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AI for Improving Construction Safety: A Systematic Literature Review

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Artificial intelligence (AI) has been adopted and applied in many fields and has now become one of the emerging technologies in the automation of the construction industry, which has gained a lot of attention from researchers in recent years. Much research work has been done on applying AI to improve construction safety. However, the current research work is focused on improving safety in separate individual construction tasks and the developed models lack real-world applications. Therefore, a systematic literature review has been conducted on the use of AI including machine learning and deep learning in improving safety in construction practice. After the review of the existing literature, the current applications and practices of AI are identified and classified. This will help in developing a new generalized framework that focuses on the entire construction process for improving safety. The limitations and the potential improvements in the existing AI techniques have been identified which will benefit future studies.

Key Words: Artificial intelligence (AI), Machine Learning, Deep Learning, Construction Safety

Introduction

It is known that the construction industry is one of the riskiest industries with many times more worker-related fatal accidents than any other industry in the world (Zhu et al. 2021). According to a report published in 2022 by the US Bureau of Labor Statistics, for the year 2020, more than 20% of worker fatal injuries in all industries are from construction workplaces. Additionally, according to (‘A look at falls, slips, and trips in the construction industry: The Economics Daily: U.S. Bureau of Labor Statistics), the number of worker’s non-fatal injuries at the workplace in the construction industry is 9.7% more than the average number in all industries. Obviously, the rate of safety improvement in the construction industry is not comparable to other industries. Therefore, revolutionary ideas are needed for improving construction safety. However, such ideas usually require a thorough analysis of existing safety performance data. With the advancement in information technology in recent years, a large amount of data can be gathered but still requires manual processing and parsing to extract useful information which is time-consuming and inefficient with many errors.

On the other hand, Artificial intelligence (AI), including machine learning and deep learning, has been rapidly developed and has been successfully used in many fields. It has been proven as an effective data mining tool to deal with a large amount of data. AI can benefit the construction industry by learning trends from previous data, minimizing human errors, and making fast decisions. Its applications in the construction industry have also significantly increased in a short period of time (Vickranth, Bommareddy, and Premalatha 2019), many of which focused on the improvement of construction safety. However, the current research work is focused on improving safety in separate individual construction tasks and the developed models lack real-world applications. Therefore, there exists a need to systematically review and analyze existing AI knowledge and applications in improving safety in construction practice and later develop possible recommendations for future research work.

The systematic literature review is a methodical procedure in research for collecting, identifying, and analyzing the existing/available literature that includes books, peer-reviewed articles, conference proceedings, etc. on a certain topic (Carrera-Rivera et al. 2022; Pati and Lorusso 2017). The main purpose of conducting a systematic literature review is to update its reader with the latest/current knowledge about a topic (B KitchenhamThe maintchenham, & Charters, 2007) and to analyze and review critical points of existing literature to suggest further research questions about a topic (Kitchenham et al. 2009). This paper reports a systematic literature review and identifies, analyzes, and classifies existing research progress on AI approaches that are focused on improving safety in construction practice. This will help in developing a new generalized framework that focuses on the entire construction process for improving safety. The limitations and improvements in the existing frameworks have also been discussed.

Methodology

The methodology used for this paper contains several steps. First, a preliminary literature review was done in an efficient manner to identify the research aim and to draw out the research questions. The question identified were:

1) How to classify improvement in safety in construction practice by using AI including machine and deep learning? and
2) What improvements can be done to existing frameworks?

Second, these questions were further investigated through a systematic literature review. The first question was addressed by collecting and reporting previous research work in tabulated form, with suggested classification. To address the second question an in-depth analysis was done on the limitations and shortcomings of existing identified research work. During the literature search, Scopus was used as the main database, which contains a vast number of peer-reviewed quality articles. To reach a broad category of information, the word "safety" was not used in the first round of searches. Instead, the keywords used were "machine learning in construction" and "deep learning in construction". Then, multiple refinements were done with a linkage to "safety" on the batch of articles shown by the search engine after using the above-stated keywords separately based on relevance, subject area, document type, and/or source type. Also, considering AI is emerging technology for construction safety, the selection of articles was from publications between 2018 to 2022. Further, articles were evaluated by analyzing their title and abstracts for final inclusion and/or exclusion. Then, the selected articles were thoroughly reviewed, and the data collected is presented in tabulated form, and went through a content classification process to reach a structured classification. As presented (in Figure 1) shows the research methodology of this study. This methodical process of selection resulted in 79 articles from various journals published between the above-stated duration/years. Conference papers were not considered for this review. Table 1 shows the breakdown of selected papers.

