A Private Blockchain Framework to Enhance Supply Chain Process in Construction

Mustapha Hakeem, Oluwaseun Ojerinde, John Alhassan and Kabiru Abdullahi

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Hakeem Mustapha Attau[1], Oluwaseun Adeniyi Ojerinde[2], John K. Alhassan[3] and Kabiru Abdullahi[4]

[1,2,3,4] Department of Computer Science, Federal University of Technology, Minna Nigeria

Abstract. In recent years, the invention of web3 technology has spread the awareness of blockchain technology, especially in the financial sector for online transactions. However, other sectors are adopting this technology due to the invention of Ethereum programmable tools on blockchain nodes for creating digital smart contracts. In the case of construction and structural engineering projects, modern-day structures come with many management requirements for the supply chain process. Current studies show that most construction companies lack efficient and recent blockchain technology mechanisms to enhance the supply chain processes. As a result, trust and transparency have become great challenges in the supply chain of construction companies. This is due to a lack of proper management and corrupt acts of the construction stockholders. Additionally, the traditional blockchain construction supply chain management network poses series of challenges due to lack of control on transaction exchange among entities, and essential data personal to an organization are visible to other organizations or users outside the supply chain. Such a system is not feasible for enterprise usage. Hence, this study proposes a private blockchain framework to enhance the construction's supply chain process.

Keywords: Hyperledger fabric, blockchain, construction, material, Ethereum.

1 Introduction

There have been a significant trend in structural engineering with unprecedented complexities in recent years. These complex designs have necessitated the consideration of performance capabilities, which are not focused on by previous researchers [1]. As technology advances rapidly and construction projects grow increasingly complex, engineering project managers or contractors must adapt to this ever-changing landscape by adopting new methods and technologies. Recently, blockchain technology is an example of a trending technology that has gained prominence [2]. Satoshi Nakamoto is known as the founder and creator of Bitcoin, who specified the various capabilities of blockchain technology as a decentralized peer-to-peer (P-2-P) system capable of addressing the challenge of maintaining a secure and transparent transaction ledger. Recently, research has shown that blockchain technology is disrupting traditional business processes in various sectors [1]. Moreover, despite its growing popularity, researchers need to conduct in-depth research to fully understand the concept of blockchain. In a report conducted in 2018, it was identified that the global survey conducted on 1,053 senior executives at companies with revenues exceeding $500 million, revealed that 43% of respondents prefer blockchain implementation among their top five strategic priorities. Additionally, 74% of executive teams believed that there was a strong business case for leveraging blockchain technology [1]. The term supply chain was first used by the manufacturing company, and the Toyota Motor Factory was the first manufacturer to adopt the concept of supply chain [3]. There are a lot of similarities between the manufacturing industries and the construction industries, which makes it easy for blockchain technology to be easily integrated with the management supply chain process [4]. Primarily, the supply chain aims to minimize inventory duration and cost of the project, which results in better project management and performance [3].

Furthermore, a smart contract is a collection of instructions that can be used to run series of transactions on the blockchain network. These instructions are executed automatically when the users initiate transactions, making them immune to tampering or modification. To write business logic on blockchain, blockchain developers use the Solidity programming language. Once the code instruction (contract or chain code) has been defined, then it can be further compiled and deployed on the Ethereum blockchain. Solidity is the official programming language for defining smart contracts, and developers can use JavaScript, or Python via the web3 layer to compile, sign and deploy Solidity code on Ethereum Network [5]. A Web3 provider is a data structure that offers a link to publicly available Ethereum nodes, and with MetaMask users can create, store, and manage their public and private keys uniquely assign to their account. Hyperledger fabric provide developers with tools to build permissioned blockchain solutions. Hyperledger Fabric implements permissioned blockchain and provides the infrastructure for developing the network [6]. In hyperledger fabric, business network participants can define transaction validation policies using a customizable blockchain consensus protocol. The business network comprises of participants who interact within it, and each participant can possess a unique identity across multiple business networks. In Hyperledger fabric, credentials are required for reading or writing to the ledger, and the participants granted access to the ledger are referred to as peers [6]. This facilitates transaction control and enhances the system's throughput. Hyperledger fabric ensures secure interactions among authorized participants to maintain privacy and confidentiality [7].

