A paradigm shift toward the application of blockchain in enhancing quality information management

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Received 5 May 2023
Revised 5 August 2023
30 October 2023
Accepted 4 November 2023

Abstract

Purpose – Lack of trust and poor quality of construction deliverables have become a serious matter nowadays. This is due to the absence of a uniform and decentralized system for managing quality information. In Kuwait's industry, many incidents have been recorded as a lack of confidence in the authenticity and integrity of the documented data in the system. This paper aims to shed the light on a framework that would tackle this matter.

Design/methodology/approach – A designed framework using Blockchain technology (Hyperledger Fabric) has been used to create a transparent and decentralized environment between the parties. A digitalized informative checklist referred to as "Smart Construction Inspection Checklist (SCIC)" has been initiated to enhance the poor information recorded between the parties.

Findings – The framework has provided a transparent, immutable, traceable and decentralized environment in which all parties are involved in transactions. In addition, the integration of the SCIC in the blockchain environment provided an advantage in which all the necessary criteria of inspection will be stated, checked by the consultant and validated by the client to approve the transaction. A preliminary testing has been conducted to support the proposed framework.

Originality/value – This study fulfils the gap in the state of art for further studies to practically apply the framework that will enhance the quality of information management in Kuwait's industry.

Keywords Blockchain, Hyperledger Fabric, Smart Construction Inspection Checklist (SCIC), Quality information

Paper type Research paper

Introduction

The construction industry is a fragmented and competitive environment in which stakeholders with different opinions, goals and levels of experience work together. Sophisticated tools and techniques are often used at different levels that add up to the complexity of this industry. What makes this industry competitive is the numerous duties of tasks that should be done in a short time taking into consideration managing different aspects such as quality information, proper communications, maintaining transparency during the execution of work and keeping the trust in the third party. In the construction industry, conflicts are inevitable since different perceptions are involved in any decision that would be taken. Consequently, if conflicts are not well handled, it may turn into disputes (Al-Humaidi, 2014). Disputes are one of the essential factors that prevent the successful completion of the project especially when disputes are raised into claims. This will influence the time of completion, quality and budget limits. Solving disputes fairly would be extremely challenging without proper documentation of events. In many instances, lack of

Construction Innovation
Vol. 24 No. 1, 2024
pp. 407-424

1471-4175
DOI 10.1108/CI-05-2023-0099

evidence is notified when cases are raised to courts for resolving disputes due to lack of documentation. This initiates difficulty in tracing information when claims occur. In Kuwait's industry, the General Directorate of Experts is the community that is responsible for investigation when claims exist among the parties. Many incidents have been recorded that a lack of confidence in the authenticity and integrity of the documented data in the system held.

The construction industry is facing many challenges in addressing the poor quality of construction deliverables, lack of adequate collaboration and communications and poor payment practices due to the involvement of the third party. In Kuwait, poor quality of deliverables is one of the most common practices in construction projects. The client often encounters asking for a particular type of construction material specifications but ends up with false alternatives. If this situation is discovered at a given time, explaining who is primarily responsible for this matter can be a strenuous mission. In many instances, the results of poor quality are not reported or documented properly, which makes finding the person or party responsible for not adhering to the specified requirements difficult.

Furthermore, in Kuwait's industry, usually, the contractor is responsible for capturing and tracking the information of the project and then sharing it among the parties. Despite the efforts of the contractors to build a well-centralized system managed by the contractor for tracing the records but may still not be an effective way to sort it out. Nevertheless, data are kept exclusively by the contractor which gives an advantage for the contractor to modify the data to exonerate itself when it occurs (Sheng *et al.*, 2020). This makes the contractor dominates over any party involved. Therefore, ambiguous cases could be existed such as fraud, corruption and malicious events.

To enhance the quality performance of construction, besides leveraging advanced construction technology, it is essential to cultivate a cooperative and trustworthy environment. Nonetheless, the prevalent contractual arrangements often revolve around confrontations, indicating a lack of trust among the involved parties (Wang *et al.*, 2017). The emerging technologies cannot ensure the security, traceability and transparency of the construction quality information that can be used in cases of quality disputes among numerous contributors in a project (Zhong *et al.*, 2020). The blockchain can be one of the best applications to solve the issue of quality of information. It is a uniform, secure and transparent system that is co-managed by stakeholders. Adopting blockchain during the construction phase has been loudly raised all over the world. As using this tool could solve several problems that have already been existing such as enhancing the transaction process, guaranteeing a database in addition to a transparent atmosphere among the parties, and eliminating the third party. Furthermore, the contribution of using a blockchain system will assist human beings in reducing errors and losing valuable information due to a lack of documentation.

Information management and blockchain technology on quality of information

Information management in the construction industry refers to the process of collecting, storing, processing and disseminating information related to construction projects. This includes all types of information, such as design documents, construction plans, project schedules, budgets, contracts and other relevant data. Effective information management is essential in the construction industry, as it helps ensure that all stakeholders have access to accurate, timely and relevant information needed for decision-making and project success. It also helps improve collaboration and communication among project teams, reducing errors, delays and conflicts. Information management in construction typically involves the use of various software tools and technologies, such as project management software, building

information modeling (BIM) and other specialized applications for document management, cost control and scheduling. In addition, many construction companies use cloud-based systems to store and share information, enabling remote access by authorized stakeholders.

It is worth mentioning to start with the most frequent application applied to enhance the quality information. BIM is an important element toward digitalization in construction. It can propose significant advantages in enhancing productivity and ensuring construction quality (Love *et al.*, 2011). Oh *et al.* (2015) proposed a BIM-based system for collaborative design, which can support the collaboration of the working drawings. Singh *et al.* (2011) proposed a theoretical framework where BIM is used as a multidisciplinary collaborative platform for better collaboration in the construction process. Ma *et al.* (2018) developed a system integrating BIM and indoor technology to make the process of construction quality management more effective. However, trust and transparency are still an issue during BIM collaboration among the stakeholders. Meanwhile, current BIM using centralized platform has the limitation on the record and traceability of data changes (Kiu *et al.*, 2022).

