A Blockchain-Enabled Conceptual Framework for Near-Miss Management in the Construction Industry

Pan Zhang, Ivan W. H. Fung*, and Raymond Yiu Yin Lee

***Abstract*—The safety problem is still a concern in the construction industry, and near-miss management has become one of the most important practices to improve construction safety. Despite good intentions, problems with near-miss management emerged. These included: a limited reporting rate of near misses, information fraud, the risk of being distorted or lost, and insufficient information sharing among construction stakeholders. These issues have an adverse impact on the effectiveness of near-miss management. Blockchain has the potential to be a reliable platform for near-miss management due to its decentralization, immutability, transparency, and autonomous enforcement of agreements with smart contracts. However, there has been limited investigation into the blockchain's possibilities in near-miss management. To bridge this gap, this paper proposed a blockchain-enabled conceptual framework for near-miss management. The challenges of near-miss management and the potential of blockchain were discussed. An overall conceptual framework was created, which could help to record near-miss information in an immutable, transparent, traceable, and secure way.**

***Index Terms*—Blockchain, near-miss management, construction safety, construction industry**

I. Introduction

Safety management is always a hot topic for the construction industry, which continues to be one of the most dangerous industries in the world Zhou *et al*. [1]. In the United States, for instance, 4674 workplace fatalities were recorded in 2020, with 976 occurring in construction (20.9%) [2]. In China, the situation is scarcely any better as the fatalities in the construction industry have been topping the list among all industries since 2012 [3]. Hence, there is an urgent need to develop effective measures to improve safety.

According to the accident pyramid, for every 300 near misses, there are 29 minor injuries and 1 major injury [4]. A near miss is defined as an unplanned event that has the potential to but does not cause damage to people, property, or the environment [5]. It follows that near misses are highly related to accidents, or rather, prerequisites for accident occurrence [6]. Recently, near misses have drawn increasing attention from the construction industry for safety accident prevention [7, 8]. For instance, Cambraia *et al*. [9] proposed guidelines for identifying, analyzing and disseminating information on near misses at construction sites. Gnoni and Lettera [10] designed a matrix and an index-based method for a near-miss event assessment and made a critical comparison between the two methodologies. Near-miss management can help safety managers unearth the context within which an accident arises, enabling accountability to be shared across different stakeholders, facilitating continuous improvement on safety [11].

However, in practice, there are several problems hindering the effectiveness of near-miss management. One of the major considerations is that near-misses can often go underreported in construction [12]. The major factors that discourage reporting are fear of disciplinary action and lack of feedback on how reported information has been used [13]. Another obstacle is that near-miss data has the risk of being distorted or lost before they reach the safety team [14]. Near-miss data is usually recorded in contractors' systems like the Project Management Information System, characterized with low transparency and reliability [15]. All these issues have an adverse impact on the traceability, transparency, sharing accuracy and timeliness of near-miss information, which affects safety improvement.

Blockchain is a type of distributed ledger technology (DLT) where all data are digitized and decentralized [16]. Technically, a blockchain is a chained data structure that combines blocks of data and information in a chronological order and records the blocks in encrypted form as a distributed ledger that cannot be tampered with or forged [17]. Due to its technical features, blockchain is featured as immutability, transparency, traceability, information sharing and monitoring. In this regard, block-chain can provide a robust mechanism for improving the effectiveness of near-miss management.

The aim of this research was to propose a blockchain-enabled framework for near-miss management in the construction industry. More specifically, objectives were twofold: (1) to identify key issues and challenges in near-miss management, and (2) to propose a conceptual framework of the blockchain-enabled model that supports near-miss management. The proposed framework facilitates the traceability, transparency, and reliability of near-miss information and contributes to near-miss information sharing and safety control.

II. Literature Review

A. Key Issues and Challenges with Near-Miss Management

Near misses and accidents have some/many common causes; learning from near misses and eliminating their causes can contribute to preventing accidents [6]. To harvest value from near-miss data, Phimister *et al*. [5] first proposed the

Manuscript received November 7, 2022; revised December 16, 2022; accepted March 15, 2023.

