency. This can help with the skilled labor shortage by allowing operators to make better use of the workforce resources already in place (Monroe, 2018). As a result, the construction industry's digitization offers chances to complete large-scale projects on schedule and within budget (Patil, 2018; Patil, 2019).

Since each party engaged in a building project has specific aims for how they wish to use the money or other resources they receive, coordination may be challenging. A high degree of oversight and control results from this, and the bulk of the written records needed to document the various parties' transactions are produced as a result. The main cause of this is the parties' poor collaboration and communication. Sustaining a constant flow of information to several stakeholders, such as clients, designers, contractors, and subcontractors, is one of the most difficult tasks in the construction business. Information technology (IT) has been effectively utilized to encourage the integration of fragmented information in the context of remote building projects in order to get over this barrier. Throughout the various phases of a building's construction, several PMISs incorporate instruments for collaboration and synchronization. With the help of these technologies, team members may share, distribute, and organize project-related documents and drawings centrally, all while maintaining the archive in a secure and convenient location. They nevertheless fall short of providing sufficient standard formats for project-related papers and information for transactions between public owners and contractors, which are required to be more open, transparent, and equally available to all eligible bidders, and where the formality and security of the data transaction are more crucial than those pertaining to private projects (Korke et al., 2023). Moreover, fully integrated building systems are not very common. With such a system, users may interact with one another through real electronic collaboration since data could be moved across programs. In order to enable electronic work sharing and communication amongst geographically dispersed suppliers, partners, and collaborators, the idea of a virtual organization, or VO, was created. This is accomplished by replying to requests online, accessing a shared application from any location, and collecting necessary data on demand from a centralized database (Purdy & Daugherty, 2016). The objective of "Industry 4.0," which calls for a great deal more automation, productivity, and reliability, is driving the area of construction project management to become more intelligent and digital. This is being done in preparation for the impending "fourth industrial revolution." Put another way, there is a significant change taking place throughout the whole construction value chain, which includes O&M, preconstruction, construction, and post-construction phases. The objective of launching the actual digital strategies in Construction Project and Management (CPM) depends on artificial intelligence (AI), which is the foundation for changing the way a construction project is carried out. Within the field of computer science, artificial intelligence (AI) focuses on training robots to think like humans and learn new abilities via experience. This enables the computers to respond intelligently, deliberately, and adaptively to complex and confusing challenges. Artificial intelligence (AI) is expanding at an astonishing rate, with machine learning receiving a disproportionate amount of this funding. This is done to enable AI to first gather reliable and comprehensive data from a variety of sources, and then utilize the knowledge gleaned from this data to make intelligent and adaptable decisions (Chui & Francisco, 2017; Korke et al, 2023). Given that AI has the potential to greatly increase the efficiency, productivity, and competitiveness of the construction industry in Iran, it is critical to identify obstacles and develop strategies for its use. As AI technologies continue to evolve rapidly, understanding the unique obstacles and opportunities within Iran's construction landscape is crucial for successful implementation. By conducting comprehensive research on the specific challenges faced by Iranian construction firms, policymakers, and stakeholders, valuable insights can be gained to tailor AI solutions that address the industry's distinct needs and constraints. Furthermore, uncovering effective strategies for integrating AI into Iran's construction industry can unlock numerous benefits, including improved project management, enhanced quality control, and reduced costs. By identifying the most pressing challenges and developing targeted strategies, stakeholders can harness AI's transformative potential to drive innovation and modernization within the sector. Moreover, fostering collaboration between academia, government agencies, and industry players is essential to facilitate knowledge transfer, capacity building, and the development of AI-enabled tools and technologies tailored to Iran's construction context. Ultimately, finding solutions to the challenges of AI adoption in Iran's construction industry can pave the way for sustainable growth, increased competitiveness, and enhanced resilience in the face of evolving market dynamics.

Literature Review

Every nation's economic prosperity and stability are aided by the building sector. However, the industry's influence is constrained by the productivity issues. Improving production efficiency is the most difficult issue facing the global construction sector, since it ensures cost savings and effective resource use (Hwang et al., 2020; Thiyagu & Dheenadhayalan, 2015; Enshassi et al., 2007). As to Thiyagu and Dheenadhayalan (2015), productivity is a crucial aspect that affects the overall performance of any construction project. It has become a serious obstacle to the performance of construction operations (CIOB, 2016). Studies show that the construction industry frequently experiences subpar project execution. For example, low productivity is one of the major problems Turkish contractors have in Turkmenistan's construction sector (Durdyev et al., 2013). Project management teams and site managers place a lot of importance on the productivity level in the construction industry. Ingle and Mahesh (2020) state that the goal of the project management team is to successfully complete construction projects at all times. According to Mahamid (2020), construction productivity is important as it affects the schedule and cost goals of projects (Osuizugbo & Alabi, 2021).