In the State of Kuwait, Soliman (2010) has discovered the main factors of failure in construction industry which may influence the time completion of the project. These are due to the financial problems between owner and contractor, delay of payments and conflict between contractor and consultant. Most of these delay causes are affected by the efficiency level of communication between project parties. In addition, the author has conducted a case study in 2017 in the State of Kuwait to evaluate and rank the communication problems that can lead to project delay throughout the execution phase. A partial of top-ranked communication problems leading to project delay includes:

- using outdated filing systems; and
- bad quality of documents due to the low quality of documentation may cause project parties misunderstanding or make the documentation inconsistency; furthermore, the author has proposed different solutions to enhance the communication problems such as using new filling system and new communication tools to accelerate the time for information handling.

Different authors have researched the influence of proper communication. Ashford (2002) illustrated that the satisfaction of the investor's requirements is to accomplish his visions in a short time and limited budget. This satisfaction can be achieved by a proper installation of a sufficient quality operation system among the parties. Gyampoh-Vidogah *et al.* (2003) have revealed from exploratory case studies in the construction industry that "the current management of information is characterized by systems such as the information exchange among project stakeholders is limited to paper, a process in which retrieval is very slow and inefficient; responsible departments for storing the data maintain their own data structured to adequate their particular needs; most information search between project parties and clients is paper-based, providing a constant source of delays; no efficient interfaces exist between departmental systems to access information electronically, and the impact of IT investment to date has been limited". These characteristics can be traced to the general lack of coherent management policy and vision on information management.

In the same area, Zhong *et al.* (2020) have defined construction quality management as a collaborative process between different participants with different pursuits of interest. Lack of trust has an impact on productivity and the quality of the deliverables. Mutual trust can improve the performance of quality information management by enhancing the construction process, improving efficiency and reducing management costs. The construction process generates a huge amount of quality information that can be used for disputes and litigations.

Recently, different technologies have been produced to enhance the construction industry in different terms. As these technologies are implemented throughout the construction phase to generate an automated system. The automated system has a positive impact on the efficiency of the workflow. Using the power of the computer to assist human beings in controlling the flow and reducing the number of errors become a must. The implementation of artificial intelligence integrated with the existing operating system throughout the execution process has widely become popular. The benefits of artificial intelligence are numerous which can be an added value to the system (Khanzode and Sarode, 2020).

In terms of information management, blockchain can provide multiple advantages. According to Golosova and Romanovs (2018) blockchain can improve the communication loop and the way of sharing information as it builds transparency and trust between the stakeholders. Everyone involved in the construction project can access and verify the information stored on the blockchain, reducing disputes and improving transparency. In addition, it creates a decentralized structure in which no central actor enables trust. It improved the security and privacy of information. It can address privacy concerns better than the traditional computer system by anonymizing data and requiring permission to limit access (Magazzeni *et al.*, 2017). Also, blockchain can provide immutability and traceability of information. Swanson (2015) has revealed the credit of using blockchain technology in terms of enhancing mutual trust among the stakeholders where blockchain can improve the lack of quality management in the construction industry. In addition, information asymmetry can be caught because all the parties have a copy of the records in a blockchain system (Rosic, 2018). These ledgers are immutable and final; once all the parties agreed on the transaction, this transaction is written to the ledger and every stakeholder has a copy of the transaction and it's unchangeable (Sharma and Kumar, 2020).

Mahmudnia *et al.* (2022) have conducted a systematic review on the characteristics of using blockchain technology to evaluate the impacts on mitigating disputes. This study focused on the analysis of old document-based systems confirms that disputes in organizations are inevitable. The results showed that blockchain technology can significantly mitigate construction disputes. Saygili *et al.* (2022) proposed a new construction-specific framework, decentralized construction enabling transparent resolution. The findings revealed that using a decentralized hybrid blockchain network would minimize disputes through reliable contract and payment execution.

On the other hand, the potential applications of blockchain technology in construction are yet to be fully explored due to the limited number of empirical studies. However, it is advantages to rely on offering tamper-proof information records, facilitating real-time information sharing and synchronization among various stakeholders and enabling automated execution through smart contracts (Helo and Hao, 2019). In the GCC region, the blockchain-based projects that have been announced in GCC are still in initial or establishment stages and a few of them are in the experimentation and testing stage, due to the novelty of the technology and the related need of core changes, rules, laws, business structure and relationships between sectors (Othman *et al.*, 2021).

Methodology

The methodology adopted for this study is proposing a blockchain framework for construction quality information management. The blockchain framework was implemented to achieve the objective of this research which is to enhance the quality of information. This framework consists of two parts: the blockchain environment and the Smart Construction Inspection Checklist (SCIC) for recording information. The methodology adopted for this research can be outlined in the following steps:

- Step 1: The authors started with exploring the process of recording and sharing information during the construction phase in Kuwait's industry.
- Step 2: An appropriate blockchain software platform has been selected to support the research goal.
- Step 3: The above step was transferred into knowledge base sharing of the process, which will enable the creation of a particular structural framework for the construction inspection checklist as a knowledge domain to apply the blockchain technology.
- Step 4: Finally, designing the SCIC using a blockchain platform taking into account the nature of the construction industry cycle of sharing and storing information.
- Step 5: Testing the proof of concept

The following sections explains in more detail these steps that were adopted in the methodology:

Step 1: exploring the process of recording and sharing information during the construction phase in Kuwait's industry