Pan Zhang and Raymond Yiu Yin Lee are with the Department of Architecture and Civil Engineering, City University of Hong Kong, Hong Kong.

Ivan W. H. Fung is with School of Civil Engineering and Geomatics, Southwest Petroleum University, Chengdu, China.

*Correspondence: ivanfungwinghong@gmail.com (I.W.H.F.)

doi: 10.18178/ijimt.2023.14.3.945

near-miss management system in the chemical industry. The main steps of an effective near-miss management system mainly including near-miss identification, reporting, analysis, solution and dissemination [6]. Recently, the near-miss management system has triggered interest from many different industries, such as industries with major accident hazards (e.g., chemical, nuclear, airline) and other sectors, like manufacturing, mining, and construction [18]. These studies have confirmed the value of near-miss management in safety improvement.

However, despite fast advances in near-miss management, the effectiveness of near-miss management in construction is a major concern [14]. Specifically, near misses are underreported because they may be used as a tool to ascribe individual or organizational blame [9]. Moreover, near misses have the possibilities to be censored before they reach the health and safety team [14]. In addition, near-miss data is usually recorded in centralized systems, which hinders information sharing among multiple construction participants. Therefore, transparency, equivalence, fairness and verifiability are difficult to guarantee [19]. An effective near-miss management approach is required.

B. Blockchain and Its Applications in Construction

Blockchain is regarded as having the potential to transform many global industries, including construction. A blockchain can be regarded as a linked list of blocks, where each block contains data and information. The two core elements of the blockchain are distributed ledger technology and smart contracts, which can ensure the immutability, traceability and transparency of information. DLT mainly involves four key techniques, namely, hashing algorithm, consensus mechanism, peer-to-peer network, and public-private key cryptography, which enable the blockchain to process information in a way that is secure, reliable, open, fair, efficient, anonymous, and intelligent [17]. Smart contracts, defined as computerized transaction protocols that execute the terms of a contract, can be employed in a blockchain system to automate business processes [15].

Due to the potential of blockchain, researchers are seeking to apply blockchain technology to construction and management practices. For example, Chong and Diamantopoulos [20] developed a comprehensive framework that integrates blockchain and other advanced technologies to address the security of payment issues in the construction industry. Similarly, an automated financial system based on blockchain was established by Elghaish *et al*. [21], and the framework would enable core project team members to automatically execute all financial transactions. Zhong *et al*. [22] proposed a blockchain-based framework for construction quality information management, which can help handle information fraud and facilitate automated compliance checking. In summary, blockchain can make construction management more efficient, transparent, and accountable for all involved participants [23].

III. Methodology

A design science research approach illustrated in [24] was adopted to design and develop the blockchain-enabled conceptual framework for near-miss management. Design science focuses on describing, explaining, and predicting observable phenomena within its field, by not only understanding problems, but also proposing solutions [25].

The research process in this study is presented in Fig. 1. Firstly, key issues and challenges with near-miss reporting in construction were identified through literature review, and the technical characteristics of blockchain and its applications in construction were introduced. Secondly, the usability and feasibility of blockchain in tackling near-miss management challenges were discussed in several focus group meetings, and the details (e.g., framework, process, participants, etc.) of blockchain-based solutions were brainstormed and proposed. Thirdly, the blockchain-based framework was determined.

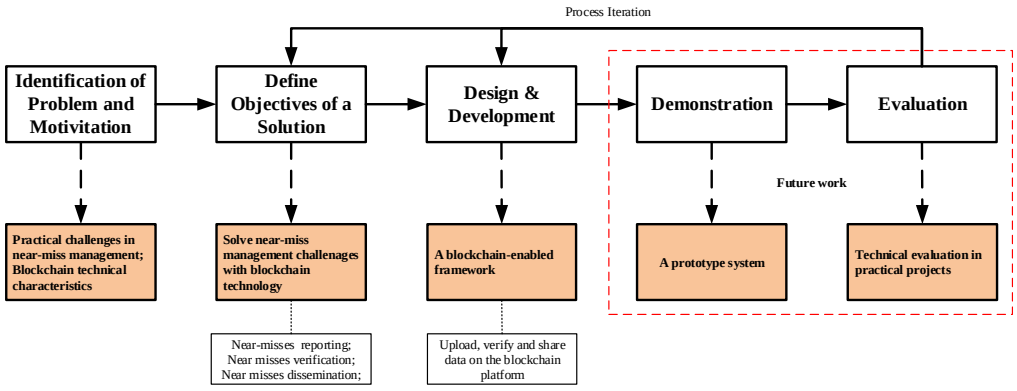

Fig. 1. Research process in this study.

