



Blockchain-Based Automatic Tracking and Extracting Construction Document for Claim and Dispute Support

Eu Wang Kim^{1a}, Min Seo Park^{1b}, Kyoungmin Kim^{1c}, and Kyong Ju Kim^c

^aMember, Dept. of Smart Cities, Chung-Ang University, Seoul 06974, Korea

^bDept. of Smart Cities, Chung-Ang University, Seoul 06974, Korea

^cMember, Dept. of Civil & Environmental Engineering, Chung-Ang University, Seoul 06974, Korea

ARTICLE HISTORY

Received 2 December 2021
Accepted 22 March 2022
Published Online 1 July 2022

KEYWORDS

Construction management
Claim & dispute support
Permissioned blockchain
Computer application
Document tracking
Authenticity verification

ABSTRACT

During a long-term construction project, numerous stakeholders participate and collaborate with each other. In such scenario, the processes of creating, storing, and managing project documents are highly complicated. Due to the nature of the construction projects, problems arise in document management such as loss of documents and difficulties in tracking, which can result in claim failure and huge damage. This study proposes a method to efficiently record, search, and manage construction documents that can protect legal rights in preparation for claims/disputes. This study designed a system that can generate, transfer, and synchronize blocks based on email communication whenever an event occurs. It also provides functions such as document search, history tracking, automatic extraction of related document, and authenticity verification for document management. The findings of the study have established that reliability of documents is secured during the recording, storing, and managing processes, and thus claim- and dispute-supporting tasks are supported.

1. Introduction

A massive number of documents of various types are generated during any long-term construction project. The management of these documents is difficult, given the different types of stakeholders involved, such as employers, engineers, contractors, subcontractors, and vendors. Unsurprisingly, over the years, many documents have been lost in the process. The consequence of deficient management and lack of proactive preparation results in insufficient evidence to prove procedural compliance. This is becoming the main driver of the huge damage to claims and disputes. Furthermore, when claims and disputes arise, the time, cost, and human resources expended in collecting, analyzing, and arranging the various types of documents that have accrued over the project period is tremendous. Therefore, appropriate pre- and post-responses to claims and disputes are required.

Blockchain technology, which involves a decentralized and transparent database (Che et al., 2019), spreads the ledger to a P2P network, which contains all pertinent information, as opposed to a centralized server (Yang et al., 2020). In other words, blockchain technology secures the reliability of shared documents within a

construction project while simultaneously managing the data shared between multiple persons effectively. Bitcoin, one of the representative examples of blockchain, utilizes the P2P network to broadcast data among all connected nodes (Zaghloul et al., 2020). In a blockchain, each block is composed of two parts: a header and a body. Each header incorporates the 'block' hash of its predecessor block, thus creating a 'chain'. The blockchain owned by each node is synchronized after block generation due to transaction occurrence and block propagation using the P2P protocol through this blockchain, the participant of the construction project can record, verify, store, access information with mutual cooperation (Kim et al., 2020).

Claims and disputes arising from global construction projects occur continuously and repeatedly in various types. According to the Global Construction Disputes Report (ARCADIS, 2020), in 2019, the global total value of disputes was \$123.1 million (USD), with the average length of disputes globally being 15 months. Disputes incur considerable economic damage to all those directly involved with regard to compensation and project time extension; considerable time and effort are spent on resolution. The leading cause of construction disputes in 2019 was poorly

CORRESPONDENCE Kyoungmin Kim ✉ kmkim75@cau.ac.kr ☒ Dept. of Civil & Environmental Engineering, Chung-Ang University, Seoul 06974, Korea

© 2022 Korean Society of Civil Engineers

drafted, incomplete, or unsubstantiated claims (ARCADIS, 2020). In addition, insufficient evidence and a lack of data availability at the claim stage were found to be the major reasons for the dispute. Ideally, when a claim or dispute arises, it is imperative to prove that the letter of the contract has been followed with regard to the corresponding matter and to prepare the detailed data and documents required to review the claim (e.g., attributable reasons, loss and expense claims, and extension of time).

Almost all data created while executing the construction project, such as contract documents, notice to proceed, progress reports, specifications, drawings, daily work reports, change orders, changes in design, statements of work, cost and quantity statements, proceedings, and letters, are deemed to be related records in proving the claim. Thus, it is very important that the recording, storing, and managing of such related data be carried out based on mutual trust between the parties.

Blockchain is a disruptive technology, given that it can build mutual trust in cooperation and enable different organizations of a project to achieve security and consistency in their information management (Zhong et al., 2020). However, the application of blockchain to the construction industry is still in its infancy (Yang et al., 2020; Hamledari and Fischer, 2020; Sheng et al., 2020; Shojaei et al., 2019; Zhong et al., 2020). Given this, this study proposes a blockchain-based system for construction document management, which can effectively support tasks associated with pre- and post-responses to claims and disputes.

2. Theoretical Background

2.1 Blockchain

2.1.1 Blockchain in the Construction Industry

One of the main challenges in this section is the need to search for and identify the right information at the right time, in the right place, and especially for the right person (Dakhli et al., 2019). Thus, numerous studies have been conducted on the storage and application of different types of project information (e.g., project documents, site information, schedule, costs, quality, materials, BIM files, and business compliance). The chaincode for business process automation has all characteristics of blockchain technology, such as traceability, immutability, and transparency. Of the studies thus far conducted on information management, Sheng et al. (2020) and Zhong et al. (2020) developed a system for storing quality facility information in blockchain. In the existing research, Furthermore, Shojaei et al. (2019) proposed a method to store all information in the blockchain from the perspective of the lifecycle by extending the partial management of each project stage.

The integration of BIM and blockchain facilitates additional value-added applications (Xue and Lu, 2020). Turk and Klinec (2017) investigated a method to store BIM directly and indirectly in the blockchain as a means of overcoming the limitations that result from the management of BIM at central storage. Nawari and Ravindran (2019) proposed a blockchain-based chaincode

that could manage workflow—request, proposal, approval, reply, and data exchange—by facilitating BIM design review by all stakeholders and proved that transparency and traceability of such workflow could be secured. Zheng et al. (2020) proposed an architecture to connect the blockchain with the BIM cloud, which is more developed than the existing method using local storage. A detailed block structure, including that of BIM metadata, was defined to track historical modifications of the BIM model. Through these studies, the authors demonstrated that effectively changing BIM tracking is possible. Liu et al. (2019) outlined how the storage and application of BIM is interrupted at each business stage and proposed a sustainable management method for building design information from the perspective of life cycle by applying blockchain with BIM. Xue and Lu (2020) indicated that the existing method for synchronizing all BIM files is ineffective in terms of time and communication because of the large size of the files and the characteristic of the blockchain technology that requires each node to possess the same file. To address this issue, the authors proposed a method for changes in the BIM metadata in the blockchain and proved that the method can facilitate the transfer and synchronization of blockchain information to a degree similar to real-time. These studies show that the advantages of blockchain can be sufficiently obtained through metadata storage without storing the entire BIM file.

In the supply chain sector, detailed systems have been proposed to overcome the limitations of existing studies that have proposed only conceptual frameworks or theoretical models. Wang et al. (2020) applied blockchain to supply chain management to resolve the problem of difficulty in identifying the status of modular precasts during the delivery process. This method enabled stakeholders to track precast status in real time; effective quality control and a smooth resolution of the claim were both established. Elghaish et al. (2020) created a framework for connecting integrated project delivery (IPD) and an automated payment system using blockchain. Kifokeris and Koch (2020) proposed a blockchain-based workflow system to oversee order, delivery, invoicing, and payment for an effective supply chain management.

Meanwhile, studies have been undertaken to resolve payment issues with blockchain, such as lack of transparency and delays, both of which can severely undermine construction projects. Das et al. (2020) proposed a blockchain framework to enable the automatic remittance of interim payments and store payment records. Moreover, the authors proposed a key management method for managing participation subjects to enhance the security of sensitive information; this study is different from other studies. Ahmadiheykhsarmast and Sonmez (2020) developed an add-on module that can connect MS Project software with the blockchain and proposed an automated payment method. Hamledari and Fischer (2020) adopted monitoring information BIM-based progress monitoring at a construction site onto a sensing technique to guarantee automated payment execution.

2.1.2 Design in Blockchain-Based System

Table 1 shows the details of the research cases that have developed

Table 1. Brief Comparison of Construction Blockchain according to the Main Domain

Research	Application domain	Blockchain Platform	Main block COMPONENT
Sheng et al., 2020	Information management	Hyperledger Fabric	Quality, progression
Zhong et al., 2020	Information management	Hyperledger Fabric	Inspection result, quality, compliance
Shojaei et al., 2019	Information management	Hyperledger Fabric (Permissioned)	LCA related info. (Material, energy)
Elghaish et al., 2020	Supply chain	Hyperledger Fabric	Package status, cost info., schedule
Wang et al., 2020	Supply chain	Hyperledger Fabric	Package status, project info., delivery status
Ahmadisheykhsarmast and Sonmez, 2020	Payment	Ethereum	Task, schedule, progression, approval status, cost
Hamledari and Fischer, 2020	Payment	Ethereum (Permissionless)	Progression, as-built BIM info., schedule
Das et al., 2020	Payment	Ethereum	Date, quantity, approval status, payment amount

an empirical system by applying blockchain technology to the construction area. These eight research papers were comparatively analyzed based on their application domains, blockchain platforms, and main block data.

First, in terms of the application domain, the detailed development and empirical case studies consist of three categories: information management, supply chain, and payment. As mentioned in Section 2.1, several exploratory studies have been conducted in an attempt to actively introduce blockchain in the BIM field; however, the number of published empirical studies is very small. As such, the adoption of blockchain technology in BIM is still in its infancy, and further research is required.

Second, the blockchain platform indicates the blockchain infrastructure used in each study. In studies addressing the topic of information management and supply chains, development was conducted exclusively using Hyperledger Fabric. This is beneficial because nodes take different roles and tasks in reaching a consensus and are thus classified according to their roles as clients, peers, or orderers (Nawari and Ravindran, 2019). Hyperledger Fabric, developed by IBM, provides blockchain applications and web UI dashboards for developers and is programmable by well-known computer languages (e.g., Golang, JavaScript, Java). Hyperledger Fabric was selected in the above studies because it has the advantage of supporting blockchain development easily and quickly. In contrast, those studies that focused on payment proposed a method whereby substantial compensation would be paid in cryptocurrency (i.e., Ether), and thus the Ethereum platform was applied. Hyperledger Fabric was not considered in studies requiring cryptocurrency because issuing tokens was not available until version 2.0 was released.

Finally, the main block components show the major data that are stored and utilized in the blockchain. The studies conducted in the information management field mainly focused on the progress status of tasks and quality test results; Shojaei et al. (2019) also included information associated with lifecycle assessment in the block data. In the case of studies that sought to develop a blockchain system with the objective of supply chain management, the block data included package status and delivery position information. The studies addressing the payment field

included data such as task, progression, cost, and approval status, with Hamledari and Fischer (2020), including as-built BIM and sensor (i.e., camera and laser scan) information in the block data.