Construction project is a sequence of tasks that has multi parties involved in it. Monitoring the progress of construction activities and assuring the proper communication and collaboration between the stakeholder's is essential. In Kuwait's industry, a paper-based form called "The Construction Inspection Checklist" is used in the construction phase; created by the contractor. This form aims to keep all day-to-day records to secure his work if any incidents occurred. In addition, the checklist could be used for different purposes such as ensuring the construction activities adhere to the specified standards and requirements, a guidance for checking completed tasks and tracking the work done in the project, a reference for retrieving information in the future and facilitating a basic channel of communication between the parties. The process of using the checklist starts from the contractor side by initiating the checklist and requesting from the consultant to supervise on the completed task in writing to let the contractor proceed to the next task. In the Kuwait industry, this form has shown some shortages. Practically, the information recorded tended to be not informative as it relies on how sufficient the engineer is to record the existed incidents or deficiencies. Also, evidence cannot be traced easily. Different cases have discovered that retrieving information from the past or a task that has been already done was extremely challenging. In addition, most of the communication and sharing of information between the parties are not written based. The existing approach of recording information has impurities that might affect the quality of the deliverables. Some deficiencies at the site could not be stated or modified after submitting the checklist without informing the client. Furthermore, it is a centralized system controlled by one of the entities. This has the advantage to add or modify information stealthily (Sheng *et al.*, 2020).

This research aims to develop a practical and informative digitalized checklist to enhance the quality of information. Chen and Luo (2014) have revealed a framework for BIM based on quality management in construction. This form has been tested in China industry and it showed effective results during the construction phase. It helps to control the defective material and obligates each entity to stick to their duties with no corruption. It is automated to send an automatic notification when any clashes exist.

An electronic form has been initiated based on the specified model as shown in Figure 1. Some modifications have been added to suit the construction industry in Kuwait due to the lack of implementation of BIM technology (Abdulfattah *et al.*, 2017). In this form, all the

Construction Inspection Checklist					
Project Name					
Subdivision				Location	
Date of Inspection				Start/End Time	
Contractor				Owner / Owner Rep.	
Inspector's Name(s)					
Describe present Task to be checked					
Inspection Criteria				Contractor Inspection Record	Consultant Record
Main Control Items	1	Quality of Cement and Admixture	Manufacturing Requirements		
	2	Number of Steel Bars	Design Requirements		
	3	Concrete Strength	Design Requirements		
	4	Capacity of the Design Element	Design Requirements		
Common Control Items	5	Drilling Location	As per Design		
	6	Depth/Height	As per ACI Code		
	7	Lapping Length	As per ACI Code		
	8	Dimensions	As per ACI Code		
Disposition of Product					
Defect Element _____ Defect Quantity _____					
Defects to be: ❑ Reworked ❑ Scrapped &replace ❑ Acceptaed as is					
Acceptance Signature					
Contractor _____ Consultant _____					

Figure 1.
Construction inspection checklist (SCIC) for structural elements

Source: Created by the authors

details would be passed through the owner for approval. Simultaneously, everything related to the design requirements will be modified by the consultant in writing and all the comments during the inspection will be classified and should be up to the standards. Nevertheless, if any defective material is observed by the consultant, it will be reported in the form and the client will be informed immediately. This aims to assure that construction products meet regulation requirements. In the end, each party should sign the form if the requirements are met to keep everything official and tamper proof. In case this process has succeeded; the project moves to the next task; otherwise, the contractor needs to amend the work, and the entire process is repeated.

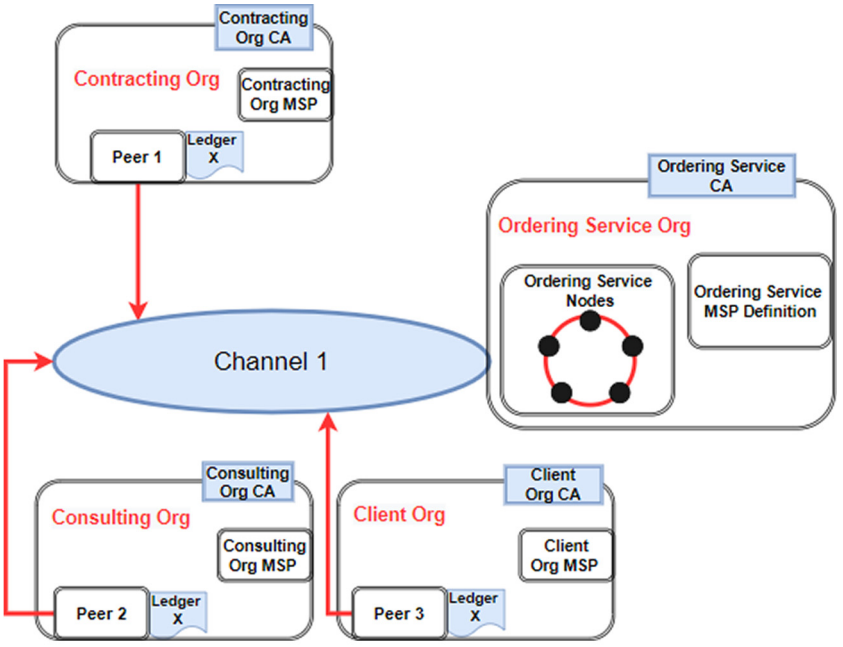
The frame of the electronic SCIC form has been carefully constructed in a style that will maintain a well-organized and includes enriched information in which extracting information would be easily and effective for the entity that would check or use the documents. It describes three categories such as organization, product and process information. The organization category gives a brief description of the entities like names, level of excess and credentials. The product category describes the material to be checked. This process will be created by the contractor based on the type of element that would be

checked by the consultant such as columns, slabs or beams. The inspection criteria are subjected to be changed based on the task is to be checked at the site. For instance, if the item is the foundation, the inspection criteria will have all the essential requirements that are necessary to be checked related to the design obligations to make sure the design element is matching with the standards during the execution.

