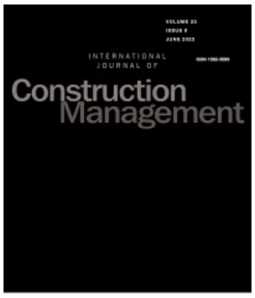

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Rebuilding trust in the construction industry: a blockchain-based deployment framework

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ABSTRACT

Trust has been acknowledged as an essential element of inter-organizational relationships, and it also affects the efficiency of work operations. Although the construction industry has been pursuing trust for a long time, trust is still lacking and fragile among stakeholders. Blockchain seems to provide a promising approach through which trust can be rebuilt. This study aims to develop a deployment framework by following which construction stakeholders can develop blockchain-based solutions for rebuilding trust. A design science research (DSR) method is used to develop a blockchain-based framework. Then, the framework is prototyped and illustrated through a case study of construction supervision. It is discovered that the proposed framework can provide a promising approach to fostering trust. One contribution of this research is to articulate a normative vs. naturalistic trust-building spectrum and position blockchain-based trust-building in it. Practically, this research develops a framework that stakeholders can develop blockchain-based solutions.

KEYWORDS

Trust; blockchain; supervision; offsite construction; deployment framework

Introduction

According to Oxford Dictionaries, 'trust' in the social context refers to the firm belief in the reliability, truth, or ability of someone or something. It is confidence or reliance on the integrity, strength, ability, and surety of a person or thing. Rousseau et al. (1998) define trust as "a psychological state comprising the intention to accept vulnerability based upon positive expectations of the intentions or behavior of another". This definition implies that trust is a *state of mind*, not a *behavior*, but it can lead to or predict, trusting, or untrusting behavior (Nooteboom 2006). Trust is a complex social construct with multiple bases, levels, and determinants (Rousseau et al. 1998). It is also a relationship lubricant (Wong et al. 2008). There are generally two strands of theories in determining the sources of trust. One strand, favoring microeconomics, sees trust as having rational, calculative elements (Susarla et al. 2020), e.g. by consciously evaluating risks and returns. This strand can be further linked to economics theories such as opportunism (Shi et al. 2018), transaction cost (Li et al. 2018), and relational contracting (Zhang et al. 2016). Another strand, with a psychological tradition, presumes that trust is sourced in a social orientation towards other people (Anvari and Lakens 2018). It is an intrinsic value of human beings; "Man is not always self-interested and opportunistic" (Laan et al. 2011). In reality, trust has both material and psychological determinations (Nooteboom 2002).

In construction, the importance of trust cannot be overemphasized. Construction projects are usually organized in the form of projects, which are temporary and one-off organizational settings (Li et al. 2020). It has never been easy to gather people with different professional backgrounds, years of experience, and strength to work on construction projects, especially complex projects (Lau and Rowlinson 2009). They lack time to engage in lengthy interactions that contribute to the development of trust in traditional, more enduring organizational forms (Liu et al. 2018). Projects often involve numerous uncertainties and risks, requiring trust between project members to foster an amicable relationship to "bridge gaps, establish faith, and synergize the strengths" (Wong et al. 2008). Nevertheless, the construction industry is often known for its lack of trust and prevalent adversarial relationship (Wong et al. 2008), resulting in widespread claims, opportunism (Qian and Papadonikolaki 2020), risk aversion, mediocre quality (Penzes et al. 2018), high cost, poor value for money, and other counter-productive consequences (Deep et al. 2019). "Lack of trust" has been highlighted as a major problem in a succession of UK-based industry reports, including "Constructing the Team" (Latham 1994), "Rethinking Construction" (Egan 1998), and "Never Waste a Good Crisis" (Wolstenholme et al. 2009).

There is a substantial body of literature to explore strategies to build trust in construction. Putting everything in a clear-cut contract has long been the effort to guarantee the delivery of a construction project. However, due to the inherently complex nature and prolonged duration of construction projects, it is exceedingly expensive (e.g. high transaction cost), if not completely impossible, to present all the future contingencies in a contract, so as to reduce the room for opportunistic behaviors (Shi et al. 2018) such as disclosing incomplete information, undermining conventional norms, or pursuing self-interest occasioning the loss of other partners. To this end, relational contracting was increasingly promoted (e.g. Grafton and Mundy 2017). The major difference between the two generic types of contracting is that parties in relational contracting value the relationships and manage their transactions within certain mutually accepted social guidelines or norms of behavior, rather than rigidly following the clauses (El-Adaway et al. 2017). A parallel line of inquiry is about procurement. Traditional design bid and build (DBB) is considered as the culprit of the untrusting culture and adversarial relationship (Park and Kwak 2017). Integrated procurement models, such as design and build, and integrated

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project delivery, are advocated (Kelly and Ilozor 2020). As both a culture and a collaborative management approach, partnering has been highly advocated (Abas et al. 2020). Chinese 'Guanxi' is explored as an exotic ingredient to build trust and lubricate relationships (Lu and Hao 2013). These strategies reflect a clear normativism – trust is a quintessence to business success, an intrinsic value of human beings, and a social norm that we should actively pursue. Nevertheless, with all due respect, trust in construction remains lacking and vulnerable, as evidenced in counterfeit construction materials or craftsmanship scandals that take place endemically.

Blockchain recently emerging from the technology sphere seems to provide an alternative strategy to rebuilding trust in construction. According to Risius and Spohrer (2017), a blockchain is a cryptographically secure shared database within a decentralized consensus mechanism. Unlike the normativism of trust-building mentioned above, blockchain-based trust-building has a root of naturalism, whereby untrusting behavior in construction is a state that is accepted, like it or not. In a sense, untrusting behavior is natural, possibly even acceptable, from a humanity perspective. From there, blockchain keeps a custody of immutable, cryptographic, and verifiable information that parties cannot deny but chose to trust with each other. Numerous articles have discussed the potential of blockchain in different industries including construction. For example, Penzes et al. (2018) published a report on blockchain in construction, numerating its potential use in smart contracts, payment, procurement and supply chain management, and building information modelling (BIM) and smart asset management. Trust-building is one of the major prospects highlighted in the report. Likewise, Arup (2017) sees blockchain as an enabler of a network of trust for the built environment. The problem is how blockchain can go beyond the rhetoric and be truly implemented to build trust in construction.

This paper aims to develop a deployment framework by following which stakeholders can develop their respective blockchain-based solutions for rebuilding trust in construction. This research has three specific objectives:

1. to review existing issues that blockchains may address in construction;
2. to develop a framework to guide construction stakeholders to deploy their blockchain-based trust-building systems and help card the logic of blockchain-based supervision processes;
3. To illustrate the framework through an illustrative case study.

The remainder of the paper is structured as follows. After this introductory section is a literature review of trust-building in construction, followed by another literature review of blockchain technology for trust-building. The next section describes the research methods. Then, the paper presents and illustrates the framework. Discussion section discusses the prospects and challenges of blockchain for rebuilding trust in construction. Conclusions are delineated in the last section.