1.1 Research Problem

Construction companies across the globe are facing challenges of trust and transparency which has led to lack of collaboration and trust issues among stakeholders [8]. However, it was identified that the traditional construction's supply chain process for construction work poses great challenges such as trust and transparency issues in building material price, and quality during exchange between the supply chain entity [9] . Current studies show that many construction industries lack efficient and state or art blockchain technology applications to enhance supply chain process. However, the utilization of private blockchain technology (Hyperledger) can address the issues of trust and transparency even better than the existing public-based Ethereum blockchain technology [10]. Moreover, Hyperledger also efficiently addresses the issues of tracking building construction digital assets, and the exchange of resources in the construction supply chain management process. Hence, this study proposes the utilization of a private blockchain technology called Hyperledger Fabric to enhance the supply chain process of construction materials and assets.

1.2 Research Goal

The study aims to develop a private blockchain framework using Hyperledger Fabric to enhance the construction supply chain process. However, the framework will be developed on the existing Hyperledger Fabric framework, and the construction supply chain process will be testing using the Hyperledger Caliper explorer tools. Finally, the framework performance will be evaluated based on CPU utilization, and latency.

1.3 Motivation of Study

In Nigeria precisely, it's difficult to establish trust among group of individuals or entities sharing or exchanging financial resources among themselves. Situation such as group project contract involving financial asset to execute and the likes. However, many construction companies in Nigeria like sophisticated and secure tool for managing transaction, raw materials and any other asset essential to construction project. This result in lots of fraud, purchase of inadequate resources, fake transaction record and the likes. This motivates the introduction of secure blockchain smart contract for construction companies in Nigeria.

2 Literature Review

This literature review will reveal growing interests in the application of blockchain technology in the construction industry, by addressing various challenges and inefficiencies prevalent in traditional practices. Researchers such as Kiu et al., [8] and Hamledari, and Fischer [11] emphasized the potential of blockchain to enhance transparency, trust, and efficiency in construction processes. Kiu et al., [8] specifically identified key areas for blockchain application, including supply chain management, building information modeling, and contract management. Hamledari, and Fischer [11] proposed a smart contract-based solution for automating construction progress payments, aiming to reduce reliance on intermediaries and streamline payment processes. The importance of smart contracts in blockchain technology is further explored by Beckert [12], who highlighted the significance of thorough analysis and formal program verification to address potential security vulnerabilities. [9] focus on the unique challenges in the construction industry, such as loose structures and complex supply chain systems, which blockchain technology can address. [9] specifically highlighted the potential of blockchain to improve information management, automation, and legal conflict resolution. Belle [13] explored the benefits of blockchain in the architecture, engineering, and construction (AEC) industry, emphasizing its

potential to enhance project organization, transparency, and performance. Perera et al., [14] critically analyzed the application potential of blockchain in construction, concluding that it indeed has credible potential. The paper discussed factors such as blockchain applications, investments, and the contribution of start-ups, contributing to its viability in construction.
Sánchez et al., [15] introduced the concept of circular supply chains and proposed a conceptual framework to support their development. The study emphasizes intensified relationships, adaptation of logistics, incorporation of smart technologies, and a conducive business environment as key dimensions for successful circular supply chains. The integration of blockchain and Building Information Modeling (BIM) is explored by Suliyanti, Salman and Sari [16], demonstrating the potential for secure BIM information exchange throughout the building lifecycle. Udding [17] and other researchers focused on the pharmaceutical supply chain, proposing blockchain as a solution for effective traceability to combat counterfeit medications. Zong et al., [18] and Yang et al., [19] contributed to the exploration of blockchain in construction quality management, presenting a consortium blockchain system and investigating possibilities of public and private blockchain technologies, respectively. Furthermore, the collective findings from different studies show the pivotal role that blockchain technology can play in revolutionizing the construction companies. [20] investigated the influence of Industrial Symbiosis (IS) and Blockchain Technology (BCT). Their exploration revealed a shift in paradigms through a Smart Contract Framework leveraging Hyperledger Fabric, promising heightened security, efficiency, and cost-effectiveness in resource-sharing practices. This framework holds the potential to reshape traditional business models, which offers a glimpse into a more sustainable and technologically advanced future for the construction sector in general.