Table 1. Breakdown of Selected Papers.

Journal/Conference Papers	Count
Journal Papers	79
Conference Papers	0

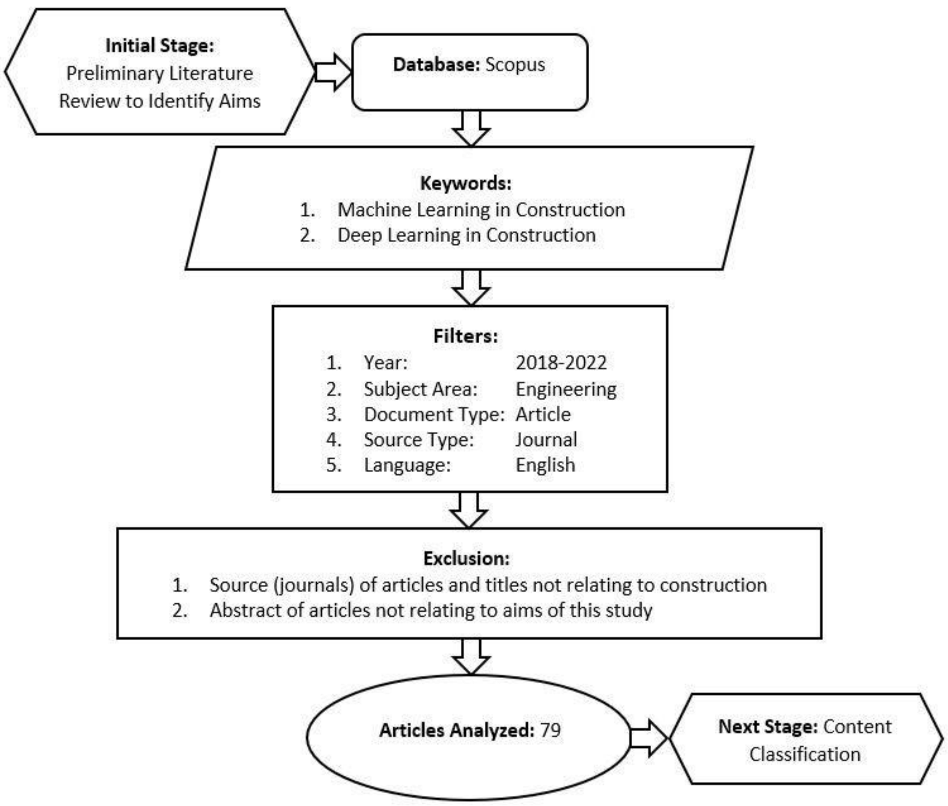

Figure 1. Research Framework

Identified AI Approaches

The three terms i.e., AI, machine learning, and deep learning are usually used interchangeably but there is a difference among them. AI refers to machines behaving intelligently like a human. Machine learning is a subset of AI where machines learn and predict using various algorithms after being trained with the previously available data. Deep learning is a subset of machine learning where machines train themselves using various neural networks and a large amount of data (Khallaf and Khallaf 2021). Further, machine learning can be divided into supervised learning, unsupervised learning, and reinforcement learning. Supervised learning, in which machines learn a trend from a labeled dataset with predetermined target variable(s), and produce prediction using new inputs, can be used for regression and classification problems, while unsupervised learning uses an unlabeled dataset without predetermined target variable(s), which can be used for clustering and data reduction. Reinforcement learning, a trial-and-error-based solution to problems, is not feasible (expensive) to be used in construction work (Xu et al. 2021). The most used machine learning algorithms are summarized in Table 2-6 containing their application, dataset, performance, and how it is used to improve construction safety, while deep learning approaches are omitted due to the limitation of the paper length; however, the discussion section will cover the deep learning as well.

Table 2. Logistic Regression (LR (Logistic)) for Improving Safety in Construction.

