BOARD #117: Exploring AI's Role in Transforming Construction Industry Practices

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Exploring AI's Role in Transforming Construction Industry Practices

Abstract

This research explores the transformative impact of Artificial Intelligence (AI) on advanced construction technologies. The study investigates how AI integration can enhance construction management processes, improve project completion rates, provide quicker updates, and reduce costs. Despite the widespread adoption of AI in industries such as software, education, and automotive, the construction sector has been slower to embrace these advancements. This research aims to identify the benefits and challenges of incorporating AI into construction projects, including its effects on social and workforce environments and cost implications. Utilizing a survey methodology and literature review, the study targets construction companies, focusing on construction professionals. The findings will cover demographics, company positions, work experience, technology usage, and the perceived advantages and disadvantages of AI in the workplace. The combined data from surveys and literature reviews will provide insights into the potential future growth of AI in the construction industry.

Keywords: AI, Construction Industry, Advancement, Managers, Project Management, Project Control

Introduction

The construction industry is on the brink of a technological revolution, driven by the integration of Artificial Intelligence (AI), both traditional and generative. While AI has been widely adopted in sectors such as software, education, and automotive, its application in construction has been relatively slow. This research aims to explore the transformative impact of AI on advanced construction technologies, focusing on how AI can enhance construction management processes, improve project completion rates, provide quicker updates, and reduce costs.

The adoption of AI in construction is expected to bring significant improvements in various aspects of project management. AI technologies, such as Machine Learning (ML), Digital Twin (DT), Large Language Model (LLM) and Generative Adversarial Networks (GANs), have the potential to revolutionize how construction projects are conceived, planned, and executed. These technologies can enhance visualization, optimize design processes, and improve communication among stakeholders, leading to more efficient and cost-effective project outcomes.

Despite the potential benefits, the construction industry faces several challenges in adopting AI. These include high implementation costs, cybersecurity risks, and lack of digital expertise [1]. Additionally, there are concerns about the impact of AI on the workforce, with fears of job displacement and the need for new skill sets. This study aims to address these challenges by providing a comprehensive analysis of the benefits and barriers to adopting AI in construction.

Through a combination of survey methodology and literature review, this research targets construction professionals and their perceptions about AI's Role in transforming US construction

industry practices. The findings will cover demographics, company positions, work experience, technology usage, and the perceived advantages and disadvantages of AI in the workplace. By understanding these factors, the study aims to provide insights into the potential future growth of AI in the construction industry and offer recommendations for successful integration.

Background and Literature Review

The growing use of Artificial Intelligence (AI) is being observed across a multitude of industries [2]. Since its initial inception in the late 1930s and early 1940s [3], AI has undergone considerable improvements, impacting industries globally. In the Architecture, Engineering, and Construction (AEC) sector, the adoption and implementation of computers marked a paradigm shift. This shift began with the use of textual data and line-based models and expanded to object-oriented parametric models, which supported the goals envisioned with Building Information Modeling (BIM).

BIM has been defined in numerous ways in the literature [4]-[6]. Broadly, it involves the adoption of software, processes, and protocols for managing the data associated with a project's lifecycle [6]. Over the last decade and a half, BIM adoption and implementation have been observed globally among many AEC stakeholders, such as architects, general contractors, and others, for various functions like visualization, scheduling, estimating, and safety [7]-[10]. Despite numerous barriers to its holistic and complete implementation [7], BIM has advanced planning, designing, and constructing skillsets. The expanded use of BIM models as Digital Twins (DT) is already being explored [8], [11]. Furthermore, integrating innovative technologies, notably Generative Adversarial Networks (GANs) and Large Language Models (LLMs) such as ChatGPT, has profoundly transformed how architects, engineers, and construction professionals conceive, plan, and execute projects [12]. Generative AI, like ChatGPT, plays a significant role in generating designs and layouts, making the construction process more optimal. AI can create designs using both text and visuals, providing flexibility to modernize workflows. It enhances the visualization of design intent and communication among stakeholders (clients, designers, general contractors, and others), ensuring that stakeholders can meet owner expectations. AI models can analyze a larger dataset of existing designs, methods, and materials, saving designers time in data gathering. This is both cost and time-efficient for engineers. However, one key problem with BIM integration is that the models created are often discipline-specific. It is expected that, on a larger scale, AI can help overcome this limitation.