Step 2: blockchain platform selection

IBM blockchain platform is one of the well-known platforms that adopts the permissioned blockchain system. As sharing such information might be uncompromisable. The IBM blockchain platform could perfectly fit the purpose of this research. Hence, IBM adopt the Hyperledger Fabric in which all the members could be defined its roles. A Hyperledger Fabric-based consortium blockchain has been initiated using the IBM platform. It implicates four main organizations such as the client, contractor, consultant and ordering service as shown in Figure 2. This network consists of one channel to share all the information through the network. Furthermore, all the peers are having the same chaincode, maintaining the same ledger and sharing the same endorsement policies. All the organizations are initiated inside one zone area with three worker nodes. The Raft consensus has been used as the default algorithm used by the IBM platform. This consensus can provide less dependency, more decentralized and the orderer nodes can be spread. Kubernetes clusters have been used for this model.

First, the certificate authority and the membership service provider have been created for each organization. Then, the membership service provider was created to give credentials to each client and peer. Different types of peers have been initiated as shown in Figure 3 (a).



Source: Created by the authors

Figure 2.
IBM Hyperledger Fabric-based consortium blockchain

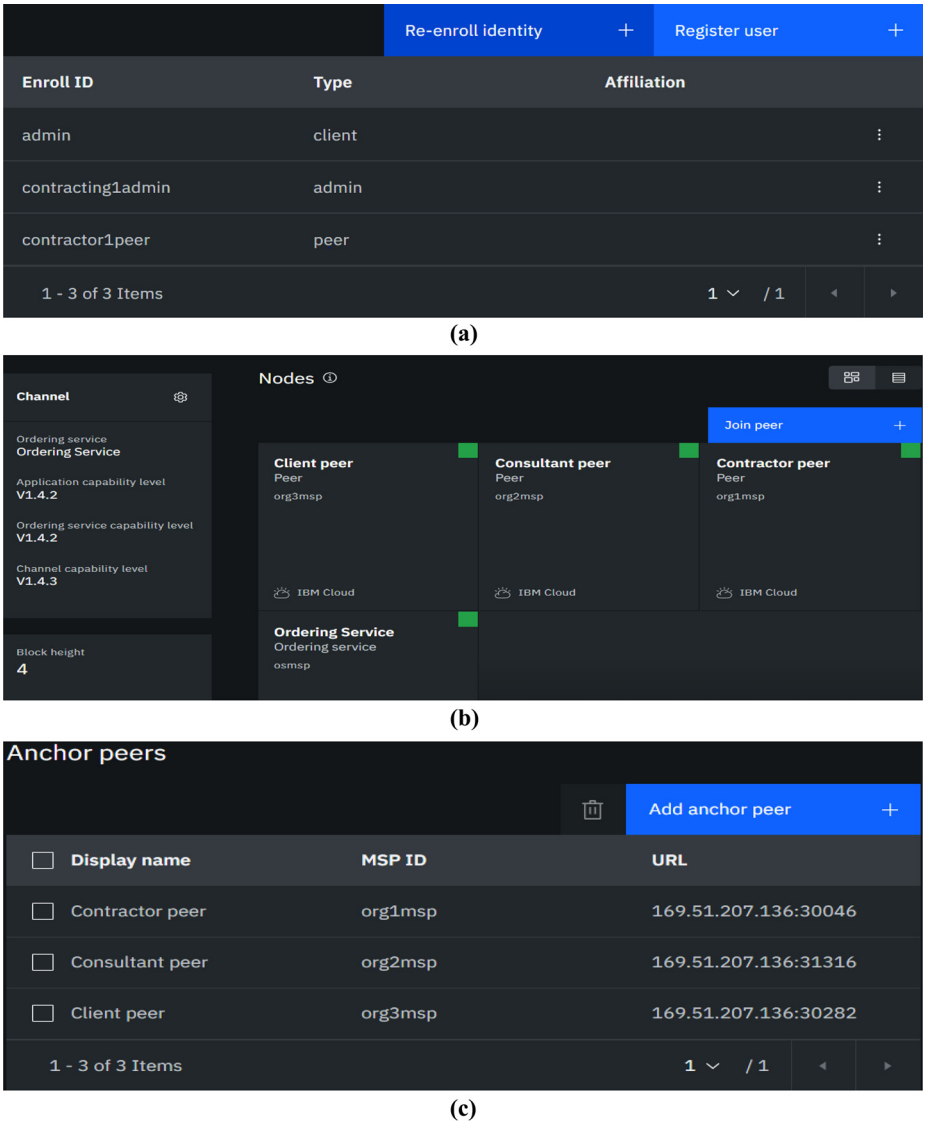


Figure 3.
Screenshots of system configuration

Notes: (a) Participant configuration; (b) channel configuration; (c) anchor peer configuration
Source: Created by the authors

A channel has been deployed on the platform connecting all the peers to share the transaction [Figure 3 (b)]. Before adding the peers to the channel, every single peer has been enrolled as a consortium member.

The ordering service has enrolled in the channel as well. Since this model is not in the production industry, only one node has been initiated. Each organization has an

administrator registered in the CA module, to obtain certificates of public and private keys. The purpose of the administrator is to send requests to other users inside his organization and obtain certificates of public-private keys.

These certificates are used for subsequent SCIC processing transactions, such as query and submission. In addition, for better communication among the peers, each peer inside the network has been marked as an anchor peer [Figure 3 (c)].

The smart contract has been installed in the consulting org. It can execute and reply to the proposed attached to that chaincode. Since the console gives a single user the ability to own and control several organizations and identities, the client org3 membership service provider (MSP) has been selected among the peers to sign the channel update request. For each entity that is enrolled inside the channel, the level of permission has been assigned as whether an operator, writer or reader.

All the organizations have been selected as a writer except the client has been selected as an operator. This will be used when any updates are requested or to be added to the channel. The default lifecycle and smart contract conditions of the endorsement policy that are provided by the IBM platform have been used during the process of deploying the chaincode in the ledger. Every chaincode has an endorsement policy which states the set of peers on a channel that must execute the execution results for the transaction to be considered valid. These endorsement policies define the organizations through their peers who must endorse (i.e. approve of) the execution of a proposal. When a peer receives a new transaction, it will invoke the validator to confirm whether the transaction is properly endorsed, including the endorsement signature and the number of endorsements according to the agreed endorsement policy.