References	Applications	Dataset	Performance	Improvements in Framework
(Tang and Golparvar-Fard 2021)	Prediction of severity level of risk of each construction worker	Previously recorded pictures and videos taken actively during construction	Accuracy-85.7% (Bricklaying) Accuracy-86.6% (Plastering)	Enhanced validation, interobserver agreement tests for annotations, use of wearable cameras
(Zhu et al. 2021)	Prediction of consequences of construction accidents	Previously recorded construction accidents investigation reports	Precision-79.8% Recall-80.3% F1-Score-80%	Larger dataset, deep learning for feature extraction
(Choi et al. 2020)	Prediction of fatal construction accidents	Previously recorded construction injuries and deaths by the authorities	AUROC-0.6326	Larger dataset
(Poh, Ubeynarayana, and Goh 2018)	Prediction of occurrence and severity level of construction accidents	Safety monthly inspection records and accidents during construction projects by a construction firm over the years	Accuracy-59% Weighted-Kappa Statistics-0.46 Recall (Major Accident)-62%	Larger dataset with many construction firms for generalization, construction health be added with accidents

Table 3. Random Forest (RF) for Improving Safety in Construction.

References	Applications	Dataset	Performance	Improvements in Framework
(Duan et al. 2022)	Prediction of risk events in construction workers material handling	Data acquired with accelerometer and gyroscope in smartphones on wrist of five volunteer workers	Accuracy-76.71% (anterior) Accuracy-80.13% (shoulder)	Model validation in real-world scenario, devices attached to other body parts as well
(Koc, Ekmekcioğlu, and Gurgun 2021)	Prediction of construction worker's post-accident permanent disability status	Previously recorded construction accidents by the authorities	Precision-97.18% Accuracy-81.61% F1-Score-88.07% AUROC-80.94%	Larger dataset with pre-accident features as well, use of proactive data
(Zhu et al. 2021)	Prediction of consequences of construction accidents	Previously recorded construction accidents investigation reports	Precision-77.5% Recall-78.9% F1-Score-77.4%	Larger dataset, deep learning for feature extraction
(Choi et al. 2020)	Prediction of fatal construction accidents	Previously recorded construction injuries and deaths by the authorities	AUROC-91.98%	Larger dataset
(Poh et al. 2018)	Prediction of occurrence and severity level of construction accidents	Safety monthly inspection records and accidents during construction projects by a construction firm over the years	Accuracy-78% Weighted-Kappa Statistics-0.70 Recall (Major Accident)-87%	Larger dataset with many construction firms for generalizability, construction health be added with accidents

Table 4. Decision Tree (DT) for Improving Safety in Construction.

References	Applications	Dataset	Performance	Improvements in Framework
(Duan, Zhou, and Tao 2022)	Prediction of risk events in construction workers material handling	Data acquired with accelerometer and gyroscope in smartphones on wrist of five volunteer workers.	Accuracy-64.51% (anterior) Accuracy-69.14% (shoulder)	Model validation in real-world scenario, devices attached to other body parts as well
(Lee et al. 2021)	Recognition and prediction of level of perceived risk by construction workers	Physiological data gathered with wristband-type biosensors from eight workers	Accuracy-70.7%	Construction hazards not perceived by worker be considered
(Abbasianjahromi and Aghakarimi 2021)	Prediction of safety performance criteria before the start of project	Identified safety performance criteria and later data on these criteria was gathered through questionnaire	Accuracy-76%	Larger dataset, safety performance criteria be enhanced
(Mahmoodzadeh et al. 2021)	Prediction of inflow of water into the during tunnel construction	Previously recorded data acquired from road tunneling projects	R^2-72.10%	Larger dataset by considering other types of tunnels be used
(Zhu et al. 2021)	Prediction of consequences of construction accidents	Previously recorded construction accidents investigation reports	Precision-77.2% Recall-78.2% F1-Score-77.5%	Larger dataset, deep learning for feature extraction
(Choi et al. 2020)	Prediction of fatal construction accidents	Previously recorded construction injuries and deaths by the authorities	AUROC-63.16%	Larger dataset
(Poh et al. 2018)	Prediction of occurrence and severity level of construction accidents	Safety monthly inspection records and accidents during construction projects by a construction firm over the years	Accuracy-71% Weighted-Kappa Statistics-0.61 Recall (Major Accident)-81%	Larger dataset with many construction firms for generalization, construction health be added with accidents

Table 5. K Nearest Neighbor (KNN) for Improving Safety in Construction.