Usage of AI

The construction industry is on the brink of a technological revolution, with AI redefining engineering and management requirements [13]. In recent years, AI, alongside Machine Learning (ML) and Digital Twin (DT) technologies, has emerged as a catalyst for enhancing productivity, collaboration, and decision-making in construction projects [13], [14]. These technologies offer numerous benefits, including improved efficiency and cost-effectiveness.

AI adoption in the AEC industry is evident in various technological advancements. For instance, robotics has introduced technologies such as 3D printing, exoskeletons, and UAVs for construction processes [14]. The adoption of 3D printing has been observed in the residential industry within the US, despite some challenges [10], [15]-[17]. Additionally, blockchain applications in construction have been used to coordinate construction materials, proving to be cost-effective, improving safety, and optimizing construction projects [14].

Until 2017, AI usage in construction was moderate. However, the number of publications on AI in construction increased from 15 papers in 2017 to 2024, indicating a growing interest in AI applications [18]. China leads in publishing research papers on AI, ML, and construction. AI offers many advantages. For example, automating processes can save companies significant amounts of money and allow them to focus more on their products. AI enables simultaneous jobs, expediting the entire construction cycle. Automation reduces the need for manual paperwork, allowing everything to reside within the system, thereby increasing productivity.

AI also addresses waste management through waste analytics, which relies on diverse data sources such as building design, material properties, and construction strategies [1]. Supply chain issues in construction can be mitigated by building robots and site monitoring systems, improving telecommunications aspects of construction management. Construction sites need better-equipped stations with internet, power, and mobile data. AI and IoT can create site monitoring systems, while reinforcement learning can enhance energy saving and health and safety management. Computer vision can improve site safety by controlling accidents, and AI can be used for risk mitigation and creating risk ratings for sites and projects.

Application of AI in Different Phases of Construction Projects

In the planning phase, AI plays a crucial role in reducing and eliminating risks associated with non-virtual aspects. Cloud-based applications can be utilized in the initial stages to enhance the company's profitability. Investing in these early stages ensures that subsequent steps are easier and less time-consuming. AI planners can provide more accurate predictions and better time management by analyzing pre-existing data on past risks and issues. This optimization extends to inspection phases, where AI can deliver more accurate results in reports. Despite the large workforce in the construction industry, there is still a shortage of skilled labor. AI can help optimize project timelines by performing tasks through robots.

In the design phase, various tools have been implemented to automate the design process, such as AutoCAD. The use of digital twins is another significant advancement. By processing data from point clouds, digital photos, thermal images, and sensor data from laser scanners, cameras, thermal imaging devices, and other sensors, digital twins provide a visual and efficient means for inspection and fault detection [19]. Businesses can integrate these technologies into their systems to reduce external labor costs and automate more processes. For example, AI can be used to monitor soil deformation during surveying.

During the construction phase, numerous changes occur as the project transitions from planning and design to implementation. Existing technologies can ease this phase. Construction monitoring helps track the progress of construction sites, ensuring the quality of materials and

labor. Autonomous rides can facilitate transportation within buildings and sites, while task-specific robots can save time and increase profitability. Smart equipment that assesses workplace dangers can reduce incidents on-site.

Despite the benefits of AI, the AEC industry faces challenges in its widespread adoption. The industry is often resistant to innovative technologies [20]. Additionally, the high cost of AI implementation is a significant barrier. While AI can enhance security and detect intrusions, it also poses risks of exploitation by hackers and cybercriminals [21]. There is a higher risk of data breaches and leaks. Natural language processing may struggle with speech recognition due to construction site noise. Other challenges include optimization and scalability issues, and a lack of digital expertise within the industry. This lack of expertise can lead to cost inefficiencies, project delays, poor quality performance, uninformed decision-making, and deficient productivity, health, and safety standards [14]. These gaps in industry knowledge can result in complex project solutions.

Thus, this research aims to comprehensively explore the role and impact of AI in construction engineering and management within the US, focusing on the potential, opportunities, and challenges.

Methodology

This research employs a mixed-methods approach, combining quantitative and qualitative data collection techniques to explore the impact of AI on advanced construction technologies. The primary data collection method is an online survey questionnaire, designed to capture the perceptions and experiences of professionals in the Architecture, Engineering, and Construction (AEC) industry regarding AI integration. The survey was developed on an online platform and included multiple sections to gather comprehensive data. The sections covered demographics, professional roles, experience levels, and specific uses of AI in construction projects. The questionnaire included both open-ended and closed-ended questions to allow for detailed responses and quantitative analysis. The survey instrument was piloted by a group of AEC professionals to ensure clarity and relevance.