Furthermore, the concept of artificial intelligence has since been linked to that of digital twins and the Internet of Things (Darko et al. 2020; Pan and Zhang, 2021; Sacks et al. 2020). From the reality capture (Scan-To-BIM) process to identifying the failures of reinforced concrete, the variety of applications is wide (Darko et al. 2020; Muñoz-La Rivera, et al. 2021; Pan and Zhang 2021; Sawhney et al. 2020). Additional applications include knowledge capture, autonomous cars and robotics, process optimization, process management, and generative design. However, in addition to the construction and infrastructure technological solutions, tests of Natural Language Processing were initiated to facilitate code checking and semi-automated scheduling applications (Zhou and El-Gohary 2021). Furthermore, AI can facilitate and assist cognitive and semi-autonomous buildings (Poleg, 2020). The majority of AI case studies in the construction sector still include R&D initiatives, and there aren't many case studies in the literature that show how AI is being applied in an industry where risks and benefits have been evaluated. Furthermore, according to Bolpagni et al. (2021) there is presently no guidance available for managing high-risk AI systems associated to the construction industry.

AI has several applications in the building process, including quality control, surveying, and equipment maintenance. (A) Surveying: According to Heikkinen and Kähkönen (2018), artificial intelligence (AI) may be used to analyze photos and data taken by drones and other surveying tools in order to produce 3D models and maps of building sites. These models may be used to track developments, anticipate possible problems, and plan and manage building operations. (B) Quality control: Artificial intelligence (AI) may be used to track building procedures and spot deviations from specifications. AI, for instance, may examine photos of a building site to find flaws in the materials or the craftsmanship, warning management of possible problems before they become serious ones. (C) Equipment upkeep: Artificial intelligence (AI) may be used to track the functionality and maintenance requirements of construction equipment. By analyzing data from sensors and other sources, artificial intelligence (AI) can forecast when equipment is likely to break, enabling maintenance personnel to proactively solve problems and minimize downtime (Breckling, 2012; Mohapatra et al, 2023).

In contrast to the design and engineering domains, the construction domain accounts for the majority of costs (85% on average) spent and utilized in the AEC business. It also has the greatest influence on the industry's long-term growth and economic expansion (Giang & Pheng, 2011). Even though the construction industry faces more difficulties and uses less AI than other industries (Rafsanjani & Nabizadeh, 2021; Young et al., 2021), AI has recently helped this industry address issues unique to the construction industry in order to improve efficiency and business and service operations. The following are the important contributions made by AI to the construction industry, which are detailed in (Abioye et al., 2021): In order to provide the best building plans for reducing cost and duration, artificial intelligence (AI) carefully monitors project duration and cost and forecasts probable construction issues. Optimizing discrete event simulation modeling is very beneficial for enhancing modeling and forecasting capacities in construction planning and scheduling procedures. AI also makes it easier to choose contractors and subcontractors and evaluates how well they adhere to the set goals. Additionally, AI can gather, evaluate, track, and store data from construction sites using cutting-edge technology. This allows for the real-time implementation of smart working environments, which improves quality, safety, cost, schedule, and site performance. Comparable to the architectural field, artificial intelligence (AI) enables the use of various text, picture, and graph-based tools to search through vast amounts of digitally preserved data in various file formats (such as reports, photographs, and videos), created by various employees of various construction projects, in order to extract the information relevant to a particular activity on a particular project site. AI is useful in the construction industry's health and safety management sector because it combines advanced rich data analytics with holistic techniques to effectively integrate sensing, detecting, and taking action to reduce occupational accidents and health concerns on construction sites. On a construction site, it might show erratic and abnormal behaviors from personnel, equipment, tools, and systems that can be hazardous, perplexing, and disruptive. Additionally, AI makes it possible to monitor sites, assess performance, manage equipment, and enhance proactive and predictive health and safety procedures by using robots, exoskeletons, and unmanned aerial vehicles (UAVs), particularly with regard to their highly automated technologies. In the building industry, AI also brought 3D printing to the forefront of task automation and resource conservation. In addition to these benefits, AI makes it possible to manage waste more accurately and evaluate sustainability, which helps to considerably lessen the negative impacts of the construction sector on the environment and natural resources (Rafsanjani & Nabizadeh, 2023).

Conducting a gap analysis of the existing literature on challenges and strategies for the application of AI in the construction industry reveals significant areas for further research and exploration. Despite the growing interest in AI technologies within the construction sector, there remains a noticeable gap in the literature concerning the specific challenges encountered during the implementation of AI solutions in construction projects, particularly in the context of emerging markets like Iran. Existing studies often focus on developed economies and may not adequately address the unique socio-cultural, economic, and regulatory factors that influence AI adoption in Iran's construction industry. As such, there is a need for empirical research that systematically identifies and analyzes the challenges faced by Iranian construction firms and stakeholders when integrating AI technologies into their operations. Moreover, the gap analysis highlights a dearth of comprehensive frameworks and strategies for effectively deploying AI in the construction industry, especially in the Iranian context. While some studies offer insights into general principles and best practices for AI implementation, there is a lack of tailored guidance and actionable recommendations specific to the challenges and opportunities within Iran's construction landscape. Furthermore, existing literature often overlooks the importance of stakeholder collaboration, capacity building, and policy support in facilitating successful AI adoption in the construction sector. Therefore, future research efforts should aim to develop robust frameworks and evidence-based strategies that address the unique needs and priorities of Iranian construction firms, policymakers, and industry stakeholders, ultimately advancing the understanding and implementation of AI in the context of Iran's construction industry.