References	Applications	Dataset	Performance	Improvements in Framework
(Lee et al. 2021)	Recognition and prediction of level of perceived risk by construction workers	Physiological data gathered with wristband-type biosensors	Accuracy-78.8%	Construction hazards not perceived by worker be considered
(Abbasianjahromi and Aghakarimi 2021)	Prediction of safety performance criteria before the start of project	Identified safety performance criteria and later data on these criteria was gathered through questionnaire	Not Available	Larger dataset, safety performance criteria be enhanced
(Mahmoodzadeh et al. 2021)	Prediction of inflow of water into the during tunnel construction	Previously recorded data acquired from road tunneling projects	R^2-76.65%	Larger dataset by considering other types of tunnels be used
(Zhu et al. 2021)	Prediction of consequences of construction accidents	Previously recorded construction accidents investigation reports	Precision-76% Recall-77.6% F1-Score-75.9%	Larger dataset, deep learning for feature extraction
(Poh et al. 2018)	Prediction of occurrence and severity level of construction accidents	Safety monthly inspection records and accidents during construction projects	Accuracy-73% Weighted-Kappa Statistics-0.62 Recall (Major Accident)-77%	Larger dataset with many construction firms for generalizability, construction health be added with accidents

Table 6. Support Vector Machine (SVM) for Improving Safety in Construction.

References	Applications	Dataset	Performance	Improvements in Framework
(Duan et al. 2022)	Prediction of risk events in construction workers material handling	Data acquired with accelerometer and gyroscope in smartphones on wrist	Accuracy-74.89% (anterior) Accuracy-78.17% (shoulder)	Model validation in real-world scenario, devices attached to other body parts as well
(Fitzsimmons et al. 2022)	Prediction of time-risk on construction projects	Construction scheduled tasks gathered from projects over the years	Accuracy>54.4% than a Monte Carlo Simulation	Larger dataset
(Lee et al. 2021)	Recognition and prediction of level of perceived risk by construction workers	Physiological data gathered with wristband-type biosensors from eight workers	Accuracy-81.2%	Construction hazards not perceived by worker be considered
(Zhu et al. 2021)	Prediction of consequences of construction accidents	Previously recorded construction accidents investigation reports	Precision-81% Recall-78.7% F1-Score-74%	Larger dataset, deep learning for feature extraction
(Gong et al. 2020)	Evaluation of safety risk for constructing deep foundation	Previously recorded deep foundation construction safety risk reports	Accuracy-90.57%	Automated method for safety risk evaluations
(Sakhakarmi, Park, and Cho 2019)	Prediction of safety conditions to monitor the scaffolding system	Previously recorded strain data sets from scaffolding columns	Accuracy-39.13% to 82.35%	Include more local failures, automatically identification of failures
(Poh et al. 2018)	Prediction of occurrence and severity level of construction accidents	Safety monthly inspection records and accidents during construction projects by a construction firm over the years	Accuracy-44% Weighted-Kappa Statistics-0.22 Recall (Major Accident)-33%	Larger dataset with many construction firms for generalizability, construction health be added with accidents

A total of 12 main AI techniques have been identified as: (1) Logistic Regression (LR), (2) Decision Tree (DT), (3) Random Forest(RF), (4) Naïve Bayes (NB), (5) K Nearest Neighbor (KNN), (6) Support Vector Machine (SVM), (7) Gaussian Process Regression (GPR), (8) Boosting Ensembles (BE), including Adaptive Boosting (AdaBoost), and Extreme Gradient Boosting (XGBoost), (9) Artificial Neural Network (ANN), (10) Convolutional Neural Network (CNN), (11) Deep Neural Network (DNN), and (12) Recurrent Neural Network (RNN), among which (1)-(8) are machine learning algorithms and (9)-(12) are deep learning. Obviously, supervised machine learning is the most widely used learning for construction safety improvement.

Discussion

Most of the work on specific topics in improving safety in construction was done with both machine learning and deep learning techniques. Table 7 summarizes the identified AI practice in construction safety, which has classified into five sub-fields: 1) Worker Risks, 2) Construction Accidents, 3) Workers PPE, 4) Construction Machinery, and 5) Site Safety. The improvement of safety in construction was done with machine learning techniques that include LR (Logistic), DT, RF, KNN, SVM, AdaBoost, and XGBoost while the deep learning methods were ANN, CNN, DNN and RNN including their variations. The application of AI to improve safety in construction practice is still a new direction and has been making exceptional progress, but there are constraints of AI technique for specific issues limiting the full potential of AI. It has been noted that the single biggest limitation is the limited amount of construction data available for training the model. The performance of machine learning and deep learning prediction models is as good as the data used for their training. From the review of the identified literature, it is observed that previous data was either limited to a few features or collected manually, and with this limited scope, the generalizability of the models has not been achieved. Broad-based automated data collection methods are to be considered covering all aspects of the problem collected not from one region but instead, the region for data collection should be broad. There is still a need to achieve the full integration of AI into the construction practice.