It was found that mainly Hyperledger Fabric and Ethereum were used as the blockchain platforms in previous studies. Since Ethereum is essentially a permissionless blockchain where the information is available to every person irrelevant to the project, its usability as a means of delivery for digital documents is highly limited. In addition, Hyperledger Fabric does not provide the functions required for document management considering the characteristics of the construction industry, and it has restrictions on customization as well.

Given these limitations, it is necessary to discuss the process of storing information in a blockchain. Sheng et al. (2020) pointed out that the construction industry is bound by convention, meaning that stakeholders tend to avoid the introduction of new technology because of the bias the stakeholders have. Consequently, the introduction of blockchain is difficult. Therefore, promoting the introduction of blockchain technology into a conservative construction industry will require the development of a user-friendly method.

2.2 Document Management for Construction Claims and Disputes

In terms of the resolution of claims and disputes using blockchain, Yang et al. (2020) indicated that the act of withholding payments can be prevented through blockchain based payments. Sheng et al. (2020) mentioned that the blockchain records the quality information, and consequently, helps reduce disputes caused by insufficient quality information. Similarly, Wang et al. (2020) asserted that a dispute can be easily addressed by storing details about the precast in the blockchain. These previous studies stated the possibility of using blockchain-based information storing and tracking to address disputes.

In the Sub-Clause 20.2 of the FIDIC (2017), “contemporary records” refers to records that are prepared or generated at the same time, or immediately after, an event or circumstance generates a Claim. The claiming Party shall maintain such contemporary records as may be necessary to substantiate the claim. Without

admitting the employer's liability, the engineer may monitor the Contractor's contemporary records and/or instruct the contractor to maintain additional contemporary records. The contractor shall permit the engineer to inspect all these records during normal working hours (or at other times agreed by the contractor), and if requested, submit copies to the engineer. According to Sub-Clause 20.2.3(Contemporary records), when a claim occurs, the claims procedure is initiated when the claiming party notifies the claim to the corresponding engineer, and at the same time, the party responsible for storing the related records is called upon to prove the claim. As described in the definition of "contemporary records," the related data required to prove the claim is defined as being the data generated or prepared at the same time, or immediately after, the claim is submitted. Moreover, the engineer can monitor the related records of the contractor. For their part, the contractor must allow the engineer to inspect the related record and provide a copy if requested.

Sub-clause 20.2 states that all records being used as evidence when filing a claim must be submitted to the other party. However, over 38% of claims submitted by construction contractors are usually rejected because of lack of verified/corroborated evidence (Nosheen et al., 2020). The four causes derived through literature analysis on the problem related to claim failure are as follows: poor record keeping (Bakhary et al., 2015; Bakhary et al., 2017), poor collection of claim documentation (Ren et al., 2001; Bakhary et al., 2015; Bakhary et al., 2017; Hansen and Rostiyanti, 2019; Asuquo et al., 2020), difficulty managing document changes (Tochaiwat and Chovichien, 2004; Shah et al., 2014; Charehzehi et al., 2017; Asuquo et al., 2020), fabrication or forgery of evidence (GIACC/TI, 2008; Chow and Chan, 2014). The availability of records and documents is essential to claim success. Thus, it needs a good documentation system which includes the record obtaining and record keeping system (Hansen and Rostiyanti, 2019).

Previous studies shows that blockchain technology has advantages in information storing, tracking and claim resolution. And email has become a common form of data collection, reciprocity, and participation in construction project (Omar and Nehdi, 2016). However, research gaps exist because no research has been conducted to store and utilize email information and construction documents on the blockchain.

The research objectives of this study are as follows. This work proposes a document management system that records document information on a blockchain easily and conveniently using email which is commonly used as a means of communication in the construction industry. In addition, the proposed system focuses on document management functions that can deal with the problems discussed above by utilizing the document information stored in the blockchain.

The methodology adopted for the achievement of the above objectives is as follows: First, a framework is designed to support problem of poor record keeping. The framework for uploading mail and attachment information to the blockchain by linking with email system is designed so that users can immediately

record, access, and manage documents easily without lost. The main governance of the blockchain is selected as permissioned network referring to previous studies. And detailed elements for system requirements such as blockchain layers, roles of nodes, access control method, block/transaction structures, and consensus algorithm are discussed in section 3. Second, a document management functions are designed to support problems such as poor collection of claim documentation, difficulty managing document changes, fabrication or forgery of evidence. The availability of records and documents is essential to claim success. Basically, blocks/transactions uploaded to the blockchain can be accessed by users. In addition, users are allowed to easily manage documents through correlation between documents using attribute values of blocks/transactions. Finally, the proposed system is verified that it is possible to effectively support tasks for pre- and post-response for claim/disputes through use-cases.

3. Blockchain Framework

3.1 Framework for a Blockchain-Based System

It is useful to describe the blockchain system as having a layered structure (Biswas and Muthukkumarasamy, 2016; Yuan and Wang, 2016; CAICT, 2018; Yu et al., 2018; López and Farooq, 2020). Separating the blockchain into layers aids in understanding its complexity. This layered model assumes the shape of an open system interconnection model, as defined in ISO/IEC 7498.

The architecture exists in five layers: the application layer, contract layer, consensus layer, network layer, and data layer, as shown in Fig. 1. This system is a permissioned blockchain that comprises basic infrastructure, extension infrastructure, and user applications. In the basic infrastructure, the data layer contains complete information, including the basic block data, encrypted data, and time stamp with the block, generated by the blockchain participant, and is based on the data layer. The network layer includes the P2P protocol, transmission control protocol/internet protocol for sending emails and data acquisition, and a simple email transfer protocol. The consensus layer enables the creation of a valid block, which is generated by the interaction between nodes and the consensus mechanism. Moreover, it ensures that all nodes possess the same blockchain information. This prevents both falsification and loss of blocks. The contract layer exhibits a programmable feature that allows scripts, algorithms, and chaincodes to be included in each block (Che et al., 2019). This layer includes the link between an email and a blockchain and a search function for documents. Moreover, the SHA-256 code, which encrypts the text data, and the text extractor, which extracts the text from the PDF document, is included in the chaincode. Finally, the application layer provides an email system and document management tool from the user's perspective.

The nodes interacting in the proposed blockchain can be classified into two types: generator node and participant node, where at least one generator node acts as an access control manager, which manages the access authority of the blockchain. In terms of Bitcoin, all nodes play the role of a router and

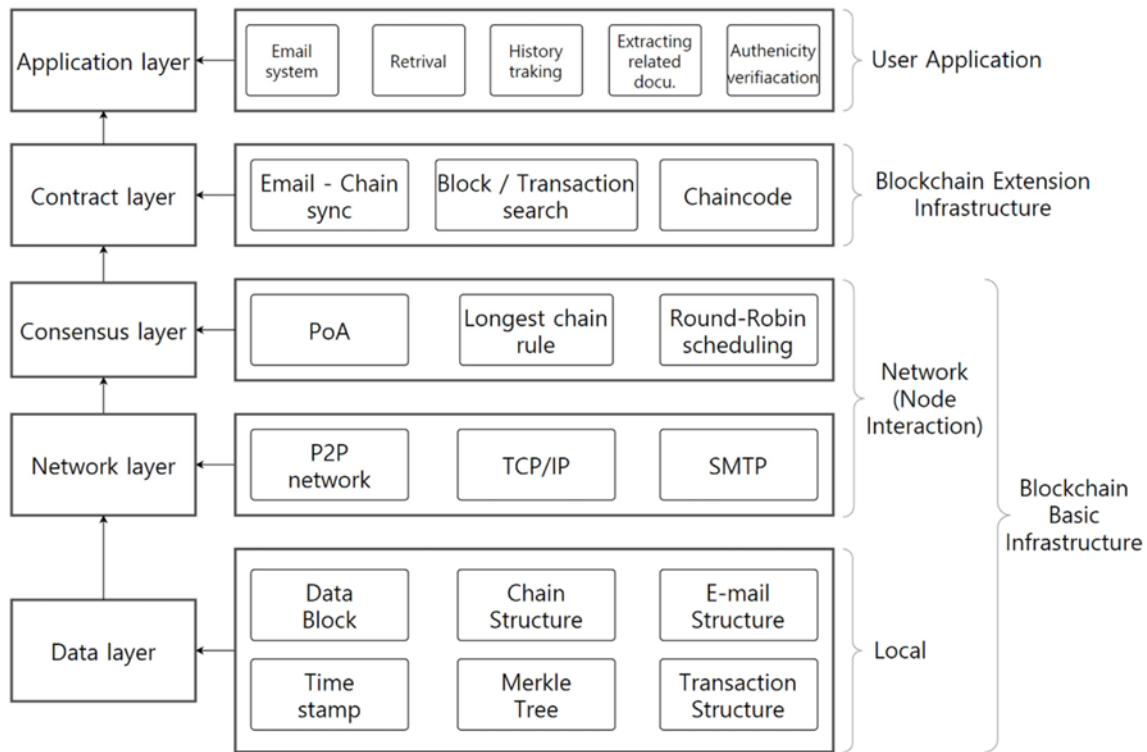


Fig. 1. Layered Architecture of Blockchain System in Construction Document Management

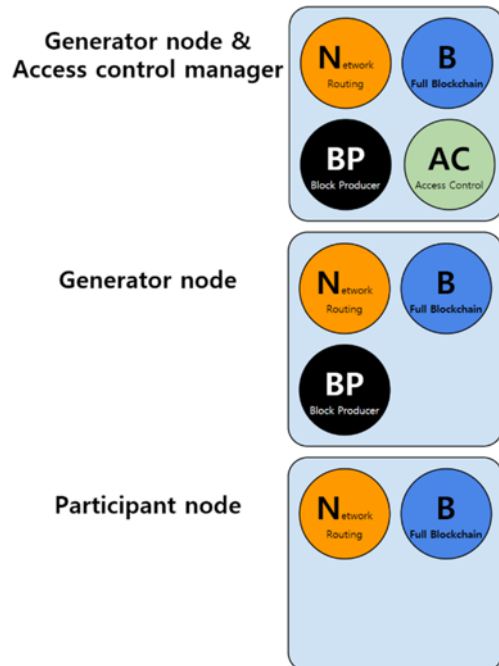


Fig. 2. Node Compositions for the Blockchain

commonly perform the block routing function, which enables effective transmission and propagation of information in the P2P network (Zaghloul et al., 2020). There is a need to set up authority for the blockchain participants by considering the business characteristics and conducting sufficient discussions among the subjects participating in the project.

Figure 2 shows the types and roles of the nodes. Both the generator and participant nodes can access all blockchain information; even if these nodes are placed in the middle of a project, all nodes can deliver the full blockchain data previously stored in the adjacent nodes and synchronize them. The generator node creates and broadcasts blocks. The subject, such as the owner or contractor, can participate from the project initiation stage to the termination stage and stably maintain the blockchain. In contrast, various site engineers, subcontractors, and vendors can participate in construction projects through contracts in the middle of the project. The participant node is assigned to participants whose contract is completed before completion.