[20], Suliyanti, Salman, Sari [15] and Kang et al., [21] introduced more into the pragmatic adoption of blockchain technology within the construction landscape. Kim, Lee and Kim [22] also revealed the potential of blockchain in the aspect of eradicating transaction costs, data forgery, and enhance flexibility. However, Kang et al., [21] revealed the technological role in enhancing project workflows and overall efficiency through in-depth interviews for a public infrastructure project. In general view, the studies specified a compelling case for the transformative impact of blockchain, by promising a more streamlined, secure, and responsive construction ecosystem.

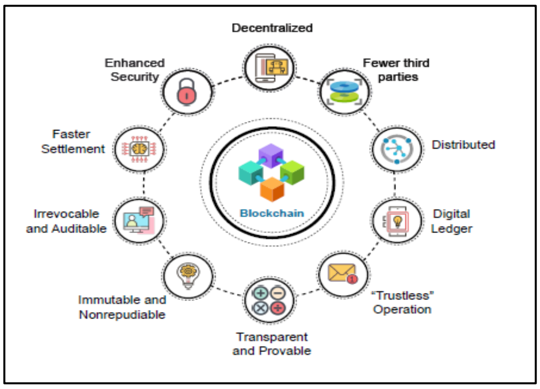

Fig. 1. blockchain technology (Hazra, et al., 2022)

Perera et al., [14] expanded the scope of previous studies by critically examining the historical resistance of the construction industries to digitization. The literature review and use case analysis shows the disruptive potential of blockchain, bridging the research gap and offering insights into the future benefit of a digitized future for construction. Suliyanti, Salman, and Sari [16], Li [23], Zhong et al., [18], and Yang et al., [20] extended the exploration into specific facets of construction by emphasizing information sharing in Building Information Modeling (BIM), advancing data-driven supply chain management for modular construction, improving quality management through consortium blockchain systems, and addressing centralization challenges.

Lastly, Li et al., [23] provided a foundational understanding of blockchain technology, elucidating its characteristics, development, and differentiation between permissioned and public blockchains. By accentuating the attributes of platforms like Hyperledger Fabric, tailored for enterprise applications, the study primes the industry for the integration of blockchain technology.

Generally, the literature review conducted collectively suggest that blockchain technology holds significant promise in addressing challenges related to transparency, efficiency and trust within the construction industry. Researchers emphasized its potential applications in various aspects, including supply chain management, payment processes, information exchange, and quality management. However, challenges such as security, scalability, and industry readiness need to be further addressed for widespread adoption.

3 System Analysis & Design

The comprehensive analysis and design concept of the proposed private blockchain framework for construction supply chain using hyperledger fabric would be introduced in this section. In addition, the design phase of the proposed framework using flowchart diagram and the system architecture would be explained.

3.1 Overall System Idea and Goal

The construction supply chain process framework would be developed using a permissioned blockchain network called hyperledger fabric. Hyperledger introduces high level of security and control over blockchain network. This makes it suitable in addressing the issues identified in the existing system such as data transparency, loss of data, lack of data integrity, consistency and trust. Furthermore, the proposed framework smart contract (chain code) would be implemented using typescript, an interface would be provided for the peers in the supply chain that is, (supplier, retailer, and contractor) who are in the permissioned network to be able to interact and transact businesses.

3.2 Requirement Specification

This subsection will be introducing the system stakeholders, user requirement, functional and non-functional requirement associated with the proposed supply chain framework

Stakeholders
The stakeholders refer to as the entities that will be using the system directly or indirectly, and this include all the entities that take part in the construction supply chain. Each entity will be discussed in this subsection.

Supplier
The supplier denotes the various companies or individuals that extract or produce the raw materials that are being used in construction, such as steel manufacturers, cement producers, lumber suppliers, and the likes.

Retailer
The retailers are one of the essential entities that plays a crucial role in the distribution of construction materials and products to end-users, such as contractors, builders, and final consumers. While retailers may not be involved in the manufacturing or production of construction materials, but they serve as intermediaries between manufacturers, distributors, and the end users.

Contractor
Contractors are the most important players in the construction supply chain. They are responsible for managing a specific construction project. They coordinate and oversee the various activities going on, which include sourcing for materials, hiring

subcontractors, scheduling, and executing the construction work. Contractors can be categorized into the following; the general contractors, specialty contractors, or subcontractors, depending on their specific roles they perform

3.3 Functional Requirement

The functional equipment reveals different operation and service that would be integrated into the final supply chain system. Expected functionalities of the supply chain are known based on the study and comprehensive analysis conducted on the traditionally supply chain process. The functional, non-functional and user requirement will be outline in this section.

