Blockchain based Framework for Verifying the Adequacy of Scaffolding Installation

Chan-woo Baek[a] , Do-Yeop Lee[a] and Chan-Sik Park[a]

[a]School of Architecture and Building Science, Chung-Ang University, Republic of Korea
E-mail: ba9899@gmail.com, doyeop@cau.ac.kr, cpark@cau.ac.kr

Abstract –

Falls are the leading cause of construction site accidents and made up more than 60 percent of all construction-related deaths in 2018, according to the Korea Occupational Health and Safety Administration (KOSHA). Accordingly, the government conducts intensive management and supervision of scaffolding and scaffolding installation at small sites while inducing safe working environments through support for system scaffolding installation. However, the timing of scaffolding installation for external work varies by site, and visiting inspections of more than 400,000 sites annually are practically limited. In particular, in the case of small sites, the work is often carried out with a high risk of falling accidents due to installation or defects that do not comply with KOSHA rule and the occurrence of accidents is frequently reported. To solve these limitations, information on whether the right amount of scaffolding has been purchased and installed at the right time according to the size and shape of each site needs to be managed by a systematic method.

In this paper, we propose a framework for verifying the adequacy of the installation of scaffolding needed at the individual construction site using blockchain technology. The system provide Dapp, an application that runs on the block chain server, so that General contract (GC) and Supplier can enter information related to ordering and procurement of scaffolding. The core information required to determine the adequacy of scaffolding installation is stored in a non-modifiable form using the distributed ledger storage technology of the block chain. As a result, scaffolding installation adequacy can be automatically verified through the algorithms that can compare the installation schedule and quantity calculation with the actually purchased quantity.

It is anticipated that using the proposed framework, government agencies can identify the safety levels of individual sites without on-site visits.

Keywords –

Scaffolding; Blockchain; Framework

1 Introduction

The death rate of domestic industrial accidents has been the highest among Organization for Economic Cooperation and Development (OECD) countries for decades. In addition, half of the domestic casualties occur in the construction industry. Particularly, the fall accident occurred from temporary structure shows high rate especially in a small site where facilities such as scaffolding are not installed [1].

Besides, according to the analysis data of major disasters in the construction industry over the past five years, 448 people died during scaffolding-related work, accounting for 23 percent of the total (2,134). Accidents occurred 63 percent at small and medium-sized sites (with a construction amount of less than 2 million USD), 44 percent due to the use of conventional steel pipe scaffolding, and 38 percent in housing-amenities construction [2]. Therefore, to prevent the risk of falling at the construction site, it is necessary to manage the appropriateness of scaffolding for more than 400,000 small and medium-sized sites annually [3]. However, at the construction site in Korea, the importance of scaffolding is still not recognized, and it is neglected for several reasons such as shortening the period and reducing costs.

