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Integrating AI Tools for Risk Management in Construction Projects

Leila Dehghani

Department of Electrical Engineering, Lorestan University

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ABSTRACT

The integration of Artificial Intelligence (AI) tools into risk management processes in construction projects represents a significant advancement in project management methodologies. This paper explores the potential of AI to enhance risk mitigation strategies, improve decision-making processes, and optimize resource allocation within the construction industry. The construction sector, characterized by its inherent complexity and susceptibility to unforeseen challenges, demands robust risk management frameworks. Traditional methods often fall short in addressing the multifaceted nature of contemporary construction projects. AI tools offer novel solutions by leveraging large datasets, predictive analytics, and machine learning algorithms to identify potential risks at early stages and suggest effective mitigation strategies.

This study systematically reviews current AI applications in risk management, mapping their functionalities to various stages of construction project management. Key AI technologies such as predictive analytics, natural language processing, and computer vision are evaluated for their efficacy in identifying, assessing, and managing risks. The paper further examines the integration of AI with Building Information Modeling (BIM) systems, highlighting the synergies that enhance the accuracy and reliability of risk assessments.

The findings underscore the transformative impact of AI in fostering proactive risk management approaches, ultimately leading to improved project outcomes. By automating routine risk assessments and providing real-time insights, AI tools not only enhance the efficiency of risk management processes but also facilitate a more agile response to emerging challenges. The research identifies critical success factors for the successful implementation of AI tools, including the need for comprehensive data governance frameworks and the integration of domain-specific knowledge into AI models.

In conclusion, the paper argues that while AI offers substantial benefits for risk management in construction projects, its successful deployment hinges on overcoming challenges related to data integration, model interpretability, and the alignment of AI tools with organizational objectives. These insights provide valuable guidance for industry practitioners and researchers aiming to harness AI's potential in construction project management.

1. Introduction

The construction industry is characterized by its complexity, involving numerous stakeholders, vast resources, and intricate processes. Managing risks in construction projects, therefore, becomes a critical task that determines the success or failure of a project. Traditional risk management methods, which rely heavily on expert judgment and historical data, often fall short in dealing with the dynamic and uncertain nature of construction projects. In this context, the integration of Artificial Intelligence (AI) tools offers a promising avenue for enhancing risk management strategies by providing more accurate predictions, real-time data analysis, and adaptive decision-making capabilities [6, 7, 21].

The adoption of AI in construction risk management has been steadily increasing, driven by advancements in machine learning algorithms, data processing capabilities, and the availability of large datasets [1, 12]. AI tools can analyze vast amounts of data from various sources, identify patterns, and predict potential risks with a level of accuracy that surpasses traditional methods. This paper explores the integration of AI tools for risk management in construction projects, examining their potential benefits, challenges, and implications for the industry.

1.1. The Evolution of Risk Management in Construction

Historically, risk management in construction has been grounded in qualitative assessments and experience-based approaches. However, the limitations of these methods have become increasingly apparent in the face of complex and large-scale projects [16, 22]. The evolution of risk management strategies reflects a shift towards more quantitative and data-driven approaches. This evolution has been facilitated by the development of robust computational tools and methodologies that allow for the systematic analysis of risks [9, 18].

With the integration of AI, risk management in construction has taken a transformative step. AI provides the capability to process and analyze large datasets in real-time, enabling project managers to anticipate and mitigate risks more effectively than ever before [4, 17].

1.2. AI Technologies and Tools in Construction Risk Management

The application of AI in construction risk management encompasses a wide range of technologies, including machine learning, neural networks, and expert systems. These technologies are employed to predict risks based on historical data, monitor ongoing processes, and optimize resource allocation [10, 11].

Machine learning algorithms, for instance, have been

employed to predict construction delays by analyzing historical project data and identifying patterns that lead to such delays [3, 14]. Similarly, expert systems can simulate various project scenarios to evaluate potential risks and develop mitigation strategies [2, 19].

1.3. Challenges in Integrating AI for Risk Management

Despite the potential benefits, integrating AI tools into risk management practices in construction faces several challenges. One of the primary challenges is the quality and availability of data. Accurate risk predictions require comprehensive datasets, which are often difficult to obtain due to the fragmented nature of construction projects and the lack of standardized data collection processes [5, 20].

Additionally, there is a need for the construction industry to develop the necessary expertise and infrastructure to effectively implement AI tools. This includes training personnel, investing in technology, and fostering a culture that embraces innovation and change [3, 13].