The target population for the online survey was construction professionals within the US. Respondents were identified through purposive sampling, ensuring that participants had relevant experience and knowledge of AI applications in construction. The survey was distributed via email and professional networks, and reminders were sent to encourage participation. The survey remained active for several weeks, during which time responses were collected and monitored. Upon closing the survey, incomplete responses were discarded, and only complete responses were included in the analysis. The final dataset comprised 16 complete responses. Quantitative data were analyzed using statistical methods to identify trends and correlations, while qualitative data from open-ended questions were analyzed thematically to extract key insights and patterns.

In addition to the survey, a comprehensive literature review was conducted to contextualize the findings and provide a theoretical framework for the study. The literature review focused on

existing research on AI applications in construction, including benefits, challenges, and future trends. This review helped to identify gaps in the current knowledge and informed the development of the survey instrument. The study acknowledges several limitations. The sample size of 16 respondents is relatively small, which may limit the generalizability of the findings. Additionally, the geographic location of respondents was not controlled, which could introduce regional biases. Future research should aim to include a larger and more diverse sample to validate the findings and provide a more comprehensive understanding of AI's impact on the construction industry.

Results and Discussions

From the perspective of respondent demographics, fifteen respondents (94%) were men (Figure 1). Regarding professional affiliation, five respondents (31%) were civil/construction engineers, six (38%) held managerial positions, two (13%) were involved in construction education, two (13%) were architects, and one (5%) was in construction estimation. All respondents reported using AI in their day-to-day jobs. The various applications of AI mentioned by respondents included automation, campus planning, designing, BIM reports, estimation, and improving project efficiency. In terms of experience within the AEC industry, the majority of respondents had less than five years of experience (early career), with 31% of respondents equally distributed between the categories of 5-9 years and more than ten years of experience (Figure 2).

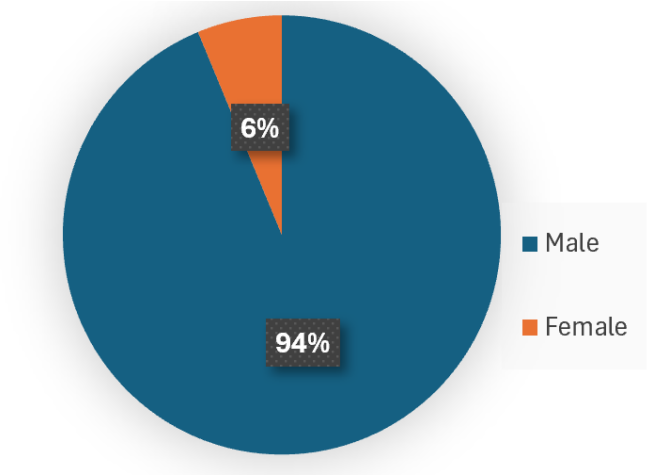

Figure 1. Respondent Gender (n=16)

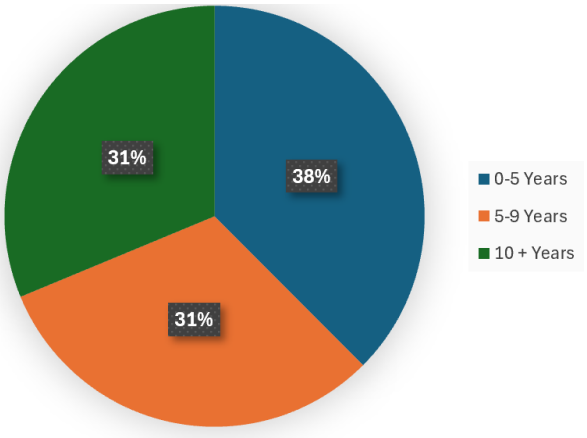

Figure 2. Respondent experience in the construction industry (years) (n=16)

According to the majority (43%) of the respondents, AI is primarily used to improve project efficiency. This is followed by 30% of respondents who indicated that AI is used to make projects more cost-effective and efficient (Figure 3). Safety is also a significant concern in construction projects, and the use of AI to mitigate these risks suggests that companies recognize AI's potential to enhance safety. The data indicates that employees predominantly use AI to boost efficiency, as reflected by the 43% of responses favoring this application.