Research Methods

The methodology employed in this paper involved a systematic approach to identify, prioritize, and address challenges associated with the application of AI in Iran's construction industry. The first step involved extracting AI challenges specific to Iran's construction sector through expert consultations and interviews with industry professionals (12 Experts). Drawing upon the insights and expertise of construction practitioners, engineers, and researchers familiar with the Iranian construction landscape, a comprehensive list of challenges related to AI adoption was compiled.

Subsequently, the prioritization of these identified challenges was carried out using the Fuzzy Analytic Network Process (Fuzzy ANP) methodology. Fuzzy ANP is a powerful decision-making technique that enables the handling of uncertainty and ambiguity in complex decision environments, making it suitable for prioritizing multifaceted challenges in the construction industry. Through pairwise comparisons, the relative importance of each challenge criterion was assessed, taking into account the opinions and expertise of the expert panel. Following the prioritization of AI challenges, the next phase of the methodology involved the development of strategies to address the identified challenges. This was accomplished through the application of Quality Function Deployment (QFD) and House of Quality (HOQ) methodologies. QFD is a structured approach for translating requirements into specific product, service or strategies characteristics, while HOQ is a graphical tool used to organize and prioritize these characteristics based on their relationship to initial needs.

Utilizing QFD and HOQ, the identified AI challenges were mapped to corresponding improvement strategies aimed at mitigating their impact and enhancing AI adoption in Iran's construction industry. This process involved cross-functional collaboration among stakeholders, including construction professionals, AI experts, and policymakers, to ensure that the proposed strategies were aligned with the specific needs and priorities of the Iranian construction sector. Furthermore, the effectiveness and feasibility of the developed strategies were evaluated through rigorous analysis and validation exercises. This included assessing the potential costs, benefits, and resource requirements associated with each strategy, as well as considering the organizational capabilities and constraints of construction firms in implementing these strategies.

Finally, the results of the methodology were synthesized and presented in a clear and structured manner, providing actionable insights and recommendations for stakeholders seeking to leverage AI technologies to drive innovation and improve project outcomes in Iran's construction sector. By integrating expert opinions, quantitative analysis techniques, and collaborative decision-making approaches, the methodology employed in this paper offers a comprehensive framework for addressing AI challenges and fostering sustainable AI adoption in the construction industry.

Results

The process of interviewing experts to uncover challenges associated with the application of AI in Iran's construction industry involved a systematic approach to gathering insights and perspectives from key stakeholders within the sector. Firstly, a diverse panel of experts comprising construction practitioners, engineers, researchers, and policymakers was identified based on their expertise and experience in AI and construction. These experts were selected to represent various segments of the construction industry, including contractors, architects, project managers, and government officials, ensuring a comprehensive understanding of the challenges faced across different roles and domains.

Once the expert panel was assembled, structured interviews were conducted to elicit their opinions and insights on the challenges and barriers hindering the effective adoption of AI technologies in Iran's construction industry. The interviews were designed to explore a wide range of topics, including the current state of AI adoption, perceived challenges, technological barriers, regulatory constraints, and opportunities for innovation. Open-ended questions were used to encourage in-depth discussion and allow experts to share their perspectives on the complexities and nuances of AI implementation in the Iranian construction context. Through these interviews, valuable insights were gathered, providing a rich and nuanced understanding of the multifaceted challenges confronting AI adoption in Iran's construction industry.

