Uluslararası İleri Doğa Bilimleri ve Mühendislik Araştırmaları Dergisi
Sayı 8, S. 118-125, 2, 2024

Araştırma Makalesi

International Journal of Advanced Natural Sciences and Engineering Researches
Volume 8, pp. 118-125, 2, 2024

Research Article

https://as-proceeding.com/index.php/ijanser
ISSN: 2980-0811

Role of artificial intelligence in construction safety: A Comprehensive Review

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(Received: 06 March 2024, Accepted: 08 March 2024)

(4th International Artificial Intelligence and Data Science Congress ICADA 2024, March 14-15, 2024)

ATIF/REFERENCE: Aftab, K., Khan, I. & Hassan, Q. (2024). Role of artificial intelligence in construction safety: A Comprehensive Review. *International Journal of Advanced Natural Sciences and Engineering Researches, 8(2), 118-125.*

Abstract – Ensuring the safety of buildings has emerged as a critical concern, encompassing not only the financial stability of buildings but also the safety of individuals. Several research studies have been carried out to investigate methods for enhancing building affordability, energy efficiency, and safety. With the development of science, artificial intelligence (AI) has become more and more integrated into the design and construction of buildings. Artificial Intelligence (AI) holds great promise for revolutionizing the construction sector, particularly regarding improving safety protocols on construction sites. Artificial intelligence (AI) can assist construction companies in detecting and anticipating potential risks, monitoring worker behaviour and equipment use, and fostering improved coordination and communication among workers using machine learning algorithms and real-time data analysis. This paper aims to provide a comprehensive overview of research on artificial intelligence and building safety conducted in the last ten years, covering the entire lifecycle of a structure from early planning to the end. By examining its many uses, this review seeks to shed light on the advantages and disadvantages of implementing AI in construction safety. By synthesizing the body of existing literature, it seeks to provide insights into the evolving field of construction safety practices and the revolutionary potential of AI-driven methodologies.

Keywords – Artificial Intelligence, Construction Safety, Machine Learning, Building Safety.

I. INTRODUCTION

Construction industry is as old as human itself and play important part in human civilization, since the industrial revolution, mankind is moving towards the easiness for this purpose he has made multiple machineries and the work which used to be done manually shifted to machines and automatically. Construction with inherent complexity is regarded as one of the most dangerous industries, which is greatly susceptible to a variety of unpredictable factors, such as participants in different roles, the changeable environment in large uncertainty, struck-by-equipment hazard, and others. Therefore, the construction industry tends to cause a small scale of fatal accidents with higher frequency than other domains, which is even responsible for 30-40% of fatalities worldwide(A. Darko, n.d.). For example, accidents on construction sites have killed more than 26,000 workers in the United States during 1989 –

2013. There were in total 782 fatal construction accidents in Europe in 2014, and the rate of casualties was about 13 per 100,000 workers. According to Korea's Ministry of Employment and Labor annual report from 2012 to 2015, the mortality rate of Korea's construction industry remained the highest among other economic sectors. Construction in China has been regarded as one of the riskiest industries, where the number of fatal accidents exceeds many developed countries without a significant downward trend. Numerous research has revealed that safety issues are tied up with hazardous working conditions and the lack of supervision, emphasizing the necessity of construction management for safety guarantee and accident prevention(J. Wang, n.d.).

Since 4th industrial revolution engineers architects and developers feel a need of integration of artificial intelligence in field of construction, behind this there was whole idea of visualizing how construction would look alike in virtual reality, and mixed reality, by creating there artificial realities it was easy to identify construction phases, potential hazards, accidents, weak links in construction, building weak parts, accident prone areas during construction and after construction. So, this paper will review the studies done in the past 10 years about role of artificial intelligence in building safety and will conclude the finding of those papers.

II. MATERIALS AND METHOD

This paper aims to review the existing literature on the role of artificial intelligence (AI) in construction safety. To achieve this, a comprehensive literature search will be conducted using academic databases such as Google Scholar, Science Direct. The search terms will include keywords such as "AI", "construction safety", "building safety", and related terms. The search will be limited to studies published in the last 10 years to ensure the most current research is included. The inclusion criteria for studies will be based on relevance to the topic, study design, and quality of the research. The exclusion criteria will include studies that do not relate to AI in construction safety, studies that are not published in English, and studies that do not meet the quality criteria.