Literature review

Trust-building in the construction industry

Trust is a belief. It is a psychological state, an intrinsic value of human beings, and an essential element underpinning our social norms. Trust also has substantial material implications as a lubricant to relationships. It can help lessen risks, reduce opportunism, nurture benevolence, and lower transaction costs. Trust is positive, valuable, and should be pursued. Wong et al. (2008) summarized three generic types of trust: System-based, Cognition-based, and Affect-based trust. In the construction industry, system-based trust often develops from formalized and procedural arrangements (Wong et al. 2008), such as organizational structure, safety policy, bureaucracies, reporting and communication systems, and contractual agreements. Cognition-based trust derives from the confidence built upon the construction-related knowledge that reveals the cognitive bearings of construction organizations (Qian and Papadonikolaki 2020). Affect-based trust builds on sentimental factors. It is like an emotional bonding among construction stakeholders, e.g. via being thoughtful, relations, clannishness, or even romance (McDermott et al. 2005). In reality, the trust could be built on a combination of these sources in construction.

Numerous studies in construction have been conducted to nurture trust. We categorize these studies in a school called "normative trust-building". By reviewing the literature, we can summarize reported normative trust-building strategies into four categories: inter-organization (e.g. a good record of collaboration experience), environment (e.g. globalization), culture (e.g. top management support), and individual (e.g. personal beliefs), as shown in Table 1. They are strategies related to developing amenable culture, leadership, policies, contract, communication, knowledge, personal value, and social norms. One can link these strategies to the three generic sources of trust mentioned above, i.e. system-, cognition-, and affect-based trust. One underlying rationale of the normative trust-building advocacy is that we do whatsoever, positively and proactively, to pursue trust, strengthen it, and institutionalize it (Wong et al. 2008).

In contrast to "normative trust-building," another school trust-building strategy is gaining momentum from the transaction by emerging trust-bearing technologies (Lankton et al. 2015). We call it "naturalistic trust-building". The "lack of trust" status is an accepted (not necessarily acceptable) feature of our contemporary society. Failure to recognize or accept endemic mistrust leads to inefficiencies in construction, including price distortion, corruption, and other forms of opportunism (Monteiro et al. 2020). The legal infrastructure that creates the formal institutions to make construction work smoothly is based on accepting the risks incurred by relying purely or principally on inter-personal trust as the basis for transactions (Penzes et al. 2018). It accepts that a lack of trust between construction parties is natural and unavoidable and has to be factored in. It is also natural to be cautious of one's clients and contractors since they have an understandable motive not to reveal complete information pertinent to a transaction. Hence, construction stakeholders do due diligence (e.g. devising trust-bearing technologies) when making significant transactions. Some significant observations were made through the literature review. First, it is seen that most research in the area of trust in construction is geared towards the "normative trust-building". There is yet limited research in the areas of "naturalistic trust-building" in the construction industry. Second, there is a lack of systematic investigation to guide construction stakeholders to build trust through emerging trust-bearing technologies such as blockchain.

Blockchain for trust-building

Blockchain has been widely explored to improve existing issues in various industries. It has been adopted to renovate the existing transaction systems in finance to secure trust-free transactions (Notheisen et al. 2017). The intermediaries in the traditional business could be eliminated, thereby lowering operational costs and increasing business efficiency. In philanthropy, blockchain

Table 1. Normative trust-building categories.

Normative trust-building categories	Normative trust-building strategies	Reference (Author-year)
Inter-organization	• Good record of collaboration experience • Problem solving jointly • Shared goals • Reasonable behaviour/Avoiding taking excessive advantage	Khalfan et al. (2007), Lau and Rowlinson (2009), and Laan et al. (2011)
	• Establish good relationships • Communications/honest negotiations • Commitment	McDermott et al. (2005), Lau and Rowlinson (2009), and Laan et al. (2011)
	• Predictability and knowledge of others	Lau and Rowlinson (2009)
	• Empower staff with authority	Lu et al. (2016)
	• Hold workshop • Good financial situation	Laan et al. (2011)
	• Involve contractor early • Implement progress evaluation system	Lu et al. (2016)
	• Contract • Project factors	Khalfan et al. (2007) and Laan et al. (2011);
Environment	• Globalisation • Current technology availability • Government regulation / Law enforcement	Chen and Saeedi (2006), and Singh and Teng (2016)
Culture Issues	• Seek similar culture partner • Top management support • Cultivate learning climate	Khalfan et al. (2007)
Individual	• Social norm • Personal beliefs • Experience • Perceptions • Economy	Chen and Saeedi (2006), Khalfan et al. (2007), and Wong et al. (2008)

has been used to track donations and enhance information transparency (Galen et al. 2018). Similarly, in agriculture, blockchain has also been used to track agricultural products in the supply chain (Hang et al. 2020). Also, blockchain has been applied to secure patient records (Hasselgren et al. 2020) and student certificates (Chen et al. 2018) in the healthcare and education industries, respectively. Additionally, blockchain has been investigated for transparent e-voting in governance (Pawlak et al. 2018). Although various industries have adopted blockchain to improve existing issues, its potential to build trust has not been systematically studied. Two relevant studies have been conducted by Zhang et al. (2019) and Tang et al. (2019), who developed blockchain-based trust frameworks, but both studies are limited to applications for Internet of Things (IoT).

Blockchain is also introduced as an alternative trust-bearing technology in construction. Table 2 summarizes the issues in construction that the blockchain has been adopted to make improvements based on 29 papers published between 2017 and 2021. These improvements may further help build trust in construction. Specifically, blockchain has been used to enhance user engagement through incentive mechanisms (Lu et al. 2021). Besides, blockchain has been implemented for enhancing real-time information sharing among stakeholders through its consensus mechanism (e.g. Heiskanen 2017). The low traceability of paper records, phone calls, and emails is another issue that blockchain has been adopted to improve as it can provide a timestamp for each transaction (e.g. Dakhli et al. 2019). Further, blockchain has been adopted to secure construction records by storing them in multiple locations, preventing a single point of failure (e.g. Turk and Klinc 2017). Blockchain has also been used to avoid construction data tampering through hash algorithms (e.g. Nawari and Ravindran 2019). Additionally, blockchain has been applied to enhance privacy by applying access control. Further, blockchain has been used with smart contracts to automate processes (e.g. Penzes et al. 2018). Although blockchain has been actively investigated for improving above mentioned issues, it has not yet been explored under the context of trust-building theories. Qian and Papadonikolaki (2020) recently studied how blockchain affects trust in construction, but their research does not provide a solution to guide construction stakeholders on using blockchain to build trust.