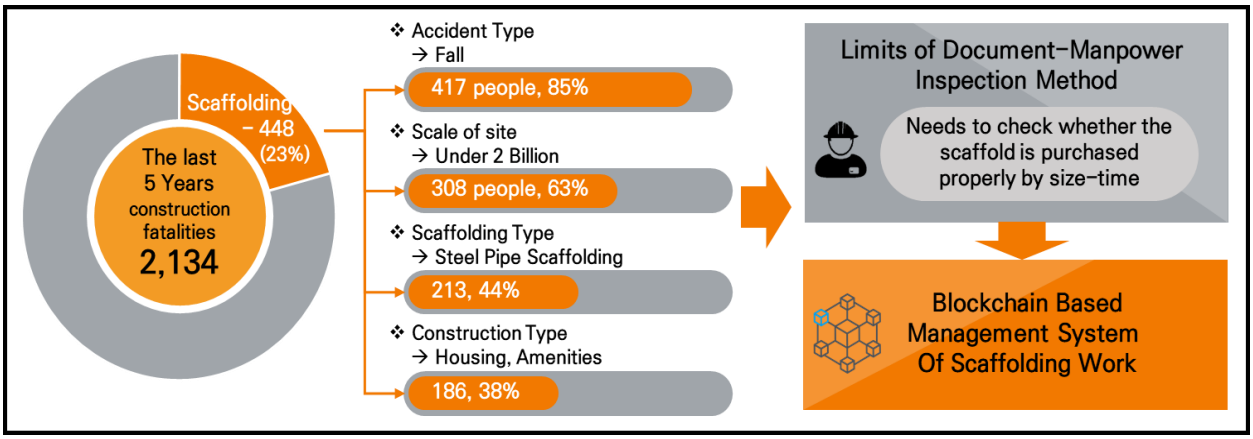


Figure 1. Construction Disaster Statistics by KOSHA (2015~2019)

Accordingly, the government induced on-site safety through a scaffold installation support system such as a clean project, and conducted inspections mainly on small and medium-sized construction sites that are vulnerable to safety accidents, but there are limitations in conducting inspections due to manpower based checking and document-oriented records. Therefore, for efficient management, it is necessary to manage information on whether the appropriate amount of scaffold is purchased and installed at the right period according to the size and shape of each site. For these reasons, this study intends to propose a blockchain-based framework for verifying the adequacy of scaffold that can automatically discriminate the information generated in the process of scaffolding work by a system other than a person and simultaneously secure the reliability of the generated information.

2 Literature Review

2.1 Scaffolding-Safety

Scaffolding is a temporary structure that is assembled and installed around a structure in order to install a construction passageway or work plate to facilitate high-rise work [2]. Due to the development of construction technology, the number of high-rise works has increased compared to the previous one, as the buildings are gradually becoming taller and larger. Therefore, as the importance and utilization of scaffolding in the field has expanded, the importance of safety issues related to scaffolding work has been emphasized.

As for the main research related to scaffolding, studies on accident analysis and countermeasures related to scaffold-safety, scaffold modeling using BIM, and risk identification are in progress. First, as research related to scaffolding and safety, Hola [4] analyzed accidents involving falls from scaffolding, which took place in Poland in the years 2008-2015. In addition, this study deduced that the biggest influence on the formation of accidents came from a lack of or inadequate equipment that secures work posts on scaffolding, and also improper collective protection measures e.g. roofing or protective nets, poor stability of scaffolding or its components and also an inadequate spatial structure of scaffolding. Kim [5] analyzed accidents that were caused by scaffolding during a fall disaster occurring at a domestic construction site. Besides, a variety of key factors affecting the fall was drawn from four aspects: worker, manager, material and construction, and design. Sakhakarmi [6] proposes a method that can be used during operation to make an automated safety prediction for scaffolds. It implements a divide-and-conquer technique with deep learning. This study emphasized that implementation will enhance the reliability of automated safety assessment systems on construction sites. Pienco [7] presented the results of analysis of 100 full-scale scaffolding structures in terms of compliance with legal acts and safety of use. He examined scaffolds in Poland located at buildings which were at construction or renovation stage from 2016~2017. Based on the analyzed scaffoldings, the most common errors concerning assembly process and use of scaffolding were collected.

Also, diverse researches are conducted related to scaffolding using BIM include automatic scaffolding design, risk identification through scaffold modeling, and safety planning. Kim [8] presented a framework and algorithms to integrate temporary structures to the automated safety analysis. Focusing on scaffolds, this research integrates temporary structures into an automated safety checking approach using BIM. Also a safety planning platform was created to simulate and visualize spatial movements of workers using scaffolding. Computational algorithms in the platform

automatically identify safety hazards related to activities working on scaffolding and preventive measures can be prepared before the construction begins. Kim [9] developed a rule-based system that automatically plans scaffolding systems for pro-active management in Building Information Modeling (BIM). Their computational algorithms automatically recognize geometric and non-geometric conditions in building models and produce a scaffolding system design that a practitioner can use in the field. We implemented our automated scaffolding system for commercially-available BIM software and tested it in a case study. project.