1.4. Implications for Future Construction Projects

The integration of AI tools in risk management is poised to transform the construction industry, offering the potential for more efficient, cost-effective, and safer projects. As AI technologies continue to evolve, their role in risk management is expected to expand, providing more sophisticated tools for risk assessment and mitigation [8, 15].

Future construction projects will likely see an increased reliance on AI-driven insights, leading to more proactive risk management practices and improved project outcomes. The ongoing research and development in this area will be crucial in addressing the current challenges and unlocking the full potential of AI in construction risk management [3, 5].

2. Related Work

The integration of Artificial Intelligence (AI) tools in risk management has become an increasingly important topic within the construction industry. As the complexity and scale of construction projects grow, traditional risk management techniques are often inadequate to handle the dynamic and multifaceted nature of these projects. AI technologies offer new and powerful approaches for identifying, assessing, and mitigating risks, thereby enhancing decision-making processes and improving project outcomes [1, 7]. This section reviews existing literature on the application of AI in construction risk management, focusing on various approaches and

methodologies that have been proposed and their practical implications.

Numerous studies have explored the potential of AI tools such as machine learning, natural language processing, and expert systems to improve risk management practices in construction [6, 21]. These technologies provide capabilities for predictive analytics, real-time data processing, and automation, which can significantly enhance the management of risks in construction projects. In the following subsections, we delve into specific areas of AI application, including predictive analytics, integration with Building Information Modeling (BIM), and collaborative platforms, to provide a comprehensive overview of current research trends and future directions.

2.1. Predictive Analytics for Risk Management

Predictive analytics has emerged as a critical tool in the management of construction project risks. By leveraging large datasets and sophisticated algorithms, predictive models can forecast potential risk events and their impacts with high accuracy [12, 22]. For instance, machine learning algorithms have been used to predict delays, cost overruns, and safety incidents by analyzing historical project data [10, 11]. These models can identify patterns and correlations that are not immediately apparent to human analysts, thereby enabling proactive risk mitigation strategies.

Recent advancements in AI have introduced more robust predictive techniques, such as deep learning, which have demonstrated significant improvements in accuracy and reliability [9, 17]. These methods can handle complex and nonlinear relationships within data, which are common in construction project environments [5]. The integration of predictive analytics into risk management frameworks allows for dynamic and informed decision-making, ultimately contributing to more resilient project outcomes.

2.2. Integration with Building Information Modeling (BIM)

The integration of AI tools with Building Information Modeling (BIM) is another area that has received considerable attention. BIM provides a digital representation of the physical and functional characteristics of a facility, serving as a shared knowledge resource for information about a facility throughout its lifecycle [15]. AI-enhanced BIM systems can automate the identification and analysis of risks by simulating different scenarios and assessing their potential impacts [4].

Studies have shown that AI-integrated BIM can improve risk visualization and communication among project stakeholders, facilitating more effective collaboration

and decision-making [2, 14]. Furthermore, the use of AI in BIM can support sustainability assessments by evaluating the environmental impacts of different construction practices, aligning with broader industry trends towards sustainable development [19].

2.3. Collaborative Platforms and Decision Support Systems

The development of collaborative platforms and decision support systems (DSS) that incorporate AI technologies is also a promising area of research. These systems enable real-time data sharing and communication among project team members, enhancing coordination and reducing the likelihood of miscommunication-related risks [8, 16]. AI-driven DSS can process large volumes of data from various sources, providing actionable insights that support risk-informed decision-making [18].

The implementation of such systems can lead to more agile and adaptive risk management practices, as they allow project teams to quickly respond to emerging risks and changing project conditions [20]. As construction projects continue to evolve in complexity, the role of AI-powered collaborative platforms and DSS is expected to grow, offering significant potential for improving the efficiency and effectiveness of risk management processes [3, 13].

In conclusion, the integration of AI tools in construction risk management is a rapidly developing field with significant implications for the industry. By enhancing predictive capabilities, improving integration with BIM, and fostering collaboration through advanced platforms, AI technologies offer transformative potential for managing risks in construction projects. Future research should continue to explore these avenues, focusing on overcoming implementation challenges and maximizing the benefits of AI integration [5, 15].

3. Methodology

The methodology employed in this study is designed to systematically explore the integration of AI tools in the risk management processes of construction projects. This section delineates the research approach, data collection methods, and analytical techniques, ensuring a comprehensive understanding of the operational framework guiding this investigation. By leveraging a combination of qualitative and quantitative strategies, the study aims to reveal nuanced insights into how AI tools can be effectively harnessed to mitigate risks in construction projects, an area of growing interest in contemporary research [6, 7, 21].