Step 3: defining the architecture structure of the construction inspection checklist

Hyperledger Fabric is an open-source blockchain infrastructure project developed by IBM; it is one of the most mature distributed ledger platforms (Androulaki, *et al.*, 2018). Accordingly, the IBM blockchain platform has been used for this study as the infrastructure of the used platform based on Hyperledger Fabric. IBM platform provides different features such as providing a permissioned architecture with providing MSP to issue the digital certificate for validation purposes to identify the members, providing high scalability and supporting several programming languages for writing smart contracts (e.g. Go, Java and Java script). Thus, the IBM blockchain platform has been chosen to develop the framework as shown in Figure 4. In this application, three types of identities have been created (client, contractor and consultant). Once the application has been invoked, these identities are stored in the wallet. Different methods have been used to perform the desired workflow. With the defined chaincode, the APIs have been used to perform the transaction and save the data on the ledger and retrieve the data from the ledger. On the other hand, the transaction data will be managed on-chain with the fabric SDK. Once the application is initiated, all the identities will be enrolled such as admin and users on the network and the information of the identities will be saved in the wallet. After providing all the identity credentials to the application and connecting it with the channel, the smart contract has been instantiated.

Step 4: Smart Construction Inspection Checklist design

Smart contracts are also referred to as chaincode in the Hyperledger Fabric. A smart contract defines the rules between different entities in executable code. It is a contract that reveals the terms and runs the functionality of defined business logic between the parties (Kannengießer *et al.*, 2021). Using a blockchain network can turn these terms and agreements into executable programs. Once deployed in the blockchain, the unique

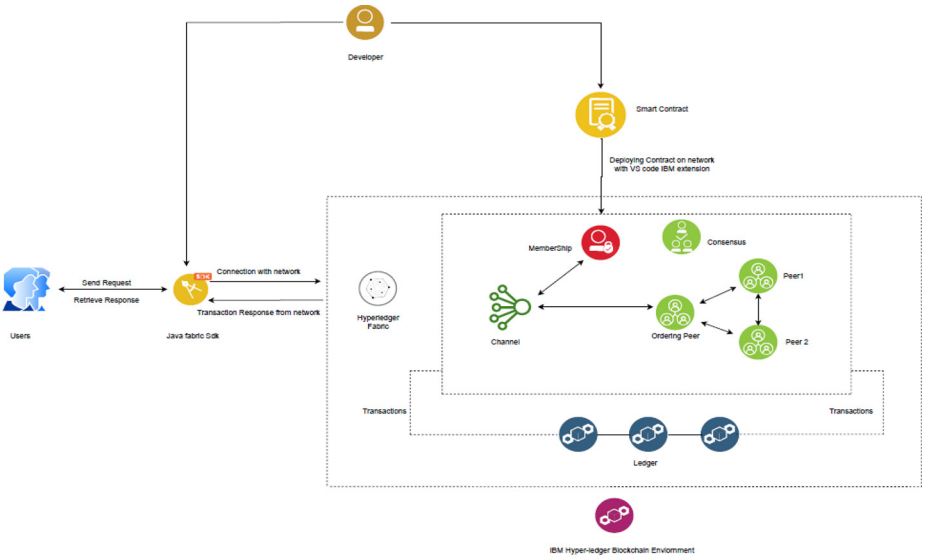


Figure 4.
Blockchain-based framework for construction quality information management

Source: Created by the authors

addresses on the chain are allocated inside the contract. A smart contract can be considered as the trigger condition of the blockchain. Once the data is inputted into the blockchain, the predefined actions in the smart contract are automatically executed (Rouhani and Deters, 2019). In this framework, VS code IBM blockchain extension has been implemented to design the SCIC using Java language as well as create the desired workflow. This extension provides the required space to create and deploy a contract such as organizations, peers, ordering peers, networks and channels. After deploying the contract, the gateway environment has been created for the contract to connect it with the channel. Then, the membership service provider has been connected and invoked the credentials for identities. Once the local workspace is settled, the Fabric SDK application will be used to interact with the smart contract. Figure 5 demonstrates a part of the initiation of the SCIC.

```
@Transaction()
public void createConstruction(Context ctx, String constructionId, String name, String loc
 String owner,String year, String subDivision, String dateOfInspection, String startEndTim
 String contractor, String inspectorName, String taskToBeChecked) {
    boolean exists = constructionExists(ctx,constructionId);
    if (exists) {
        throw new RuntimeException("The asset "+constructionId+" already exists");
    }
    Construction asset = new Construction();
    asset.setName(name);
    asset.setLocation(location);
    asset.setOwner(owner);
    asset.setYear(year);
    asset.setSubDivision(subDivision);
    asset.setDateOfInspection(dateOfInspection);
    asset.setStartEndTime(startEndTime);
    asset.setContractor(contractor);
    asset.setInspectorName(inspectorName);
    asset.setTaskToBeChecked(taskToBeChecked);
    ctx.getStub().putState(constructionId, asset.toJSONString().getBytes(UTF_8));
}
```

Figure 5.
Part of the construction inspection checklist (SCIC)

Source: Created by the authors

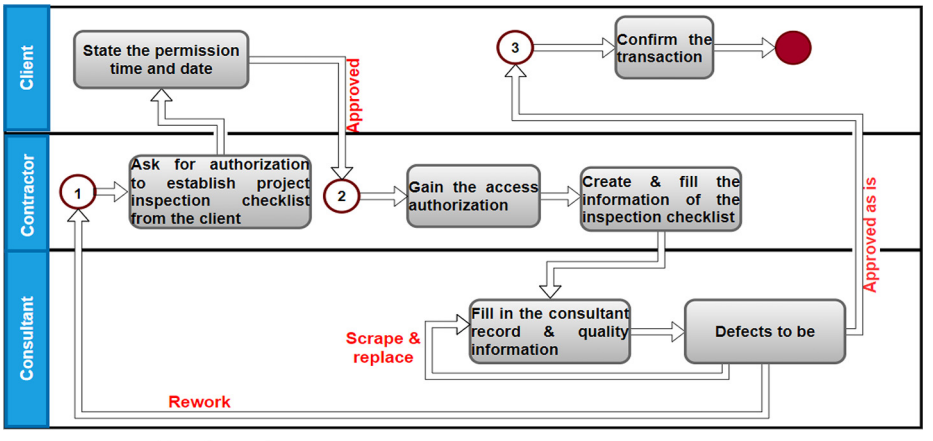
To achieve a high level of quality information with maintaining the same practical procedure of the job role for each participant, the workflow of the smart contract has been created as shown in Figure 6. The business logic of the desired smart contract has been defined according to the workflow.