Functional Requirement

i. Registering of new members to the supply chain
ii. Updating of world state record.
iii. Generating credentials or certification for validating membership.
iv. Interaction of the system with the chain code smart contract.

User Requirement

i. Initiating transactions using chain code (Read/write transactions)
ii. Checking consensus algorithm.
iii. Viewing and receiving transaction history and agreement
iv. Updating world state

3.4 Non-Functional Requirement

The non-functional requirements are the system's level of efficiency, operations, availability and constraints that might be associated to a system. Non-functional requirements do not consider core requirement of the proposed supply chain process application.

i. The system will provide adequate security.
ii. 24/7 availability of the system service.
iii. Simple user interface for easy navigation.
iv. Should be highly scalable for expansion.

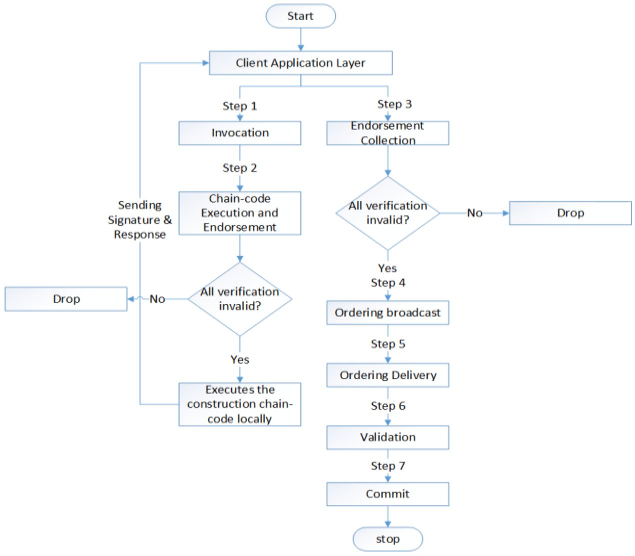

Fig. 2. Flowchart Illustration.

Figure 2 shows the proposed construction hyperledger framework data flow using flowchart illustration. The data flow of the proposed construction supply chain process includes 7 major steps. The Stage 1: invocation stage which is initiated by a supply chain member on the client application layer, this further prompt the application layer to send proposal signature to the pair conducting the endorsement. Step 2: Chaincode execution & endorsement, which entails verification of the transaction proposal and the client (submitter) signature is correct. Finally, this stage entails authorization to update the channel word stage. Stage 3 (Endorsement collection): this stage entails the process where the endorser peers collate all the application endorsement and validate if the endorsement policy is fully followed. Stage 4 (Ordering broadcast): this stage ordered all the transactions and broadcast them into an ordering service by the client assemble endorser. Stage 5 (Ordering Delivery): this stage helps in arranging the transaction in a chronological order, thus according to the transaction channel ID's. Step 6 (Validation): involved the distribution of committer peers blocks by the ledgers peers, Finally, Step 7 (Commit): entails updating the ledger by appending each peer block into the ledger.

3.5 The Construction Supply Chain Framework

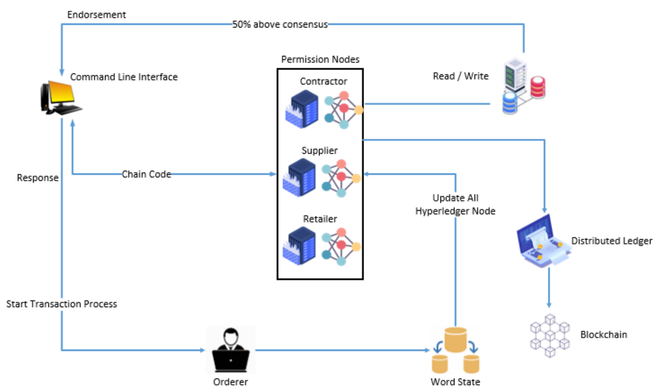

Fig. 3. Conceptual Framework

The hyperledger fabric would be used to develop a permissioned network on a private blockchain network to manage construction material assets, ensure transparency, and foster trust among the construction supply chain members/entities. Chain codes will be developed (containing business logic and contract that runs on the hyperledger fabric network) and uploaded on the hyperledger network using the Go Language. However, the orderer is the entity that activate transaction, and update the word state of the hyperledger Node. However, approval for read and write operation can only be reached on the hyperledger blockchain if there is 50% consensus agreement between the permission nodes.