To sum up, blockchain has been adopted to improve numerous existing issues in various industries, including construction. As a result, seven factors that blockchain can help build trust are summarized: incentives, information sharing, traceability, security, immutability, privacy, and smartness. A prevalent misunderstanding is that blockchain can guarantee the genuineness of information. Indeed, the blockchain components (e.g. cryptographic algorithms, distributed ledgers, and decentralized consensus mechanisms) all make it formidably tricky for any party to alter or temper the transaction information unilaterally (Li et al. 2021). However, Lu et al. (2021) pointed out that blockchain cannot go beyond its digital world to ensure what is happening in the off-chain world. Considering the feasibility of the new framework, using blockchain oracles to build trust between the on-chain and off-chain worlds in construction is not included in this study. Thus, the research gap identified can be summarized as follows. There is a lack of a framework to guide construction stakeholders to deploy their blockchain-based trust-building systems and help card the logic of blockchain-based supervision processes.

Research methods

This study adopts an exploratory research methodological method for examining the issues and investigating the alternate courses of action, which develops knowledge and contributes to the body of theory. In the next section, this study presents an artifact that endeavors to be a potential solution to the identified issues. This requires a philosophy from the design sciences, called the design science research (DSR) philosophy. DSR is an analytical and creative approach involving people experimenting, creating, prototyping, and testing models around user concerns, interests, and values (Razzouk and Shute 2012). The strategy

Table 2. Existing issues that blockchain may improve in the construction industry.

ID	Reference	Lack of incentive	Low information sharing	Low traceability	Single point of failure	Tampering	Privacy leakage	Manual processing
1	Heiskanen (2017)		√					√
2	Wang et al. (2017)		√		√			
3	Turk and Klinc (2017)				√		√	
4	Penzes et al. (2018)		√	√	√			√
5	Dakhli et al. (2019)							√
6	Hargaden et al. (2019)				√			√
7	Li et al. (2019)			√	√		√	
8	Nawari and Ravindran (2019)		√	√	√	√		√
9	San et al. (2019)				√	√		
10	Safa et al. (2019)						√	
11	Xiong et al. (2019)			√	√	√	√	
12	Das et al. (2020)					√		√
13	Elghaish et al. (2020)	√						√
14	Hunhevicz and Hall (2020)		√			√		√
15	Kim et al. (2020)					√		
16	Kiu et al. (2020)		√					
17	Perera et al. (2020)	√	√	√	√	√		√
18	Qian and Papadonikolaki (2020)		√		√			
19	Sheng et al. (2020)		√	√				
20	Shemov et al. (2020)					√		
21	Sharma and Kumar (2020)					√	√	
22	Tezel et al. (2020)		√					
23	Xue and Lu (2020)			√		√		
24	Yang et al. (2020)		√	√				
25	Zhong et al. (2020)		√	√	√	√	√	
26	Zhang et al. (2020)			√	√	√		√
27	Adamska et al. (2021)		√			√		
28	Lu et al. (2021)	√	√	√		√	√	√
29	Li et al. (2021)		√	√	√	√	√	√

followed by this study takes a problem-centered initiation path adjusted from Peffers et al. (2007).

This study used five steps. Firstly, empathy was built by understanding the target audience. This study mainly concerned construction stakeholders such as clients, contractors, manufacturers, and suppliers. The second step was to define the critical issue. The specific issue here was to develop a framework by following which a blockchain-based system could be built for trust-building in construction. Then, brainstormed with group members by analyzing and synthesizing literature obtained from the literature review stage. In this way, each participant could offer their opinions, and the whole group gained the overall picture of the potential direction. The process was non-linear because it required several iterations to develop a promising solution, as some solutions were feasible but not the most promising.

Next, the conceptual framework was proposed and graphed for the most promising solution. Finally, the framework is illustrated through a case study in modular construction off-site production. The case study allows investigations about contextual realities and differences between planned and actually happened activities. The research strategy used for this case study had relied on the description, aggregation, interpretation, and replication logic of the case. In this case study, the research strategy aimed to answer: how and why the framework will reinforce the cognition of the phenomenon. The research method leaned on the development of a prototype system.

Data analyses, results, and findings

A blockchain-based deployment framework

A blockchain deployment framework is developed in this study (see Figures 1 and 2). It consists of two parts: one connects the technology with the project life cycle, stakeholders, and their potential applications, and the other is used to establish supervision in a blockchain-based system to enhance trust. For Part I (Figure 1), one can read it from the inner circle of the project lifecycle, which ranges from project inception, design, construction, facility management, renovation, and finally, demolition. Blockchain technology can be underlying in the whole lifecycle of a project. Throughout the lifecycle, blockchain can serve different stakeholders such as clients, contractors, and bankers. It can serve various architecture, engineering, construction, and operation (AECO)-related applications such as quality inspection, progress tracking, and smart contracts.

After selecting the application, one can use the second part of the framework to build trust (Figure 2). One can read it from left to right. By answering relevant questions, the supervision processes can be established in the blockchain system architecture. Therefore, the issues affecting trust-building can be improved by using blockchains. For example, in a construction project, the owner can first be defined in the membership service to control the certificate authorities (CAs) and issue certificates to allow the manufacturer, logistics company, and contractor to join the blockchain network as members. Then, when developing the system, this definition can be input into the blockchain. In addition to the application layer mentioned in Part I, the blockchain system architecture has five other layers: blockchain as a service (BaaS), execution, consensus, data, and network (Figure 2). The communication and access control (e.g. configuring, controlling, and managing the data) between the Network and the Applications is through the BaaS layer, particularly its various software development kits (SDK). The Execution layer handles the logical of construction business and define semantics via smart contract, world state and semantic web.

The Consensus layer manages the agreement between stakeholders about the transactions in blockchains. Consensus algorithms such as Proof-of-Work and Crash Fault Tolerance (CFT) operate at this layer. Users can choose the appropriate consensus protocol according to the situation. The Data layer handles the

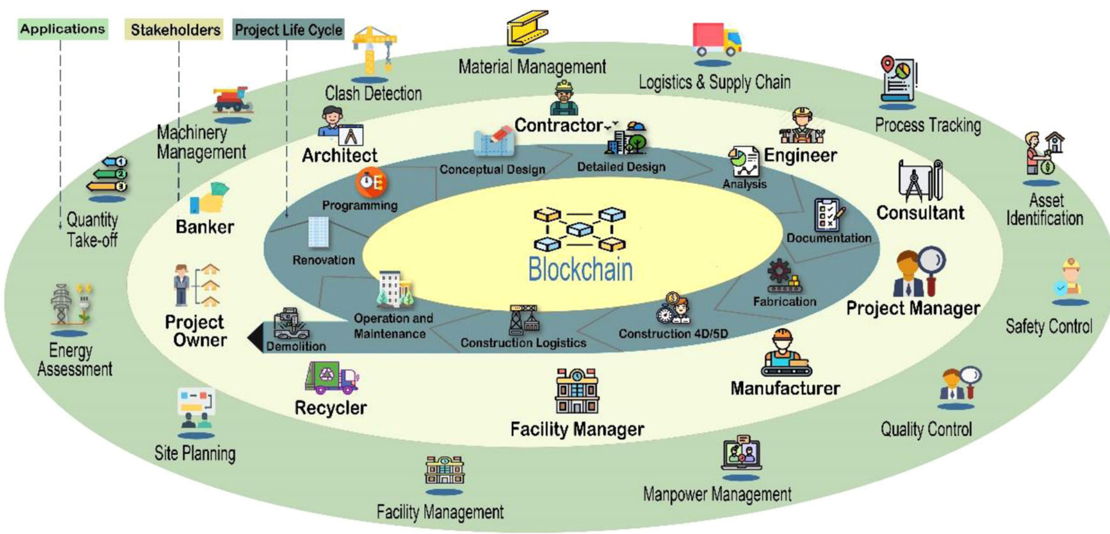

Figure 1. Blockchain-based deployment framework – part I: Lifecycle, stakeholders, and applications.