After the studies have been identified, they will be screened for eligibility based on the inclusion and exclusion criteria. Relevant data will be extracted from the studies and synthesized using a narrative review approach. This will involve summarizing and synthesizing the findings of each study and identifying common themes and patterns across the literature. The synthesized data will then be analyzed and interpreted to identify the potential benefits, challenges, and limitations of using AI in construction safety. Finally, the findings will be discussed, and recommendations for future research and implementation of AI in construction safety will be made.

III. HISTORY OF AI USE IN CONSTRUCTION INDUSTRY

AI stands for "Artificial Intelligence." It refers to the development of computer systems that can perform tasks that would typically require human intelligence, such as perception, reasoning, learning, and decision-making(P. Martinez, n.d.). The development of AI has its roots in the 1950s, when computer scientists began to explore the possibility of creating machines that could think and learn like humans. Early work in AI focused on developing algorithms and rule-based systems that could solve specific problems. Over time, AI has evolved and diversified to include a range of techniques and approaches, including machine learning, neural networks, and natural language processing. Advances in computer hardware, such as the development of more powerful processors and cloud computing, have also played a role in the growth of AI(S. Martinez, n.d.).

AI has been used in the construction industry in various ways, including for building design, project management, and safety. The first uses of AI in construction safety can be traced back to the early 2000s when researchers began exploring the use of intelligent agents and sensors to monitor worksites and identify potential hazards(B.F. Spencer Jr., n.d.). Since then, AI has been adopted in various forms, including computer vision systems, machine learning algorithms, and predictive analytics tools, to improve safety outcomes on construction sites.

IV. ENHANCING CONSTRUCTION SAFETY

The Construction Engineering Management field is currently undergoing a rapid digital transformation towards Industry 4.0, marked by constant innovations in digitalization and intelligence. This transformation aims to significantly improve automation, productivity, and reliability throughout the entire construction value chain, from planning to operation and maintenance. Artificial Intelligence (AI) plays a critical role in enabling real digital strategies in Construction Engineering Management. As a branch of computer science, AI allows computers to sense and learn inputs like humans for perception, knowledge representation, reasoning, problem-solving, and planning(S.O. Abioye, n.d.). Investment in AI is rapidly growing, with machine learning accounting for a significant proportion of the investment. According to a report from Accenture, AI has the potential to boost labor efficiency by 40% and double annual economic growth rates in 2035, indicating the significant impact AI can have on the construction industry. Despite the considerable increase in engineering data, the adoption of AI techniques lags other industries(J. Che, n.d.).

To address this gap, a computer-vision approach has been developed to improve the efficiency and effectiveness of safety inspection processes and reduce the number of fall-from-height (FFH) incidents. This approach uses deep Convolutional Neural Networks (CNN) to detect if workers are wearing their harnesses, enabling site management to proactively identify unsafe behavior and take immediate action to mitigate the likelihood of FFH incidents. Additionally, the approach can act as a safety intervention by highlighting potential hazards to workers and their potential consequences(K. Amasyali, n.d.). Harness monitoring systems have become increasingly important for contractors to ensure their duty of care towards workers' health and safety. In countries with strong trade union presence in the construction industry, the use of automatic harness monitoring systems requires contractors to collaborate with unions to ensure that the system is not being used for any other intended purpose and to penalize workers. The research presented in this paper demonstrates that deep CNN can accurately detect if a harness is being worn despite challenges associated with the color of the harness, differing viewpoint, and illumination. Overall, the use of deep CNN provides a robust method for automatically detecting unsafe behavior and improving safety in the construction industry(Vidhya, n.d.).

V. AI BASED HAZARD IDENTIFICATION SYSTEM

Regarding construction safety, before 1995, research was heavily invested in the analysis of lagging statistics. The aim of such studies was to observe trends in accident numbers and postulate correlations with a limited number of circumstantial factors to suggest future safety measures or research avenues. At the same time, statistics concerning safety incidents and their associated cost were used to create financial motivation for safety research. Neither of these applications attempted to empirically forecast future trends or safety events, but rather examined the current state and postulated positive actions towards reducing incident rates(Varma, n.d.).