First, the contractor will ask for permission from the client to create and fill in the information required in the form. The contractor will fill in the inspection checklist. After that, the consultant will fill in all the records including quality information. After filling in the details of the inspection area based on the site condition, the consultant will fill in the details of the disposition of the product section.

There are three checkboxes in the created form and the consultant should select one of them. If the selection is rework option, the process will be repeated and this transaction will be saved as a rejected order to keep every single detail up to date with the client. If the selection is the scrape and replace option, then the consultant will fill in the inspection details. Once again for the defective item to give the contractor a chance to edit the work before rejecting the order. If the consultant selected accept as is an option, then this form will go directly to the client to confirm the process. During that time, the transaction will take place and will be adhered to the block, whereas the ledger is updated and returned to the user.

Step 5: testing the proof of concept

For revealing the feasibility of blockchain technology in construction quality information management, the following development environment was deployed for the blockchain network. IBM cloud (2.5.4) with 8 GB of DDR4 memory and Intel Core i5 processor CPU has been used to initial all the credentials and memberships. For Fabric SDK, Spring Tool Suite (IDE) has been used to develop the application with Java version 1.8. while VS IBM blockchain extension version 2.0.8 has been used to create the smart contract. Furthermore, Hyperledger Fabric version 2.0, Docker version 20.10.12 for running the Hyperledger environment, NPM version 20.10.12 and Python version 3.8.10 have been implemented to successfully run the fabric SDK and deploy the smart contract. After connecting the IBM cloud through the Visual Studio application by installing the IBM blockchain platform onto it to test it locally as shown in Figure 7. A preliminary testing has been conducted. All the