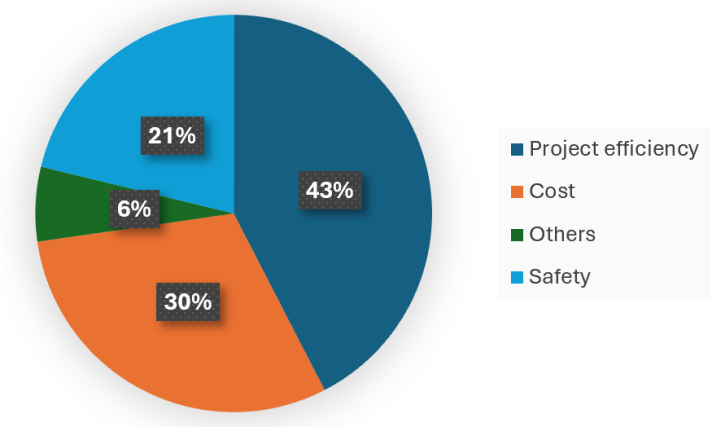

Figure 3. Company use of AI (n=16)

Industry members who have not heavily invested in AI often struggle to envision its future potential. However, those who have invested in AI predict that it will prove valuable in the future. The industry could undergo significant transformation with AI integration, and employees would recognize the benefits of incorporating AI into construction projects. The primary reason some individuals do not foresee a future for AI is their early career stage, with experience ranging from 0-5 years. This may be due to a lack of knowledge about company tools and software, as well as insufficient communication with the research and development team.

Table 1. Future of AI vs AI training for employees (n=16)

Do you see a future of AI in construction?	Has your company invested in AI usage training for employees?
Yes	Yes, Alot
Yes	Yes, Alot
Yes	Yes, Alot
Yes	Yes, Alot
Yes	Yes, Alot
Yes	Yes, Alot
Yes	Yes, Alot
Yes	Yes, Alot
Yes	Yes, Alot
Yes	Yes, Alot
Yes	Yes, Alot
Yes	Yes, Alot
Yes	Yes, Alot
Yes	Yes, Alot
Cannot say right now	No
Cannot say right now	Yes, But not a lot

When asked about the likelihood of using AI, the majority of respondents (82%) indicated a substantial interest in its adoption (Figure 4). Respondents acknowledged the benefits AI can offer when applied to their projects. Even with varied levels of experience, there is no significant inclination to reject AI, suggesting a gradual and positive introduction of AI into construction projects.

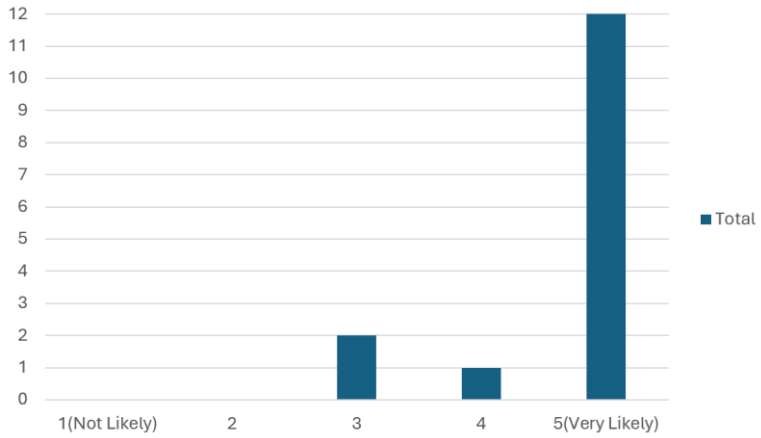

Figure 4. Scaling of Surety of Using AI (n=16)

Comprehensive Recommendations based on Responses

The survey responses provide valuable insights into the current state and potential of AI in the construction industry. Key areas to focus on include practical applications of AI, such as improving cost estimation accuracy and enhancing project planning through BIM. Addressing

challenges like learning how to use AI, training, and adaptability is crucial, with recommendations for structured training programs and continuous learning opportunities. Additionally, discussing future prospects and innovations, such as machine learning algorithms for predictive maintenance and AI-driven robotics, can provide a forward-looking perspective.

Furthermore, specific recommendations for industry adoption of AI should include best practices for integration, guidelines for selecting AI tools, and strategies for measuring AI's impact on project outcomes. Addressing ethical and security considerations is also essential, with recommendations for safeguarding sensitive data and ensuring ethical AI use. By incorporating these recommendations, this research can enhance the practical understanding of AI's role in transforming construction industry practices, building trust and confidence among industry stakeholders.