IV. Blockchain-Based Conceptual Framework for Near-Miss Management

A. Overall Conceptual Framework

The proposed conceptual framework is shown in Fig. 2. Four crucial participants are involved in the near-miss management process: inspectors, contractors, safety supervisors, and owners. Inspectors are responsible for near-miss identification and reporting near misses in the construction process, while safety supervisors check whether the reported near misses are valid and whether identified near misses are rectified by contractors or not. Safety supervisors can also report near misses in their routine inspection and

observation. The contractor is responsible for taking rectification measures for near misses. The owner of the project can monitor all the processes via the real-time operation information on the blockchain. This operation information refers to information of all operations, which include near-miss name, location, report time, a description of the event, rectification measures, and status.

In practice, the issues in real-time communication and information sharing among construction participants often result in a lag in risk identification and control. In contrast, with blockchain-based near-miss management, near-miss information is accessible to all participants at any time. In particular, each party can monitor frequent near misses and high-risk near-miss incidents. Four peers, namely, inspectors and owners, construction contractors, and safety supervisors are included in the block-chain network, and each of them has a copy of the ledger, enabling them to gain in-formation concerning any operation. Within the network, near misses are regarded as the entity, and each transaction represents each operation regarding near misses in the chain, including near-miss reporting, checking and assessment. An operation cannot be confirmed as valid until qualified endorsing peers reach a consensus on its authenticity. The near-miss information is recorded in the ledger and can be updated via the smart contract once the validity is admitted.

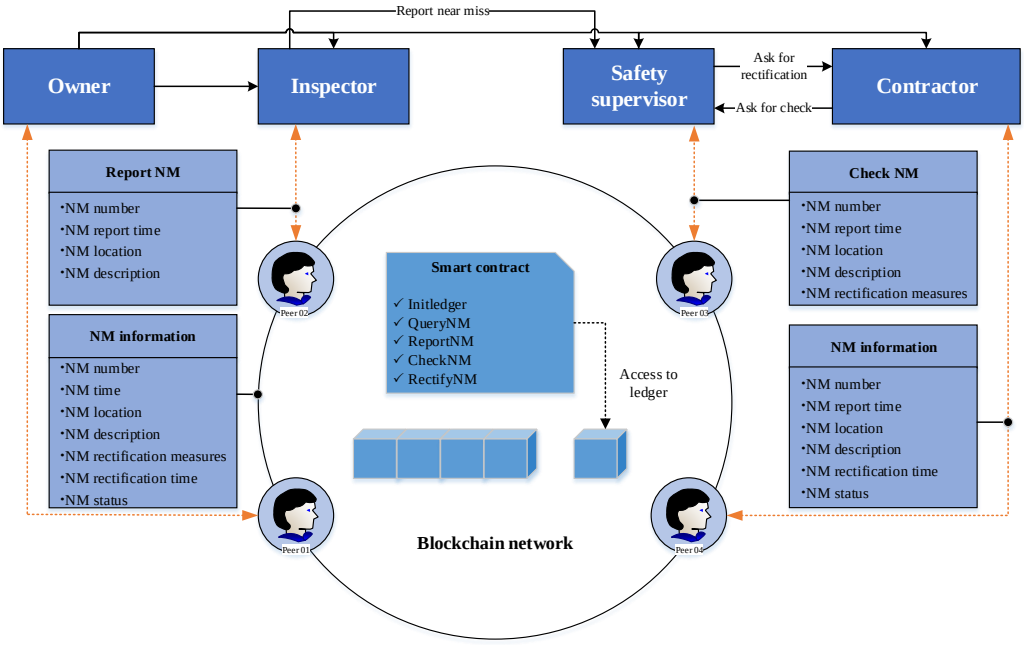

Fig. 2. Framework for blockchain-based construction near-miss management.