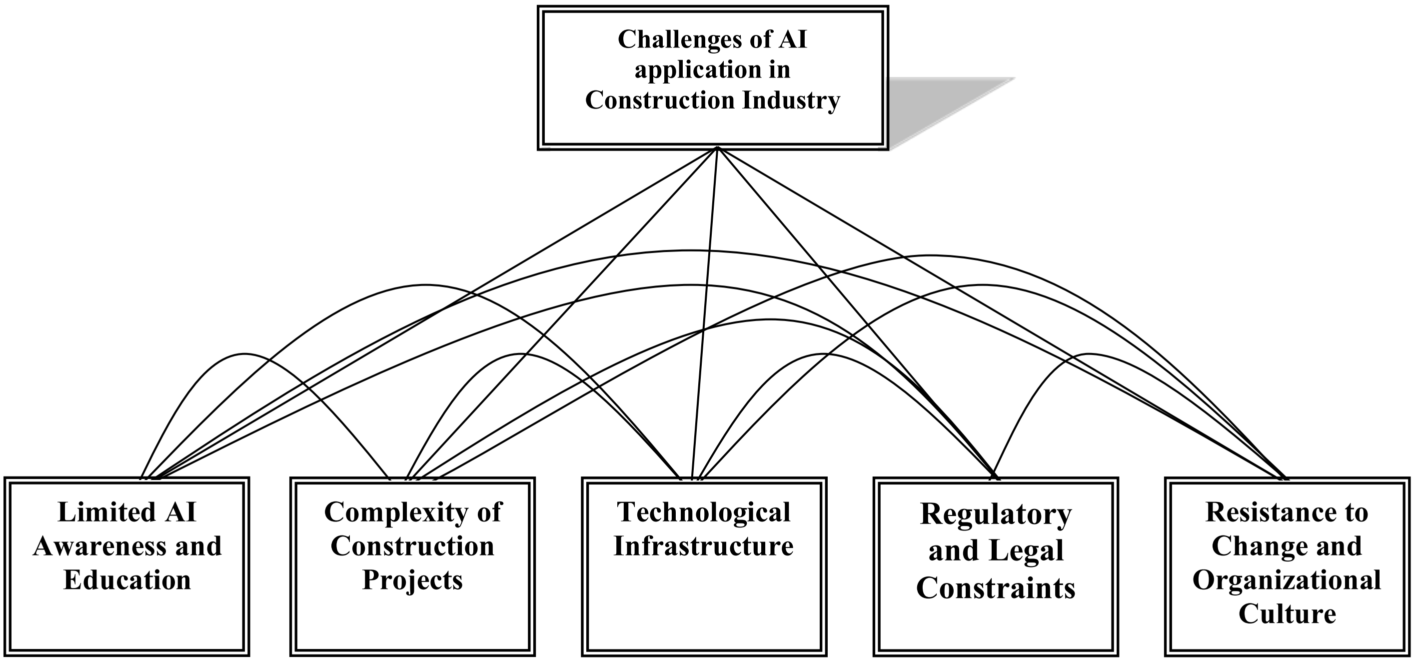


Figure 1: Challenges of AI application in construction Industry

Limited AI Awareness and Education:

- Lack of awareness among construction professionals about the potential benefits and applications of AI.
- Inadequate training programs and educational initiatives focused on AI technologies in construction.
- Low adoption of AI-related courses and certifications in academic institutions offering construction-related programs.

Complexity of Construction Projects:

- Inherent complexity and variability of construction projects, making it challenging to develop AI models that can accurately predict outcomes.
- Multi-disciplinary nature of construction projects requiring integration of diverse data types and expertise from various domains.
- Dynamic and unpredictable project environments with evolving requirements, constraints, and stakeholder preferences.

Technological Infrastructure:

- Inadequate technological infrastructure and IT systems to support AI deployment and integration within construction organizations.
- Limited access to computing resources, cloud services, and high-performance computing clusters for AI model development and deployment.

- Compatibility issues with existing software tools and platforms used in the construction industry, hindering seamless integration of AI solutions.

Regulatory and Legal Constraints:

- Lack of clear regulatory frameworks and standards governing the use of AI technologies in construction projects.
- Uncertainty surrounding liability, accountability, and intellectual property rights related to AI-generated outcomes and decisions.
- Compliance challenges with data protection regulations and privacy laws when collecting, storing, and processing construction data for AI applications.

Resistance to Change and Organizational Culture:

- Resistance to change among construction professionals and stakeholders accustomed to traditional methods and practices.
- Cultural barriers to adopting AI technologies, including skepticism, fear of job displacement, and reluctance to embrace automation.
- Organizational inertia and bureaucracy inhibiting the adoption of innovative technologies and processes in construction firms.

Addressing these challenges and sub-criteria is crucial for successful AI application in construction industry. By understanding and prioritizing these dimensions, construction managers can develop tailored strategies and practices to enhance AI application, foster innovation, and ensure the timely and successful delivery of construction projects.

In order to gather the experts' opinions, we calculated the geometric mean of the respondents' pairwise comparisons. The following table shows the geometric mean of the opinions of the expert’s team regarding the comparison of five challenges.

Table 1: The geometric mean of the pairwise comparisons of each of the five challenges in relation to the main target

Prioritization of challenges	Resistance to Change and Organizational Culture	Regulatory and Legal Constraints	Technological Infrastructure	Complexity of Construction Projects	Limited AI Awareness and Education
Resistance to Change and Organizational Culture	(1, 1, 1)	(2.52, 2.14, 1.82)	(0.73, 0.59, 0.49)	(1.26, 1, 0.8)	(0.35, 0.31, 0.28)
Regulatory and Legal Constraints	(0.56, 0.47, 0.4)	(1, 1, 1)	(0.7, 0.53, 0.4)	(1.59, 1.22, 0.88)	(0.25, 0.24, 0.22)
Technological Infrastructure	(2.09, 1.71, 1.39)	(2.52, 1.92, 1.45)	(1, 1, 1)	(0.91, 0.7, 0.56)	(0.32, 0.29, 0.26)
Complexity of Construction Projects	(1.26, 1, 0.8)	(1.15, 0.83, 0.63)	(1.82, 1.45, 1.11)	(1, 1, 1)	(0.32, 0.29,0 .26)
Limited AI Awareness and Education	(3.64, 3.28, 2.89)	(4.65, 4.33, 4)	(3.92, 3.56, 3.18)	(3.92, 3.56, 3.18)	(1, 1, 1)

Then, in order to obtain the matrix, we must first calculate the geometric mean of each of the tables of pairwise comparisons of the five challenges. Tables (2-7) show the geometric mean of these comparisons.

