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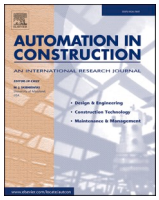

Financial management of construction projects: Hyperledger fabric and chaincode solutions

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ABSTRACT

This paper proposes a novel interconnected financial management system based on Hyperledger fabric and chaincode solutions to address endemic problems with financial management practices adopted within construction projects. Increasingly complex construction projects have necessitated a corresponding evolvement of financial management tools and systems to augment security and control. A decentralised financial management system is introduced to deal with all financial tasks across various construction stages using blockchain technology. Under different delivery approaches and payment methods, the proposed system enables parties to record/invoke their transactions safely and automatically, with no third party involvement. Moreover, the proposed approach allows non-owner parties to control remaining financial rights during the Defects Liability Period (DLP) automatically through a pre-agreed endorsement policy. The proposed system is tested on a real-life case project, where results corroborate its ability and workability in providing a secure and scalable platform for all project parties.

1. Introduction

Deficiencies in the management of construction project cash flow are myriad and include [1]: slow owner payment/partial payment [2]; employer's withholding interim payment [3]; pay when got paid clause issue [4]; human errors in submitted invoices [5]; delayed payment due to contractual issues and unfair practices by the client [2,6]; misuse of the Defects Liability Period (DLP) by the client to retain remaining payments [7]; and deficiencies to leverage the usage of Building Information Modelling (BIM) to develop reliable project cash outflow [8].

Various attempts have been made to use digital technology tools to mitigate traditional construction financial system deficiencies. For example, Lu et al. [9] developed a cash flow-based 5D BIM to facilitate decision making. However, the proposed solution was partial because it did not consider the cash flow data for sub-contractors, and new data should be entered manually. Elghaish and Abrishami [10] developed a web-based management system to implement three cost management tasks: estimation, budgeting, and control. However, the system was centralised, and the human error issues persisted. All mentioned solutions were centralised, requiring a server and manual data entry. Consequently, a decentralised system is required to enable project parties to control their transactions automatically and minimize human interference in this process thus augmenting greater trust and transparency among project parties.

Recently, blockchain was introduced as a distributed ledger - characterised by decentralising the information among all network participants. According to the agreed ordering policy, all information will be endorsed automatically through an approved consensus mechanism, which is automatically shared among participants [11,12]. Accordingly, both researchers and practitioners have commenced the development of solutions-based blockchain to reduce fragmentation in different project stages. Construction management academics have given significant attention to employing blockchain to automate various tasks such as: developing an automated sharing risk/reward system [13]; securing

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interim payment during the construction stage [14]; enhancing the quality of construction information workflow [15]; tracking precast elements automatically [16]; and managing document(s) workflow in a secure decentralised system throughout the different project stages [17]. Even though there has been a noticeable growth of blockchain utilisation in construction management, most solutions are still considered exploratory solutions.

Existing solutions exist to manage construction cash flow-based blockchain technology, such as a secure interim payment system [14]; public and private blockchain network to manage construction financial transactions [18]; and a proposed workflow to integrate emerging technologies and blockchain to issue payment certification based on autonomous progress evaluation [19]. However, these systems do not provide a comprehensive solution in terms of: (1) providing smart contract functions for all parties (i.e., client, contractor, and sub-contractor); (2) automating reports in the closeout stage to determine remaining financial duties; (3) utilising BIM integration as a source of cost information; and (4) providing a smart contract function to manage remaining duties during the DLP.

Against this contextual setting, this paper proposes an interconnected financial management system based on Hyperledger fabric and chaincode solutions. The proposed 'proof of concept' solution will enable all project parties to invoke transactions throughout the entire project life cycle. The functions will be categorised as 'Client to Contractor', 'Contractor to Client' and 'Sub-contractors to Contractor'. Therefore, the system will facilitate the tracking of all financial movements in an interconnected platform. Furthermore, the proposed solution fits all procurement methods given it covers a wide range of functions that can be tailored to the project management team's individual predilections.

2. Conceptual background

2.1. Financial management challenges for construction projects

Construction project delivery faced a wide range of financial management challenges during the project's lifecycle and the operation stage [20,21]. Abdul-Rahman et al. [2] state that delayed and/or partial payment are critical issues that lead to terminating and/or delaying the delivery of construction projects. Delayed payment can stem from unfair contractual clauses, which hinder project delivery [6]. There is also a financial challenge-based contract issue, namely 'pay when paid clause issue' [4,22]. This issue causes a delay in paying sub-contractors invoices, given the sub-contractor payment is premised upon payment from the client to the main contractor and often, there is no direct contract between sub-contractors and clients [23,24]. Moreover, Gad et al. [6] proffer that unfair payment clauses in the lump sum design-build delivery approach constitute the main barrier to delaying interim payment.

Even though the contract includes clear clauses to manage the interim payments, there are unfair practices to delay the approved payments by the client, such as delaying issuing payment certification [25,26]. Moreover, a critical financial challenge is occurs when the client withholds payment after handing over the project [3]. In addition to challenges by project parties and contract issues, errors in submitting payment invoices are also a critical problem in delaying interim payment [5].

DLP is an agreed period that the contractor is obliged to return to the project to remedy any revealed defects and usually, the client withholds payments for the contractor during this period [27,28]. However, there is a noticeable misuse of the DLP that leads to disputes from the client-side to ask the contractor for additional work to return agreed payment during this period [7].

Digital technologies (such as BIM) have been started to be employed as a panacea to project cash flow management during the last few years. However, digital solutions adopted lack integration and interoperability to develop and monitor cash flow [29]. Moreover, the manual process of monitoring cash outflow-based BIM is not efficient during construction projects. Therefore, there is a compelling need to automate the process using Hyperledger fabric—Distributed Ledger Technology (DLT) in coupling with BIM [30,31].

2.2. Blockchain in construction

Kumar and Mallick [32] define blockchain as a tamper-proof technology that provides a wide range of solutions to avoid a variety of bad practices for different industries. Similarly, the blockchain network maintains a high level of security due to its ability to check all the recorded data regarding the sequence and the interrelationship between newly added blocks [12]. This minimizes the probability of data being tampered with within the blockchain network [32]. Therefore, it is highly efficient to secure computing solutions [33,34]. Moreover, there is great potential for blockchain in the banking industry to enhance transparency and security of financial transactions has explored its applications. Parn and Edwards [35] proposed the integration of blockchain into the common data environment (CDE) to automate record changes in the status of documents and represent all information as a set of verified blocks. Shojaei et al. [36] examined the blockchain's validity to develop construction contracts by converting clauses to smart contract functions. Results revealed a high level of complexity, which requires intensive research to achieve this aim. Mature blockchain developments in the construction industry focused on: (1) automating interim payments among project parties [14]; (2) enabling tracing supply chain automatically for precast elements [16]; (3) sharing risk/reward fairly among Integrated Project Delivery (IPD) core team members [13]; (4) checking the quality of shared information [15]; and (5) linking between cash-inflow and project progress automatically [37].

Moreover, recently, the Blockchain of Things (BCoT) is also introduced to the construction industry by Rahimian et al. [38] to leverage the capabilities of blockchain and the internet of things (IoT) to minimize fragmentation in construction industry in terms of the supply chain, communication, and remote control of project resources. This noticeable growth in blockchain research and development in construction has hitherto failed to validate solution developed through real-life case studies [38]. Unlike various industries (i.e., automotive industry), the construction industry is yet to bridge the existing fragmentation gap as recommended by Elghaish et al. [39].