3.2 Access Control for a Blockchain System

Given that the system is designed to be a permissioned blockchain, the authority to access the blockchain is required. In a construction project, various participating subjects (e.g., owner, general contractor, pm/cm, engineer, subcontractor, and vendor) are involved in a contractual relationship, and their tasks are completed as their individual contract is terminated; thus, participation and termination time points differ for each subject. Thus, the system should be designed to allow new participation in the blockchain network in the case of contract signing and not allow access upon contract termination. Considering this characteristic, the access control manager is assigned when the blockchain is initially created.

Figure 3 shows the process by which the access control manager provides and regulates access authority. In a real-life situation, the new participant sends a participation request to the access control manager after the contract is signed. The access control

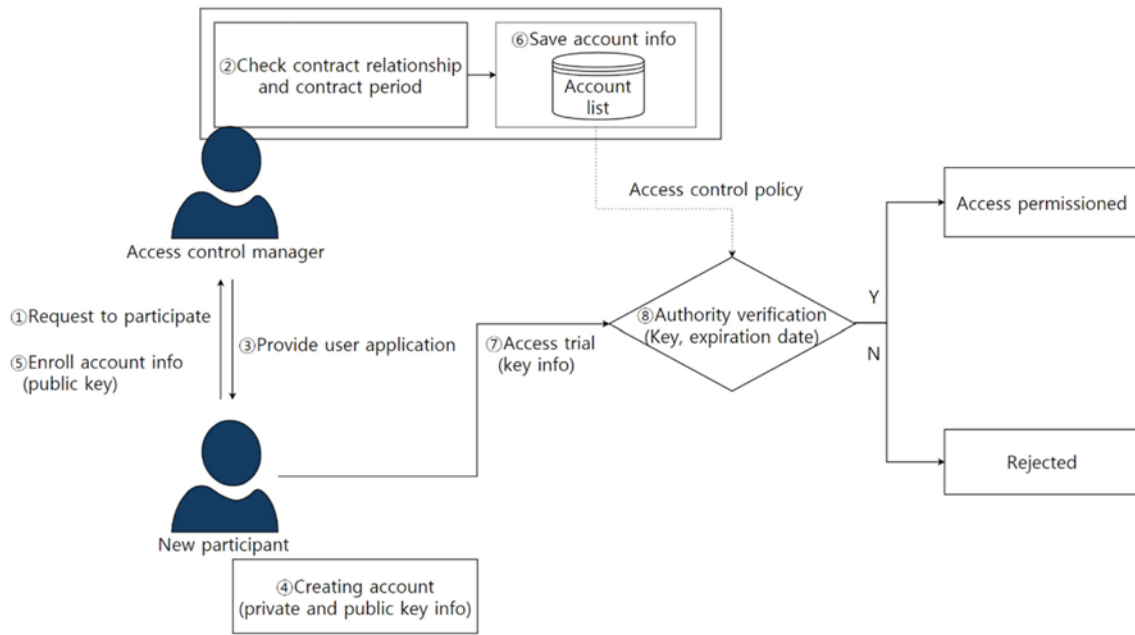


Fig. 3. User Identity Registration and Enrollment in the Blockchain

manager confirms the contract conditions, such as parties and the period, and provides a user application to the new participant while assigning them authority to simultaneously generate one private key. Only one private key is assigned to each company, and it can generate several public keys so that IDs can be assigned to each employee. The new participant creates private and public keys to access the blockchain using the provided user application and sends the public key information to the access control manager to register it on the account list. During this process, the account list includes both key information and expiration data to limit access to the blockchain network after the contractual relationship is concluded. After preparing the user application, key information, and access control policy, the new participant attempts to access the network using the generated key information. At this point, authority verification is performed based on the access control policy, and if key information is valid, access to the blockchain is granted.

3.3 Document Communication Using Email

A construction project amasses considerable amounts of data, and construction organizations frequently encounter difficulties with regard to storing and managing documents. The issue of storing records related to past projects is another major issue faced by organizations (Perera et al., 2020). Owing to its ease of use, email has become a common tool for bidirectional communication in construction projects. The importance of email usage has increased in the area of communicating and storing major information, given that email can be employed as a technique to track, store, and extract progress data (Omar and Nehdi, 2016). Email is an important business communication tool, and email records are regarded as legal documents similar to other business documents (Lindsell-Roberts, 2008). Because email is not a

technical document management system, it suffers from several functional limitations, including versioning, searching, and insufficient storage (Vacek, 2014). Furthermore, email-based communication incurs various management problems, such as loss caused by the deletion of records or changes in the person in charge and difficulty in collecting information from several emails. Therefore, given email limitations, this paper proposes a method that can be easily used for long-term storage while supporting the document background search and tracking function. The proposed method improves the shortcomings of email-based document management.

3.3.1 Email Data Extraction

Referring to previous studies related to BIM, this study applies the method for storing the only metadata of emails and attachments to the blockchain. Therefore, the task of extracting metadata from email and attachment should be preceded.

The connection between the email server and the blockchain is shown in Fig. 4. In the email service environment, the mail user agent (MUA) is used during the process of composing the screen offered to users when using mail services such as Outlook, the Mail Delivery Agent (MDA) is used during the process of extracting information from the email, and the mail transfer agent (MTA) is used in the process of sending an email. When the sender sends an email using the MUA, it is delivered to the recipient by the MTA. If the recipient receives the email normally, its contents can be identified through the MUA after the email has been extracted by the MDA. The email server on the sender side confirms the successful completion of the incoming and outgoing mails, and the sender enters additional user-input data to prepare for generating new blocks. Finally, based on the email information stored in the email server and additional user-input

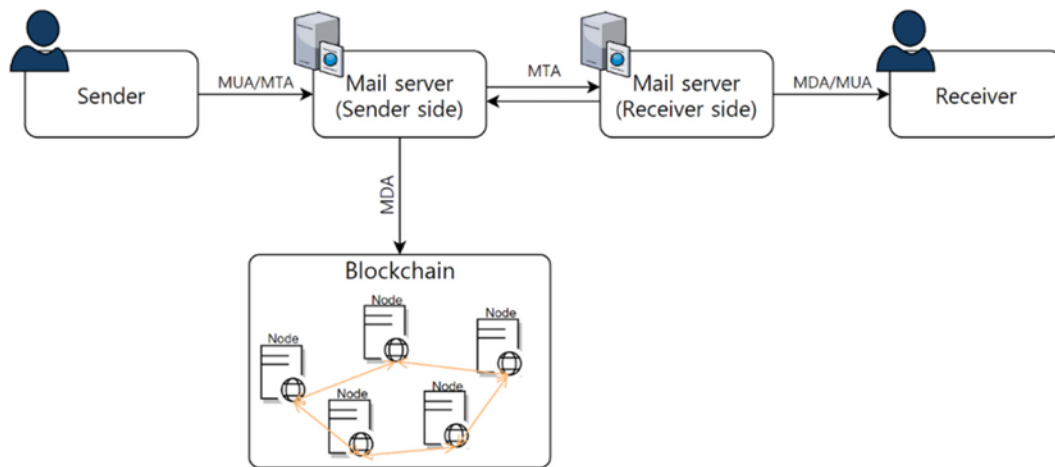


Fig. 4. Connection between Email Server and Blockchain

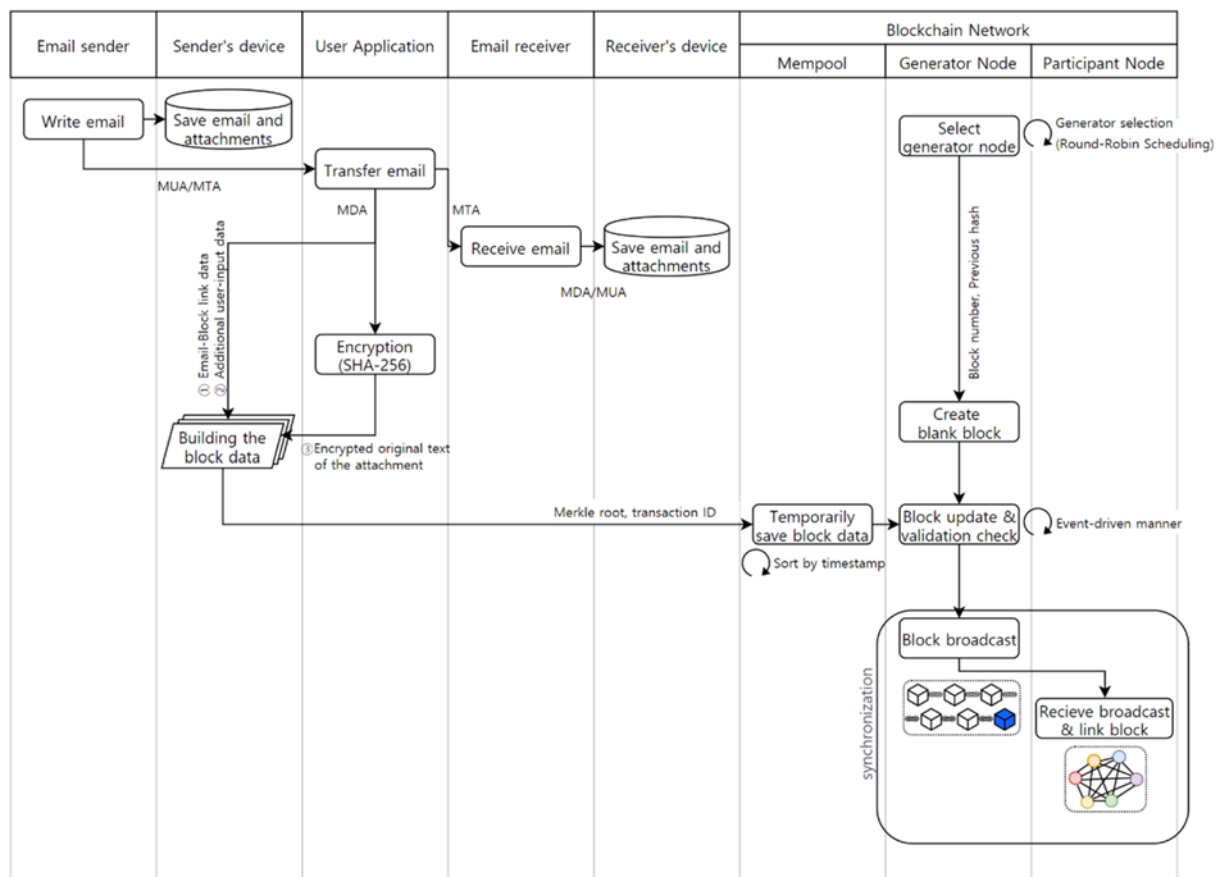


Fig. 5. Process of the Valid Block Generation

data, new blocks are generated and stored in the blockchain.