Table 2: Geometric mean of pairwise comparisons of landscapes relative to (Resistance to change and organizational culture)

Resistance to Change and Organizational Culture	Regulatory and Legal Constraints	Technological Infrastructure	Complexity of Construction Projects	Limited AI Awareness and Education
Regulatory and Legal Constraints	(1, 1, 1)	(1.42, 1.19, 1)	(1.23, 1, 0.82)	(0.82, 0.66, 0.5)
Technological Infrastructure	(1, 0.85, 0.71)	(1, 1, 1)	(1.74, 1.3, 1)	(0.25, 0.2, 0.17)
Complexity of Construction Projects	(1.23, 1, 0.82)	(1, 0.78, 0.58)	(1, 1, 1)	(1, 0.78, 0.58)
Limited AI Awareness and Education	(2, 1.53, 1.23)	(6, 5, 4)	(1.74, 1.3, 1)	(1, 1, 1)

Table 3: Geometric mean of pairwise comparisons of landscapes relative to (Regulatory and Legal Constraints)

Regulatory and Legal Constraints	Resistance to Change and Organizational Culture	Technological Infrastructure	Complexity of Construction Projects	Limited AI Awareness and Education
Resistance to Change and Organizational Culture	(1, 1, 1)	(0.87, 0.75, 0.64)	(1, 0.85, 0.71)	(0.21, 0.17, 0.15)
Technological Infrastructure	(1.59, 1.35, 1.16)	(1, 1, 1)	(5.66, 4.59, 3.47)	(1.23, 1, 0.82)
Complexity of Construction Projects	(1.42, 1.19, 1)	(0.29, 0.22, 0.18)	(1, 1, 1)	(1.23, 1, 0.82)
Limited AI Awareness and Education	(6.93, 5.92, 4.9)	(1.23 ,1, 0.82)	(1.23 ,1, 0.82)	(1, 1, 1)

Table 4: Geometric mean of pairwise comparisons of landscapes relative to (Technological Infrastructure)

Technological Infrastructure	Resistance to Change and Organizational Culture	Regulatory and Legal Constraints	Complexity of Construction Projects	Limited AI Awareness and Education
Resistance to Change and Organizational Culture	(1, 1, 1)	(0.25, 0.2, 0.17)	(0.21, 0.17, 0.15)	(0.5, 0.45, 0.41)
Regulatory and Legal Constraints	(6, 5, 4)	(1, 1, 1)	(1.42, 1, 0.71)	(1.23, 1, 0.82)
Complexity of Construction Projects	(6.93, 5.92, 4.9)	(1.42, 1, 0.71)	(1, 1, 1)	(0.36, 0.26, 0.21)
Limited AI Awareness and Education	(2.45, 2. 24,2)	(1.23, 1, 0.82)	(4.9, 3.88, 2.83)	(1, 1, 1)

Table 5: Geometric mean of pairwise comparisons of landscapes relative to (Complexity of Construction Projects)

Complexity of Construction Projects	Resistance to Change and Organizational Culture	Regulatory and Legal Constraints	Technological Infrastructure	Limited AI Awareness and Education
Resistance to Change and Organizational Culture	(1, 1, 1)	(0.5, 0.34, 0.25)	(0.29, 0.22, 0.18)	(0.5, 0.34, 0.25)
Regulatory and Legal Constraints	(4, 3, 2)	(1, 1, 1)	(0.5, 0.45, 0.41)	(2, 1.74, 1.42)
Technological Infrastructure	(5.66, 4.59, 3.47)	(2.45, 2.24, 2)	(1, 1, 1)	(4.9, 3.88, 2.83)
Limited AI Awareness and Education	(4, 3, 2)	(0.71, 0.58, 0.5)	(0.36, 0.26, 0.21)	(1, 1, 1)

Table 6: Geometric mean of pairwise comparisons of landscapes relative to (Limited awareness and education)

Limited AI Awareness and Education	Resistance to Change and Organizational Culture	Regulatory and Legal Constraints	Technological Infrastructure	Complexity of Construction Projects
Resistance to Change and Organizational Culture	(1, 1, 1)	(5.66, 4.59, 3.47)	(1, 0.85, 0.71)	(0.25, 0.2, 0.17)
Regulatory and Legal Constraints	(0.29, 0.22, 0.18)	(1, 1, 1)	(0.25, 0.2, 0.16)	(0.25, 0.2, 0.17)
Technological Infrastructure	(1.42, 1.19, 1)	(6.33, 5.2, 4)	(1, 1, 1)	(1, 0.78, 0.58)
Complexity of Construction Projects	(6, 5, 4)	(6, 5, 4)	(1.74, 1.3, 1)	(1, 1, 1)