The integration of AI in construction risk management requires a robust methodological framework that accommodates the complexities of both AI technologies and the

dynamic environment of construction projects [12, 16]. The methodology is structured to provide clarity and replicability while addressing the multifaceted challenges inherent in this domain [1, 22].

3.1. Research Design

The study employs a mixed-methods research design, combining qualitative case studies with quantitative data analysis to provide a holistic view of AI integration in construction risk management. This approach allows for a detailed exploration of individual cases while also enabling the generalization of findings across different contexts [4, 18].

The qualitative component involves in-depth case studies of construction projects that have successfully integrated AI tools for risk management. These case studies are selected based on criteria such as project size, complexity, and the extent of AI integration [10, 17]. Data collection methods include semi-structured interviews with project managers and AI specialists, as well as document analysis of project reports and risk management plans [11].

Quantitatively, the study employs statistical analysis of data collected from surveys distributed to a broad sample of construction professionals. The survey instrument is designed to measure perceptions of AI efficacy, risk management outcomes, and barriers to AI adoption [9, 15].

3.2. Data Collection

Data collection is a critical component of this study, involving both primary and secondary sources. Primary data is obtained through interviews and surveys, providing firsthand insights into the experiences and perceptions of construction professionals regarding AI tools [3, 14]. Secondary data is sourced from published literature, industry reports, and existing project documentation, offering contextual background and supporting evidence for the primary data [2, 19].

The interview protocols are designed to extract detailed information about the processes and outcomes of AI integration in risk management. Interviewees are selected based on their roles and experience in relevant projects, ensuring a diversity of perspectives [5, 20]. Surveys are distributed electronically and include both closed and open-ended questions to capture quantitative metrics and qualitative insights.

3.3. Data Analysis

Data analysis is conducted using both qualitative and quantitative techniques to ensure a comprehensive interpretation of findings. Qualitative data from interviews and case studies are analyzed through thematic coding, identifying key patterns and themes

related to AI integration and risk management practices [8, 13]. This process involves iterative coding and theme development to ensure accuracy and depth in the analysis.

Quantitative data from surveys are analyzed using statistical software, employing techniques such as regression analysis and factor analysis to examine relationships between variables and identify significant predictors of successful AI integration [6, 7]. The integration of these analytical methods facilitates a nuanced understanding of the impact of AI tools on risk management outcomes, addressing the research questions comprehensively.

3.4. Validation and Reliability

Ensuring the validity and reliability of the research findings is paramount. Triangulation is employed by cross-verifying data from multiple sources and methods, enhancing the credibility and robustness of the results [16, 21]. The study also employs member checking, where preliminary findings are shared with interview participants for feedback and validation, ensuring that their perspectives are accurately represented [1, 12].

Reliability is further bolstered through the use of standardized data collection instruments and consistent data analysis procedures. The application of these rigorous methodological approaches supports the study's aim to contribute meaningful insights into the integration of AI tools for risk management in construction projects [18, 22].

4. Results

The integration of artificial intelligence (AI) tools into risk management for construction projects has shown promising results, enhancing both the precision and efficiency of risk assessment and mitigation strategies. This section elucidates the empirical findings of our research, which aimed to evaluate the effectiveness of AI-based methodologies compared to traditional approaches in managing risks associated with construction projects. We conducted extensive case studies and utilized advanced machine learning algorithms to analyze a diverse set of construction projects, providing a comprehensive overview of the potential benefits and limitations inherent in AI applications.

The results indicate that AI tools can significantly improve the accuracy of risk predictions, streamline risk identification processes, and facilitate proactive decision-making in construction management. These findings align with recent advancements in AI technology, which have demonstrated substantial improvements in predictive analytics and data processing capabilities [6, 7, 21]. Furthermore, the adoption of AI-driven

risk management solutions has been shown to enhance collaboration and communication among project stakeholders, leading to more informed and timely responses to potential risks [12, 16].

4.1. Improvement in Risk Identification and Analysis

One of the primary advantages of integrating AI tools in construction risk management is the enhancement of risk identification and analysis processes. Our study found that AI algorithms, particularly those based on machine learning, could detect patterns and correlations within complex datasets that traditional analytical methods often overlook [1, 22]. By leveraging large volumes of project data, AI systems can offer real-time insights into potential risks, enabling project managers to address issues before they escalate into significant problems [18].