2.2 Blockchain Technology

Blockchain as a Distributed Ledger Technology (DLT) is a distributed data logging and maintenance system that depends on and is ensured by the consensus mechanism implemented by the agents. The autonomy and updating of the information contained in the blocks are subject to verification and authorization by all participants [12]. All participants with transaction data and management authority form a peer-to-peer (P2P)-type network to verify the previously centrally managed data by all participants within the network to ensure data integrity and reliability. The types of blockchains classified according to their characteristics include public blockchain that anyone can participate in, private blockchain that can only participate with permission, and consortium blockchain [10]

Table 1. Classification of Blockchain

	Participant	Anonymity	Usecase
Public Blockchain	Anyone	o	Bitcoin
Private Blockchain	Optional	x	Nasdag's Linq
Consortium Blockchain	Optional	x	Hyperledger Fabric

A representative function of blockchain is smart contract. A smart contract is a system that automatically fulfills a contract when all programmed conditions are met. Previously, a lot of documents were required until the contract was concluded and executed, but smart contract is a technology in which the terms of the contract are specified in computer code, and the contract is made when the terms are met.

Although the applying blockchain technology and smart contracts in the construction industry has not yet been conducted, many researches have been done to apply to the construction industry in recognition of the advantages and necessities of each technology. Major research areas related to construction include procurement, payment, and data reliability through connection with BIM.

Wang [11] proposed a blochchain-based information management model. The study suggests that proposed model can enhance real-time information communications among the different stakeholders and improve the efficiency of supply chain management. Besides, they also mentioned that through an adjustment in the smart contract, the model can also be applied to tackle issues in other traditional supply chains. Kim [12] proposed a procurement management system that applied Block Chain and Big Data technology within the construction industry. Through this, he emphasized that information generated as the project progresses can be applied to Block Chain to secure the immutable information and records, and that distributed network interworking can contribute to minimizing conflicts between project management and project entities by contributing to increased connection and reliability of information. Giuda [13] emphasizes that the progressive introduction of BIM based on the blockchain technology can provide a trustworthy infrastructure for information management during the design, tender, and construction phases. Luo [14] proposed a blockchain-based smart construction contract framework for semiautomatic execution of construction contracts for interim payments. They developed a smart contract implementation framework that satisfies the sequential approval process requirements in a distributed environment such as the construction industry by utilizing blockchain technology. Kang [15] emphasized that through smart contracts, transactions between interested parties can be managed in a decentralized manner, reducing the risk of contract changes and inducing reasonable transactions with transparent transaction terms. Besides, he also proposed that an Ethereum-based smart contract could be solved, which is difficult to solve with the centralized control method of the current construction industry. Lanko [16] referred that almost none of the fields of human activity can do without supply chain management. Therefore, in this study, the necessity and limitations of blockchain technology application were presented by taking the manufacturing process and delivery process of ready-mixed concrete as an example. Turk [17] emphasised that blockchain has the potential to address some issues that discourage the industry to use BIM such as confidentiality, provenance tracking, disintermediation, non-repudiation, multiparty aggregation, traceability inter-organizational recordkeeping, change tracing, data ownership, etc. Moreover, they also mentioned that on the construction site, blockchain could improve the reliability and reliability of construction logbooks, works performed and material quantities recorded. San

[18] referred that the application of blockchain technology can improve the construction process that shows the limitations of centralized technology in the current construction project lifecycle. In addition, Dakhli [19] emphasized that block chain technology can improve the limitations of the design and construction process and reduce costs.

2.3 The necessity of Blockchain Framework

Recently, interest in the smart contract technology, which is automatically traded when the reliability and security of data and conditions are met through the distributed ledger, a representative characteristic of blockchain, is growing in all industries. In particular, the construction industry expects that the problem of chronic distrust in the construction industry will be resolved if transparency and completeness of transactions can be secured in subcontracting, material delivery, and real estate transactions. For this reason, various blockchain platforms and functions are developed and continued research is conducted according to the purpose of utilization. However, there is no research on safety management related to scaffolding construction based on blockchain technology. In this regard, the blockchain-based framework that determines the adequacy of scaffolding installations presented in this study is needed.