Source: Created by the authors

Figure 6.
The workflow of the SCIC

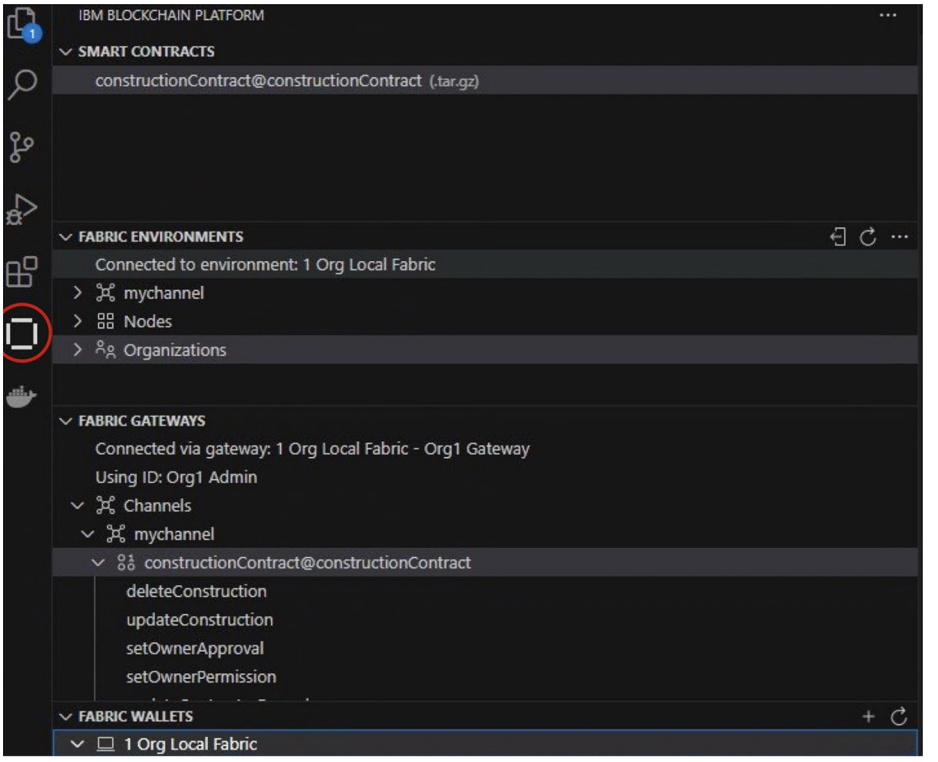


Figure 7.
Screenshot of the consortium blockchain network

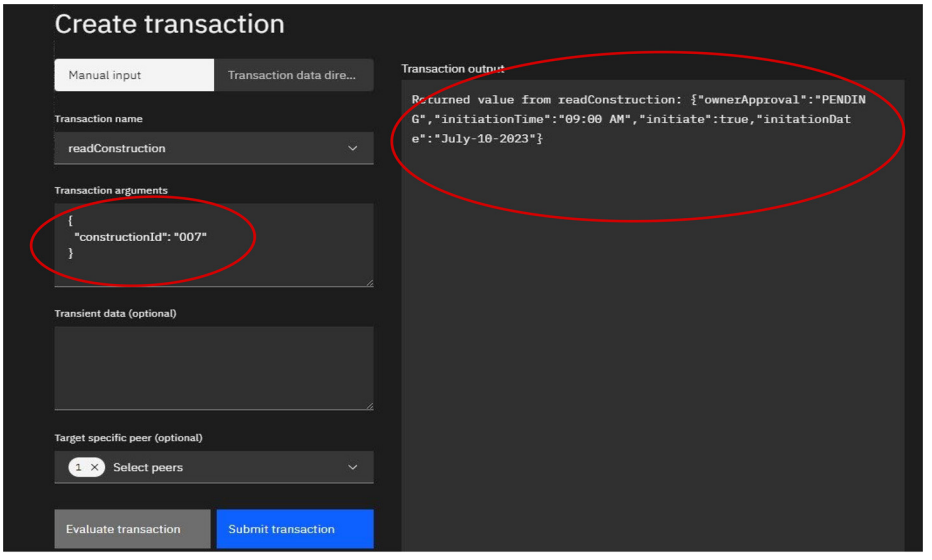
Source: Created by the authors

credentials, channels and entities are retrieved from the IBM cloud. The smart contract is deployed through the environment to achieve the desired goal of the proposed framework. Furthermore, the IBM blockchain platform allows internally to browse the ledger items and can also monitor and query blockchain network including view blocks and transactions.

The benefits of the proposed framework

Connecting the physical and social realities as revealed in this research is an essential step toward an effective process of enhancing quality information. The proposed framework has been delivered from the observation of the job site (physical condition) to perform an electronic form (social reality) with maintaining a high level of transparency during the approval process and reducing centralization. This study aims to enhance the quality of information management in Kuwait's construction industry. The current process shows some shortages in terms of centralization of quality information and lack of communication in which most of the time the contractor has the power to control the flow and pass limited information if needed. At the same time, the client will be the last party who would have the updated information in the cycle. In addition, the manual storing of the data might get some files lost due to a lack of organization between the parties since this procedure depends on the efficiency of the human potential in keeping records of the files. This will increase the risk of losing essential data.

In addressing these issues, based on the IBM blockchain platform, the construction quality information would be transformed into transactions and then stored in the block through the consensus process. Figure 8 shows the details of block 007 in which represents a request for a new transaction, the contractor will start the process by asking the client for approval to initiate the SCIC form by clarifying the date and time of the submitted request. The peer of owner will read the block and has two options to respond based on the condition at the site. It is either approved or rejected with notifying the time and date of the given action. Meantime, the status of the request remains pending until the peer of owner takes action. The action will be saved after getting the permission in that block and returned to the contractor to start filling the SCIC with all the information mentioned in Figure 1. The peer of consultant will check the store information and state the proper comments inside the consultant record column. Then, the consultant has three options such as approved as is, scrape and replace and rework. If the checklist was accepted from the consultant, the final decision goes to the peer of client to accept or refuse. If the case was rejected, this will be saved as a transaction with a given number and hash code. All the necessary information that may be needed will be recorded and stored. On contrary, if the case was accepted, Figure 9 illustrates the information that will be saved inside the block. Consequently, the implementation of the blockchain system enables transparent and traceable information management. As the quality information remains immutable and accessible to all participants on the chain through query transactions, accountability for quality issues becomes efficient. This fosters a high level of trust among the participants, ultimately leading to enhanced efficiency and quality performance in the construction process as the transaction is unchangeable. In addition, since all the data will move through the owner from the beginning until the end of the transaction and everything will be saved on the chain, all the parties are obligated to perform a high level of professionalism. In case any disputes are held, all the information will be easy to trace for evidence. The proposed SCIC



Source: Created by the authors

Figure 8. Screenshot of information of the block and transaction in consortium blockchain network based on IBM blockchain platform

```
"initiate": true,"initationDate": "26/06/2022","initiationTime": "9:00 AM",
"ownerPermission": "APPROVED","permissionDate": "26/06/2022","permissionTime": "9:30 AM",

"name": "Commercial project ","location": "Kuwait","owner": "Client","year": "2022",
"subDivision": "Construction work","dateOfInspection": "27/06/2022", "startEndTime": "11:00-11:30 AM",
"contractor": "Contractor company","inspectorName": "Consultant office",
"taskToBeChecked": "Construction element",
"criteriaNameFirst": "Quality of Cement and Admixture", "criteriaNameSecond": "Number of Steel Bars ",
"criteriaNameThird": "Concrete Strength","criteriaNameFourth": "Capacity of the Design Element",
"criteriaNameFifth": "Drilling Location","criteriaNameSixth": "Depth/Height",
"criteriaNameSeventh": "Lapping Length","criteriaNameEight": "Dimensions",
"contractorRecordForFirst": "As per manufacturing requirements ",
"contractorRecordSecond": "As per design requirements",
"contractorRecordThird": "As per design requirements",
"contractorRecordFourth": "As per design requirements",
"contractorRecordFifth": "As per design",
"contractorRecordSixth": "As per ACI code",
"contractorRecordSeventh": "As per ACI code",
"contractorRecordEight": "As per ACI code",
"consultantRecordForFirst": "No comments","consultantRecordSecond": "No comments",
"consultantRecordThird": "No comments", "consultantRecordFourth": "No comments",
"consultantRecordFifth": "No comments", "consultantRecordSixth": "No comments",
"consultantRecordSeventh": "No comments", "consultantRecordEight": "No comments",

"defectElement": "No element is defected", "defectQuantity": "0",
"actionToTake": "ACCEPT_AS_IS",
"ownerApproval": "APPROVED"
```


Figure 9.
Final transaction saved on the blockchain based on IBM blockchain platform

Source: Created by the authors

was constructed in an informative way to enhance the quality of information. These peculiarities have been achieved by implementing the blockchain with the integration of the SCIC form. Nevertheless, the communication loop and delivery of sharing information between the parties have been developed.

A link between the proposed framework and the common data environment (CDE).

The core of blockchain is a chain data structure in which each node in the network operates data in a distributed environment with the help of cryptography, a consensus algorithm and a smart contract. As a new distributed computing paradigm, blockchain provides a decentralized, immutable, transparent and traceable distributed database solution (Cui *et al.*, 2019). As the blockchain technology becomes a demand, consortium blockchains have significantly raised attention in practical applications due to their decentralization and immutability. However, the performance of current consortium blockchains remains a significant obstacle to large-scale commercial adoption (Lu *et al.*, 2023). In that aspect, the proposed framework has used a high-performance Raft consensus algorithm that leverages node server performance.