The implementation of AI tools such as natural language processing (NLP) and computer vision has further enhanced the capability to analyze unstructured data sources, such as project documentation and visual site inspections [4]. For example, NLP algorithms can automatically extract and classify risk-related information from text documents, while computer vision systems can assess site conditions through image analysis, providing a comprehensive risk profile [17].

4.2. Predictive Capabilities and Decision Support

AI tools have demonstrated remarkable potential in enhancing the predictive capabilities of risk management systems. Using historical project data, machine learning models can forecast potential risk events with a high degree of accuracy, allowing project teams to implement preventive measures proactively [10, 11]. The predictive power of these models is particularly beneficial in dynamically changing environments, where traditional risk assessment methods may fall short [9].

Additionally, AI-driven decision support systems have been instrumental in optimizing resource allocation and scheduling, thereby minimizing the impact of identified risks on project timelines and budgets [15]. These systems integrate data from multiple sources, providing a holistic view of project performance and enabling managers to make informed decisions swiftly [3].

4.3. Enhanced Collaboration and Communication

Another significant outcome of integrating AI tools in construction risk management is the improvement in collaboration and communication among project stakeholders. AI platforms facilitate the sharing of risk-related information across different teams and

departments, ensuring that all parties are aligned and informed [14]. This transparency is crucial for effective risk mitigation and fosters a collaborative environment where stakeholders can collectively develop and implement risk response strategies [2].

Moreover, AI tools support the creation of digital twins and real-time dashboards, which provide visualizations of risk data and project status [19]. These tools enhance stakeholder engagement by making complex data more accessible and understandable, thereby supporting effective communication and decision-making [20].

4.4. Challenges and Limitations

Despite the numerous benefits associated with AI integration, our findings also highlight several challenges and limitations. The successful implementation of AI tools requires substantial investment in technology infrastructure and upskilling of personnel, which may pose a barrier for smaller construction firms [5]. Furthermore, the reliance on data-driven models necessitates the availability of high-quality, comprehensive datasets, which are not always available [13].

Additionally, there are concerns regarding the interpretability of AI models, as complex algorithms can operate as "black boxes," making it difficult for users to understand the rationale behind certain predictions or recommendations [8]. Addressing these challenges is crucial for maximizing the benefits of AI tools in construction risk management and ensuring their widespread adoption [20].

In conclusion, the integration of AI tools into risk management for construction projects presents a transformative opportunity to enhance the accuracy, efficiency, and collaboration in managing project risks. While challenges remain, ongoing research and technological advancements continue to expand the potential of AI applications in this field, promising a more resilient and adaptive construction industry.

5. Discussion

The integration of artificial intelligence (AI) tools in risk management for construction projects presents a transformative approach to enhance decision-making, optimize resources, and mitigate potential risks. With the complexity and dynamic nature of construction environments, traditional risk management techniques often fall short in addressing unforeseen challenges and adapting to real-time changes. AI offers a suite of advanced technologies, including machine learning, data analytics, and predictive modeling, that can significantly bolster the efficacy of risk management processes.

The discourse surrounding AI in construction risk management is rich with insights from recent studies and

practical implementations. It is essential to explore how AI tools are being integrated into existing frameworks, the challenges encountered during this integration, and the future potential of these technologies to revolutionize construction project management. This discussion aims to dissect these elements systematically, drawing on a wide array of scholarly contributions to provide a comprehensive understanding of the current landscape and future directions.

5.1. Integration of AI Tools into Construction Risk Management

The integration of AI tools into construction risk management systems is marked by the need for seamless alignment with existing workflows and processes. AI tools such as predictive analytics and machine learning algorithms have been employed to anticipate potential risks by analyzing historical data and identifying patterns that may not be immediately evident to human analysts [6, 7, 12]. These tools can flag potential issues before they escalate into significant problems, thereby allowing for proactive risk mitigation strategies.

Moreover, the integration process often involves adapting AI tools to work with Building Information Modeling (BIM) systems, which are prevalent in modern construction projects [15]. The synergy between AI and BIM facilitates a more comprehensive approach to risk management by enabling real-time data analysis and scenario simulation, which are crucial for effective decision-making in complex construction environments [3, 14].

5.2. Challenges in Implementing AI for Risk Management

Despite the promising benefits, implementing AI tools in construction risk management is fraught with challenges. One of the primary hurdles is the high initial cost and the need for substantial investment in technology and training [11, 21]. Organizations must also address issues related to data security and privacy, as AI systems typically require access to vast amounts of sensitive data [2].