Furthermore, the framework to be proposed in this paper is expected to improve the limitations of the existing construction management process by using reliable data and the decentralization of information through distributed storage, a typical characteristic of blockchain technology.

3 Proposing Framework

3.1 Framework Overview

The framework proposed in this study is focused on preventing falls during scaffolding operations that are severe in the construction industry. To this end, the framework will be designed as a system process that manages the suitability of scaffolding installation by discriminate the purchase of scaffolding quantities.

1) The proposed framework utilizes a Hyperledger fabric, a kind of Consortium blockchain, so that only designated users can have access to data. Through this, we will give authority only to construction participants such as GC, suppliers, and inspection agency. Then we will configure the scope of data access differently according to the characteristics of each participant.

2) As a technical method for automatically verifying scaffolding-related power generation information, a structure will be designed that automatically calculates the time and quantity of scaffolding installation based on design information such as 4D-BIM, compares them with the order-procurement information entered through the app, and stores the results in the block chain system.

3) Blockchain technology utilizes core composition technologies such as channel composition for authority setting by participating parties, consensus algorithm for ledger records and viewing, and guarantee policy. We will set up Membership Service Providers (MSP) for channel configuration and form a system for data access and verification in conjunction with the blockchain network. We will also design a separate system structure of the On-Chain, Off-Chain network to prevent overload of the blockchain network.

4) The key demand for this framework is the Government Inspection Agency, which conducts on-site inspections. It is intended to design a system structure that can store information that needs to be verified when checking the appropriateness of scaffolding at individual sites of this system in a blockchain manner and provide the information needed for verification from the inspector's point of view.

3.2 Key functions of Blockchain Framework

This section describes the core functions of the framework proposed. The framework utilizes various key technologies in the blockchain to identify the entered data and store the identified data as reliable data. Key functions are as channeling, smart contract, text mining, consensus algorithm and on/off chain.

- *Channeling*

Channeling defines participants who participate in scaffolding-related activities of construction projects and sets different access authority to information by subject. Channel composition can be divided into groups that generate information through scaffolding-related activities and groups that view them. The first group that generates information is a supplier that procures scaffolding and a contractor that orders scaffolding. The supplier grants authority only to the relevant field channel, so that information from other sites cannot be viewed, preventing sensitive information such as order history and cost from being shared with other suppliers. The contractor grants authority to all managed sites so that data can be provided and viewed for scaffolding. The inspection agency is designed to allow access to all data, such as ordering-procurement data and discrimination results so that it can be determined whether appropriate scaffolding is installed.