2.3. Blockchain and BIM

Throughout the last few years, BIM has been utilized as the main process and technology to support the construction industry's digital transformation [40,41]. The entire change requires integrating BIM into other emerging digital technologies such as blockchain and the IoT to leverage BIM capabilities to automate design, construction and management tasks [38]. Coupling blockchain and BIM research started in 2018 with Mason and Escott [42] asserting that blockchain and BIM integration will soon be attainable given an increasing adoption of IoT sensors to collect and share data automatically, enabling blockchain to process gathered data automatically. In congruence, Cousins [43] states that the transition to BIM level-3 requires technology such as a blockchain to enable all project parties to share, manage and validate information automatically within the BIM adoption processes and stages. Recently, Abrishami and Elghaish [30] proposed a framework including the corresponding blockchain applications throughout different project stages with BIM dimensions aligned in integration with blockchain development. Due to the high level of recommendation to integrate BIM and Blockchain, BIMCHAIN is a plug-in developed to create a trusted environment by validating BIM data automatically and enabling open collaboration [44,45]. Additional examples of coupling BIM and blockchain integration include Elghaish et al. [13], who developed a

proof of concept to automate sharing risk/reward among project parties. Xue and Lu [46] minimised the redundancy in information by using the semantic differential transaction (SDT) technique to record changes in the BIM model and develop a chain of timestamped data for all changes. Subsequently, all changes will be automatically synchronized in the blockchain network. BIM and blockchain have also been employed to automate the supply chain process by retrieving information from the 3D BIM model, then placing orders and paying suppliers according to the agreed endorsement policy in the smart contract [36]. In other related research, Srećković et al. [47] proposed a modelling process to employ blockchain to develop an autonomous process of checking and validating BIM information during different design stages.

With all the aforementioned in mind, it is apparent that BIM and blockchain are highly recommended to facilitate the transition to BIM level 3. However, most recent developments focus on the theory's validity and developing exploratory 'proof of concepts' solutions. Therefore, there is a need for additional research that integrate blockchain into BIM using more practical and scalable solutions.

2.4. Research gap and motivation

Blockchain solutions have been offered since 2019 to bridge the gaps in knowledge and practice in delivering construction projects. Only a few studies were conducted to develop workable solutions— 'proof of concept' and prototypes. Table 1 shows the focus of the study, methods, findings and limitations of each research output.

Based on these limitations, a comprehensive solution is needed that enables all project parties to invoke their payments automatically in an integrated/interconnected platform. Moreover, an endorsement policy requires development to include all parameters to check the validity of transactions, regardless of the sender's role (project party).

3. Research methodology

This research uses an experimental approach as the main method for testing assumptions regarding the effectiveness and workability of the proposed decentralised financial platform-based blockchain for construction projects. This is because experiments effectively reveal whether real data supports or refutes the conceptualisations proposed in developmental research. According to Zellmer-Bruhn et al. [48] *"experiments isolate causal variables and enable a strong test of the robustness of a theory: they provide convincing evidence for theories."* In other words, the validity of assumptions proposed in this present study on causes and effects (in which a match between data and theory is observed), is demonstrated through experiments [49,50]. Fig. 1 illustrates the logic of the research and its design.

Fig. 1 illustrates that the created framework proposes a solution that addresses the issues of traditional financial management within different delivery approaches, particularly, Design-Bid-Build (DBB) and Design and Build (DB) approaches. The proof of concept is then developed, using the following tools to test the applicability of the framework:

- IBM® Blockchain platform is user-friendly [13] and does not require a significant level of competency. Hence, this easy-to-use platform is appropriate for developers across the AEC industry [51,52]; and
- IBM® VSCode extension for blockchain enables the smart contract development by providing functions and variables to support novice users to build the chaincode [55,56] correctly.

4. Framework development

To implement blockchain in construction financial management, a framework is developed to revolutionise traditional construction transactions and processes to fit the Hyperledger fabric environment. The framework development is divided into two main sections: section one develops and articulates different transactions between different construction parties under the traditional contracting and design-build approach. Section two develops all requirements such as smart contract functions and data retrieval methods from BIM to the blockchain. To implement blockchain in construction financial management, new processes should be developed, such as the structure of the transaction,

Table 1
Relevant research-based proof of concepts and prototypes developments.

Item	Authors	Focus of study	Methods	Limitation
1	Das et al. [14]	Develop a framework to automate interim payments in a secured decentralised environment.	Develop a 'proof of concept' including the architecture of blockchain network components.	Variables of smart contracts are not structured for each project party. As well as the created smart contract does not cover the DLP
2	Elghaish et al. [13]	To develop an automated risk/reward sharing system-based Hyperledger fabric.	Using IBM blockchain beta clould-2 to develop a blockchain network and VScode extension to develop the chaincode (smart contract). The outcome was validated using a real-life case study.	The created chaincode was developed to meet the characteristics of Integrated Project Delivery (IPD) approach and functions can not work with other delivery approaches.
3	Hamledari and Fischer [37]	Develop a framework to integrated blockchain into robotic reality capture technologies in order to secure construction payments.	Proposing a software architecture system for mentioned integration.	The proposed smart contract is conceptual and should be extended to cover all payments scenarios and all project parties.
4	Wang et al. [16]	Employing blockchain to enhance the traceability of supply chain items for precast construction.	Creating a model, which is called 'BIMF-PSC'-based Hyperledger fabric (version 1).	The model can not retrieve information from various sources such as designing firms, supervision units and maintenance department.
5	Yang et al. [18]	Measuring the validity and scalability of utilising public and private blockchain networks in the AEC industry using two real cases.	Testing Ethereum and Hyperledger fabric for two case studies in construction.	The developed solutions were for validation purpose, therefore, the proposed procurement smart contract does not include all functions that can be used for most of cases.
6	Zhong et al. [15]	Utilize the Hyperledger fabric to automate quality management tasks for construction projects.	'proof of concept' is a developed-based Hyperledger fabric to automate checking the quality of recording information from all project parties.	The proposed solution is exploratory, and additional validation should be carried out.

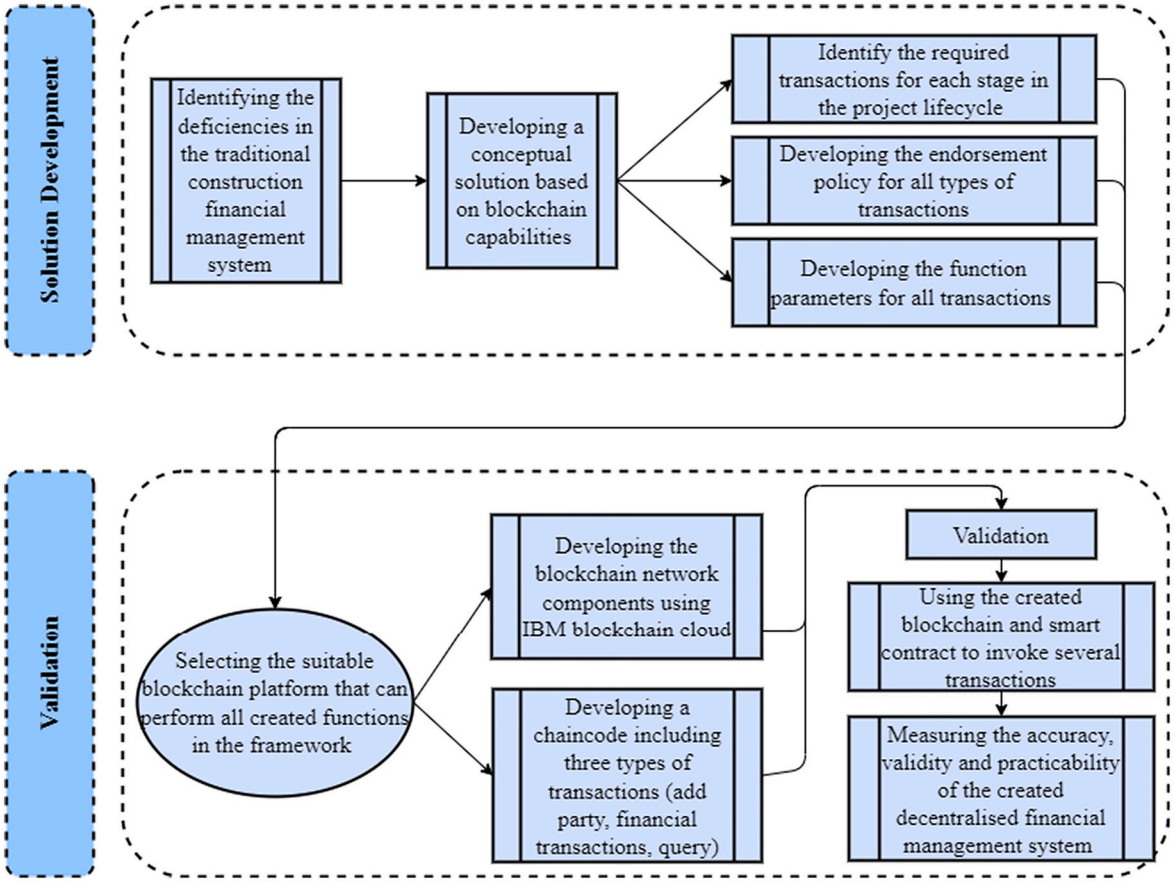

Fig. 1. Research methods, design and tools.

the conditions of consensus mechanism, and the mechanism of ordering transactions among designed blockchain channels to ensure the privacy of project parties.