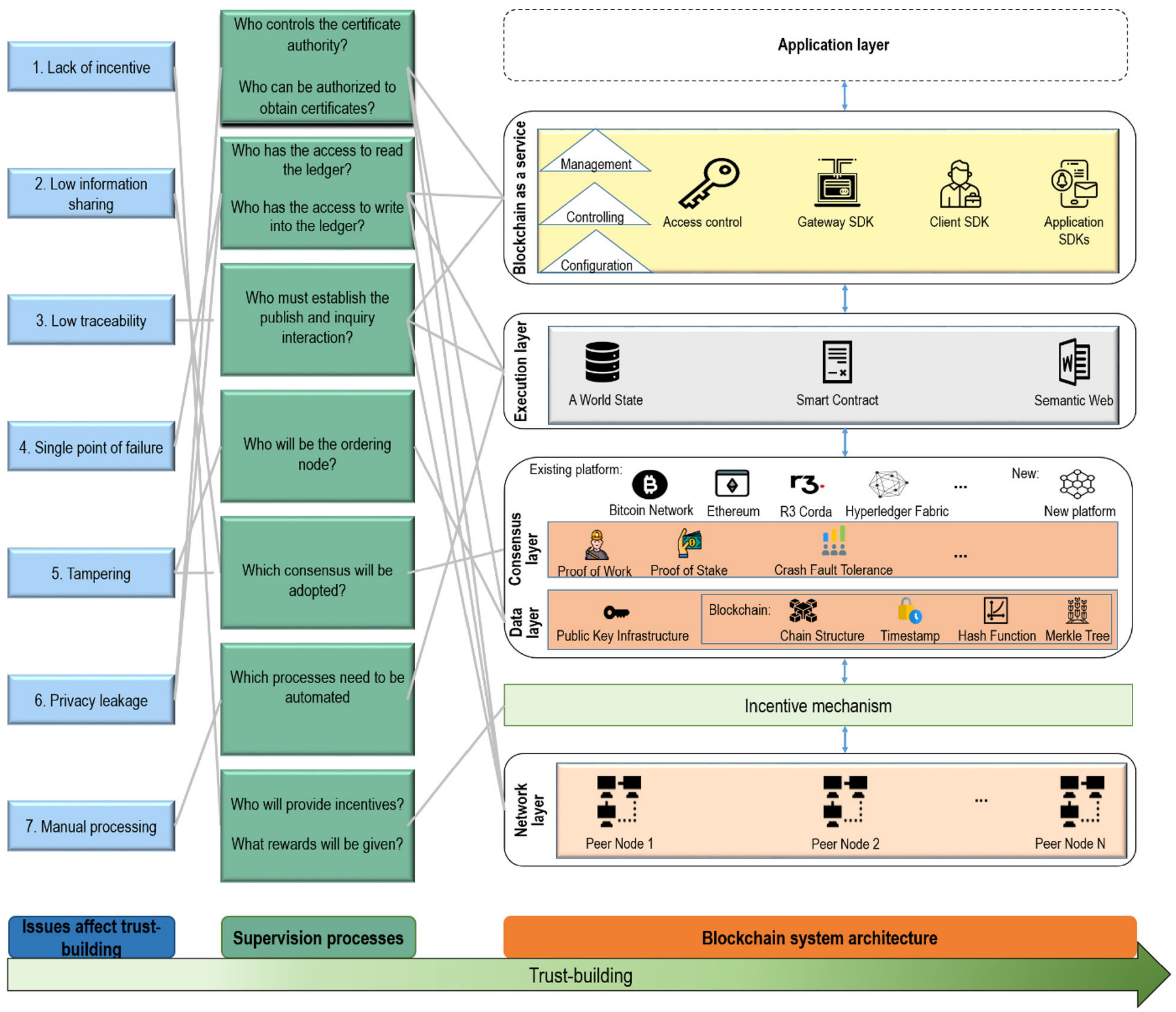

Figure 2. Blockchain-based deployment framework – part II: System architecture.

blockchain transactions by using the chain structure, timestamp, Merkel tree, hash function, and public key infrastructure. One can use existing platforms such as Bitcoin network, Hyperledger Fabric, or develop new platforms for hosting the Consensus and Data layers. The agreed data will be distributed to the peer nodes in the Network layer to function. The incentive mechanism can be integrated into the blockchain to encourage user participation and publish transactions promptly.

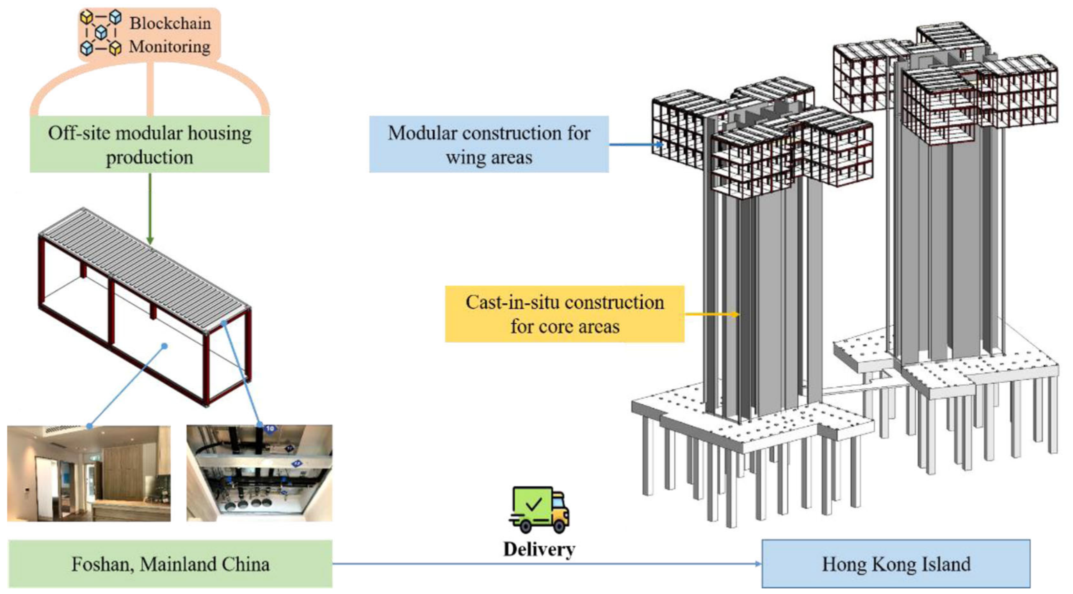

Figure 3. Project overview.