Table 7: First matrix of five challenges

	Resistance to Change and Organizational Culture	Regulatory and Legal Constraints	Technological Infrastructure	Complexity of Construction Projects	Limited AI Awareness and Education
Resistance to Change and Organizational Culture	(0, 0, 0)	(0.15, 0.13, 0.12)	(0.09, 0.08, 0.07)	(0.11, 0.08, 0.07)	(0.22, 0.19, 0.16)
Regulatory and Legal Constraints	(0.26, 0.22, 0.19)	(0, 0, 0)	(0.39, 0.32, 0.27)	(0.29, 0.25, 0.21)	(0.08, 0.06, 0.06)
Technological Infrastructure	(0.19, 0.16, 0.14)	(0.42, 0.36, 0.31)	(0, 0, 0)	(0.58, 0.51, 0.43)	(0.34, 0.29, 0.25)
Complexity of Construction Projects	(0.25, 0.21, 0.17)	(0.2, 0.17, 0.14)	(0.3, 0.24, 0.2)	(0, 0, 0)	(0.56, 0.47, 0.4)
Limited AI Awareness and Education	(0.5, 0.42, 0.35)	(0.41, 0.36, 0.31)	(0.42, 0.37, 0.32)	(0.21, 0.17, 0.14)	(0, 0, 0)

Table 8: Second matrix of five challenges

	Resistance to Change and Organizational Culture	Regulatory and Legal Constraints	Technological Infrastructure	Complexity of Construction Projects	Limited AI Awareness and Education
Resistance to Change and Organizational Culture	(1.17 ,0.87, 0.65)	(1.48, 1.14, 0.88)	(1.22, 0.92, 0.69)	(1.26, 0.95, 0.7)	(0.32, 0.26, 0.22)
Regulatory and Legal Constraints	(1.68, 1.21, 0.87)	(2.28, 1.55, 1.06)	(1.37, 1.02, 0.75)	(1.24, 0.91, 0.67)	(0.38, 0.29, 0.23)
Technological Infrastructure	(2.38, 1.78, 1.3)	(3.13, 2.37, 1.79)	(2.81, 2.05, 1.43)	(2.8, 2.13, 1.57)	(0.7, 0.57, 0.46)
Complexity of Construction Projects	(2.96, 2.22, 1.63)	(4.11, 3.08, 2.3)	(2.76, 2.11, 1.58)	(3.04, 2.23, 1.61)	(0.78, 0.64, 0.52)
Limited AI Awareness and Education	(1.85, 1.38, 1.02)	(2.96, 2.08, 1.48)	(1.43, 1.04, 0.76)	(1.86, 1.27, 0.86)	(0.48, 0.36, 0.28)

Table 9: Fuzzy weight of each of the five scenes

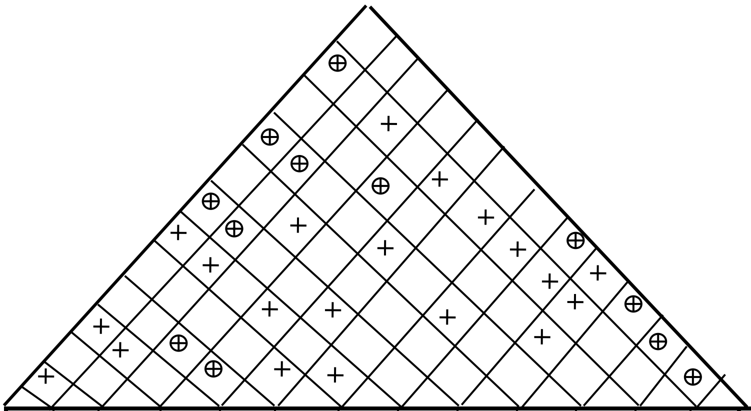
$\left(\prod_{j=1}^{5} a_{kj}^{s}\right)^{1/5} \quad s \in \{l, m, u\}$			$w_k^s = \dfrac{\left(\prod_{j=1}^{5} a_{kj}^{s}\right)^{1/5}}{\sum_{i=1}^{5}\left(\prod_{j=1}^{5} a_{kj}^{m}\right)^{1/5}}$			**Fuzzy weight**
l	**m**	**u**	**l**	**m**	**u**	
0.566	0.737	0.959	0.093	0.121	0.158	(0.16, 0.13, 0.1)
0.633	0.867	1.190	0.104	0.143	0.196	(0.2, 0.15, 0.11)
1.184	1.595	2.094	0.195	0.262	0.344	(0.35, 0.27, 0.2)
1.375	1.826	2.395	0.226	0.300	0.394	(0.4, 0.31, 0.23)
0.766	1.059	1.467	0.126	0.174	0.241	(0.25, 0.18, 0.13)
	6.084					

According to the results, (Complexity of Construction Projects, Technological Infrastructure, Limited AI Awareness and Education) explain most weight of challenges. Now it is important to analysis strategies for improvement.