4.1. Formulation of transaction-based smart contract

Blockchain adoption in the construction process requires the development of mathematical models that can quantify all potential transactions that represent the different financial tasks. Transactions in this present paper are designed to meet both traditional contracting and design-build approaches. Accordingly, this ensures the applicability and scalability of the proposed system. Moreover, the proposed transactions are designed under BIM dimensions viz. 4D BIM (planning and scheduling) dimension and 5D BIM (cost management) dimension outcomes are considered to determine values of transactions. These transactions are classified into specific sections as follows:

4.1.1. Main contractor-to-owner

This represents invoices submitted by the main contractor throughout the project life cycle. If traditional contracting is employed, the main contractor should submit invoices during the construction and closeout stages. For a design-build approach, the main contractor can submit invoices throughout the design, construction and closeout stages. Eq. 1 shows the structure of payment requests by a main contractor to the client.

$$T_{i,n} = (VCW_n + MV) - (RV) \quad (1)$$

Where $T_{i,n}$ is the payment request for a project *I* regarding performed works in month *n,* VCW_n is the monetary value of the performed works in a payment milestone *n*, MV is the mark-up value (UK pounds '£' sterling), and RV represents the value all agreed retentions in the contract (£).

After determining the $T_{i,n}$ monetary value, the transaction should be sent in structure as seen in Fig. 2.

After the contractor's representative invokes the transaction, it should be checked automatically according to an agreed consensus mechanism (i.e., the time of gathering the transaction, the range of transaction value £, etc.). in the next section.

4.1.2. Owner-to-contractor

The owner-to-contractor transaction responds to the previous submitted 'contractor-to-owner' transaction, so synchronisation between two transactions should be considered. Hence, if the invoked transaction by the contractor is rejected, the owner-to-contractor transaction should not be invoked. Fig. 3 shows the parameters of the 'owner-to-contractor' transaction-based smart contract.

4.1.3. Contractor-to-sub-contractor and suppliers

Given, the blockchain network enables network parties to share different information among specific parties through nominated channels, the contractor can include subcontractors and suppliers in a single blockchain for the project. All data accrued will be encrypted and all other parties (such as owner and consultant) cannot reach this data. The parameters of smart contract transactions should be designed to include the name of the subcontractor/suppliers and an indication of the construction trade package. As in both design-build and traditional contracting approaches, the subcontractors and suppliers are not usually involved at the early stage design and construction. Accordingly, the transaction parameters should include names of their companies and trade packages (i.e., ceiling package, lighting and fixture package, etc.), see Fig. 4.

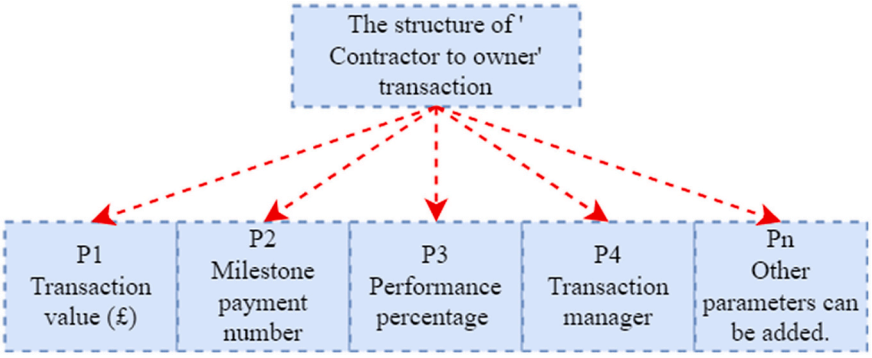

Fig. 2. Structure of the contractor to owner transaction-based smart contract.

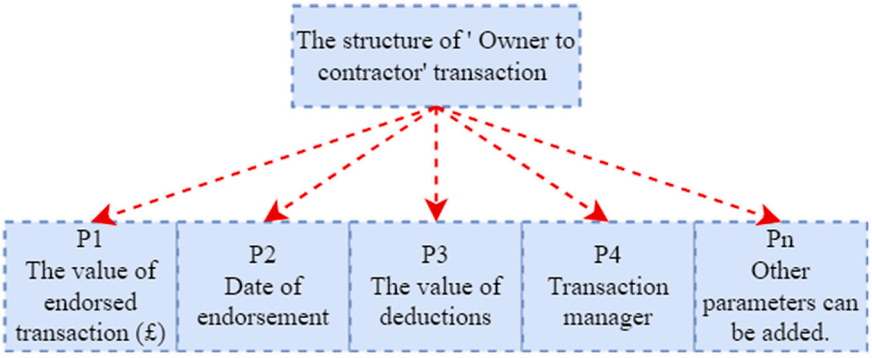

Fig. 3. Structure of the owner to contractor transaction-based smart contract.

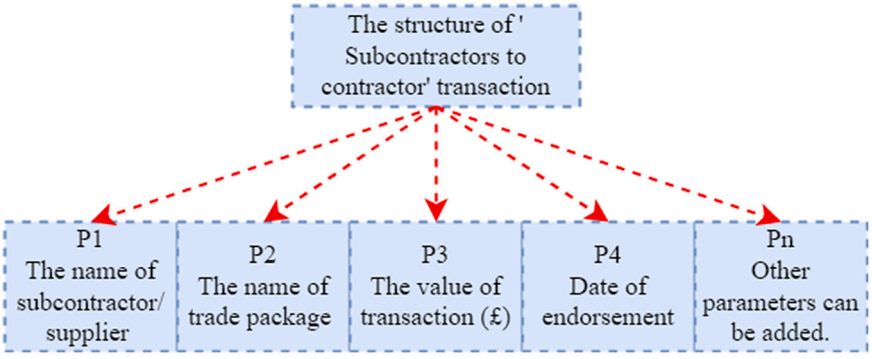

Fig. 4. Structure of the contractor to subcontractors/suppliers' transaction-based smart contract.

4.1.4. Structure of the chaincode-based construction transactions

Fig. 5 shows the structure of the proposed chaincode that includes three categories, namely: adding a party to the project network, specifically, subcontractors during the construction stage; financial transactions; and query transaction.

The proposed smart contract is consistent with both design-build and traditional contracting due to the transaction's parameters that can be used for the construction stage.

4.2. Blockchain and smart contract component structure

This section presents the Hyperledger components' design, including the endorsement and ordering policies. Given, that BIM is used to retrieve schedule and cost data (4D and 5D BIM), the interrelationships between BIM and the blockchain systems must be considered.