- *Smart Contract*

Smart contract is one of the key functions of the

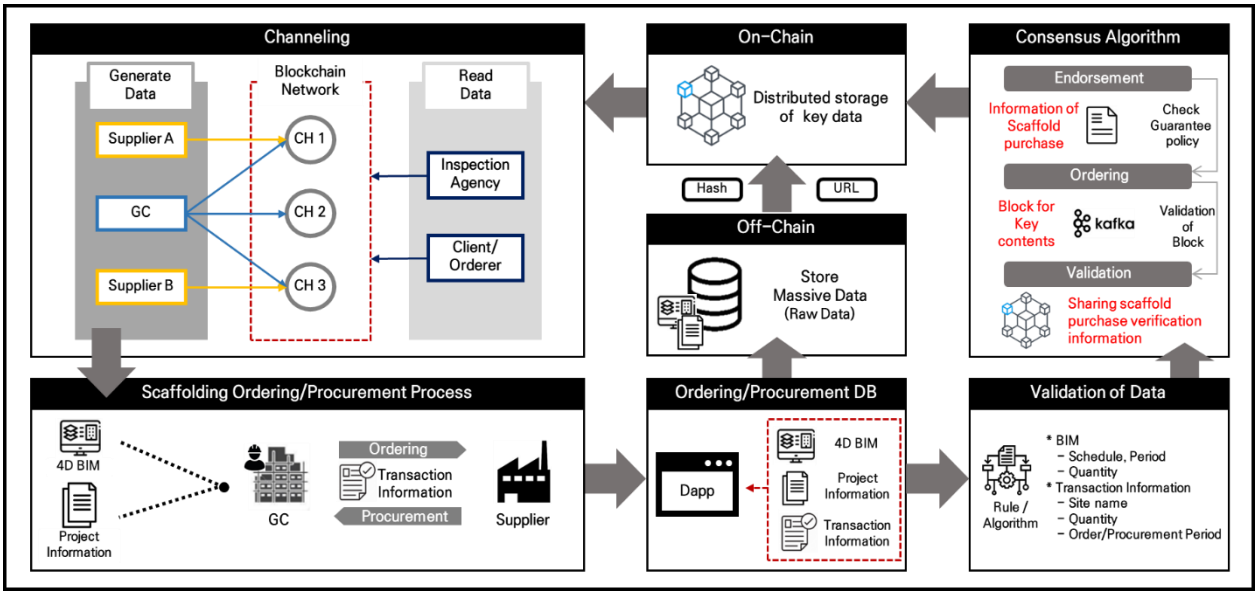


Figure 2. Blockchain-based scaffolding management process and key features

blockchain. It implements functions such as reading and storing data from the blockchain server so that the algorithm on the application can compare the data entered in the order-procurement process with the key data such as area, time, and installation quantity identified in the 4D BIM data.

- *Dapp*

Dapp is an application that works on distributed ledger systems. It is used by the transaction participant to input information generated during the ordering and procurement process and basic information of construction. In addition, Inspection agency can view the scaffold installation suitability and related data derived through data verification.

- *Consensus Algorithm*

This algorithm automatically uploads discriminative data from verification of proper scaffold purchase to On-Chain to prevent forgery of data due to third-party intervention that may occur before being recorded in distributed ledger. In addition, by checking the authority of the viewer, it is possible to prevent ledger access by unauthorized users to the corresponding blockchain network or channel.

- *On-Chain / DLT*

This technology is a function to store verified data on the blockchain. Every participant in the channel maintains a copy of the ledger on its own and the copy goes through a consensus process to keep it consistent with the copies of all other peers. Through this, it is possible to prevent forgery and falsification of all scaffolding-related data input to the ledger and ensure data reliability.

- *Off-Chain*

Off-chain is a method of recording data outside the blockchain. If large capacity data is stored in the on-chain, processing speed may be reduced and overload may occur. To prevent this, massive data (photo, BIM, etc.) is stored in a single DB outside the block chain and the hash and URL of the data are recorded in the distributed ledger.

4 Scenario of proposed framework

In this section, we would like to present a sample scenario of the proposed framework to demonstrate the process of the entire framework.

Based on the basic information of the project and the 4D-BIM, the GC calculates the amount of scaffolding installed by construction period. Then, order the materials from the supplier and receive them. Through the ordering-procurement process, information about the transaction between GC and supplier is generated, such as ordering and procurement quantity and ordering time. The generated transaction information is uploaded by the participant through the dapp. Then uploaded data is verified through the data comparison algorithm to discriminate whether the proper scaffolding purchase and installation.