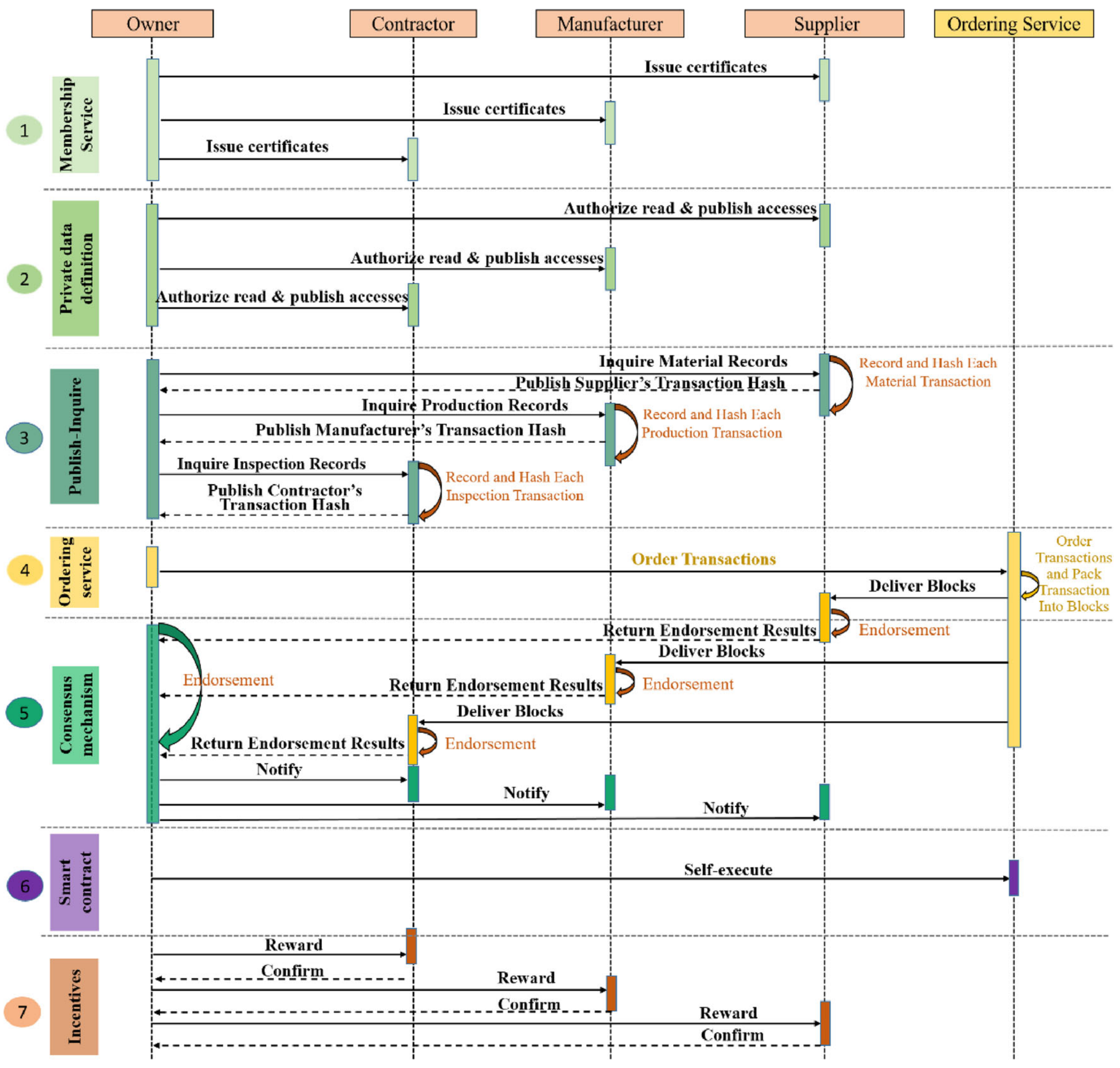

Figure 4. The implementation of supervision processes.

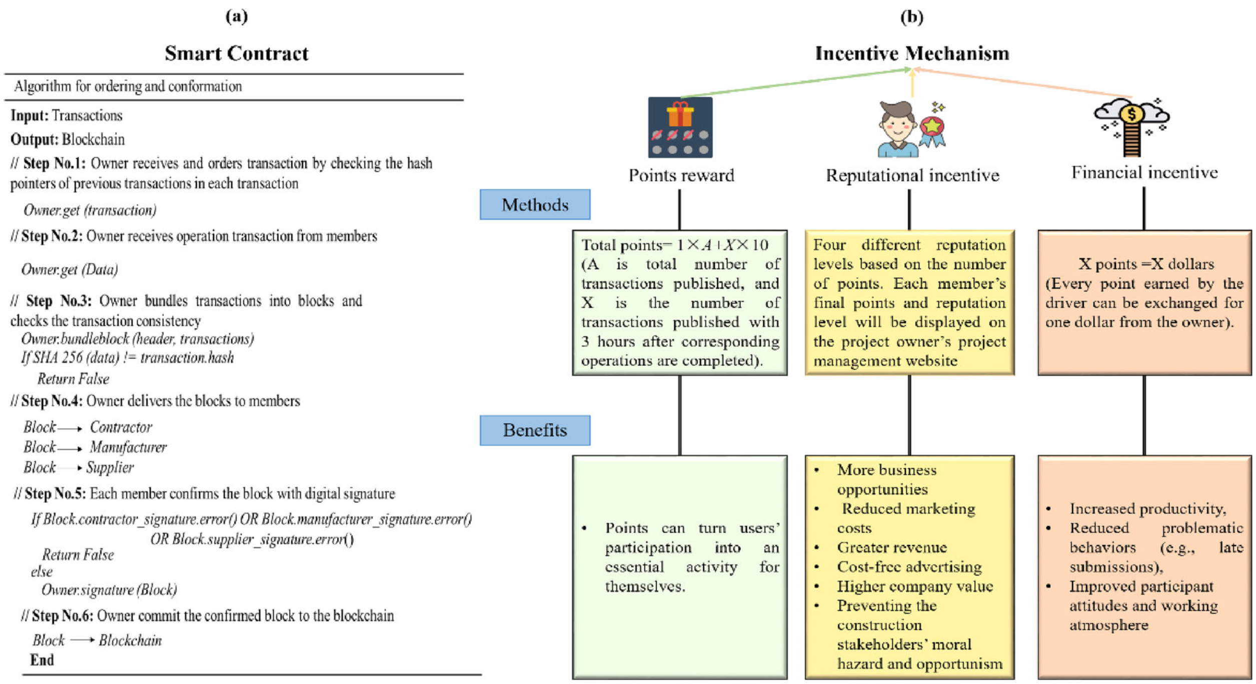

Figure 5. Smart contract and incentives: (a) smart contract; (b) incentive mechanism.