Building Information Modelling (BIM) is a tool used to gather information management approach and solution in the Architecture, Engineering, Construction and Operations (AECO) industry that can improve information flows and lead to enhanced building management along the lifecycle (Sacks *et al.*, 2018). Information management workflow in BIM-based collaboration is based on using a CDE. The practical implementation of CDEs proposed by ISO19650 could be a challenge due to exposing all relevant data as a single source of truth to facilitate continuous collaboration between stakeholders.

Jaskula *et al.*, 2022 have demonstrated the challenges of CDE adoption in which the level of privacy and using multiple CDEs simultaneously leading to data accountability, transparency and reliability issues. In line with the worldwide standards, some technologies are being investigated to enhance the functionality of the CDEs such as blockchain

technology. Preciously Raft consensus could have a strong impact on coordinating data replication across multiple nodes and the integrity of the data. It allows CDEs to remain available even if some nodes fail. If one node goes down, it can quickly elect a new leader to continue processing data and serving requests. Scalability is another challenge for the CDE when multiple nodes are added, Raft consensus can support the scaling process. It allows for dynamic membership changes, enabling nodes to join or leave the CDE without causing disruptions. Since security is a crucial aspect for modern applications and system, Raft consensus can be implemented to enforce access control and security policies within the CDE. Only authorized nodes can participate in the consensus process, ensuring that the data remains secure. Nevertheless, in a CDE, conflicts between concurrent updates are common. Raft can be used to resolve conflicts in a deterministic manner, ensuring that all nodes eventually converge to the same state. In terms of transactions, Raft can be used to order transactions in the CDE and provided an auditable log of all changes made to the CDE. This log can be used for accountability purposes and for tracking changes over time.

Limitations and future work

After revealing the functionality of the SCIC and the achievement of the proposed framework in quality information management, some limitations should be highlighted:

- The chosen platform for creating the blockchain environment has a special way to calculate expenses. It depends on how many CPUs are used per month for the implementation of the blockchain system and stored data. The more you build, the more you pay for storage and users which would be added overhead expenses for the investors.
- The proposed framework is presented by three parties such as the contractor, consultant and client. There are more participants that are involved throughout the inspection process. This would be limiting the implementation of the proposed framework in the mega projects.
- Theoretically, the proposed framework is established on the assumption of all the stockholders have the willingness to implement a blockchain system to manage the quality information. However, the system implementation is a challenge, especially in Kuwait industry. Using a blockchain system would solve some deficiencies, but the overhead expenses would be an issue for limited-budget projects, especially at the initial stage.
- At present, limited data formats can be supported to upload to the blockchain. Some large files will degrade the performance of the blockchain.
- The blockchain is a strong tamper-proof capacity, but there are no guarantees that fraudulent data will not be uploaded. Although the confirmation will not take place unless the client approves the transaction which carries a lot of responsibilities from both parties to be aware that everything should be related to the site condition. However, preventing fraudulent data completely would be difficult. This matter can be resolved by implementing one of the latest methods such as using drones or sensors for capturing the condition at the site.
- In general, human beings are reluctant to accept new technologies and always prefer the traditional style. Furthermore, the diversity in the construction industry will make the implementation even harder due to the high variation in computerization skills between the fresh graduate and the experts in the field. As elderly participants are against learning or changing the process most of the time. In addition, the traditional thinking of maintaining the privatization of documents inside the ledger should be changed, which might be resisted by conservatives to some extent.

For future work, the proposed framework was designed to fit the construction industry in Kuwait to enhance quality information management. Indeed, more investigations will be conducted on a case study in Kuwait to visualize the benefit of using the proposed framework as well as evaluate the acceptance of implementing blockchain in Kuwait. However, the Web application should be integrated with the proposed framework before testing the model to help the interaction between different users. Some modifications will be added to the framework such as considering multiple participants including project leader, project management, quality assurance, construction technician and quality inspector to get fully the benefits of using blockchain. More justifications will be conducted practically on the SCIC to validate the proposed checklist.

Conclusion

Recently, there is a paradigm shift toward digitalization in the construction industry, a demand that is rapidly accelerated due to the need of enhancing the deficiencies throughout the lifecycle of the project. Precisely, enhancing the quality of information, communication of sharing information and reducing disputes caused by inaccurate documentation. Due to the inequality of leverage, a centralized system for recording information is difficult to gain the trust of the stakeholders. Furthermore, the traditional system has a high risk of failure and becomes unattractive to investors in the construction industry.

Blockchain is a powerful technology that aims to break the trust crisis in the distributed cooperation environment, especially for the participation of multiple parties' industries. In terms of quality management in construction, blockchain can provided a new secure system and infrastructure, which enable every stakeholder in the project to achieve consistent, secure and decentralized quality information management.

This study proposed a blockchain-based framework for managing construction quality information that enables immutability, traceability and transparency. The IBM consortium blockchain network is adopted for construction quality management in which the parties' roles are presented as well as the setup of the environment. Furthermore, supported by the SCIC for trusted quality information management in the construction industry is discussed, which can improve efficiency and avoid lack of information. Meanwhile, the framework defines clear transactions amongst the project participants (contractor, consultant and client). Each member can perform their duties and can securely access and share the quality information on the SCIC form. Lastly, a preliminary testing is conducted, and the IBM blockchain platform is used to visualize this network to present its feasibility on information management. This study covers the gap in the state of the art in quality management in Kuwait's construction industry. However, additional evidence from practical implementations is needed for confirmation as the paper is largely conceptual in nature. Further modifications and investigations to be conducted on the proposed framework for further studies.

The research on blockchain in the GCC region for the construction industry is still under development. However, this study might have some assets for future implementations and exploration in the GCC region.

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