4.2.1. Endorsement policy-based BIM

Transactions can be accepted or rejected according to agreed conditions in the Hyperledger fabric. These conditions are called the endorsement policy. Given, Hyperledger-fabric is a suitable platform to develop a cash flow system for construction projects [13]. Therefore, the process of endorsing and ordering the transactions should comply with the construction process. Fig. 6 shows the four processes of committing a transaction. The process starts by invoking a transaction. This transaction must meet the agreed endorsement policy (see section 4.2.1.1), then the endorsed transaction is assigned to the committing peer (i.e., owner, contractor, subcontractors) through designed channels. Three main channels should be designed in the construction project approach to provide a high level of privacy for parties, namely: channel-1 to transfer the endorsed transactions from the contractor-to-owner (involved parties can be contractor, owner and consultant); channel 2 to move the endorsed transactions from owner-to-contractor (it can include the same members as channel-1 so the consultant can track all

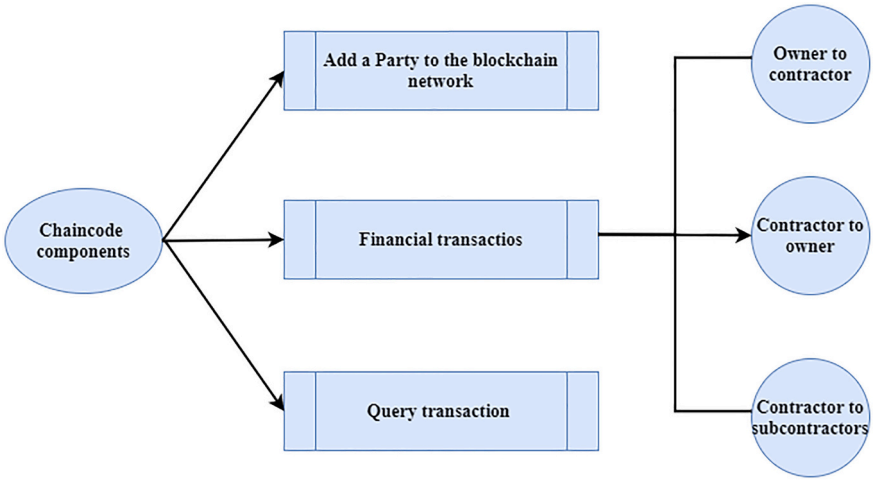

Fig. 5. Proposed chaincode transactions for a construction project.

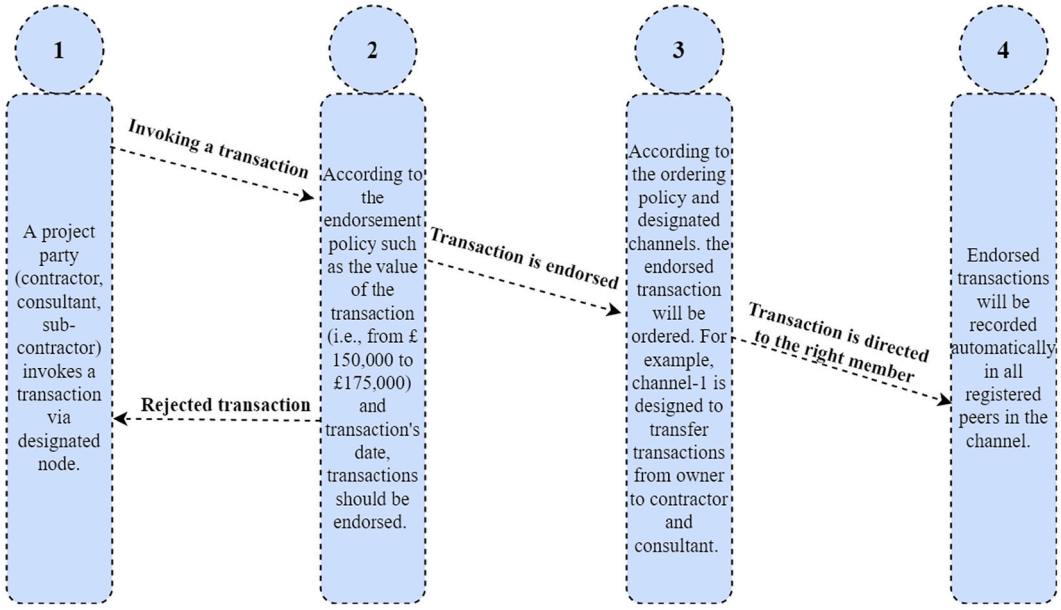

Fig. 6. The process of endorsement based Hyperledger-fabric for construction projects.

financial movements in the project); and channel 3 to link the main contractor with all other subcontractors. Therefore, this channel category can be more than one according to the number of involved subcontractors and suppliers (consultant and the owner may not be involved here if the subcontractors are domestic, not nominated).

4.2.1.1. Endorsement policy parameters. There are two main conditions that must be fulfilled for each transaction, namely, the time of invoking the transaction and the value of the transaction (£). Therefore, there should be a correlation between the outcome of 4D and 5D BIM and the Hyperledger consensus mechanism, including the endorsement and ordering policies. Fig. 6 depicts the interrelationships between BIM and Hyperledger-fabric. 4D BIM is employed to retrieve the information of each milestone payment for each trade package in the project. Meanwhile, the 5D BIM is utilized to: (1) define the estimated and actual cost of each milestone and for each trade package; and (2) calculate the performance percentage as it is a parameter that should be submitted with 'contractor-to-owner' transactions. Fig. 7 illustrates the relationship between BIM, endorsement policy and ordering channels. Endorsement policy includes three main parameters, time, monetary value and the project performance percentage. The proposed methodology in this framework enables parties to link project performance and the acceptance/rejection of each payment in each milestone. This could enable the main project parties to avoid disputes if there is an additional payment (where the payment method is the target cost).

4.3. Construction projects hand over-based Hyperledger fabric system

Given that all endorsed transactions are recorded in both parties ledgers, it can support automating the calculations of the closeout stage. According to the employed and agreed payment method (i.e., lump-sum, cost-plus, etc.), all project parties' outstanding financial duties and rights should be calculated. Fig. 7 shows the mechanism of using the proposed blockchain network and smart contract (chaincode) to retrieve the data and estimate various parties' financial duties and rights. For a lump-sum payment, the financial closeout will be straightforward. All parties can invoke the query transaction to check the accumulative payment and compare the accumulated transaction value with the agreed contract value. However, the process is not as straightforward for cost-plus or target cost payment methods. First, the owner and