B. Consortium Blockchain Network for Near-Miss Management

Blockchain can ensure that information is immutable, traceable and transparent; smart contracts deployed on the blockchain can continuously monitor data changes and automatically execute predefined terms once the conditions are met. These ad-vantages can facilitate solving the issues in near-miss management. By establishing a blockchain-based near-miss management framework, construction stakeholders can share near-miss information effectively and identify safety risks efficiently. In construction projects, various participants involve in safety management and collaborate with each other to ensure construction safety. Multiple organizations play an important role in the near-miss management process. Thus, a consortium blockchain is considered proper.

To develop a consortium blockchain, the Hyperledger Fabric (HLF) platform was adopted. Hyperledger Fabric is a Hyperledger project of blockchain frameworks and tools, and it can support complex transactions and business processes. In a HLF net-work, all nodes have an identity, which can be divided into three roles: 1) Client: to submit a transaction proposal and send the transaction for ordering; 2) Peers' roles: to execute a transaction proposal, validate the transaction, and maintain blockchains; 3) Orderer' roles: to collect transactions from clients and determine the overall order of all transactions. Besides, there are other design components included in the HLF net-work. For instance, a channel provides a separate communication layer for certain participants to maintain the privacy of communication and data, and chaincode is used to package one or more smart contracts together to be installed on a particular channel. The peers in the network can create various channels according to the business requirements. Each channel has a ledger, which can only be accessed by the peers in the channel.

As shown in Fig. 3, a consortium blockchain network is developed for managing near-miss information based on the HLF platform. Inspectors, contractors, safety supervisors and owners are involved in the network. In a construction project, these participants are in one channel, which can ensure the transparency of information. The parties can set up one or multiple peers and new nodes can join the blockchain network system through the client. It is worth noting that the parties can change based on the lifecycle of the participants in a project. For example, the subcontractors can exit the blockchain system once they finish construction work. If the participant comes out of the channel on the blockchain, they do not have access to the near-miss information ledger. Table I shows the permission and lifecycle of different participants on the blockchain.

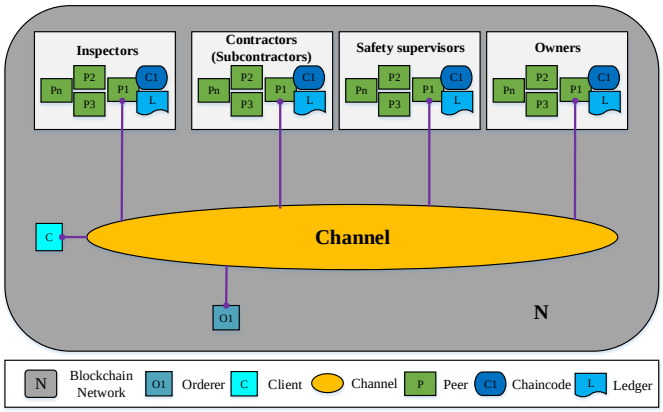

Fig. 3. Consortium blockchain network based on Hyperledger Fabric.

TABLE I: PARTICIPANTS' LIFECYCLE ON THE CONSORTIUM BLOCKCHAIN

Participants	Permissions	Lifecycle on the chain
Inspector	"Report", "Query" near-miss information	Always on the chain
Contractor	"Query", "Report" near-miss information	Contractors will always be on the chain; Subcontractors will exit the chain when the contract tasks are finished
Safety supervisor	"Query", "Report", Check" near-miss information	Always on the chain
Owner	"Query", Check" near-miss information	Always on the chain

C. Transaction Flow in the Blockchain Network

The transaction flow in the blockchain network is illustrated in Fig. 4. The consortium blockchain can provide control and privacy for the participants, and a person without registration cannot join the blockchain network. In the blockchain network, the in-formation is transformed into transaction proposals that need a consensus agreement generated by predefined peers before being added to the ledger. The consensus process of the blockchain network can be divided into three steps: 1) transaction proposal and execution, 2) ordering transactions, and 3) transaction validation. In fact, the essence of the transaction is the invoking of a smart contract, which is deployed into the blockchain network to enable interaction with the shared ledger. The smart con-tract can self-execute the terms of a contract upon the fulfillment of preset conditions. A smart contract can be written to facilitate operation according to peers' requirements. The blockchain network and smart contracts are detailed in the following sections.