In another relevant study, the authors rely on 13 project management and safety-related leading indicators from monthly inspection data (before incident occurrence) to make severity forecasts. While this approach is valid and interesting, it cannot be directly compared to the present study, as using leading indicators and fundamental attributes are two different approaches. In one paper, the authors validated the Natural language processing + Machine Learning approach by showing that attributes still have high predictive power when the safety outcomes are external and independent. Also, even *injury severity* was well predicted(Kelly, n.d.). Other improvements included, first the use of a much larger dataset, second two new state-of-the-art models, and the third is model stacking; the adoption of a more straightforward experimental setup with more appropriate performance metrics, and an analysis of per-category attribute importance scores. Results also showed that the Natural language processing tool can perform well outside of its original domain. The proposed approach can be used to complement the current methods used in the construction safety community, which are dominated by opinion-based judgments, perceptions, and risk assessments(Rane, n.d.).

VI. USE OF ARTIFICIAL INTELLIGENCE AND AUGMENTED REALITY FOR HIGHWAY WORK ZONE SAFETY

Another article conceptualizes and co-designs an integrative framework levering Artificial Intelligence (AI) and Augmented Reality (AR) to address the highway work zone safety concern. To this end, it presents and investigates three major pillars of the proposed framework which are: (1) AR user interface design for multimodal notification, (2) real-time deep learning for vehicle detection/classification from distance, and (3) real-time wireless communication. This article also presents the results of an early mixed-method user research that investigated end users' perception toward the proposed framework and the conceptualized interface through a cognitive walkthrough using a low-fidelity prototype(Duan, n.d.). Overall, the early results demonstrate that the trained AI model achieved 48.7% mAP for detecting vehicles from distance with 24.83 Frame Per Seconds (FPS) execution latency on Nvidia Jetson Xavier embedded platform. The outcomes also indicate that the real-time execution and communication latencies combined are within 46 margins on average, which provides the foundation for emitting on-spot notification to highway workers and enabling them to show a timely reaction to the identified dangers. The early user research also reveals that the proposed safety framework and the designed interface were positively welcomed by the body of the highway maintenance and operation community(M.Q. Raza, n.d.).

VII. USE OF MULTI-OBJECTIVE ROBUST OPTIMIZATION FOR SAFETY DURING LARGE DIAMETER TUNNEL CONSTRUCTION

Another study proposes an approach to improve safety in large-diameter tunnel construction by using a multi-objective robust optimization (MORO) method with an interactive and explainable AI system. The approach involves simulating 500 samples with Finite Element M analysis considering 16 variables and 3 outputs, followed by training an ElasticNetCV cored pipeline model. The MORO process handles EFP and ETD as objectives and includes GSS as a constraint, while the TOPSIS technique selects the optimal solution from the Pareto front(Q. Lu, n.d.). The study also uses the SHAP technique to analyze the contribution of each feature to the improvement potential. The study finds that a box uncertainty set generates the most conservative solution in MORO, while robust optimization is the most conservative among robust optimization, deterministic optimization, and stochastic optimization. However, if the uncertainty set size is set adequately small, the degree of improvement from robust optimization will be close to DO and SO. Compared to DO and SO, RO offers reasonable conservativeness, which aligns with the worst-case scenario design logic in engineering problems. MORO provides a zero-risk method to enhance the safety of tunnel construction, which is particularly important considering the complexity of underground conditions(J. Xu, n.d.).

VIII. AI ROLE IN FIRE SAFETY USING PERFORMANCE-BASED DESIGN AND SAFE EGRESS TIME CONCEPT

In another research the researchers utilized the Performance-Based Design (PBD) approach, specifically the Available Safe Egress Time (ASET) concept, along with acceptance criteria such as smoke-layer height and visibility to train the AI model and evaluate the effectiveness of ASET in randomly selected cases. The study also involved consulting with six professional fire engineers who conducted case studies using their own expertise and PBD with Computational Fluid Dynamics (CFD) tools(S.K. Baduge, n.d.). Finally, the study compared the performance of human professionals and AI agents to demonstrate the effectiveness of the proposed AI approaches in designing fire safety for atriums. Which concluded that in practical performance-based fire safety design, the focus is on comparing Available Safe Egress Time and Required Safe Egress Time. ASET accuracy determines design success, while visibility above 2.0 m at 20 min after ignition determines design pass or fail. Large ASET values are not needed unless RSET changes. The applicability of AI in fire engineering PBD, potentially leading to cost and time savings in creating fire-safe structures. Tuning the AI model with more layers, units, and diverse fire scenarios and building parameters in a larger database could improve performance(E. Brynjolfsson, n.d.). Furthermore, validating the AI model through real- or large-scale fire tests in the constructed building is crucial. Future research should focus on these aspects to enhance smart fire engineering design.