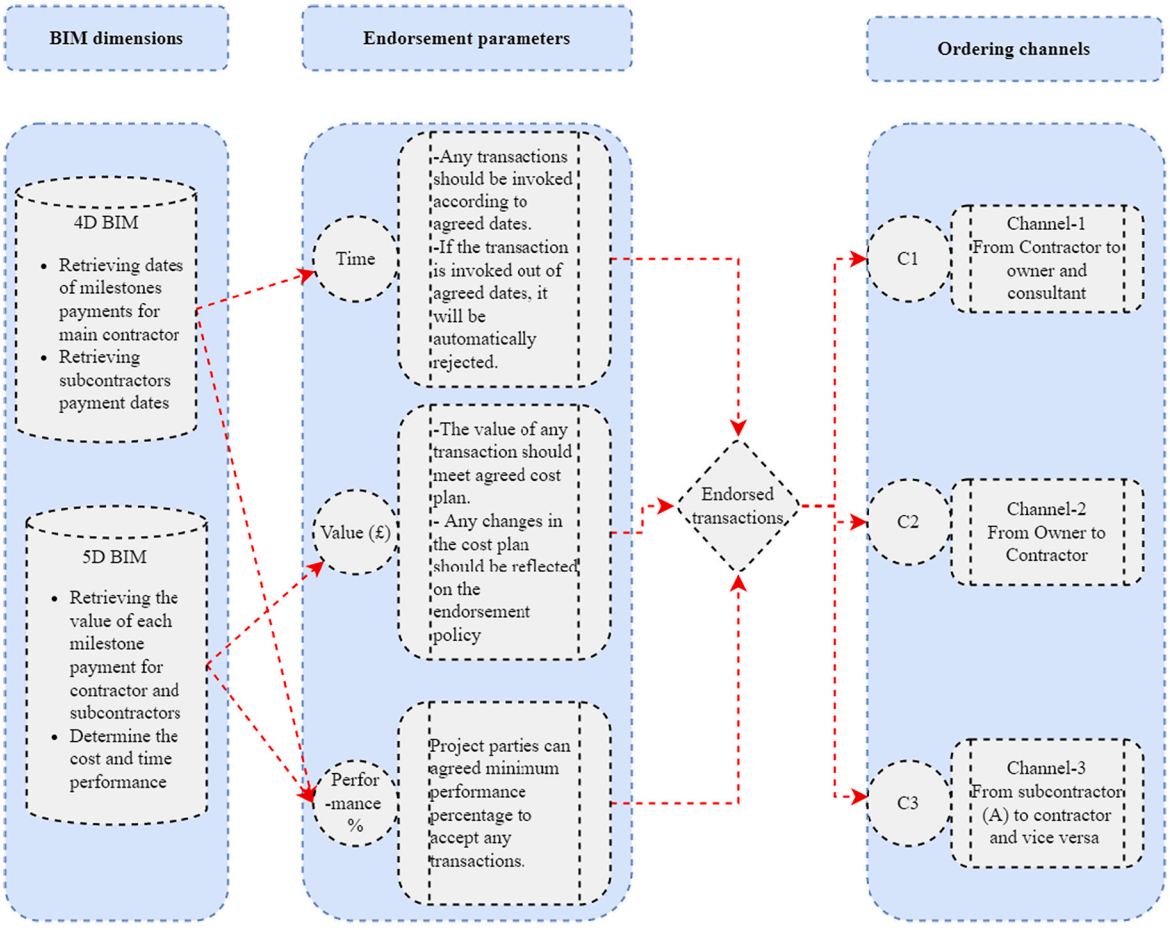

Fig. 7. The interrelationships between BIM and Hyperledger-fabric consensus mechanism.

contractor should check the received reimbursed cost against the agreed project value, including the price and agreed mark-up. If the parties agree that all invoices are paid, the blockchain network and smart contract can receive the retention percentage. However, when outstanding invoices are not fully paid, the smart contract can be used to obtain these invoices, and the closeout stage will be suspended until all financial duties are delivered (see Fig. 8).

The closeout stage should be considered in developing the endorsement policy by adding an endorsed parameter such as the DLP. Therefore, any transaction is invoked after the agreed date should be rejected automatically. Where the payment method is lump-sum, the Remaining Financial Duties (RFD) that client should pay should be calculated by determining the owed Accumulative Value (AV) from a client (i) to a contractor (j) for all project works and the Accepted Project Transactions Value (APTV) from a client (i) to a contractor (j). Where cost-plus/target cost payment methods are employed, the Paid Profit (PP) should be calculated by determining the difference between the APTV and the paid Project Cost (PC) from a client (i) to a contractor (j), then estimate the remaining profit value.

4.4. Alignment of the decentralised financial system with construction delivery stages

The decentralised financial 'proof of concept' should be developed throughout the construction project delivery stages. Fig. 9 shows the system architecture considering the differences between payment method characteristics, particularly lump sum and cost-plus/target cost. During the construction stage, the process of invoking transactions should be repeated for each payment milestone. Three transactions should be gathered that contain interrelationships between them; if the transaction from contractor-to-owner is rejected, therefore, both transactions from owner-to-contractor and subcontractors-to-contractor should not be invoked. This could ensure consistency between all cost accounting systems for all parties. Even though the same transactions should be gathered for the last payment during the closeout stage, specific checks must be completed before the DLP period starts. For example, checking the paid reimbursed costs and profit (particularly if the payment method is a cost-reimbursable contract), and the paid cost should be compared to the agreed cost. Therefore, the outstanding yield can be estimated.

5. Proof of concept protoitype and case study

A blockchain network is built for a hospital project that is executed using the traditional contracting approach. Therefore, the project parties are the client, consultant, main contractor, and specialist trade contractor for the cladding package. BIM is implemented for this project; thus, all schedule and cost data should be retrieved from the 4D and 5D BIM models. The project parties agreed to use blockchain technology to automate the endorsement of the project financial transactions and record these transactions in the right ledgers for each party.

The IBM blockchain platform is used to develop the blockchain network for the project due to its user-friendly nature [51] and ease of use. Therefore, this easy-to-use tool is applicable for practitioners across the Architecture Engineering, Construction and Operations (AECO) industry, even for junior and novice users [13].

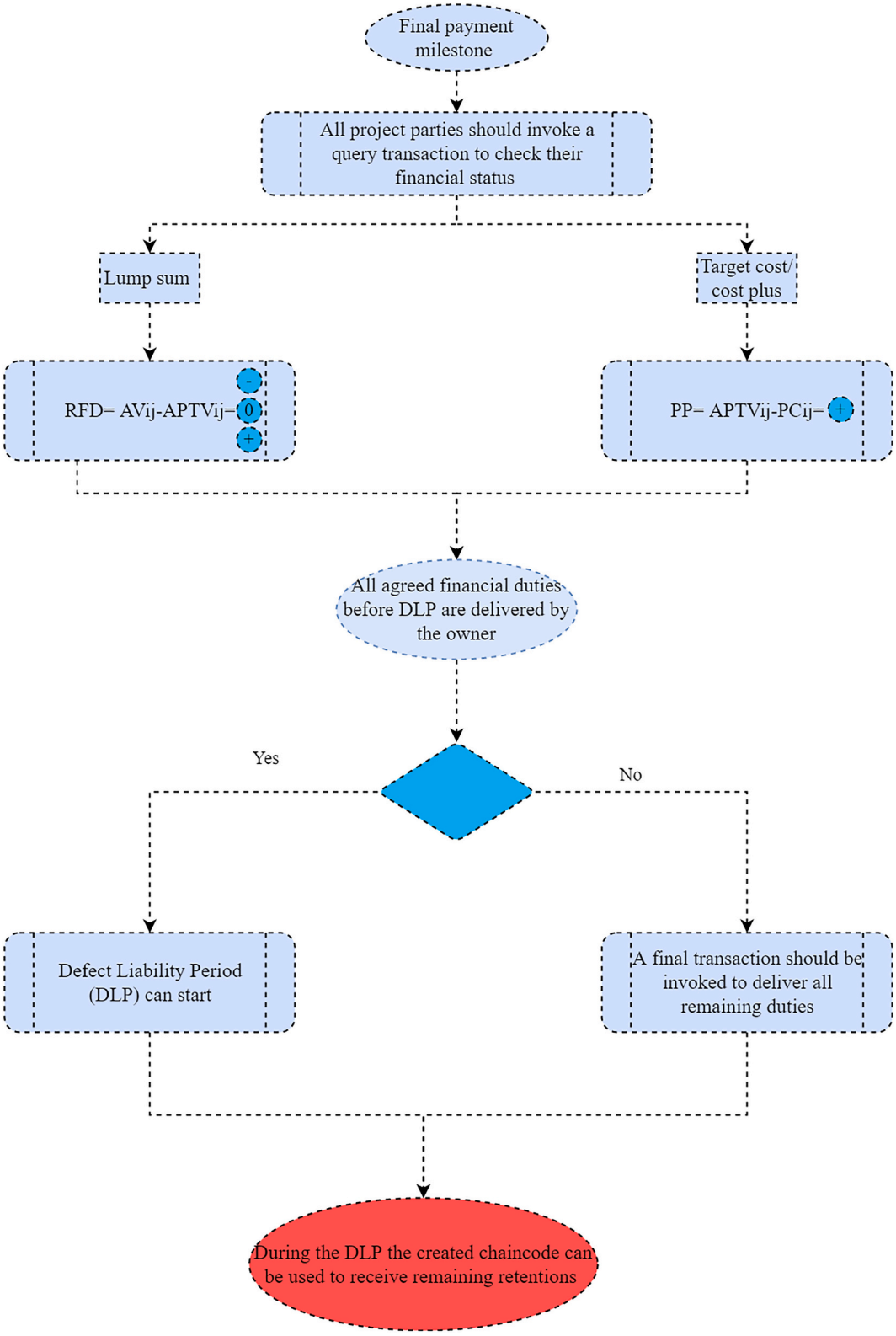

Fig. 8. Construction projects handover-based Hyperledger fabric system.

5.1. Developing a blockchain network

The Hyperledger fabric platform is used as a permissioned blockchain tool to develop the network components viz.: (1) the network nodes that represent the project parties; (2) Certificate Authorities (CA) and Membership Service Provider (M.S.P.) to identify parties; (3) channels to share transactions among the project parties; and (4) a wallet for each member of the project management team.