The filling process of the House of Quality (HOQ) in the Quality Function Deployment (QFD) model for extracting strategies to improve AI application in the construction industry involves a systematic and collaborative approach. Firstly, cross-functional teams comprising construction professionals, AI experts, and stakeholders are assembled to participate in the HOQ filling process. These teams bring together diverse perspectives, domain knowledge, and technical expertise necessary for identifying and prioritizing improvement strategies.

During the HOQ filling process, the teams begin by translating the identified challenges and requirements into specific strategies and performance metrics. This involves mapping each challenge identified in the earlier stages of the research to corresponding technical requirements and specifications. Subsequently, the teams evaluate the interrelationships between the identified challenges and potential improvement strategies, considering factors such as feasibility, effectiveness, and resource requirements. Through iterative discussions, brainstorming sessions, and consensus-building exercises, the teams prioritize improvement strategies that address the most critical challenges and align with the overarching goals of AI application in the construction industry. The filled HOQ serves as a comprehensive framework for guiding decision-making and action planning, facilitating the development and implementation of targeted strategies to enhance AI adoption and drive innovation in the construction sector.

Figure 2: House of Quality for improvement strategies based on three main challenges



	Investment in AI Education and Training	Data Collection and Integration	AI-Driven Design and Planning	Predictive Maintenance and Asset Management	Safety Monitoring and Risk Prediction	Smart Construction Materials and Technologies	Supply Chain Optimization	Quality Control and Defect Detection	Collaborative Construction Planning and Coordination	Energy Efficiency and Environmental Sustainability	Remote Monitoring and Control	Regulatory Compliance and Legal Risk Management	Continuous Improvement and Innovation	Importance degree	Current situation of Construction Industry in Iran	Current situation of Construction Industry in competing countries
Technological Infrastructure	9	3	9	3	3	7	9	3	5	3	5	9	7	0.349	3.9	4.3
Complexity of Construction Projects	3	5	7	9	7	9	3	3	3	9	9	7	9	0.35	3.6	4.1
Limited AI Awareness and Education	9	7	5	7	9	5	3	5	5	7	9	9	5	0.301	3.4	3.8
The degree of difficulty	2.1	2.2	4.3	3.8	2.7	2.5	3.5	3.3	4.6	2.1	4.3	4.7	3.9			
The cost of achieving the goal	2.1	2.5	4.5	4.4	2.7	2.3	4.1	2.1	2.3	3.5	4.2	4.5	4.3			
Iran's situation in the amount of efforts to implement the strategy	1.3	1.4	2.1	2.6	2.3	1.8	2.1	1.4	1.7	2.4	1.2	1.5	1.1			
Competitors situation in the amount of efforts to implement the strategy	1.7	2.2	2.9	3.2	2.4	2.1	2.5	1.6	2.1	2.1	1.1	1.3	1.2			
Absolute weight	7	5	7	6	6	7	5	4	4	6	8	8	7	81		
Relative weight (percentage)	9	6	9	8	8	9	6	4	5	8	9	10	9	100%		

The implementation of improvement strategies for challenges in construction management yielded significant and positive results. Through QFD, strategies to address challenges like the complexity of construction projects, technological infrastructure limitations, and limited AI awareness and education can be systematically developed for enhanced AI application in the construction industry of Iran. For instance, to tackle the complexity of construction projects, QFD helps identify strategies such as implementing AI-based project management tools to streamline workflows, optimize resource allocation, and mitigate risks associated with project variability. These strategies are directly linked to addressing the specific needs and priorities of construction stakeholders, ensuring alignment with overarching goals for AI adoption.

Secondly, QFD enables the prioritization of improvement strategies based on their impact and feasibility in addressing the identified challenges. For instance, in addressing technological infrastructure limitations, strategies such as investing in cloud computing infrastructure or establishing partnerships with technology providers can be prioritized based on their potential to improve data accessibility, scalability, and interoperability. Furthermore, QFD encourages cross-functional collaboration and stakeholder engagement throughout the strategy development process, ensuring that the perspectives and insights of construction professionals, IT experts, and policymakers are incorporated into the decision-making process. By systematically mapping requirements to improvement strategies and prioritizing actions based on their potential impact and feasibility, QFD facilitates the development of targeted and actionable strategies for overcoming challenges and driving successful AI application in Iran's construction industry.

Discussion and conclusion

This study has examined the significant challenges hindering the effective adoption of AI in the construction management domain of Iran, and proposed strategies to address these obstacles. Through a comprehensive analysis, it was revealed that challenges such as the complexity of construction projects, limited technological infrastructure, and insufficient AI awareness and education are impeding the widespread integration of AI technologies in the construction industry. These challenges pose significant barriers to innovation, efficiency, and competitiveness within the sector. However, through the application of QFD, tailored strategies have been developed to mitigate these challenges and enhance AI application in construction management.