IX. BENEFITS OF ADOPTING AI FOR CONSTRUCTION SAFETY

There are several potential benefits of adopting AI in construction safety, including:

1. Enhanced safety: One of the most significant benefits of AI in construction safety is the potential to enhance safety for workers on construction sites. AI can help identify potential safety hazards, monitor workers for fatigue or signs of injury, and alert supervisors in real-time if an accident occurs, allowing for a rapid response.
2. Improved efficiency: AI can help optimize construction processes by identifying areas for improvement and automating tasks that are currently performed manually. This can lead to improved efficiency and reduced risk of accidents caused by human error.
3. Reduced costs: By automating tasks and improving safety, AI can help reduce costs associated with accidents, injuries, and delays. This can lead to significant cost savings for construction companies.
4. Predictive analytics: AI can analyze data collected from construction sites and predict potential safety hazards before they occur. This can help prevent accidents and injuries, as well as identify areas for improvement in safety protocols.
5. Improved training: AI can be used to provide personalized safety training to workers, based on their specific job roles and tasks. This can help ensure that workers are properly trained to perform their jobs safely and reduce the risk of accidents and injuries.

   Overall, the adoption of AI in construction safety has the potential to significantly improve safety, efficiency, and cost-effectiveness in the construction industry.

X. CHALLENGES IN ADOPTING AI IN CONSTRUCTION INDUSTRY

As the construction industry continues to grow, ensuring the safety of workers on job sites remains a top priority. With the advancement of artificial intelligence (AI), there is an opportunity to improve construction safety by using data and machine learning algorithms to identify and mitigate potential hazards. However, the adoption of AI in construction safety comes with its own set of challenges(Abazid, n.d.). From data quality and integration with existing systems to ethical considerations and resistance to change, there are many factors that must be considered when implementing AI solutions for construction safety. In this context, it is essential to identify and address these challenges to ensure that AI technology can effectively contribute to a safer construction environment.

1. Data Quality: One of the biggest challenges in adopting AI in construction safety is the availability and quality of data. There may not be enough data on safety incidents or near-miss incidents to develop accurate AI models, or the data that does exist may be incomplete or inaccurate.
2. Integration with Existing Systems: AI applications for construction safety often need to be integrated with existing safety systems and processes. This can be challenging because the systems may be incompatible, the data may be in different formats, or the processes may be difficult to modify.
3. Lack of Expertise: Implementing AI requires specialized expertise, such as data scientists and machine learning engineers. However, there may be a shortage of professionals with the necessary skills and knowledge to design and implement AI solutions for construction safety.
4. Cost: Developing and deploying AI solutions can be expensive, particularly for smaller construction companies. The cost of hardware, software, and personnel can be a barrier to adoption.

5. Ethical and Legal Considerations: There are ethical and legal considerations to be addressed when implementing AI solutions in construction safety. These include issues such as data privacy, bias, and accountability.
6. Resistance to Change: Resistance to change is a common challenge when adopting new technology, and AI is no exception. Construction workers may be resistant to using new safety technology, particularly if they feel it is unnecessary or intrusive.
7. Complexity: AI solutions for construction safety can be complex, requiring significant technical expertise to develop and maintain. This complexity can be a barrier to adoption, particularly for smaller companies with limited resources.

Limited Generalizability: AI models are often specific to the data they are trained on, which means they may not generalize well to new situations or contexts. This can limit the effectiveness of AI solutions in construction safety, particularly in dynamic and unpredictable environments.