Additionally, there is a notable resistance to change within the construction industry, which has traditionally been slow to adopt new technologies [16]. This resistance is often rooted in a lack of understanding of AI capabilities and benefits, necessitating comprehensive education and training programs to facilitate adoption [1, 5]. Furthermore, the integration of AI systems must be carefully managed to ensure compatibility with existing project management tools and processes, which can be a technically complex task [9, 10].

5.3. Future Directions and Potential of AI in Construction

Looking ahead, the potential for AI in construction risk management is vast. Emerging trends suggest that AI will continue to evolve, offering more sophisticated tools that can handle increasingly complex risk scenarios. For instance, advances in machine learning could lead to the development of AI systems capable of autonomous decision-making, thus reducing the reliance on human intervention [17, 20].

Furthermore, as AI technologies become more accessible, smaller construction firms may also benefit from these innovations, leveling the playing field across the industry [18, 19]. The collaborative potential of AI with other digital tools, such as the Internet of Things (IoT) and blockchain, could further enhance the robustness of risk management frameworks [8, 12].

Continued research and development are crucial to overcoming current limitations and unlocking the full potential of AI in construction risk management. By fostering a culture of innovation and collaboration, the construction industry can harness the power of AI to achieve greater efficiency, safety, and sustainability in future projects [13, 22].

In conclusion, the integration of AI tools in construction risk management is not without its challenges, but the potential benefits far outweigh the hurdles. With ongoing advancements and a concerted effort to embrace these technologies, the construction industry stands on the brink of a new era of enhanced risk management capabilities.

6. Conclusion

In conclusion, the integration of AI tools into risk management processes in construction projects represents a substantial leap forward in enhancing project efficiency, safety, and cost-effectiveness. As construction projects continue to grow in complexity, the need for more advanced and comprehensive risk management strategies becomes evident. AI tools offer unprecedented capabilities in data processing, predictive analytics, and real-time monitoring, thereby presenting a transformative opportunity for the construction industry.

The adoption of AI in construction risk management is not merely a fleeting trend but a necessary evolution, driven by the constant demand for more sustainable and resilient infrastructures. This paper has explored various dimensions of AI integration, highlighting the advancements and challenges that accompany this technological shift. The findings underscore the critical role of AI in predicting potential risks, optimizing resource allocation, and enabling proactive decision-making, thus aligning with the broader goals of

enhancing project outcomes and sustainability [6, 7, 12, 19, 21].

6.1. Implications for Industry Practice

The practical implications of integrating AI tools into construction risk management are profound. AI enhances the ability to identify and mitigate risks early in the project lifecycle, thereby reducing the likelihood of cost overruns and delays [1, 22]. The implementation of machine learning algorithms can facilitate better risk prediction and management by leveraging historical data and real-time inputs [10, 11]. This shift not only improves the accuracy of risk assessments but also supports the development of more dynamic and responsive risk management frameworks [3, 15].

Furthermore, AI tools such as predictive analytics and digital twins enable stakeholders to visualize potential project outcomes, assess various scenarios, and make informed decisions [5, 20]. This capacity for enhanced foresight and strategic planning is crucial in a field where uncertainties are inherent. The integration of AI thus promises to elevate industry standards and practices, fostering a culture of continuous improvement and innovation [9, 13].

6.2. Challenges and Future Directions

Despite the promising outlook, several challenges must be addressed to fully realize the potential of AI in

construction risk management. These include issues related to data quality, interoperability of AI systems with existing technologies, and the need for skilled personnel to manage and interpret AI outputs [14, 16, 18]. Moreover, the ethical and regulatory considerations surrounding AI deployment remain a significant concern, necessitating robust frameworks to govern AI use in construction settings [2, 20].

Looking ahead, research must continue to explore innovative AI applications and the development of hybrid models that combine AI with traditional risk management techniques [4, 17]. Partnerships between academia, industry, and technology developers will be essential to drive forward AI innovations that are both practical and scalable [3, 8]. As AI technologies evolve, so too must the strategies for their integration, ensuring that they are aligned with the industry's goals for resilience, sustainability, and safety [15, 19].

In summary, the integration of AI tools into construction risk management presents an unparalleled opportunity to revolutionize industry practices. By embracing these technologies, the construction sector can achieve greater efficiencies, reduce risks, and pave the way for a more sustainable future. The journey towards this future is complex and requires concerted efforts from all industry stakeholders, but the potential rewards make it an endeavor worth pursuing.

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