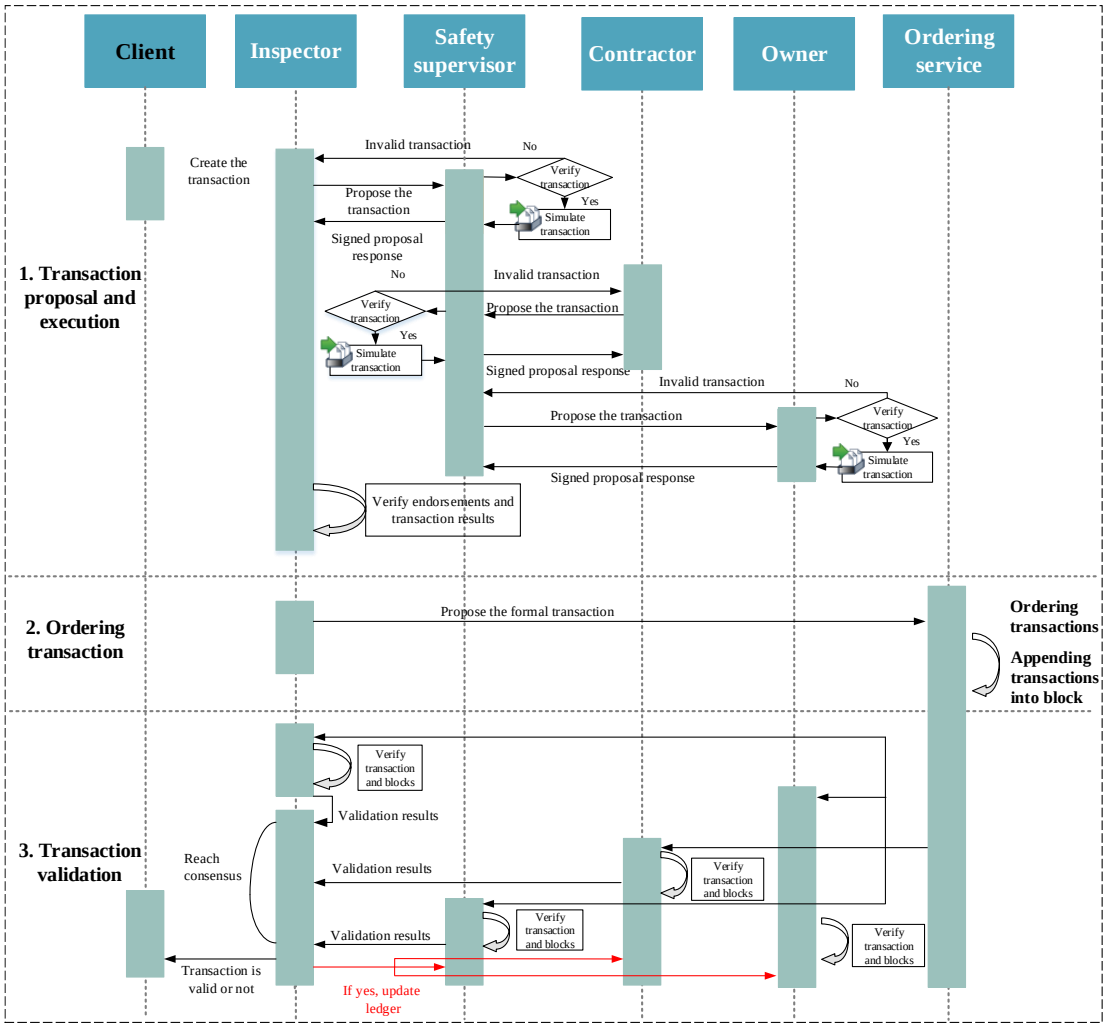

Fig. 4. Transaction flow of blockchain network.