For verification, key information of each original

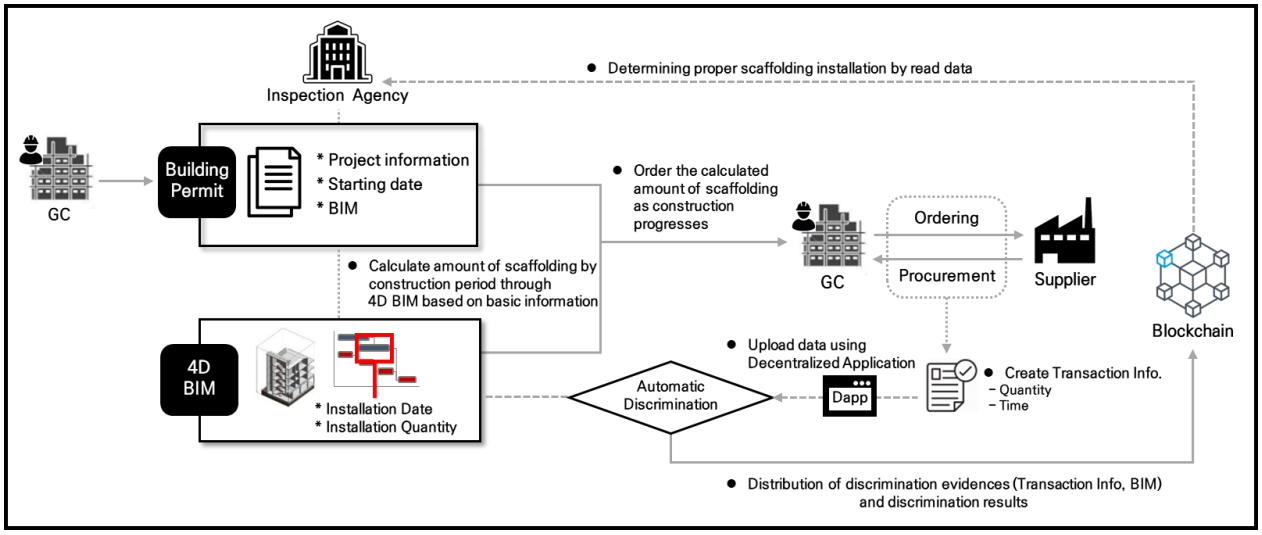
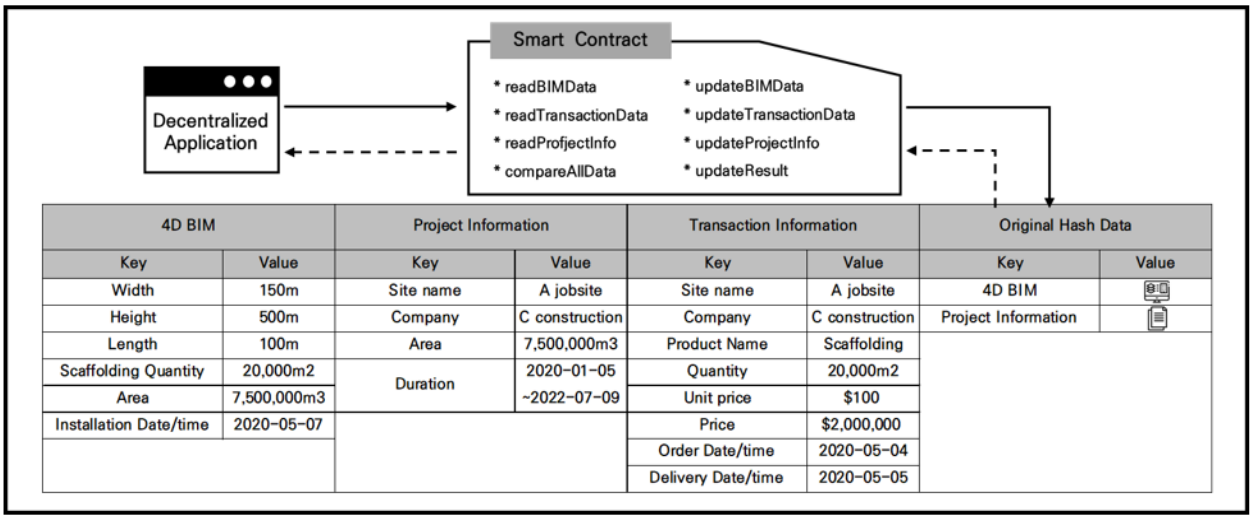