As the transaction simultaneously occurs in the Fintech and supply chain fields, the time-based manner (e.g., the block times for Bitcoin and Ethereum are approximately 10 min and 10 s, respectively) is commonly applied as a block-generation method for high processing efficiency. In contrast, the proposed blockchain system does not require high transaction per second (TPS) performance. Hence, in this study, the event-driven method was

applied, which transforms email information into blocks when an email event occurs.

3.3.2 Block Creation from Email Data

After the email is stably transmitted, the block data are built by extracting and connecting the email information from the mail server on the sender's side, which is then temporarily stored in the mempool and sent to the blank block via the first-in-first-out

method. In the events where emails are simultaneously generated, the information regarding the first occurring email is generated as a block by using the timestamp value to prevent conflict. Meanwhile, in the blockchain network, the block-generation order among the generator nodes is decided by round-robin scheduling, which is a method of assigning the sequence consecutively, and the selected node generates the empty block. Subsequently, a valid block is built by entering the block information waiting in the mempool to the empty block, and a validity check is performed, followed by the propagation of the new block. The detailed process of generating the block by connecting it with the email system is shown in Fig. 5.

3.4 Block Structure Design

3.4.1 Block Structure

Each block comprises two parts: a header and a body. Each header incorporates the block hash of its predecessor block (Zaghloul et al., 2020), ensuring that the blocks are connected in order. The block body is composed of transactions, and several attachments can be sent together through one email. In this study, each block was designed to include only one email, with each attachment regarded as a transaction, and several transactions were included in a block body. The proposed block header and body are composed of three types of data (i.e., email-block-linked data, automatically generated data, and additional user-input data), as shown in Fig. 6.

3.4.2 Email-Block-Linked Data

The email-block-linked data are connected to the block by extracting information from the communicated email. Because the email system is generally based on the RFC 2821 standard format, it supports email in standard formats, such as Gmail, Hotmail, and Yahoo Mail. The basic structure of the email comprises a header and a body. The header includes components such as from, to, cc, subject, and date, whereas the body includes

content and attachment. Therefore, in this study, the components included in the standard format at the time when the email was transmitted, namely, from, to, cc, subject, date, contents, and attachment, were connected to the block structure. Of these, the original text data are extracted from the attachment file and encrypted using the SHA-256 algorithm, which is a one-way encryption method that ensures data privacy between the sender and receiver.

3.4.3 Additional User-Input Data

An additional function was required to manage the communication document so that it was designed to input additional user-input data. The additional user-input data includes attributes such as document classification code, related keywords, previous transaction ID, attachment version, and previous attachment version. In basic blockchain technology, the previous block’s information is encrypted to derive the hash value, which is included in the header of the next block to chain successive blocks. In this study, to support the related document extraction and history tracking functions, continuous blocks are connected by a chaining mechanism. Related but discontinued blocks were also artificially connected by text tagging. In particular, continuous and repetitive events, such as approvals, certificates, consents, determinations, and notices and requests, can occur during the communication process among the parties. Given the fact that numerous results can be extracted, the function of secondary filtering is enabled by document classification codes and related keyword attributes. Detailed descriptions are provided in Section 3.2.

3.4.4 Automatically Generated Data

The information automatically generated by referring to the existing blockchain (e.g., automatically generated data) includes the block number, previous hash, Merkle root, and transaction ID, of which the block number and previous hash are generated by referring to the final block of the current blockchain. The

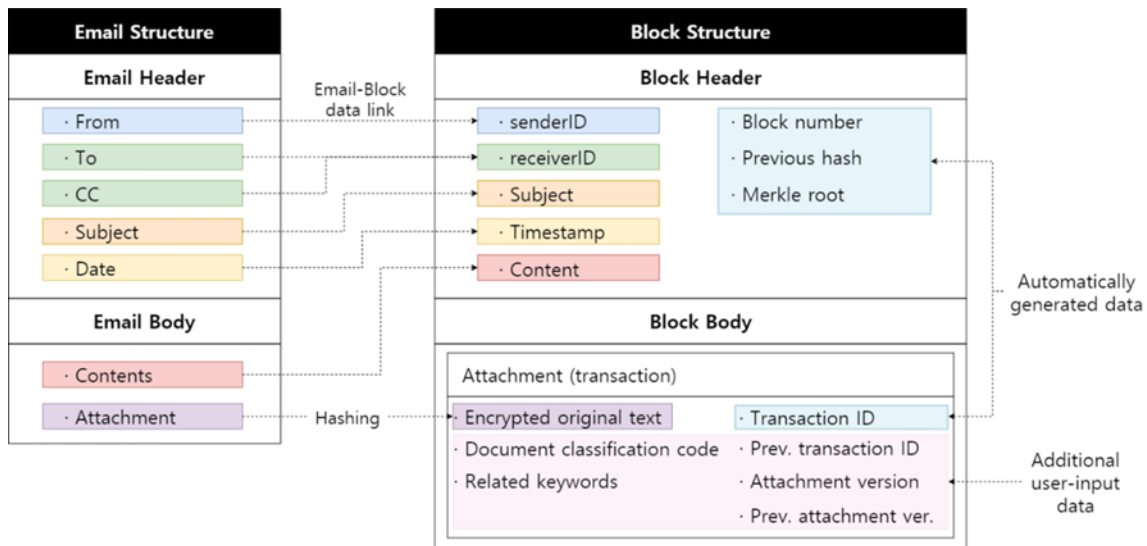


Fig. 6. Block Structure and Block Data Source

block number is increased by one according to the creation of a new block, and the previous hash is an encrypted value of all attributes of the previous block. The Merkle root is a root node located at the top that binds various attachment data in a binary tree. The transaction ID represents the sequence of the attachment documents included in a specific block.

3.5 Synchronization of Blockchain

The process of broadcasting the newly created block to other nodes and synchronizing the blockchain is necessary. The proof

of authority (PoA) can be used to create a private blockchain by using the value of the participants' identities to create a set of authorities. Only those authorities are allowed to create new blocks and secure the blockchain network (Daraghmi et al., 2019). The consensus algorithm used in the generation, verification, and broadcast processes of new blocks in the proposed blockchain system was carried out using PoA.

The synchronization process is shown in Fig. 7. All nodes store the blockchain separately in the local environment owned by each node. Each node possesses consistent information by

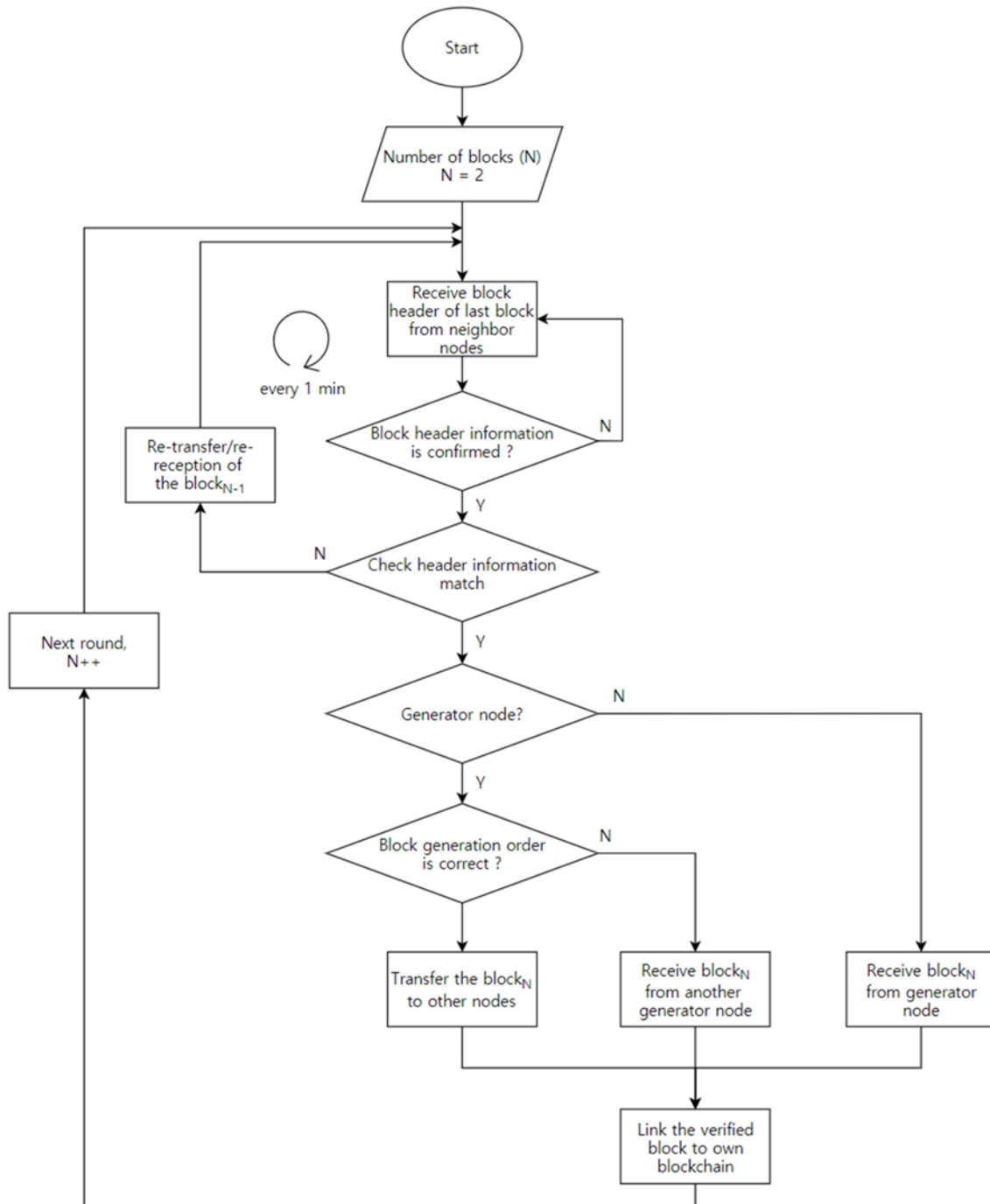


Fig. 7. Block Synchronization Flowchart

comparing the corresponding blockchain information with the neighboring nodes every minute. The intercompared information includes the last block hash value and block number. If the last block hash values match, the nodes are considered to be in the same chain. If the values do not match, a conflict arises because one or several nodes do not possess a valid blockchain. At this time, the block numbers are compared secondarily. This involves the blockchain of the node holding the highest block number (that is, the node holding the longest blockchain) being determined to be correct according to the longest chain rule. This node, possessing the correct blockchain, transmits its information to the node(s) that causes the conflict. This substitution resolves the conflict that occurs because blockchain information is different.