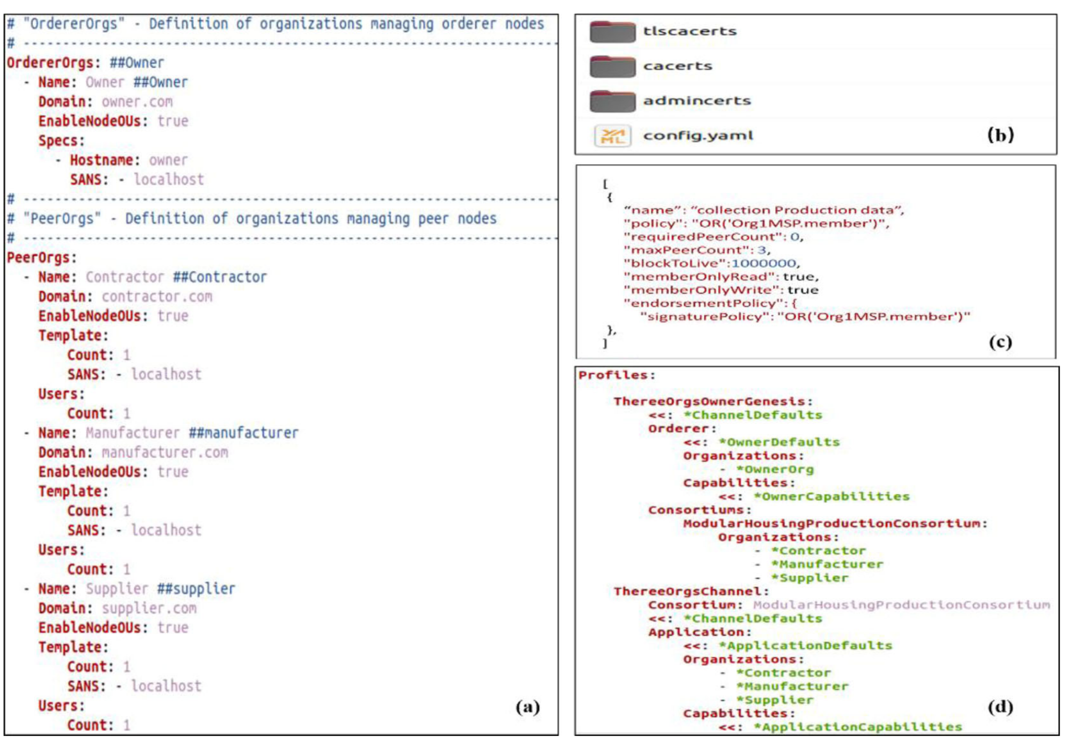

Figure 6. System configurations for: (a) members; (b) certificates; (c) private data; (d) genesis block.

Case study

The proposed framework is illustrated through a case study in this section. The selected case is the ongoing student residence project at the Wong Chuk Hang site, Hong Kong. The project consists of two 17-story student residence towers, which are built upon a 3-story podium structure (Figure 3). In this project, all 1,224 modules will be manufactured in Foshan, Mainland China, and then transported to Hong Kong for installation. Due to the COVID-19 pandemic, the local governments have restricted population movement, and blockchain plays a vital role in cross-border supervision. Referring to Part I of the framework, the project owner decided to use blockchain with the supplier, manufacturer, and contractor to supervise off-site modular production. According to Li et al. (2021), transferring all process data from an existing system to a newly built blockchain platform may result in high technology, training, and learning costs.

The implementation of supervision processes

After answering questions corresponding to the trust-building criteria in Figure 2, the above four participants established the

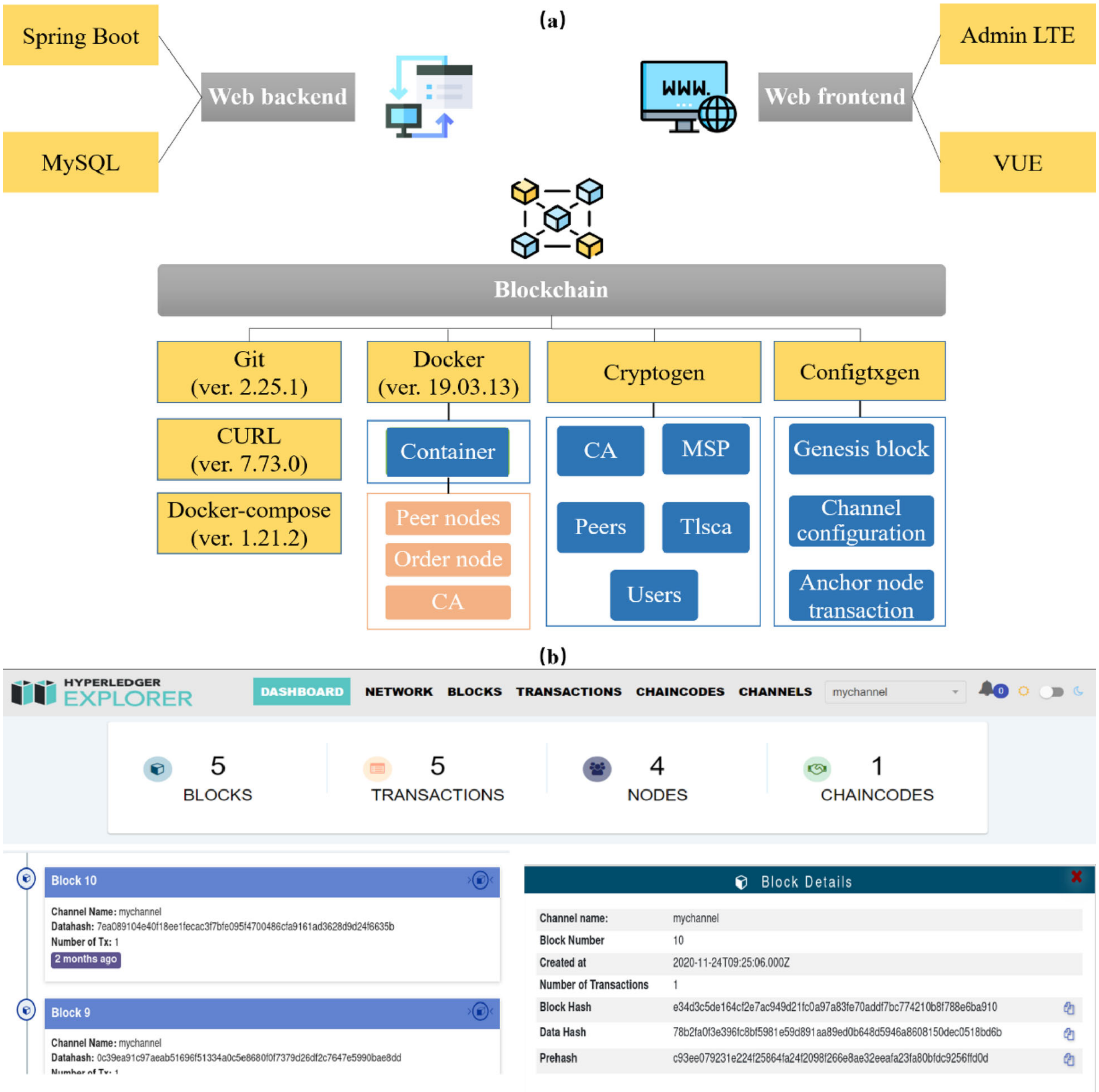

Figure 7. Prototype development: (a) frameworks, tools, and components involved in the prototype development; (b) hyperledger fabric explorer.