XI. FUTURE OF AI IN CONSTRUCTION SAFETY

1. The future role of AI in construction safety is likely to be significant. As AI technology continues to advance, it has the potential to revolutionize the way construction safety is managed and implemented. Here are some potential future roles for AI in construction safety: Predictive safety analytics: AI can be used to analyze safety data from various sources, such as sensors and wearables, to identify potential safety hazards and predict accidents before they occur. This would enable safety managers to take proactive measures to prevent accidents.
2. Real-time safety monitoring: AI can be used to monitor workers in real-time and identify any unsafe behavior or conditions. This would enable safety managers to take immediate corrective action and prevent accidents.
3. Autonomous safety systems: AI can be used to develop autonomous safety systems, such as drones and robots, that can perform hazardous tasks, such as inspecting high-rise buildings and bridges, without putting human workers at risk.
4. Virtual safety training: AI can be used to develop virtual training programs that simulate real-world safety scenarios and provide workers with the necessary skills and knowledge to perform their jobs safely.
5. Decision support: AI can be used to provide safety managers with decision support tools that can help them make informed decisions about safety policies, procedures, and equipment.

The future role of AI in construction safety is likely to be transformative. By leveraging AI technology, construction companies can improve safety outcomes, reduce accidents, and create a safer work environment for their workers.

XII. DISCUSSION

Overall this review paper examined multiple research papers addressing the safety challenges during construction and their proposed solutions using Artificial intelligence, either it be fall from height and its prevention using safety harnesses and their deflection control by AI or it be enhanced safety using AI in large diameter tunnel construction, the methods are very well defined with all the challenges and limitations in application, for example to have immediate response from AI real time tracking is required and also machine learning techniques should be thoroughly integrated in new systems to make it more practical and easy to use.

One more thing which demands ultimate attention that as the use of AI is increasing day by day in construction industry so here comes the important part from all above research articles it is analyzed that to implement AI based safety systems there develops a need of fully educated and trained professionals to manage and control this system at any particular work place, AI can also be used to detect as well as

repair the issue which means there is room for future researchers to use AI in such a way in construction field which not only identify the issue but also take care of that on its own which demands high level of machine learning integration with construction safety system.

XIII. RESEARCH GAPS

1. Lack of implementation: Despite the potential benefits of AI in construction safety, the technology is not yet widely implemented in the industry. More research is needed to identify and overcome the barriers to implementation, such as cost and lack of expertise.
2. Limited focus on worker safety: Most research on AI in construction safety has focused on equipment and site safety. However, worker safety is equally important, and more research is needed to explore how AI can improve worker safety on construction sites.
3. Limited research on long-term impacts: Most research on AI in construction safety has focused on short-term impacts. More research is needed to understand the long-term impacts of AI implementation, such as changes in safety culture and worker behavior.

XIV. CONCLUSION

In every era human life always stays as utmost importance in every aspect of life, in world of technology the best use of technology includes the purpose which ensures the safety of workers and human life, that's why use of artificial intelligence and machine learning to ensure construction and building safety is among the best use of AI. This paper thoroughly investigated the use of AI algorithms and machine learning techniques to analyze and avoid accidents during construction, safety measures system and accident-prone zones in construction.

There is yet more work to be done in this field like the use of robots for identification of safety breach, or use of AI to overall check the safety breach on daily basis and proposed solution for that to avoid incidents and major accidents at safety site. In conclusion, the construction industry faces numerous safety challenges that can result in serious injuries and fatalities for workers. The adoption of AI in construction safety has the potential to address many of these challenges by improving hazard identification, risk assessment, and safety training. However, there are also challenges that need to be addressed for successful adoption, such as data quality, privacy concerns, and resistance to change. Despite these challenges, the benefits of AI adoption in construction safety are too significant to ignore. AI has the potential to transform safety practices in the construction industry, reducing the number of accidents and improving the overall safety culture. As AI technology continues to advance and become more accessible, it is likely that more construction companies will begin to adopt these technologies to improve safety outcomes.

It is important to note that AI is not a silver bullet for all safety challenges in construction, and that it should be viewed as a complementary tool to existing safety practices and not a replacement. As with any new technology, the successful adoption of AI in construction safety requires collaboration and coordination among stakeholders, including construction workers, safety professionals, and technology providers. Overall, the integration of AI into construction safety practices is an exciting and promising development that has the potential to significantly improve safety and well-being.

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