Next, the node is divided into three forms. These are 1) the generator node in the next block-generation order, 2) the other generator nodes, and 3) the participant node. First, a check is performed to determine whether it is a generator node. When this is not the case, the node is considered to be a participant node, which then receives a new block from an adjacent neighbor node. If it is the generator node, it is then established whether the node is in the right block-generation order by round-robin scheduling. In the event that it is not in the right block-generation order, the node receives a block similar to the participant node. However, if it is in the block-generation order, it generates, verifies, and broadcasts a new block. The process of connecting the new blocks to the blockchain of each node was finally performed. When the next block is generated in the following round, synchronization is repeated from the beginning.

4. Blockchain-Based System for Document Management

Construction projects accumulate considerable amounts of data. Given this, construction organizations face many difficulties in data storage and managing large amounts of documents (Perera et al., 2020). Sub-clause 20.2 of the FIDIC (2017) states that all records to be used as evidence when filing a claim must be submitted to the other party. However, over 38% of claims submitted by construction contractors are usually rejected because verified/corroborated evidence is lacking (Nosheen et al., 2020).

Blockchain by its very nature encourages consensus, transparency, accountability, and control, which can lead to better collaboration (Lamb, 2018). Thus, the blockchain-based system can be used as a tool to transparently manage documents exchanged between project participants and, by doing so, enables everyone to trust the data. According to international standards (i.e., ISO 15489-1) established for information and documentation, “business records require attributes of authenticity, reliability, integrity, and useability” (ISO, 2016). In Section 3, the method of recording the documents communicated to the blockchain within the project via email is described, and the four attributes required for the records proposed by ISO obtained through this process. In this section, we propose a tried-and-true, efficient method for managing documents generated during

project using blockchain information.

4.1 Framework for Document Management

Securing data objectivity is essential when submitting supporting evidence for the process of claim/disputes related to a construction project. Even when project documents, such as contract documents, official documents of order, construction progress reports, daily work reports, bills of quantity, and statements of works, —are written in detail, they cannot be recognized as evidential data if the history of the writing and collection is unclear. Using the proposed blockchain system, the information generated within the project is stored in the blockchain almost in real time, and participants can access the uploaded information without limitations. Hence, in the event of claims and disputes, blockchain data can be used as evidentiary materials to prove the validity of contractual rights and compensation claims.

The characteristics of a construction project—multiple subjects engaged in complicated tasks—can lead to difficulty in finding the required document and valid evidence. Furthermore, the process of identifying the cause-and-effect relationship and attributable reasons for claims/disputes is time-consuming. Thus, this paper proposes the use of history tracking and the related automatic document extraction function as measures that can resolve this issue in a timely and accurate manner. The history tracking function shows how document versions have been modified and revised chronologically. In addition, the related automatic extraction function supports searching for block information by focusing on the association of the document.

Moreover, it is often the case that records are maliciously manipulated at the claim/dispute stage; human resources are wasted in identifying such document forgeries manually. Authenticity verification, which is required to resolve this issue, is a function that compares the document to be verified with the attachment uploaded on the blockchain and then determines whether it is authentic or not. A document forgery can be rapidly identified by encrypting and uploading an attachment to the blockchain through the proposed system. As shown in Fig. 8, when the block information generated from the email communication is uploaded to the blockchain, the user can use it for document management. As discussed in Section 3, a new block is generated based on the email information and additional user input data and added to the blockchain. In other words, all nodes have access to the same blockchain information, and thus, users can utilize the functions of document retrieval, history tracking, automatic extraction, and authenticity verification.

4.2 Document Retrieval, History Tracking, and Automatic Extraction

4.2.1 Mechanism for Connecting Noncontinuous Blocks

In business practice, a search for a document is normally undertaken using the document’s title, chronological search, or keyword search. Given this, an accurate and rapid search for the reason for a complex dispute can be difficult. In this section, we outline a

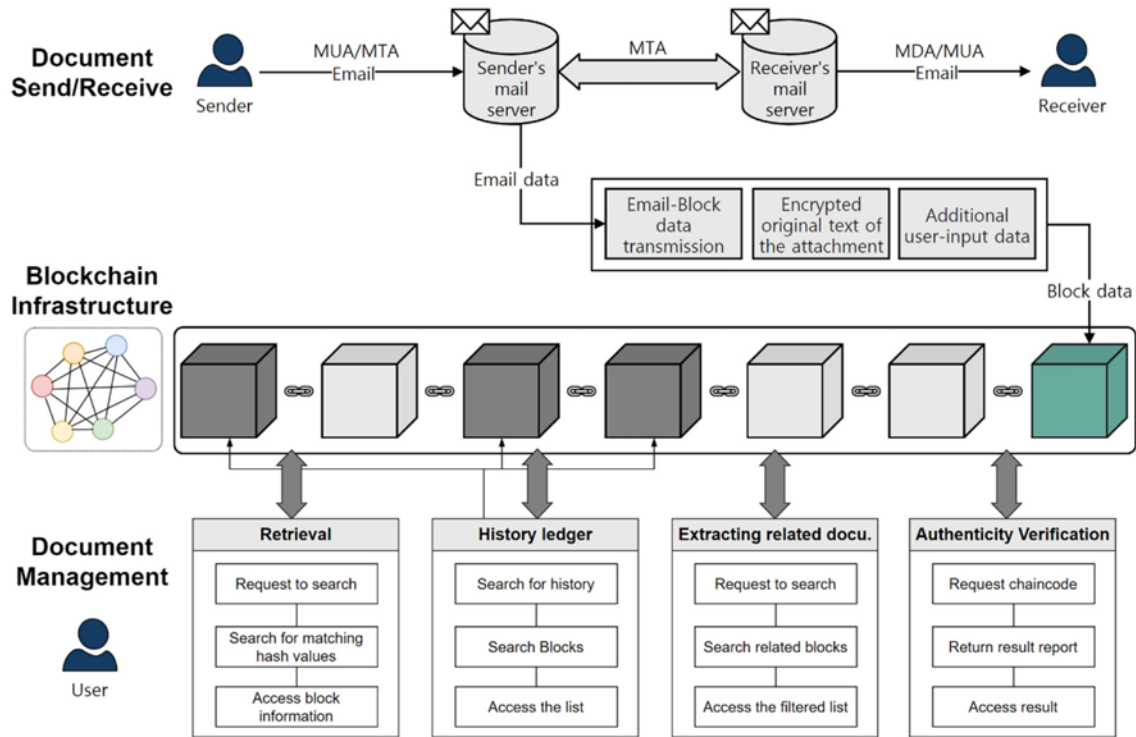


Fig. 8. Concept of Document Management Using Blockchain

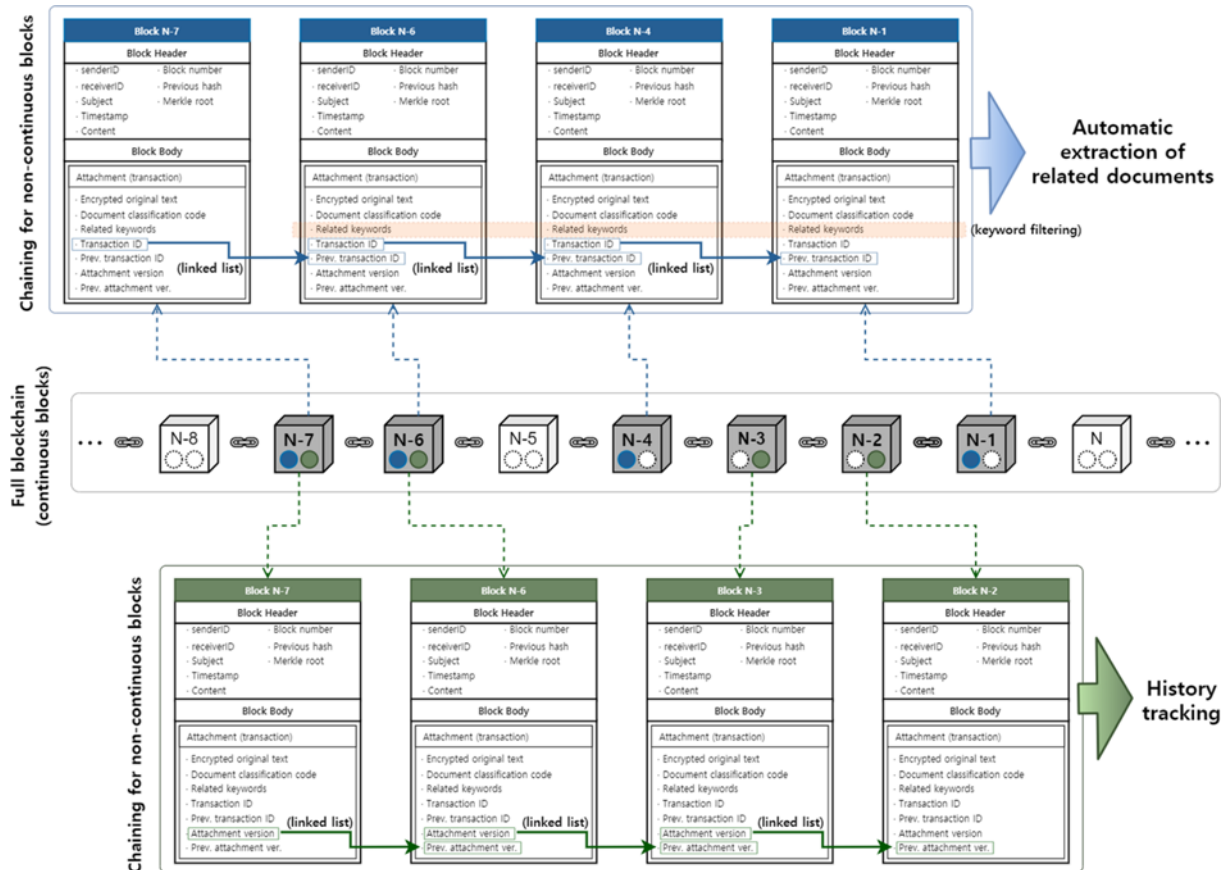


Fig. 9. Mechanism for History Tracking and Automatic Extraction of Related Document

more effective document search method. This is followed by an explanation of the mechanism, based on the chronologically connected blocks, which also connects discontinued blocks by using attributes such as attachment version, transaction ID, and related keywords.

By tagging text information on each block, interrelated non-contiguous blocks are chained among the continuous blockchain. As shown in Fig. 9, the full blockchain, in which all blocks are connected chronologically, is located at the center. The lower part represents discontinued blocks (N-7, N-6, N-3, and N-2), which are connected to history tracking based on characteristics such as attachment version and previous attachment version. For instance, when searching the N-2 block, connected blocks—N-7, N-6, and N-3 blocks—can be easily derived. Furthermore, the upper part shows the status that discontinued blocks (N-7, N-6, N-4, and N-1) are connected with characteristics such as transaction ID and previous transaction ID for the automatic extraction of related documents. In addition, filtering is enabled using the related keyword property, as too many results can be extracted. Finally, the discontinued blocks—N-6, N-4, and N-1 (excluding N-7)—can be searched through the related document extraction function. The document flow can be easily identified by connecting blocks using the text tagged for history tracking and automatic extraction of the related document.