Table 7. Identified AI Approaches for Improving Safety in Construction.

References	AI Approach	Topics
(Duan et al. 2022)	DT, RF, SVM, ANN	Worker Risk Events
(Fitzsimmons et al. 2022)	SVM	Time-Risk on Projects
(Koc, Ekmekcioğlu, and Gurgun 2022)	ANN	Construction Accidents
(Xiao et al. 2022)	Mask R-CNN	Off-Site Worker Tracking
(Pan et al. 2022)	CNN+word2vec	Equipment Security Data
(Arashpour et al. 2022)	DNN	Monitoring Heavy Machinery
(Pan and Zhang 2022)	DNN + GDO	Risk in Tunnel Construction
(Antwi-Afari et al. 2022)	LSTM+BiLSTM+GRU	Awkward Worker Posture
(Koc et al. 2021)	RF, AdaBoost, GBM, XGBoost	Worker Post-Accident Disability
(Tang and Golparvar-Fard 2021)	LR (Logistic)	Worker Risk Severity Level
(Harichandran, Raphael, and Mukherjee 2021)	ANN	Auto Construction Operations
(Zhu et al. 2021)	LR (Logistic), DT, RF, NB, KNN, SVM, ANN	Construction Accidents Consequences
(Lee et al. 2021)	DT, KNN, SVM	Worker Perceived Risk
(Abbasianjahromi and Aghakarimi 2021)	DT, KNN	Safety Performance Criteria
(Mahmoodzadeh et al. 2021)	DT, KNN, GPR	Water Inflow in Tunnel Construction
(Wang, Antos, and Triveno 2021)	Mask R-CNN	Masonry Building Prone to Earthquake
(B. Kim et al. 2021)	DenseNet	Buildings Steel Frames
(K. Kim, Kim, and Shchur 2021)	CNN	Site Monitoring for Unsafe Activities
(Chen and Demachi 2021)	YOLOv3	Monitoring PPE at Site
(Son and Kim 2021)	YOLOv4	Worker & Machinery Tracking
(Kim and Cho 2021)	LSTM	Worker Motion & Activity
(Luo et al. 2021)	GRU	Detecting Machine Poses
(Choi et al. 2020)	LR (Logistic), DT, RF, AdaBoost	Fatal Construction Accidents
(Gong et al. 2020)	SVM, AdaBoost	Safety Risk for Deep Foundations
(Guo, Xu, and Li 2020)	OAF-SSD	Dense Vehicles Identification
(Zhong et al. 2020)	CNN	Construction Accident Text Evaluation
(Nath, Behzadan, and Paal 2020)	YOLOv3	PPE at Site
(Sakhakarmi et al. 2019)	SVM	Safety for Scaffolding
(Son et al. 2019)	ResNet152+R-CNN	Identify Workers with their Poses
(Kouzehgar et al. 2019)	CNN	Cracked Glass Detection with Robot
(Poh et al. 2018)	LR (Logistic), DT, RF, KNN, SVM	Construction Accidents
(Kolar, Chen, and Luo 2018)	VGG-16	Safety Guardrails at Site
(Fang et al. 2018)	Faster R-CNN	Worker Hardhat Detection

Conclusion

A systematic literature review has been conducted to identify AI techniques including machine learning and deep learning techniques that have been used for the improvement of construction practice by focusing on the safety aspect. It was concluded that most of the research work related to AI in construction has been done on the improvement of the safety aspect of construction, while the other major fields are productivity and cost. For safety, however, the focus has been on the improvement of specific or individualized safety-related tasks and not considering the overall safety of the construction practice as a whole. Considering this, a structured classification has been done in which sub-fields have been identified (1-Worker Risks, 2-Construction Accidents, 3-Workers PPE, 4-Construction Machinery, and 5-Site Safety) for the improvement of the overall safety of a project and also identifies specific AI techniques that should be used for improving safety. This here also provides a sense of direction for future work in which an AI-based comprehensive framework should be developed that covers all safety aspects and which should help improve the overall safety of construction projects. This review also identified the limitations and shortcomings of the existing frameworks for the contribution of AI techniques in improving safety in construction practice. It was concluded that with many specific limitations, the dataset used for training the AI techniques is small due to the lack of availability of the construction data which is stopping the generalizability of the developed models. A bigger and broader dataset is needed to be developed to use AI in the real-world.

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