Blockchain network peers: Fig. 10 shows the developed peers for the project parties. Each peer carries the information for a project party, and all correspondence among project parties are conducted through these peers. Each party has a CA and MSP to issue certificates, validate

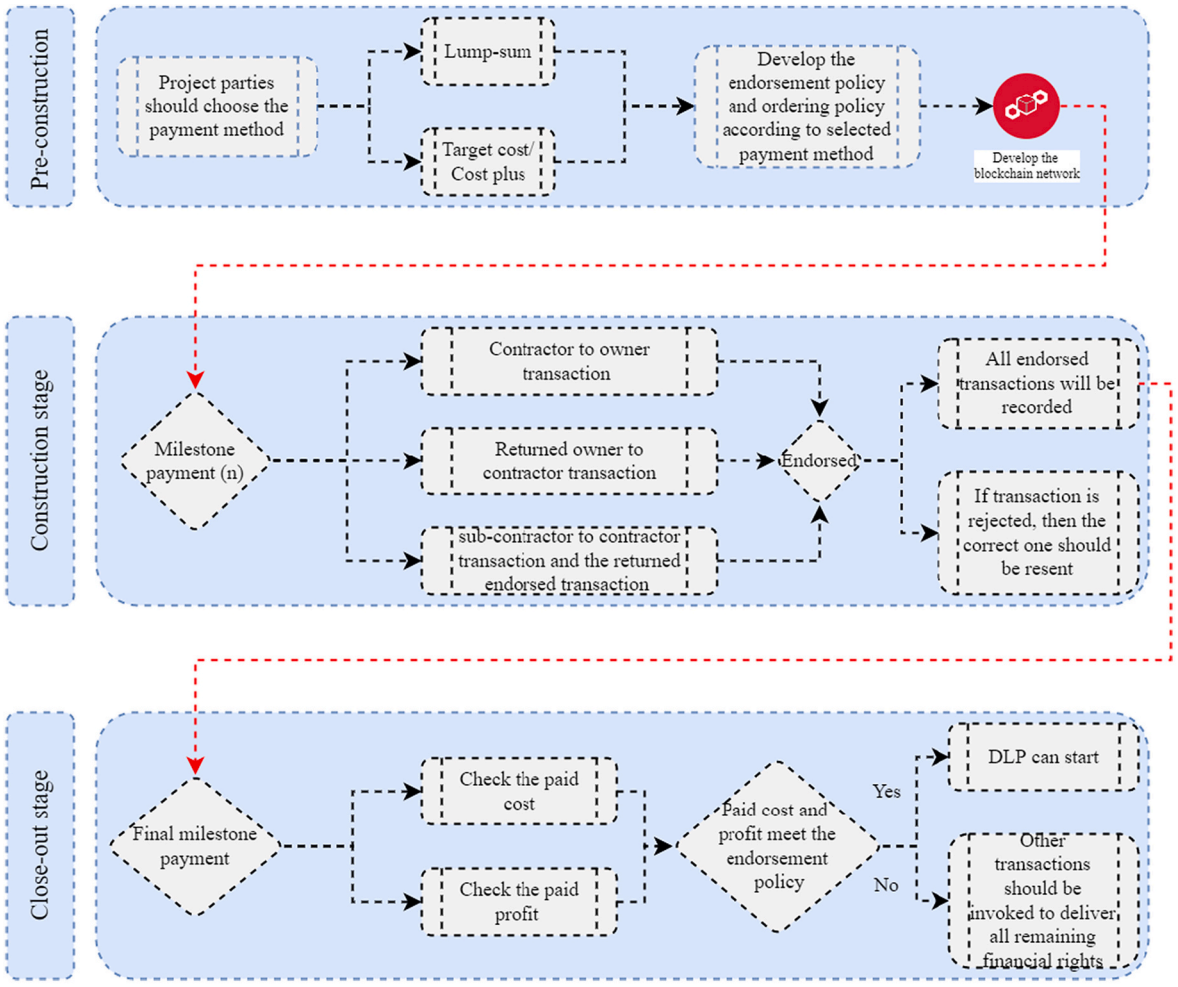

Fig. 9. The alignment of the decentralised financial system with construction delivery stages

certificates and authenticate users.

Developing an orderer peer: An orderer peer should be developed to register the project parties' peers in channels. For example, Fig. 11 depicts a snapshot of the developed ordered peer named 'Hospital-Ordered-Peer'. The four parties' peers are registered in the consortium members panel as this enables the developer to add those registered parties to different channels.

Developing the project channel: According to the proposed framework, four types of media should be developed for the construction project: 'client-to-contractor', 'consultant-to-client', 'consultant-to-contractor' and 'contractor-to-subcontractors'. Having multiple channels respects the privacy of sharing the information among project parties, particularly if the delivery approach is traditional contracting (Design-Bid-Build). For instance, the sub-contractor should not receive information about the transactions between a client, contractor and consultant. The channel includes the peer of each party and the orderer peers. For example, the client-to-contractor channel in Fig. 11 consists of three peers, namely, the contractor, client and hospital orderer peer. The MSP (s) are also included for each member who is involved in the channel.

Wallets for involved parties: Wallets provide an interface for storing and accessing identity information for registered members in the blockchain network. Therefore, the stored identity information in a wallet is used by parties to connect to the Hyperledger Fabric network and so is adopted for the presented case study (refer to Fig. 12).

5.2. Developing a chaincode-based construction transaction

Fig. 13 shows a snapshot of the proposed smart contract that was structured into three main categories viz.: transactions to add any new party to the blockchain network because suppliers and subcontractors could be involved during the project lifecycle; transactions between 'Contractor-to-Client', 'Client-to-Contractor', and Contractor-to-subcontractors/suppliers - therefore, all parties can add their financial transactions; and transactions that enable parties to inquiry about their ledgers data.

This chaincode should be instantiated and uploaded to the blockchain network, and project parties can invoke these transactions at each milestone payment. The query transaction enables parties to explore the status of their ledger during the construction and closeout stage and mentoring payments via the DLP. Moreover, all parties can use the stored data to evaluate the financial performance in all previous projects and avoid any deficiencies in future projects.

6. Discussion, limitation and future research

The proposed financial system-based blockchain provides a comprehensive solution to deal with various financial management challenges occurring during a construction project's delivery. The provided solutions corresponding to each challenge are:

- Slow owner payment/ partial payment: Abdul-Rahman et al. [2] stated that partial payment is one of the crucial delay reasons. The