4.2.2 Process for Document Retrieval, History Tracking, and Automatic Extraction

4.2.2.1 Document Retrieval

The basic search function is presented in Fig. 10, box 1. The hash value of the search target document is entered to search for the block information. In the user application, a request in the blockchain initiates the search for a specific block from within the blockchain. Blockchain then searches to establish whether a block possessing the same value as the entered hash value exists. Subsequently, if the hash value of the document is included in the blockchain, the corresponding block information is returned so that the user can browse the search results.

4.2.2.2 History Tracking

The main purpose of the history tracking function is to manage the history of version changes as a document is modified and revised, which is similar to the revision control system (RCS). Because it inputs the attachment version and previous attachment version as attribute values and combines them into a linked list when generating blocks, it can collectively search the change history of the document.

The history-tracking process is shown in Fig. 10 (box 2). After the user selects the search target block, the user application sends a request for a history search to the blockchain. The chaincode on blockchain then searches for the corresponding block and all blocks connected through the linked list, whereupon it arranges and returns the results chronologically. Next, the user can browse the detailed history of the document

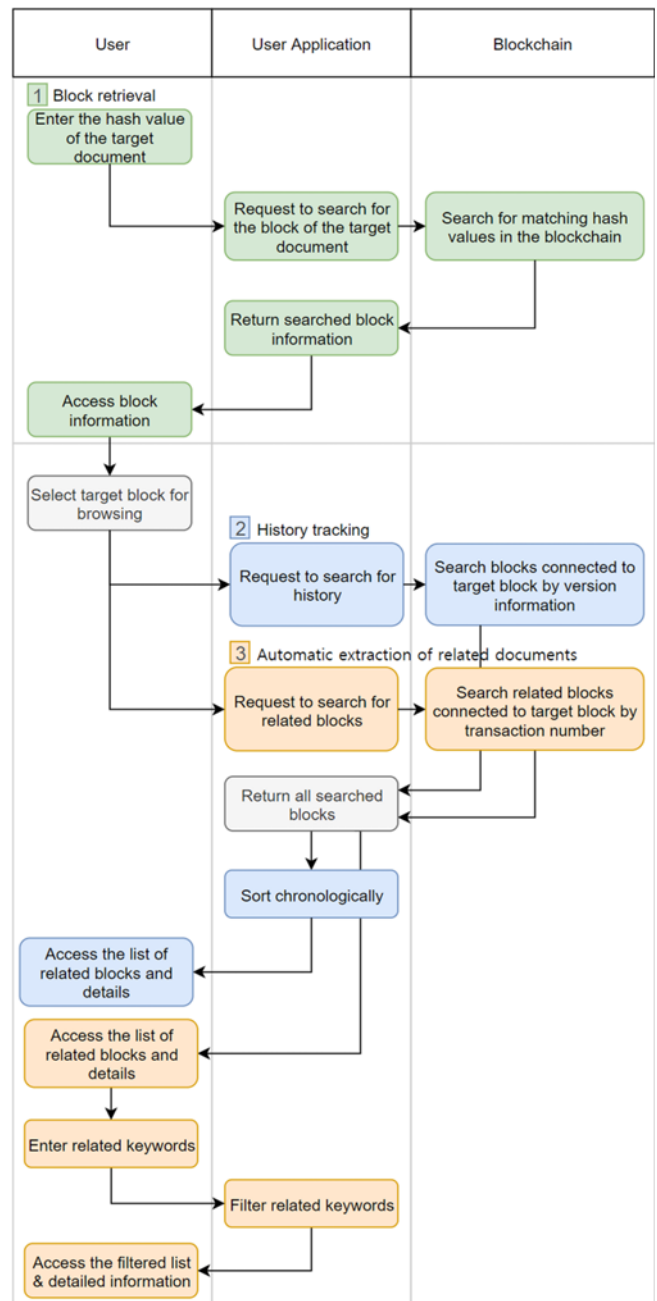


Fig. 10. Process for Document Search, History Tracking, and Automatic Extraction

using the returned results.

4.2.2.3 Automatic Extraction

The automatic extraction of related documents searches for block information stored in the blockchain by focusing on the association. In construction projects, a document transfer event occurs with the objective of approvals, certificates, consents, determinations, and notices and requests, followed by a reply. Therefore, the initial and reply events are linked to a linked list. Since transaction ID and previous transaction ID are entered as attribute values and combined into a linked list, it is possible to

collectively search related documents.

The process of automatically extracting the related document is shown in Fig. 10, box 3. When a user selects a search target block, the user application sends a request for the extraction of all related documents to the blockchain. Subsequently, the blockchain searches the corresponding block, and all blocks are connected through the linked list, whereupon it returns the results to the user. If additional filtering using the keyword is required, the user can enter a related keyword and read the sorted search results.

4.3 Authentic Verification of Document

Given that information stored in the blockchain is immutable, then providing the hash value of the document is stored in the blockchain, only the hash value corresponding to this information can be returned. In other words, the authenticity verification function establishes authenticity by comparing the hash value of the document to be verified with that of the attachment uploaded to the blockchain. Text data should be used to identify document authenticity, discrete construction projects, PDF files, and spreadsheets, with word processing software being mainly used for this purpose (CBC, 2020). In this study, text data were

extracted from the PDF file by means of a separately developed text extractor code.

Figure 11 shows the procedure for the authenticity verification process. First, the user uploads the PDF file required for authenticity verification to the user application, which then requests and obtains the text extractor and SHA-256 chaincodes from the blockchain. Next, the chain code was executed using the attachment as an input. Once the text data are extracted and encrypted, the hash value is derived. Subsequently, a search resolves whether the same value as the output hash value exists in the blockchain, whereupon the verification results are returned to the user. After this process, the user can browse the authenticated verification results.

5. Implementation of the Blockchain-Based System

5.1 Execution Environment

The execution environment of the proposed blockchain system is listed in Table 2. It was executed in a CPU environment with 16 GB RAM, i7-7700HQ, Quad-Core, and Mac OS operating system. A total of six nodes were used: three generator nodes and three participant nodes. For the hash function, the SHA-256 function was operated, and the blockchain infrastructure was self-developed. PoA and round-robin scheduling were used as consensus algorithms. The block size was a minimum of 0.15 MB and a maximum of 1 MB. Each block was generated using an event-driven method.

5.2 System Verification

5.2.1 Block Generation through Email Communication

Figure 12 contains a use-case for sending meeting minutes via email. First, as described in Section 3.3.2, the email information corresponding to the access control policy is entered, and then basic information, such as the email address of the recipient, title, contents, and attachment, is entered (Step 1). After the email is sent, additional user-input data for document are entered, as shown in Step 2. Once the email and user-input data are created, a generator node builds a new block and broadcasts it in Step 3.

Table 2. Components of the Blockchain System

Component	Description
OS System	mac OS Catalina v10.15.3
RAM	16 GB
CPU	Core i7-7700HQ
Nodes amount	6 (generator: 3, participant: 3)
Hash algorithm	SHA-256
Blockchain application	Self-developed (Golang based)
Blockchain client system	Self-developed (Golang based)
Consensus mechanism	PoA, Round-robin scheduling
Range of block size	0.15 – 1.0 MB
Block generation method	Event-driven