1) Transaction proposal and execution

A reporting operation needs to be conducted when inspectors spot a near miss on a construction site. In this case, the inspector peer submits the reporting proposal via the client application to the endorsing peers, that is, the safety supervisor peer, or the own-er peer (when the near-miss is of high risk). The reporting proposal contains the near-miss information, including its name, location, report time, description, etc. Then, these endorsing peers check the validity of the reporting proposal and send back their responses to the proposal with their signatures. The endorsement policy varies in different cases, which is encoded in the smart contract. For instance, inspectors are the reporter of near-miss incidents and safety supervisors are responsible for checking near-miss events and deciding what rectification measures should be taken. This is why they are endorsing peers in this case. Significantly, the ledger is not updated at this point, and this process can be regarded as a simulation of executing the transaction, which has the objective of verifying whether the near miss information is properly reported, whether the format of near miss information is correct, whether the risk of near-miss incidents is under control, and so on. The involvement of relevant stake-holders in the consensus process can ensure the authenticity of a transaction. After the endorsing peers sign the initial transaction proposal, a proposal response will be sent back to the client. In a similar vein, the reporting operation of near-miss rectification progress in the blockchain can also be performed by corresponding participants.

2) Ordering transaction

The "proposal response" is verified to check whether the endorsement policy has been followed. Subsequently, the "proposal response" is assembled as a formal trans-action for the ordering service. The ordering service is designed to order the transactions chronologically and collects them into new blocks by channel based on a specific ordering algorithm.

3) Transaction validation

The block containing the transaction is broadcast to all peers in the same channel and the relevant peers can validate the transactions. Each transaction is tagged as valid or invalid by each peer. If the reporting proposal is verified to be valid, then the ledger will be updated. Meanwhile, the ledger held by each peer is modified simultaneously. Finally, the peers will be informed that the new block has been added to the blockchain, and, at this time, the transactions are no longer editable.

In short, near-miss management can be proposed, executed, validated and updated in the blockchain network. The proposed model can enhance near-miss management from the following perspectives: (1) information sharing among participants, (2) information immutability, (3) safety traceability, and (4) collaboration.

V. Conclusion

This study proposes a blockchain-enabled conceptual framework for near-miss management in construction. In this framework, near-miss data reported by construction participants were recorded in blocks after the consensus process. The framework can guarantee traceability, transparency, and reliability of near-miss information, protect privacy of reporters and facilitate information sharing among multiple construction stakeholders. Future work is required to emulate the effectiveness of the proposed framework.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Pan Zhang and Ivan W. H. Fung conceived the study and were responsible for the design and development of the methodology; Pan wrote the paper; Raymond Yiu Yin LEE reviewed and edited the paper; all authors had approved the final version.

References

[1] Z. Zhou, Y. M. Goh, Q. Shi, H. Qi, and S. Liu, "Data-driven determination of collapse accident patterns for the mitigation of safety risks at metro construction sites," *Tunnelling and Underground Space Technology*, vol. 127, 2022.

[2] Occupational Safety and Health Administration. *Commonly Used Statistics*. [Online]. Available: https://www.osha.gov/data/commonstats

[3] B. Tang, S. Guo, J. Li, and W. Lu, "Exploring the risk transmission characteristics among unsafe behaviors within urban railway construction accidents," *Journal of Civil Engineering and Management*, vol. 28, no. 6, pp. 443–456-443–456, 2022.

[4] J. Hinze, C. Pedersen, and J. Fredley, "Identifying root causes of construction injuries," *Journal of Construction Engineering and Management*, vol. 124, no. 1, pp. 67–71, 1998.

[5] J. R. Phimister, U. Oktem, P. R. Kleindorfer, and H. Kunreuther, "Near-miss incident management in the chemical process industry," *Risk Analysis: An International Journal*, vol. 23, no. 3, pp. 445–459, 2003.

[6] M. G. Gnoni and J. H. Saleh, "Near-miss management systems and observability-in-depth: Handling safety incidents and accident precursors in light of safety principles," *Safety Science*, vol. 91, pp. 154–167, 2017.