The strategies proposed in this paper offer actionable insights for construction stakeholders, policymakers, and industry leaders seeking to leverage AI technologies to drive innovation and improve project outcomes. By addressing key challenges and harnessing the potential of AI, construction firms can unlock new opportunities for efficiency gains, cost savings, and sustainability. Moving forward, it is imperative for construction organizations to embrace a culture of innovation, invest in workforce development, and foster collaboration across disciplines to realize the full potential of AI in construction management. Through concerted efforts and strategic initiatives, the construction industry of Iran can position itself at the forefront of AI-driven innovation, driving sustainable growth and development in the years to come. Here are 13 strategies for improving AI applications in the construction industry of Iran:

1. Investment in AI Education and Training:

Establish training programs and workshops to enhance awareness and understanding of AI technologies among construction professionals.

Collaborate with educational institutions to develop specialized AI courses and certifications tailored to the needs of the construction industry.

2. Data Collection and Integration:

Implement data collection strategies to gather high-quality and relevant construction data from various sources, including sensors, IoT devices, and project management systems.

Develop data integration frameworks to consolidate heterogeneous data sources and create unified datasets for AI model training and analysis.

3. AI-Driven Design and Planning:

Leverage AI technologies such as generative design and optimization algorithms to automate and optimize building design processes for energy efficiency, cost-effectiveness, and sustainability.

Utilize AI-powered planning tools to optimize project scheduling, resource allocation, and risk management in construction projects.

4. Predictive Maintenance and Asset Management:

Deploy AI-based predictive maintenance systems to monitor equipment health, detect potential failures, and schedule maintenance activities proactively.

Implement AI-driven asset management solutions to optimize the lifecycle performance of construction assets and infrastructure.

5. Safety Monitoring and Risk Prediction:

Use computer vision and sensor technologies to monitor job site safety and identify potential hazards in real-time, enabling proactive intervention and risk mitigation.

Develop AI models for predicting and assessing construction project risks, including schedule delays, cost overruns, and safety incidents.

6. Smart Construction Materials and Technologies:

Explore the use of AI-powered materials and technologies, such as self-healing concrete and 3D printing, to improve construction efficiency, durability, and sustainability.

Investigate the application of AI algorithms for optimizing material selection, procurement, and usage in construction projects.

7. Supply Chain Optimization:

Implement AI-driven supply chain management systems to optimize procurement, inventory management, and logistics operations in the construction industry.

Utilize predictive analytics and machine learning algorithms to forecast material demand, minimize lead times, and reduce supply chain disruptions.

8. Quality Control and Defect Detection:

Deploy AI-powered image recognition systems and automated inspection tools to detect defects, deviations, and quality issues in construction materials and finished products.

Integrate AI-driven quality control processes into construction workflows to ensure compliance with regulatory standards and project specifications.

9. Collaborative Construction Planning and Coordination:

Utilize AI-enabled collaboration platforms and project management tools to facilitate communication, coordination, and information sharing among project stakeholders.

Implement AI-driven decision support systems to optimize resource allocation, resolve conflicts, and streamline decision-making processes in construction projects.

10. Energy Efficiency and Environmental Sustainability:

Develop AI-based energy management systems to optimize building energy consumption, reduce carbon emissions, and enhance environmental sustainability in construction projects.

Leverage AI algorithms for analyzing environmental impact assessments, conducting life cycle assessments, and implementing green building strategies.

11. Remote Monitoring and Control:

Deploy AI-powered remote monitoring and control systems to enable real-time monitoring of construction activities, equipment performance, and environmental conditions from remote locations.

Integrate AI-driven automation and robotics technologies to enhance productivity, efficiency, and safety in remote construction sites and hazardous environments.

12. Regulatory Compliance and Legal Risk Management:

Implement AI-driven compliance monitoring systems to ensure adherence to regulatory requirements, codes, and standards governing construction operations.

Utilize AI-based risk assessment tools to identify, evaluate, and mitigate legal and regulatory risks associated with construction projects, contracts, and operations.

13. Continuous Improvement and Innovation:

Foster a culture of innovation and continuous improvement by incentivizing experimentation, knowledge sharing, and collaboration among construction industry stakeholders.

Establish mechanisms for collecting feedback, measuring performance, and iteratively refining AI applications to adapt to evolving industry needs and technological advancements.

Looking ahead, several recommendations and directions can be proposed to further advance the application of AI in Iran's construction industry. Firstly, there is a need for continued investment in research and development to drive innovation and technological advancement in AI specifically tailored to the challenges and opportunities within the Iranian construction context. This includes fostering collaboration between academia, industry, and government agencies to support interdisciplinary research initiatives, develop cutting-edge AI solutions, and address industry-specific challenges. Additionally, efforts should be made to promote knowledge sharing, capacity building, and skills development to ensure a workforce that is equipped with the necessary expertise to effectively utilize AI technologies in construction projects. This can be achieved through the development of specialized training programs, workshops, and certification courses focused on AI applications in construction management, engineering, and design. Furthermore, policymakers and industry stakeholders should work collaboratively to establish supportive regulatory frameworks, standards, and incentives that facilitate the responsible and ethical deployment of AI in the construction industry, while also addressing concerns related to data privacy, security, and liability. By embracing these recommendations and fostering a culture of innovation and collaboration, Iran's construction industry can harness the transformative power of AI to drive sustainable growth, enhance productivity, and improve project outcomes.

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