supervision processes, as shown in Figure 4. First, in the membership service stage, contractors, manufacturers, and material suppliers were registered as members through the owner. The owner runs the CAs and issues certificates to members so that they can join the network. Second, the owner defines ledgers' privacy permission by authorizing read or publish access to each member. Third, the owner established publish-inquire interaction with members. For example, the manufacturer recorded the latest production information and then published it to the owner in the blockchain. Fourth, the owner then packed the received transactions into blocks and delivered them to the members for confirmation. Fifth, in the consensus stage, members endorsed the order and correctness of transactions through CFT consensus algorithm. According to Hyperledger (2020), CFT does not involve cryptocurrencies to promote public approval of transactions. Therefore, the risk of attacks and computational energy consumption can be reduced. The digital signing was performed for validating transactions.

Sixth, smart contract was used to automate the ordering service. Figure 5(a) shows the algorithm of the smart contract. The smart contract was used to collect transactions published by members and bundle them into blocks. Next, the smart contract sent the bundled blocks to the members for confirmation and updated the confirmed blocks to the members' ledgers. Finally, an incentive mechanism that combines points, reputation, and finances was used to encourage users to participate and promptly publish transactions. Figure 5(b) provides the details of the incentive mechanism. In this study, each member earned 1 point reward for every published transaction, and if the transaction was published within three hours after the corresponding operation is completed (e.g. quality inspection), an additional 10 points were offered. Points are used because they can turn user engagement into necessary activities for themselves (Farzan et al. 2008). The members' final points were divided into four reputation levels (New bee, Worker bee, Busy bee, Super bee) and displayed on the owner's website. A good reputation has many

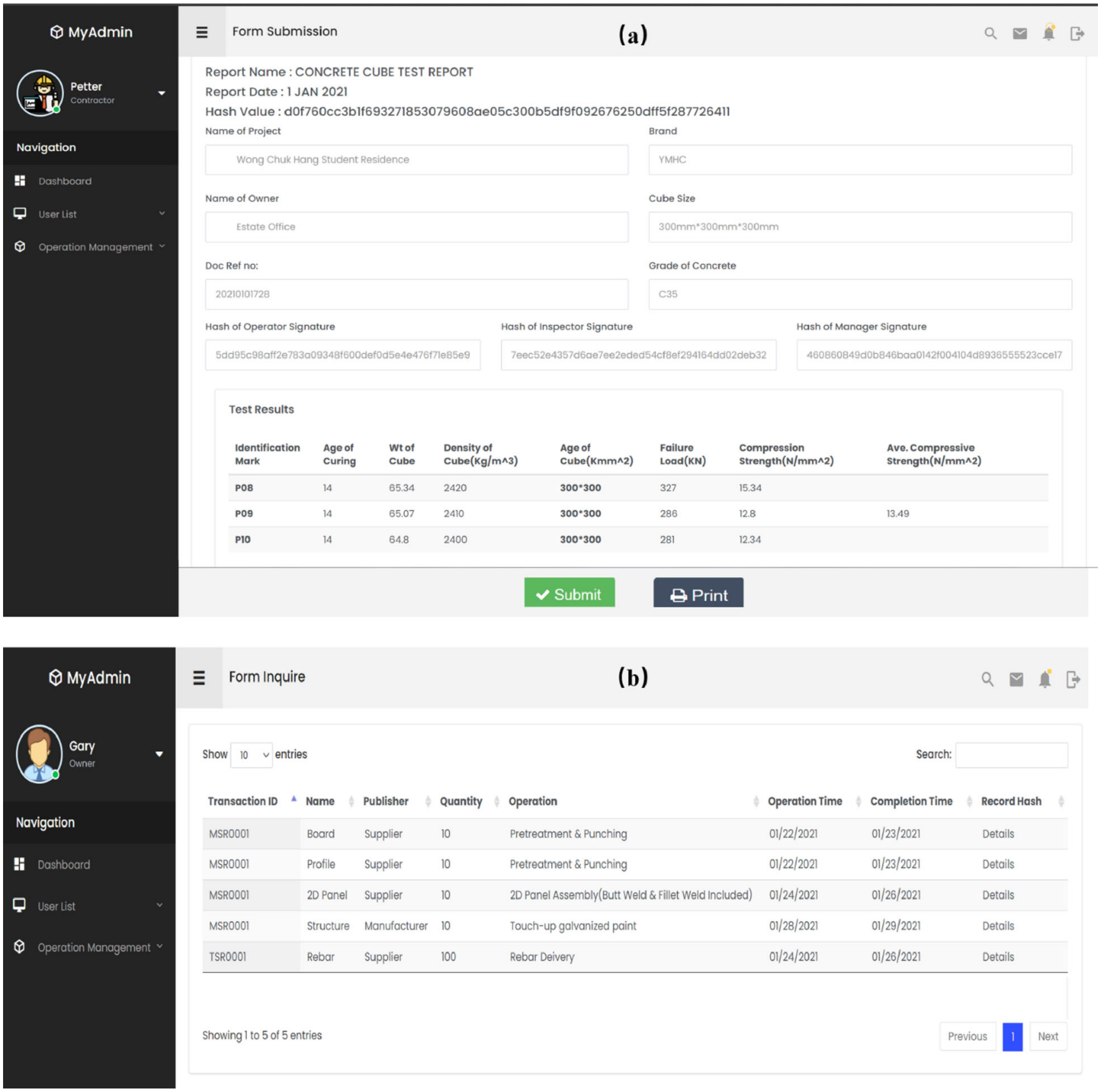

Figure 8. Prototype interfaces: (a) Contractor's interface for publishing transactions; (b) owner's interface for inquiring historical transactions.

advantages, including more business opportunities and cost-free advertising (Huang et al. 2021). The incentive mechanism was also incorporated with financial incentives. According to Marteau et al. (2009), financial incentives can improve participant attitudes. In this case, every point earned by the members was exchanged for one dollar from the owner.