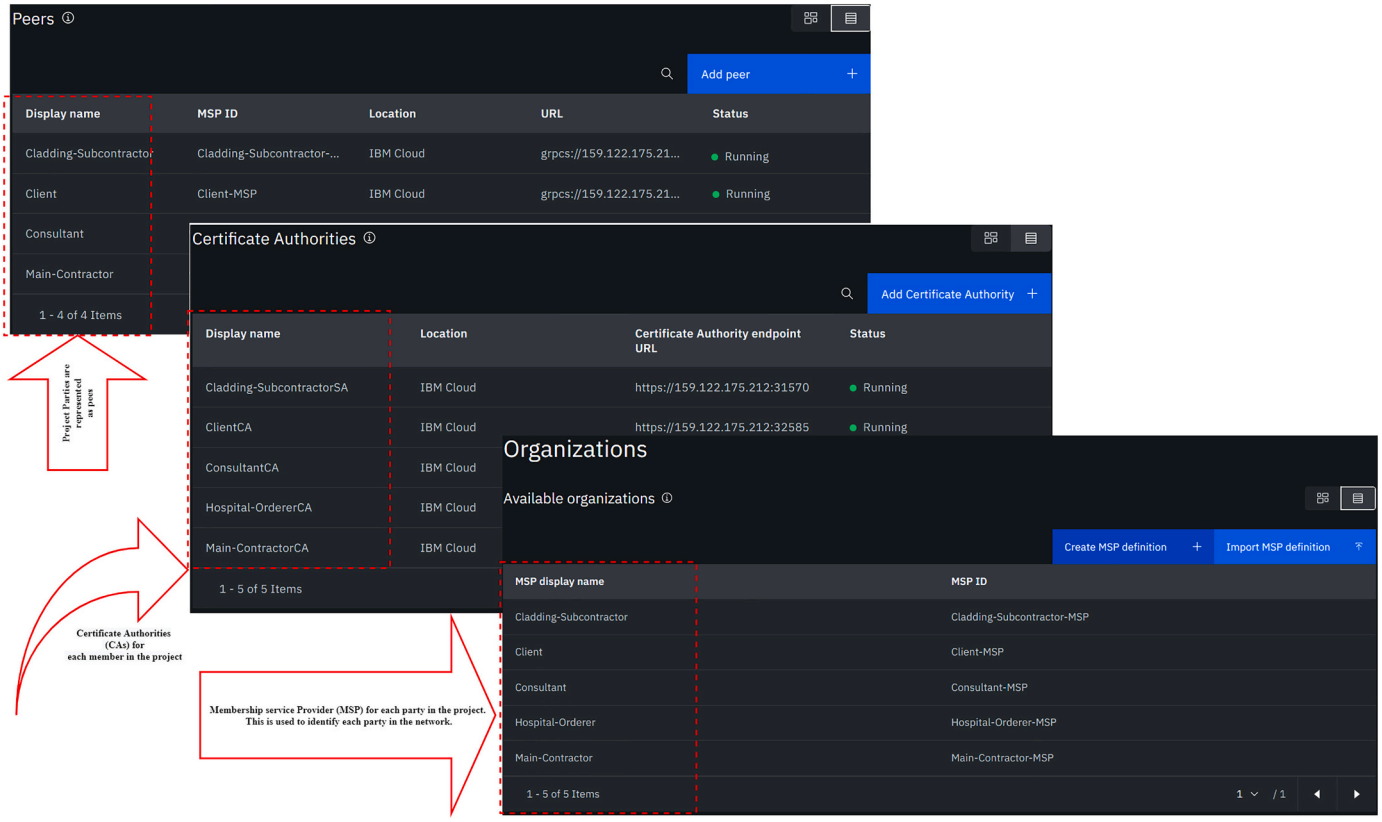

Fig. 10. Hospital-project parties peers, CA and M.S.P. different channels.

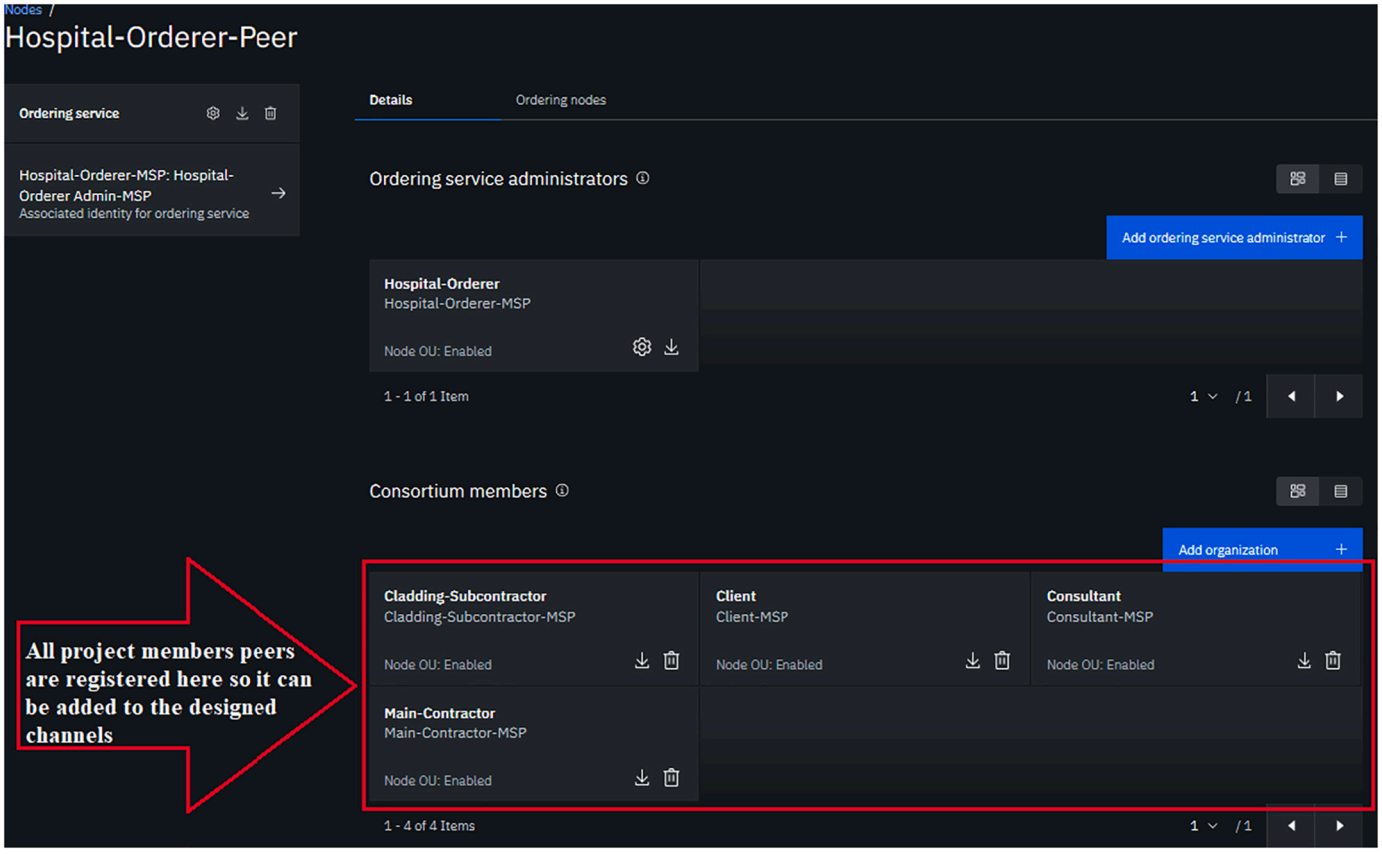

Fig. 11. The network orderer peer for the hospital project case study.

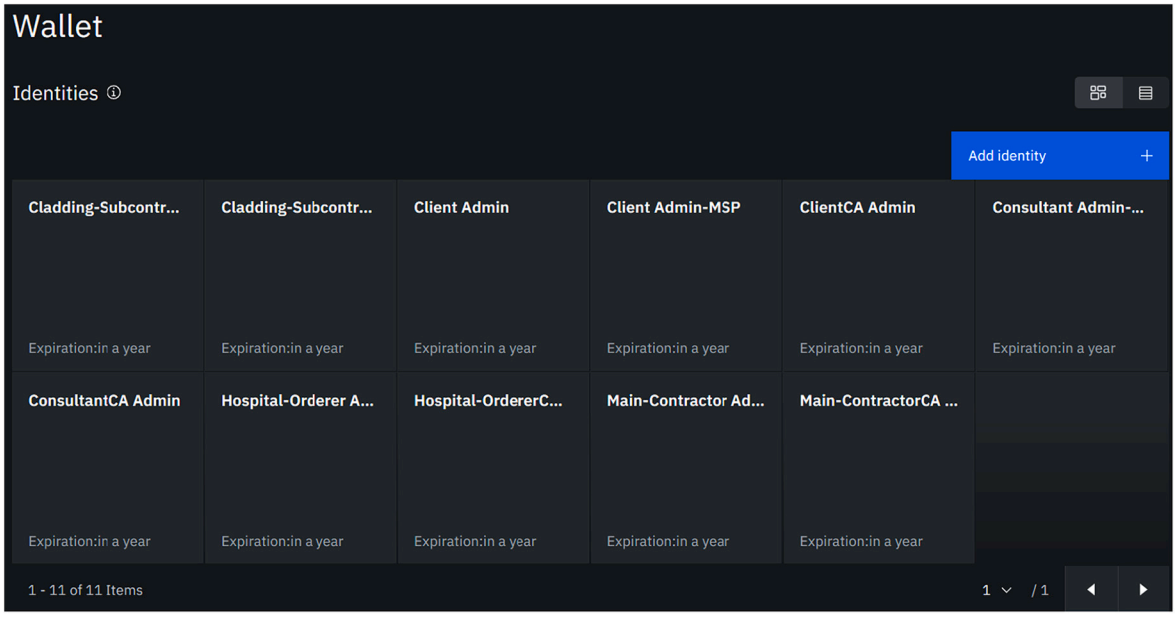

Fig. 12. Wallets for all project parties.

proposed financial-based blockchain system will enable non-owner parties to submit their invoices and automatically endorse them according to the agreed endorsement policy.