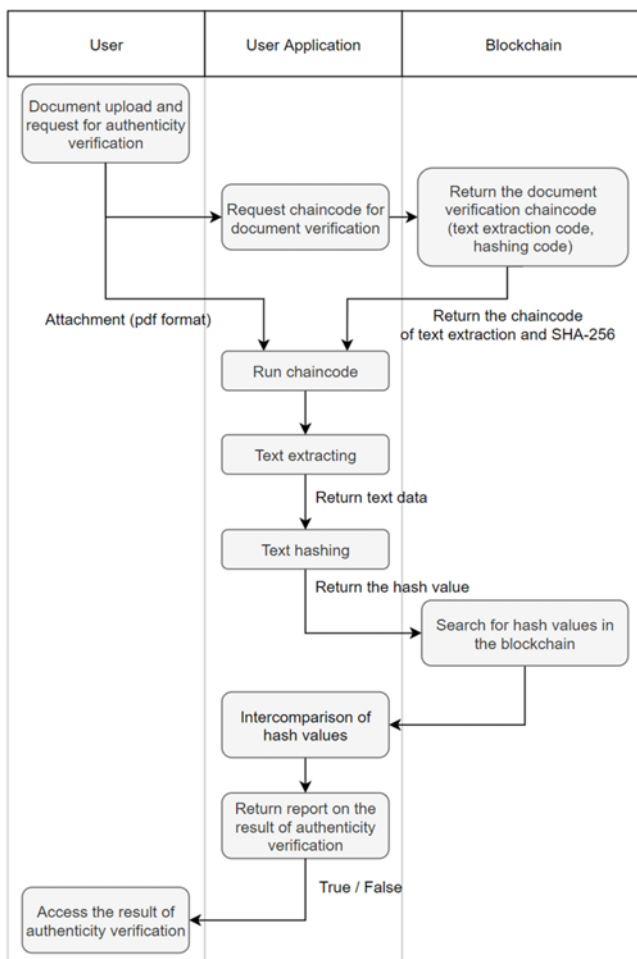


Fig. 11. Process of Authenticity Verification

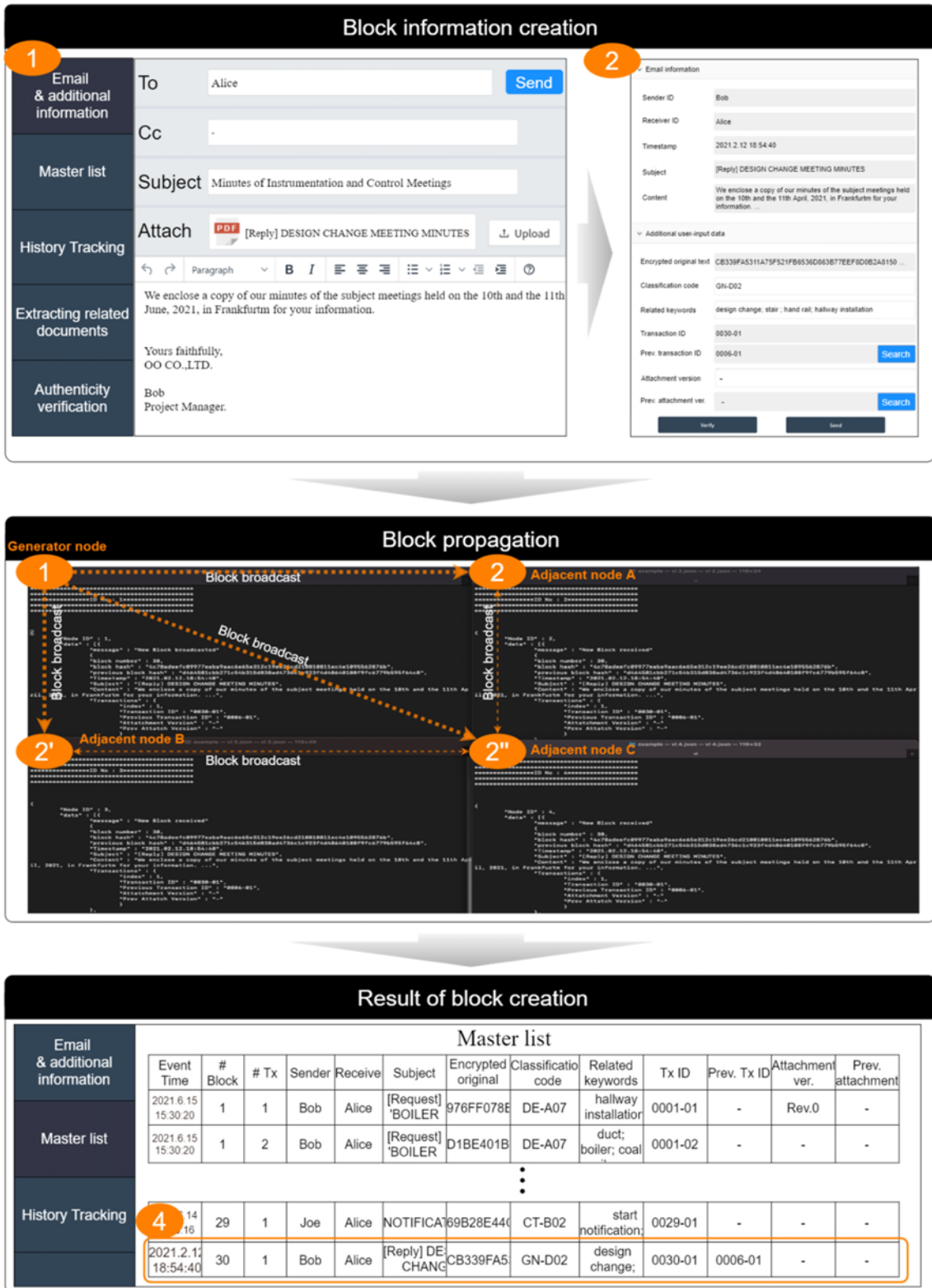


Fig. 12. The Process of Creating a Block through Email and Additional User-Input Information

Next, as shown in the execution results of Step 4, the information of the new block is added to the user application. All block generation results are shown to all blockchain participants in the master list of the application.

5.2.2 History Tracking

For the history tracking of the attachment version, additional user-input data (i.e., attachment version) are used when generating the block. The execution and results of history tracking are

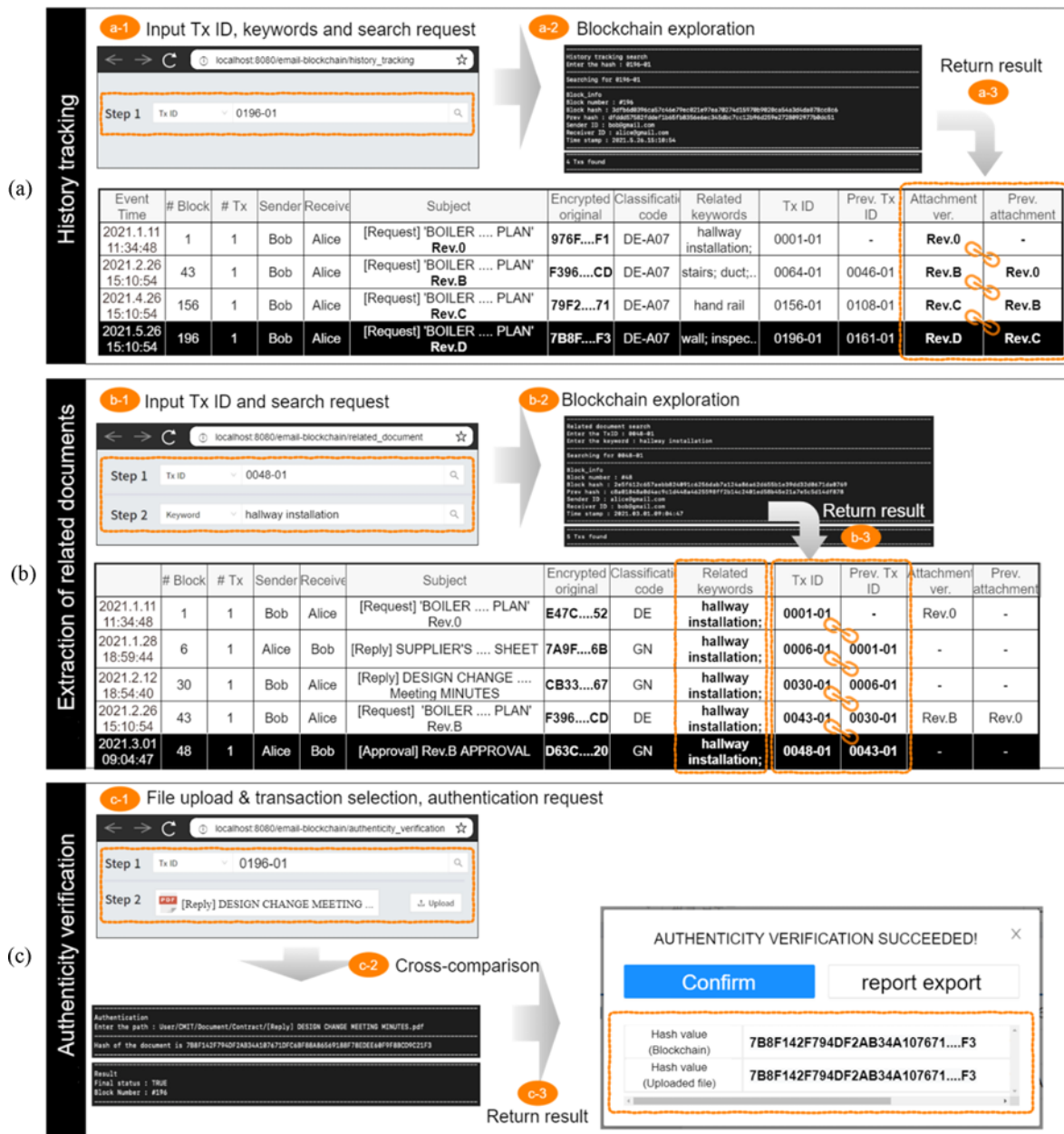


Fig. 13. Use-Case of the User Application: (a) History Tracking, (b) Automatic Extraction of the Related Document, (c) Authenticity Verification

presented in Fig. 13(a). First, the hash value of a specific document (i.e., “7B8F...”) is entered (see a-1). In step a-2, The transaction corresponding to the input hash value is searched on the blockchain. And four transactions were identified as the hash value search results by the chain mechanism. Detailed block information is returned to the user application (see a-3). Like this use-case, users can search the change history of documents.

5.2.3 Automatic Extraction of the Related Document

For the automatic extraction of the related document additional user-input data, such as the previous transaction ID, is used when generating a block. The execution and results of the automatic extraction of related documents for use-case are shown in

Fig. 13(b). First, the hash value of a specific document (i.e., “D63C ...”) and related keywords (i.e., “hallway installation”) for filtering are entered in Step b-1. In Step b-2, four transactions are identified by the search results on the blockchain. Detailed block information is returned to the user application (see a-3). Like this use-case, users can collectively search documents from an initial email to subsequent responses.

5.2.4 Authenticity Verification

The authenticity verification procedure is presented in Fig. 13(c). Authenticity verification is performed after receiving the local storage path, in which the document to be verified is located as input data, as presented in Step c-1. After the document is

entered and the chaincode is executed, the character string is extracted inside the document and encrypted through the hash function. Afterwards, the authenticity is verified by identifying whether the derived hash value is included in the blockchain (see a-2), and when the matched result is searched, a true or false is returned to the user application (see a-3).

6. Discussion

6.1 Contribution

This study suggested the method to apply blockchain in document management tasks such as delivery, storage, and utilization of documents for construction projects. The method secures the basic advantages of a blockchain technology that is fully reliable for stored information and enables efficient document management in terms of cost and speed.

The advantages of the proposed solution are as follows: First, it provides visibility for the document flows occurring within the project. Participants are possible to access all information of blockchain, so they can monitor which mails and attachments are coming and going within the project. Stakeholders' engagement and termination often occur because of the structural characteristics of the construction project. The system is thus designed to synchronize all previously created information by the P2P network and consensus mechanism, even if stakeholders are newly involved in the middle of the project. Second, the blockchain system can be operated at low cost. The construction projects have been involved numerous small- and medium-sized companies. Considering there aren't enough computer resources in those companies, the capacity of each block is designed to under 1.0 MB. Therefore, the expected capacity of the full blockchain is very small.

Third, data structure was designed to be easily integrated the system with existing business practice. The related information of emails and attachments is immediately stored in the blockchain so that human errors such as loss can be prevented. In addition, since email may include business privacy between contracting parties, attachments are not exposed to other stakeholders by applying encryption algorithm. By including the metadata of email and attachments in the block structure, additional document management functions can be used such as History tracking, Automatic extraction of related documents, and Authenticity verification. And these functions can supplement for the lack of manpower.

6.2 Limitations and Future Studies

This study supports the document management tasks required for claims/disputes using blockchain systems. While the proposed system has its characteristics and advantages, as discussed in Section 6.1, it also includes a few limitations from a long-term and operational perspective.

In the construction industry, program and portfolio management has been emphasized, rather than the management of a single project. Several studies (Das et al., 2020; Xue and Lu, 2020;

Yang et al., 2020) have focused on the blockchain system at the project level; research on the program/portfolio level has not yet been developed. Data storage and management of past projects continues to be a major problem faced by organizations (Perera et al., 2020). To increase the opportunities to reuse the records after the termination of the project, a long-term preservation method that separately stores blockchain information needs to be discussed.

There are limitations to the operational aspects of the proposed system. This paper proposes an access management method for a permissioned blockchain, coupled with the role of an access control manager. However, the issue of who will take the exact role of the access control manager needs to be discussed. Various alternative methods can be used, such as the project delivery method and multiple access control managers. Meanwhile, to implement the authenticity verification function, a chaincode that extracts text data from the PDF format attachment has been developed and utilized. However, in actual business practice, various electronic file formats besides the PDF format are used, with CAD files and BIM models being two such examples. Therefore, an expansive solution for various file formats is required.

7. Conclusions

Despite the excessive human resources and time allotted to document management, claim failures still occur frequently due to data loss and lack of evidence. Therefore, this study proposes a blockchain-based construction document management framework and system. This system effectively secures the reliability of recording, storing, and managing documents generated during construction projects. It also effectively supports tasks associated with claims and disputes using blockchain technology.

Through the proposed system, the user can communicate using emails in the same manner as actual business practice. Blocks are generated through email information stored on the email server and within additional user-input data. Moreover, all nodes possess the same blockchain using the P2P protocol and consensus algorithms. The validation results of the system show that the functions for efficient document management of construction projects—document search, history tracking, related document automatic extraction, and authenticity verification—are feasible.