4 Experimental Setup

In order to develop the Hypterledger construction supply chain process, its essential to setup certain development requirement such as development OS, blockchain network server, chain code, framework installation and the likes.

4.1 Window Linux Subsystem (WLS)

Currently running an hyperledger fabric based framework only support the Linux operating system environment. however, developer who uses window operating system can use the sandbox virtual environment for Linux OS setup or a Windows Linux Subsystem (WLS). This study will set the WLS option for ruining the Linux environment in the Window Subsystem.

4.2 Docker Environment (Linux Based Server)

The Hyperleder fabric private blockchain will be run on the Docker Toolbox version for the window operation system. Since Docker is Linux Based it can be easily use to run the hyperledger fabric framework in a local server.

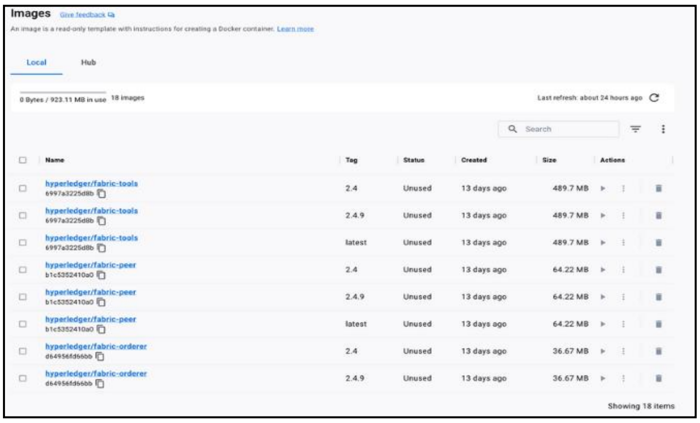

Fig. 4. Puling Hyperledger Image

Fig. 4 shows the instance where the Docker is used to pull the hyperledger fabric image from their GitHub official page. Hence, in other to pull this images its essential to install Git Base command line integration along with other programming language installation setup such as Node Js, GO language, and Java in some cases depending on the choice of language for chain code implementation.

4.3 Hyperledger Caliper

To critically evaluate the Construction Supply chain hyperledger Fabric based framework, the Hyperledger Caliper exploration tools is used in this study. Fig 5. Shows the dashboard interface of the explored supply chain.

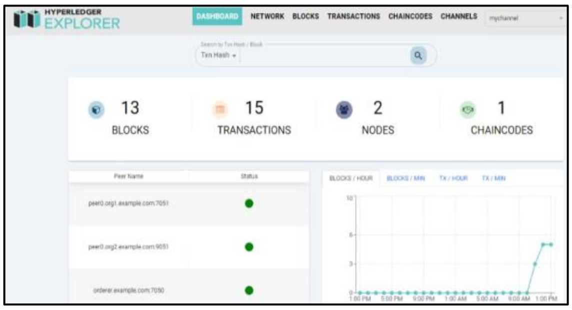

Fig. 5. Hyperledger Caliper

5 Experimental Result

In the section the designed framework is evaluated using benchmark metric such as CPU utilization, and Latency. Furthermore, a comparative analysis will be conducted between existing blockchain based system and the adopted hyperledger fabric framework for construction supply chain process. For the CPU utilization, and Latency evaluation the benchmark parameter is divided into three experimental parameter setup, and this includes Experiment 1: Content block interval = 1, Experiment 2: Content Transaction Arrival Rate (TAR) = 100, and Block Size (BS) =150 Experiment 3: Content TAR (100), and Block Interval (1) (Xu et al, 2022).