- Employer's withholding payment: To avoid any conflict between parties regards withholding financial payment after handing over the project [3], the proposed system enables the issuing payments automatically according to the agreed endorsement policy.
- Pay when paid clause issue: delayed payment to subcontractors is an issue arising from any financial issues between the client and main contractor [4]. The proposed blockchain system links the client, main contractor and sub-contractors, which enables sub-contractors to be announced when the main contractor receives any payment. This level of transparency could enhance the relationship between contractor and sub-contractor and raise trust between them – this fostering a far more collaborative culture (as was the original purpose of digital technologies such as BIM).
- Errors in submitted claims: when the contractor submits invoices which contain errors, payment is delayed and the project's progress is affected [5]. Therefore, the automation in the proposed system manages this issue through automatic checks against the endorsement policy. If any mistake is revealed, the transaction will be rejected simultaneously, and delays are avoided. The contractor will be able to invoke the correct transaction directly.
- Delayed payment caused by contractual issues: unfair clauses in construction contracts could lead to late payment [6]. Using the proposed blockchain financial system enables parties to code the endorsement policy and build a payment plan earlier, which will detect any unfair written clauses.
- Unfair practice of Interim payment: the delay of interim payment reflects adversely on the project schedule progress [2]. Therefore, having scheduled interim payments for the entire project (as stated in the proposed system) highlights the minimum and maximum of each milestone payment in the endorsement policy. Even though Das et al. [14] developed a secured interim payment platform-based blockchain, the proposed system in this present study considers the preparation of interim payment, the conditions of the endorsement policy and the DLP payments. Therefore, the developed blockchain solution in this present research proposed a more comprehensive solution rather than a secure payment platform.
- Integrating BIM to develop the budget/payment plan: BIM is highly recommended to prepare and estimate interim payments [8,10]. However, the practical solution is limited to utilising BIM for that purpose. Therefore, this research integrates BIM into blockchain to develop an automated financial solution for the key revealed financial management issues identified in construction projects.
- Misuse of DLP by the client: During this period, clients have some bad practices to retain contractor's payments and ask for disagreed works [7]. This issue was resolved using the proposed solution as payments will be automatically issued according to the early agreed endorsement policy. Therefore, the opportunity for any misuse of rights is removed.

Given these palpable benefits, this present paper provides an agile and practical solution to manage key issues in construction cash flow management through integrating BIM into blockchain. Moreover, the automation of manging construction financial transactions can significantly enhance trust among project parties, which minimizes the disputes and stimulates genuine mutual collaboration.

Even though the research outcomes were validated using an illustrative case study, the approach and results showed that the created decentralised financial system is valid and practical throughout the different project stages. However, the system must be validated through a real-life case study for a long period to observe its capability under different scenarios and for several projects.

Existing attempts to integrate blockchain into other advanced technologies are apparent. Such projects include Teisserenc and Sepasgozar [53] who developed a framework to enable the integration of digital twin into blockchain for Construction Industry 4.0. The created chaincode can be used to develop a smart supply chain system that includes functions to automatically placing orders based on 4D BIM schedule and enable all suppliers to invoke transactions to receive their financial rights. Blockchain is also employed to monitor consumptions of energy such as Tahreen et al. [54] who proposed a smart solution-based blockchain to automatically optimise and monitor energy consumption. Emerging technologies such as drones and IoT can be used to collect data from construction sites on materials consumption which in turn can interact with a blockchain network to place orders automatically. This will be a prominent step towards digital construction transformation.


```
//update ledger with a greeting
async instantiate(ctx) {
  let greeting = { text: 'Instantiate was called!' };
  await ctx.stub.putState('GREETING', Buffer.from(JSON.stringify(greeting)));
}

//add a member along with their email, name, address, and number
async addParty(ctx, email, name, address, phoneNumber) {
  let member = {
    name: name,
    address: address,
    number: phoneNumber,
    email: email
  };
  await ctx.stub.putState(email, Buffer.from(JSON.stringify(member)));
  return JSON.stringify(member);
}

async Contractortoowner(ctx, Transactionvalue, milestone, Performance, Transactionmanager) {
    let Contractortoowner = {
      Transactionvalue: Transactionvalue,
      milestone: milestone,
      Performance: Performance,
      Transactionmanager: Transactionmanager
    };
    await ctx.stub.putState(milestone, Buffer.from(JSON.stringify(Contractortoowner)));
    return JSON.stringify(Contractortoowner);
  }

  async Ownertocontractor(ctx, EndorsedContractortoownervalue, DateofTransaction, valueofTransaction,
    Transactionmanager) {
    let Ownertocontractor = {
      EndorsedContractortoownervalue: EndorsedContractortoownervalue,
      DateofTransaction: DateofTransaction,
      valueofTransaction: valueofTransaction,
      Transactionmanager: Transactionmanager
    };
    await ctx.stub.putState(Transactionmanager, Buffer.from(JSON.stringify(Ownertocontractor)));
    return JSON.stringify(Ownertocontractor);
  }
 // Look up data by key
 async ContractorToSubcontractors(ctx, Transactionmanager, TradePackage, value, DateofTransaction,
  Transactionmanager) {
    let ContractorToSubcontractors = {
      Transactionmanager: sender,
      TradePackage: TradePackage,
      value: value,
      DateofTransaction: DateofTransaction
    };
    await ctx.stub.putState(Transactionmanager, Buffer.from(JSON.stringify(ContractorToSubcontractors)));
    return JSON.stringify(ContractorToSubcontractors);
  }

  // Look up data by key
 async query(ctx, Transactionmanager) {
    console.info('querying for key: ' + Transactionmanager  );
    let returnAsBytes = await ctx.stub.getState(Transactionmanager);
    let result = JSON.parse(returnAsBytes);
    return JSON.stringify(result);
  }
}
```

Fig. 13. Chaincode-based Hyperledger fabric for construction cash-flow transactions.

7. Conclusion

This study provided a decentralised and interconnected financial 'proof of concept' system that solves the revealed deficiencies of financial management within different stages of construction projects. The study's primary added value to the body of knowledge is to exceed the conceptual stage of existing studies by initiating empirical research on a real-life application of blockchain through a case project. This provides a stepping-stone from which to direct future research studies.

As the construction industry lurches towards a complete digitalisation of its processes and tasks based on BIM, the created framework integrated BIM into blockchain to retrieve pertinent cost and schedule information. This retrieved information is used to develop the endorsement policy and estimate the transaction value for each milestone payment based on 4D and 5D BIM models.

In broader terms, this research provides a point of departure for the required transition beyond the sophisticated financial management systems for construction projects by showcasing the capabilities of Hyperledger fabric and its applicability as a future element of cash flow management throughout the project and asset lifecycle.

The created system provides a wide range of solutions to interim payment issues such as delay of payments by including an advance prepared payment schedule that is inextricably linked to the endorsement policy. Therefore, transactions will not be accepted if invoked out of the pre-agreed dates. Moreover, the misuse of DLP is also solved by an advance agreed and coded range of payment dates with a specific value of transactions. Therefore, there is no need for a third party to manage the financial transactions after handing over the project.

The system was developed to provide financial management solutions based on conventional payment methods (e.g., lump-sum, cost-plus and target cost). However, the modern financing approach such as Public-Private Partnership (PPP) needs new features added to the system, such as the financial transaction during the concession period and the client's role. There are no transactions from the client to contractor as same as traditional financing approaches.

Declaration of Competing Interest

We confirm that we have no conflicts of interest to disclose regarding this submission.

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