Through the application of the framework and system, the process of creating and delivering documents is transparently managed; the user can secure the objectivity of the documents and prevent inconsistency of evidence and loss of documents. Moreover, specific documents can be tracked easily and rapidly, based on how the documents are correlated. The system is thus expected to help resolve the issue of considerable time spent in identifying cause-and-effect relationships and other attributable reasons. This study contributes to the field by proposing detailed solutions to problems related to claims and disputes by introducing blockchain technology to the management of construction documents that have not been sufficiently covered.

Acknowledgments

This research was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science and ICT (No. 2019R1A2C2010794) and the Chung-Ang University Graduate Research Scholarship in 2019.

ORCID

Eu Wang Kim  <https://orcid.org/0000-0002-1248-1767>
 Min Seo Park  <https://orcid.org/0000-0002-0425-2948>
 Kyoungmin Kim  <https://orcid.org/0000-0002-1131-7148>

References

- Ahmadisheykhsarmast S, Sonmez R (2020) A smart contract system for security of payment of construction contracts. *Automation in Construction* 120:103401, DOI: 10.1016/j.autcon.2020.103401
- ARCADIS (2020) Global construction disputes report. ARCADIS, Retrieved April 9, 2021, <https://www.arcadis.com/en/knowledge-hub/perspectives/middle-east/2020/global-construction-disputes-report-2020>
- Asuquo CF, Udo IE, Otali M (2020) A conceptual framework for managing construction claims in the face of the COVID-19 pandemic in Nigeria. *International Journal of Real Estate Studies* 14(S1):98-106
- Bakhary NA, Adnan H, Ibrahim A (2015) A study of construction claim management problems in Malaysia. *Procedia Economics and Finance* 23:63-70, DOI: 10.1016/S2212-5671(15)00327-5
- Bakhary NA, Adnan H, Ibrahim A (2017) Improving construction claim management in Malaysian construction industry. MATEC web of conferences, August 22-25, Les Ulis, France
- Biswas K, Muthukumarasamy V (2016) Securing smart cities using blockchain technology. IEEE 18th international conference on high performance computing and communications, December 12-16, Sydney, Australia
- CAICT (2018) Blockchain white paper: China Academy of Information and Communication Technology rusted Blockchain Initiatives, Retrieved April 14, 2021, <https://www.constructionblockchain.org/white-papers>
- CBC (2020) Blockchain & construction cash flow. Construction Blockchain Consortium, Retrieved August 30, 2021, <https://www.constructionblockchain.org/white-papers>
- Charehzehi A, Chai C, Yusof AM, Chong HY, Loo SC (2017) Building information modeling in construction conflict management. *International Journal of Engineering Business Management* 9:1-18, DOI: 10.1177/1847979017746257
- Che Z, Wang Y, Zhao J, Qiang Y, Ma Y, Liu J (2019) A distributed energy trading authentication mechanism based on a consortium blockchain. *Energies* 12(15):2878, DOI: 10.3390/en12152878
- Chow KF, Chan Chuen Fye P (2014) Building and construction law. *Singapore Academy of Law Annual Review of Singapore Cases* 15:102-132
- Dakhli Z, Lafhaj Z, Mossman A (2019) The potential of blockchain in building construction. *Buildings* 9(4):77, DOI: 10.3390/buildings9040077
- Daraghmi EY, Daraghmi YA, Yuan SM (2019) UniChain: A design of blockchain-based system for electronic academic records access and permissions management. *Applied Sciences* 9(22):4966, DOI: 10.3390/app9224966
- Das M, Luo H, Cheng JCP (2020) Securing interim payments in construction projects through a blockchain-based framework. *Automation in Construction* 118:103284, DOI: 10.1016/j.autcon.2020.103284
- Elghaish F, Abrishami S, Hosseini MR (2020) Integrated project delivery with blockchain: An automated financial system. *Automation in Construction* 114:103182, DOI: 10.1016/j.autcon.2020.103182
- FIDIC (2017) Construction contract (red book), 2nd edition. International Federation of Consulting Engineers, Geneva, Switzerland, 96-100
- GIACC/TI (2008) Anti-corruption training manual—(infrastructure, construction and engineering). Global Infrastructure Anti-Corruption Centre, Retrieved August 30, 2021, https://issuu.com/transparenyuk/docs/anti_corruption_training_manual_e_w
- Hamledari H, Fischer M (2020) Construction payment automation using blockchain-enabled Smart contracts and reality capture technologies. *Automation in Construction* 132:103926, DOI: 10.1016/j.autcon.2021.103926
- Hansen S, Rostiyanti SF (2019) Indonesian contractor professionals' perception on problems in construction claim management. *Malaysian Construction Research Journal* 27(1):69-78
- ISO (2016) Information and documentation — Records management. ISO 15489-1, International Organization for Standardization, Geneva, Switzerland
- Kifokeris D, Koch C (2020) A conceptual digital business model for construction logistics consultants, featuring a sociomaterial blockchain solution for integrated economic, material and information flows. *Journal of Information Technology in Construction* 25(29):500-521, DOI: 10.36680/j.itcon.2020.029
- Kim K, Lee G, Kim S (2020) A study on the application of blockchain technology in the construction industry. *KSCE Journal of Civil Engineering* 24(9):2561-2571, DOI: 10.1007/s12205-020-0188-x
- Lamb K (2018) Blockchain and smart contracts: What the AEC sector needs to know. University of Cambridge, Retrieved August 30, 2021, https://www.cdbb.cam.ac.uk/news/2018JulyRep003_Blockchain
- Lindsell-Roberts S (2008) 135 tips on email and instant messages. Houghton Mifflin Harcourt, Boston, MA, USA, 5-6
- Liu Z, Jiang L, Osmani M, Demian P (2019) Building information management (BIM) and blockchain (BC) for sustainable building design information management framework. *Electronics* 8(7):724, DOI: 10.3390/electronics8070724
- López D, Farooq B (2020) A multi-layered blockchain framework for smart mobility data-markets. *Transportation Research Part C: Emerging Technologies* 111:588-615, DOI: 10.1016/j.trc.2020.01.002
- Nawari NO, Ravindran S (2019) Blockchain and the built environment: Potentials and limitations. *Journal of Building Engineering* 25:100832, DOI: 10.1016/j.job.2019.100832
- Nosheen A, Arewa AO, Akhtar HM (2020) Preventive approach to unsubstantiated claims and disputes in the UK construction industry. Proceedings of the international conference on civil infrastructure and construction (CIC 2020), February 2-5, Doha, Qatar
- Omar T, Nehdi ML (2016) Data acquisition technologies for construction progress tracking. *Automation in Construction* 70:143-155, DOI: 10.1016/j.autcon.2016.06.016
- Perera S, Nanayakkara S, Rodrigo MNN, Senaratne S, Weinand R (2020) Blockchain technology: Is it hype or real in the construction industry? *Journal of Industrial Information Integration* 17:100125, DOI: 10.1016/j.jii.2020.100125
- Ren Z, Anumba G, Ugwu O (2001) Construction claims management:

- Towards an agent-based approach. *Engineering, Construction and Architectural Management* 8:185-197, DOI: [10.1108/eb021181](https://doi.org/10.1108/eb021181)
- Shah A, Bhatt R, Bhavsar J (2014) Types and causes of construction claims. *International Journal of Engineering Research & Technology* 3(12):732-735
- Sheng D, Ding L, Zhong B, Love PED, Luo H, Chen J (2020) Construction quality information management with blockchains. *Automation in Construction* 120:103373, DOI: [10.1016/j.autcon.2020.103373](https://doi.org/10.1016/j.autcon.2020.103373)
- Shojaei A, Wang J, Fenner A (2019) Exploring the feasibility of blockchain technology as an infrastructure for improving built asset sustainability. *Built Environment Project and Asset Management* 10(2):184-199, DOI: [10.1108/bepam-11-2018-0142](https://doi.org/10.1108/bepam-11-2018-0142)
- Tochaiwat K, Chovichien V (2004) Contractors construction claims and claim management process. *Engineering Journal of Research and Development* 15(4):66-73
- Turk Ž, Klinc R (2017) Potentials of blockchain technology for construction management. *Procedia Engineering* 196:638-645, DOI: [10.1016/j.proeng.2017.08.052](https://doi.org/10.1016/j.proeng.2017.08.052)
- Vacek M (2014) Email overload: Causes, consequences and the future. *International Journal of Computer Theory and Engineering* 6(2):170-176, DOI: [10.7763/ijcte.2014.V6.857](https://doi.org/10.7763/ijcte.2014.V6.857)
- Wang Z, Wang T, Hu H, Gong J, Ren X, Xiao Q (2020) Blockchain-based framework for improving supply chain traceability and information sharing in precast construction. *Automation in Construction* 111:103063, DOI: [10.1016/j.autcon.2019.103063](https://doi.org/10.1016/j.autcon.2019.103063)
- Xue F, Lu W (2020) A semantic differential transaction approach to minimizing information redundancy for BIM and blockchain integration. *Automation in Construction* 118:103270, DOI: [10.1016/j.autcon.2020.103270](https://doi.org/10.1016/j.autcon.2020.103270)
- Yang R, Wakefield R, Lyu S, Jayasuriya S, Han F, Yi X, Yang X, Amarasinghe G, Chen S (2020) Public and private blockchain in construction business process and information integration. *Automation in Construction* 118:103276, DOI: [10.1016/j.autcon.2020.103276](https://doi.org/10.1016/j.autcon.2020.103276)
- Yu FR, Liu J, He Y, Si P, Zhang Y (2018) Virtualization for distributed ledger technology (vDLT). *IEEE Access* 6:25019-25028, DOI: [10.1109/ACCESS.2018.2829141](https://doi.org/10.1109/ACCESS.2018.2829141)
- Yuan Y, Wang FY (2016) Towards blockchain-based intelligent transportation systems. IEEE 19th international conference on intelligent transportation systems (ITSC), November 1-4, Rio de Janeiro, Brazil
- Zaghloul E, Li T, Mutka MW, Ren J (2020) Bitcoin and blockchain: Security and privacy. *IEEE Internet of Things Journal* 7(10):10288-10313, DOI: [10.1109/JIOT.2020.3004273](https://doi.org/10.1109/JIOT.2020.3004273)
- Zheng Z, Xie S, Dai HN, Chen W, Chen X, Weng J, Imran M (2020) An overview on smart contracts: Challenges, advances and platforms. *Future Generation Computer Systems* 105:475-491, DOI: [10.1016/j.future.2019.12.019](https://doi.org/10.1016/j.future.2019.12.019)
- Zhong B, Wu H, Ding L, Luo H, Luo Y, Pan X (2020) Hyperledger fabric-based consortium blockchain for construction quality information management. *Frontiers of Engineering Management* 7(4):512-527, DOI: [10.1007/s42524-020-0128-y](https://doi.org/10.1007/s42524-020-0128-y)