Summary and Conclusion

This research has explored the transformative impact of Artificial Intelligence (AI) on advanced construction technologies, focusing on its integration within the construction industry. The findings indicate that AI has the potential to significantly enhance construction management processes, improve project completion rates, provide quicker updates, and reduce costs. Despite the widespread adoption of AI in other industries, the construction sector has been slower to embrace these advancements.

The study highlights several key benefits of AI integration, including increased efficiency, cost-effectiveness, and improved safety. AI technologies such as Machine Learning (ML), Digital Twin (DT), and Generative Adversarial Networks (GANs) have shown promise in optimizing various phases of construction projects, from planning and design to execution and monitoring. These technologies facilitate better decision-making, enhance collaboration among stakeholders, and streamline construction processes.

However, the research also identifies significant challenges to AI adoption in the construction industry. These include high implementation costs, cybersecurity risks, and a lack of digital expertise. Additionally, there are concerns about the impact of AI on the workforce, with fears of job displacement and the need for new skill sets. Addressing these challenges requires targeted investments in training and education, as well as the development of robust cybersecurity measures.

The survey results reveal a substantial interest in AI among construction professionals, with the majority recognizing its potential benefits. However, there is a need for greater awareness and understanding of AI tools and their applications. Companies that invest in AI training and development are likely to see significant returns in terms of efficiency and cost savings.

In conclusion, while there is still a long way to go in fully integrating AI into the construction industry, the potential benefits are substantial. Continued research and investment in AI technologies, along with efforts to address the identified challenges, will be crucial in driving the future growth of AI in construction. By leveraging AI, the construction industry can achieve

greater efficiency, safety, and sustainability, ultimately transforming how projects are conceived, planned, and executed.

Limitations and Future Research Areas

This study acknowledges several limitations that may impact the generalizability and comprehensiveness of the findings. Firstly, the sample size of 16 respondents is relatively small, which may limit the ability to draw broad conclusions about the entire construction industry. A larger sample size would provide more robust data and enhance the reliability of the results.

Secondly, the geographic distribution of the respondents was not controlled. The participants may come from different regions, which could introduce regional biases and affect the applicability of the findings to specific areas. Future research should aim to include a more geographically diverse sample to ensure the findings are representative of the broader industry. Thirdly, the study relies on self-reported data from the survey respondents. This method can introduce biases such as social desirability bias, where respondents may provide answers they believe are expected rather than their true opinions. Additionally, the accuracy of the responses cannot be independently verified.

Lastly, the rapid pace of technological advancements in AI means that the findings of this study may quickly become outdated. Continuous research is necessary to keep up with the evolving landscape of AI applications in the construction industry. Despite these limitations, the study provides valuable insights into the current state of AI integration in construction and highlights areas for future research and development.

With emerging technologies, there is significant scope for understanding and researching AI. AI-based technologies are expected to be increasingly adopted and diffused across all core areas of the Architecture, Engineering, and Construction (AEC) industry [19]. However, it remains unclear which AI-based technologies will become standardized and widely accepted, and which will be rejected, along with the reasons behind these decisions. As mentioned, the transition to using Digital Twins (DTs) for construction operations and maintenance is underway. Further research is needed to fully understand the implications of moving away from physical assets to DTs, including how DTs can simplify calculations, decision-making, and diagnostics.

In addition to these tools, market research is essential. It is anticipated that the future construction process will become more product-based, with design and production occurring off-site [20]. Another critical area of research is developing cost-effective strategies for creating technologically advanced environments. This research will support the broader adoption of AI in the construction industry and help address the challenges associated with its implementation.

The integration of Artificial Intelligence (AI) in the construction industry presents numerous opportunities for future research. As AI technologies continue to evolve, it is essential to explore various aspects to fully harness their potential and address existing challenges. The following areas are recommended for future research: 1. AI and Digital Twin Integration, 2. AI-Driven Safety Solutions, 3. Cost-Effective AI Adoption, 4. AI in Construction Waste Management, 5.

AI and Workforce Development, 6. AI for Sustainable Construction, 7. Cybersecurity in AI-Enabled Construction, 8. AI and Blockchain Integration, 9. Market Research and AI Adoption, and 10. AI in Construction Project Lifecycle. By addressing these research areas, the construction industry can better leverage AI technologies to enhance efficiency, safety, and sustainability, ultimately transforming how construction projects are conceived, planned, and executed.

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