Figure 3. Example scenario of Framework

data is used (shown in figure 4). First, information about the scaffolding quantity required according to the progress of the construction is collected through the area, the scaffolding quantity calculated, and the construction schedule data from 4D-BIM. This data is compared with major data among transaction information such as order quantity and procurement time uploaded through dapp to determine whether the necessary scaffolding is prepared on site at the appropriate time. After that, the results of the verification will be distributed and stored in the blockchain network through a consensus process along with key information such as transaction information and 4D-BIM. At the same time, massive data such as 4D-BIM data is stored separately in off-chain to prevent overload of the blockchain system, and only hash or URL of the data is stored on-chain together. Finally, the inspection agency checks whether the proper amount of scaffolding has been purchased by viewing the stored data and checks whether the proper scaffolding is installed or not. And it will determine whether an on-site inspection is necessary. Moreover, if such data were accumulated later to form big data, it could be used to calculate and verify the necessary scaffolding quantities depending on site characteristics, even without BIM. And it is expected that this could be reflected as a big advantage in small sites where BIM is



4D BIM		Project Information		Transaction Information		Original Hash Data	
Key	Value	Key	Value	Key	Value	Key	Value
Width	150m	Site name	A jobsite	Site name	A jobsite	4D BIM	
Height	500m	Company	C construction	Company	C construction	Project Information	
Length	100m	Area	7,500,000m3	Product Name	Scaffolding		
Scaffolding Quantity	20,000m2	Duration	2020-01-05	Quantity	20,000m2		
Area	7,500,000m3		~2022-07-09	Unit price	$100		
Installation Date/time	2020-05-07			Price	$2,000,000		
				Order Date/time	2020-05-04		
				Delivery Date/time	2020-05-05		

Figure 4. Type and flow of Key information

not available in the field due to costs and other issues.

In addition, this framework can be applied not only to the scaffolding proposed in the study, but also to various supplies. For example, ready-mixed concrete is also worked through the process of 'Quantity calculation-Order&Procurement-Installation'. Although there are differences in several processes such as quality verification in the intermediate process, it is expected that it can be applied as similar processes are being conducted in a large framework. As such, it is expected that the proposed framework can be applied to various supplies of construction work to improve the current construction process.

5 Conclusion

The construction industry is becoming increasingly high-rise, large-scale and complex due to the development of technology. As a result, the proportion of dangerous work and complaint work is increasing, and the frequency of 'falling' is increasing. However, at the construction site, there are still many small construction sites do not recognize the importance of the scaffolding that should be basically installed to prevent fall accidents and do not properly install it even if it is omitted or installed. Recognizing this situation, the government has proposed counterplan such as increasing the number of on-site inspections. However, they still has difficulties due to lack of manpower.

For this reason, this paper proposed a blockchain framework to determine whether the proper scaffolding is installed according to the characteristics of the construction site and to ensure the reliability of the information. The proposed framework secures the reliability of data such as project information, scaffold purchase information and BIM through distributed ledger technology. In addition, it also can verify the suitability of scaffolding installation automatically by compare and determine scaffolding-related information

By using the proposed framework, the inspection agency can check the results of the adequacy of scaffolding installation utilizing blockchain network without the need to visit the site, which requires a lot of manpower. Ultimately, it is anticipated that efficient management will reduce the occurrence of accidents at the construction site.

If a method to acquire the state of the scaffold installed in the actual site is devised, it will be possible to more effectively verify the suitability of installing the scaffold. For example, on-site manager uploads and confirms the installation status of a scaffold on the site as a photo, or a method of confirming the installation status of a site scaffold through CCTV installed on the site. As an available technology, it is expected that scaffolding can be identified and confirmed through images acquired in the field using image recognition technology.

Acknowledgement

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