5.1 CPU Utilization Result

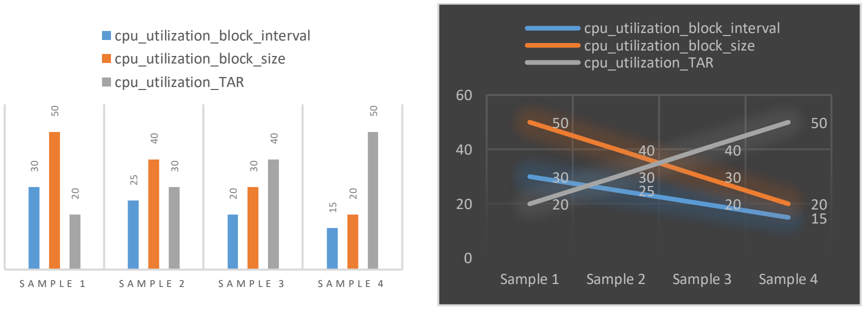

Fig. 6. CPU Utilization Based on Block Interval, Block Size, and TAR

Fig 6. Reveal certain key observation which is comprehensively translated. Based on the figure its observed that the transaction arrival rates increase, as the CPU utilization usage rises due to the higher computational load and increased data transmission, while larger block sizes and shorter block intervals lead to higher CPU utilization usage, and longer block intervals can stabilize CPU utilization by processing transactions less frequently.

5.2 Latency Result

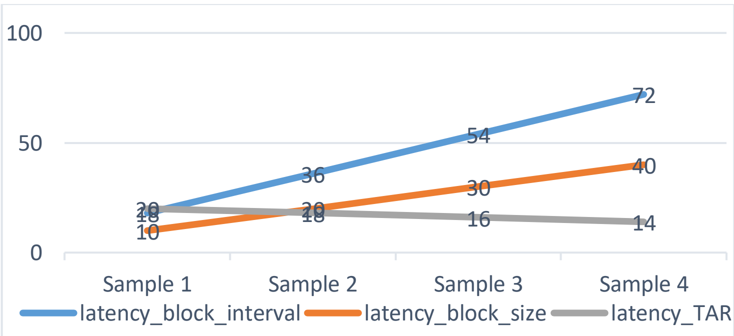

Fig. 7. Latency Based on Block Interval, Block Size, and TAR (Line Chart)

Fig 7. Reveal certain key observation including the observation that block interval and size improves the performance of the construction supply chain. While the Transaction Arrival Rate (TAR) reduces the latency performance of the system.

5.3 System Comparative Evaluation

Table 1. System Evaluation and comparison

S/N	Author, Techniques	Application	Public Blockchain	Private Blockchain	Permissioned network	Data Security	Management	Transparency
1	Adamu and Howell, [24]. Last Planner	construction	No	No	No	No	Centralized	No
2	Lu et al., [25]. SCOs-BOs	Construction	Yes	No	No	Semi-secure	Decentralized	Yes
3	Baldawa [26]. Blockchain	Construction	Yes	No	No	Semi-Secure	Decentralized	Yes
4	Elghaish [27]. Hyperleger	Financial transaction in	No	Yes	Yes	Yes	Semi-Decentralized	Yes

5	Proposed Framework, 2023. Hyperledger Fabric	Building Materials supply chain	No	Yes	Yes	Yes	Semi-Decentralized	Yes

Table 1 shows the comparative analysis between the proposed framework for construction material supply chain process, and various existing system in terms of application, chain type, network type, data security level, ownership level (centralized, decentralized, or semi-decentralized) and transparency. Existing systems that are based on public chain are identified to be completely decentralized, and any member/user can participate in the network chain without the consensus of other member. In the domain of blockchain and construction supply chain process, there is limited application of hyperledger framework specifically in construction supply chain process. Moreover, due to the privacy and certification requirement (verification scheme) of a member or entity participating in the private blockchain (hyperledger) makes the propose construction supply chain implementation better than existing works.

6 Conclusion and Recommendation

In conclusion, with the adoption of a hyperledger fabric framework for the development of the supply chain process, transactions can be more secure and exchanged via a secure medium. Based on the performance analysis tested again CPU resource utilization, and Latency under different transaction parameters, it is revealed that the proposed system is highly resource-efficient, and performs efficiently in terms of latency even if the block size and interval are increased. Hence, a highly secured, private, permissioned, and transparent history of transactions among groups of entities is achieved based on the Evaluation conducted using the Hyperledger Explorer. Finally, the comparison between the existing systems and the hyperledger fabric shows that the proposed framework is more efficient in terms of security, data privacy, and also provides more data control than the existing systems. Further study can be conducted on how an application layer can be integrated easily with the proposed framework for real-life business usage in the construction material supply chain process.

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