[7] F. Wang, H. Li, and C. Dong, "Understanding near-miss count data on construction sites using greedy D-vine copula marginal regression," *Reliability Engineering & System Safety*, vol. 213, 107687, 2021.

[8] C. Zhou, L. Ding, M. J. Skibniewski, H. Luo, and S. Jiang, "Characterizing time series of near-miss accidents in metro construction via complex network theory," *Safety Science*, vol. 98, pp. 145–158, 2017.

[9] F. B. Cambraia, T. A. Saurin, and C. T. Formoso, "Identification, analysis and dissemination of information on near misses: A case study in the construction industry," *Safety Science*, vol. 48, no. 1, pp. 91–99, 2010.

[10] M. G. Gnoni and G. Lettera, "Near-miss management systems: A methodological comparison," *Journal of Loss Prevention in the Process Industries*, vol. 25, no. 3, pp. 609–616, 2012.

[11] P. E. D. Love and K. Tenekedjiev, "Understanding near-miss count data on construction sites using Greedy D-vine Copula Marginal Regression: A comment," *Reliability Engineering & System Safety*, vol. 217, 108021, 2022.

[12] K. Santiago, X. Yang, E. C. Ruano-Herreria, J. Chalmers, P. Cavicchia, and A. J. Caban-Martinez, "Characterising near misses and injuries in the temporary agency construction workforce: qualitative study approach," *Occupational and Environmental Medicine*, vol. 77, no. 2, p. 94, 2020.

[13] M. Winkler, Y. Perlman, and S. Westreich, "Reporting near-miss safety events: Impacts and decision-making analysis," *Safety Science*, vol. 117, pp. 365–374, 2019.

[14] D. Oswald, F. Sherratt, and S. Smith, "Problems with safety observation reporting: A construction industry case study," *Safety Science*, vol. 107, pp. 35–45, 2018.

[15] H. Wu, B. Zhong, H. Li, J. Guo, and Y. Wang, "On-Site construction quality inspection using blockchain and smart contracts," *Journal of Management in Engineering*, vol. 37, no. 6, 04021065, 2021.
[16] R. Yang *et al*., "Public and private blockchain in construction business process and information integration," *Automation in Construction*, vol. 118, 2020.
[17] Y. Lu, "The blockchain: State-of-the-art and research challenges," *Journal of Industrial Information Integration*, vol. 15, pp. 80–90, 2019.
[18] M. G. Gnoni, F. Tornese, A. Guglielmi, M. Pellicci, G. Campo, and D. De Merich, "Near miss management systems in the industrial sector: A literature review," *Safety Science*, vol. 150, 2022.
[19] Z. Ma, W. Zhao, S. Luo, and L. Wang, "TrustedBaaS: Blockchain-enabled distributed and higher-level trusted platform," *Computer Networks*, vol. 183, 107600, 2020.
[20] H.-Y. Chong and A. Diamantopoulos, "Integrating advanced technologies to uphold security of payment: Data flow diagram," *Automation in Construction*, vol. 114, 103158, 2020.
[21] F. Elghaish, S. Abrishami, and M. R. Hosseini, "Integrated project delivery with blockchain: An automated financial system," *Automation in Construction*, vol. 114, 103182, 2020.
[22] B. Zhong, H. Wu, L. Ding, H. Luo, Y. Luo, and X. Pan, "Hyperledger fabric-based consortium blockchain for construction quality information management," *Front. Eng. Manag.*, pp. 1–16, 2020.
[23] S. Perera, S. Nanayakkara, M. Rodrigo, S. Senaratne, and R. Weinand, "Blockchain technology: Is it hype or real in the construction industry?" *Journal of Industrial Information Integration*, vol. 17, 100125, Mar 2020.
[24] K. Peffers, T. Tuunanen, M. A. Rothenberger, and S. Chatterjee, "A design science research methodology for information systems research," *Journal of Management Information Systems*, vol. 24, no. 3, pp. 45–77, 2007.
[25] J. E. V. Aken, "Management research based on the paradigm of the design sciences: the quest for field-tested and grounded technological rules," *Journal of Management Studies*, vol. 41, no. 2, pp. 219–246, 2004.