The development of frontend and backend prototypes

The supervision processes were implemented on Hyperledger Fabric (version 2.2). Hyperledger Fabric is an enterprise-grade permissioned distributed ledger framework for developing solutions and applications. Javascript was used to write smart contracts (a group of smart contracts is called chaincode in Hyperledger Fabric). The prototype includes the owner, contractor, manufacturer, and material supplier. Figure 6(a) shows the configuration information of these participants. As shown in Figure 6(b), cryptogen was used in Hyperledger Fabric to issue certificates, such as admincert (for each member's administrator), cacert (for CA authorization), and tlscacert (for establishing secure connections), allowing participants to become members. The determined private data definition was written into the access control function named "endorsementPolicy" in Hyperledger Fabric to realize the publish-inquire interaction (Figure 6(c)). Moreover, to initialize the ordering service, the blockchain's genesis block was configured, as shown in Figure 6(d).

In this case, frontend and backend prototypes were developed by utilizing SpringBoot (ver. 2.4) and AdminLTE (ver. 3.0) for each member, comprising frameworks, tools, and components, as presented in Figure 7(a). AdminLTE is a frontend framework, which provides standard components for rapid development. Springboot is a Java-based backend framework for developing a database management system. Also, Hyperledger Explorer was used to visualize the details of the blockchain, as shown in Figure 7(b).

Figure 8(a) and (b) demonstrate the user interfaces for operation transaction publishing and inquiring. For example, after the production operation of fixing steel bars and pouring concrete, the inspection report of the concrete cube test was submitted to the blockchain, as shown in Figure 8(a). The report was converted into a JavaScript Object Notation (JSON) file through a JSON form plug-in and then encrypted by a hash algorithm in the blockchain network. After reaching a consensus, the operation transaction of this report was updated to the latest block. The inquiry interface in Figure 8(b) demonstrates that each member's historical transactions can be traced, thereby building trust between members. Members can check the corresponding block details by clicking on one of the transactions.

Discussion

Traditionally, normative trust-building strategies are used to nurture trust. When one strategy does not work, more strategies are introduced. Numerous normative trust-building strategies have been introduced to the construction industry (Wong et al. 2008), but due to their questionable effectiveness, fatigue towards them is widely witnessed (Qian and Papadonikolaki 2020). Conversely, naturalistic trust-building accepts untrusting behavior as human nature. People do their due diligence to avoid or deter opportunistic behaviors and encourage choosing trust as an ideal state. Blockchain as a naturalistic trust-building strategy is like a breeze drifting into this fatigue. This study sketched a normative vs. naturalistic trust-building spectrum and positioned blockchain as a naturalistic trust-bearing technology in the spectrum. That said, it does not mean the two strands of trust-building strategies should be mutually exclusive. Instead, managers can still choose to establish a good relationship, encourage disclosure of complete information, and formulate amenable institutions or other normative strategies on top of a blockchain-based trust-building system.

This research shows the great potential of blockchain in rebuilding trust in an AECO setting. However, there is a long way to go before blockchain is mainstreamed in construction. The technology is developed from a general computer science background. It adopts a unique set of terminologies and system architectures, which are less accessible to laymen and construction practitioners. During this research, our industrial partners showed some initial interests, mainly owing to the hyper boost from the public media. However, most of them did not have the in-depth knowledge or the time to explore it further. How to engage both the blockchain and construction professionals is key to its success in this unique industry. Increasingly, researchers are exploring BIM and blockchain integration. For example, Xue and Lu (2020) have developed an original approach to host BIM, the construction information hub, in blockchains by minimizing the information redundancy in BIM. Our engagement with the industry discovered a sensible strategy to treat BIM as a frontline while blockchain as a backend database technology instead of hard selling the complicated blockchain terminologies and architectures.

The case study showed that the deployment of blockchain is relatively flexible. It can be used either in a particular stage or throughout the project lifecycle. It can serve all or a specific set of stakeholders (e.g. clients, contractors, or suppliers). It can help rebuild trust in particular fields (e.g. inspection) or a broader range of transactions related to AECO. Nevertheless, there is a significant research gap to test blockchain in the construction industry. In order to move from rhetoric to reality, many research works are still needed. For example, prior studies usually rested blockchain on a long-lasting organization with numerous stakeholders involved in it. What is an ideal blockchain structure (e.g. one-layer, two-layer, or others) for an AECO project? Some of the information is a commercial secret that must be respected and not distributed to other blockchain members. What type of incentive mechanisms can be better integrated with blockchains? All these questions related to blockchain in projects need to be answered.

Despite these advantages, this study still faces limitations from the following aspects. First, the performance of the framework is not quantitatively tested in the case study. Future research can establish an evaluation model to measure the performance of blockchain in trust-building in the construction industry. Second, the smart contract in the proposed framework is only used for the block ordering process. Studying how smart contracts can help build trust by improving payment certainty and efficiency can be carried out in future research. Third, the proposed incentive mechanism is not evaluated in the study. Future research can explore the dynamic incentive mechanism for blockchain users. Finally, the proposed framework cannot ensure that it helps users build trust in the off-chain world. Future studies can focus on quality assurance technologies and blockchain "Oracle" to bridge the physical- and cyber-worlds.

Conclusions

Trust is of paramount importance to AECO. Numerous strategies have been proposed to build trust but it remains rare and vulnerable in this heterogeneous industry. Blockchain is gaining attention for its ability to rebuild trust to facilitate AECO transactions but it remains rhetoric. This study tried to demystify the technology by proposing a normative vs. naturalistic trust-building spectrum and positioning it in the spectrum. It is discovered that blockchain has broad prospects, which can enhance trust in the construction industry through distributed consensus, smart contract execution, encryption algorithms, and distributed ledgers, thereby enhancing transparency, efficiency, and equity. An interesting finding is that blockchain adopts a set of unique terminologies and system architectures, which may not be readily accessible to AECO practitioners; to treat it as a decentralized and distributed database technology and link it to the popular term of BIM is a promising approach of demystification.

This study contributed a framework for interested users to deploy their blockchain-based trust-building systems. The deployment framework has two parts. One is to delineate the potential of blockchain in serving project lifecycle, its associated stakeholders and pertinent AECO applications. The other is to probe into the system architecture of an applicable blockchain system. Typically, five layers including BaaS, Semantic, Consensus, Data, and Network, are organized in the system architecture. The framework was further prototyped and demonstrated through a case study: modular construction off-site production. The result shows that practitioners can use the proposed framework as a guide to plan their blockchain-based solutions to build trust in construction.

Gaps and misunderstandings exist in the deployment framework and the broad field of trust-building using blockchain. Future research is recommended to develop an evaluation model to measure the performance of blockchain in trust-building in the construction industry. Besides, investigating how smart contracts can help build trust by improving payment certainty and efficiency can be carried out in the next step. In-depth investigations of the incentive mechanisms are also expected. Notably, there is a misunderstanding that blockchain can guarantee the genuineness of information before it enters the blockchained cyber-world. More studies on quality assurance technologies and "Oracle" to bridge the physical- and cyber-worlds are expected. Finally, one should not rely solely on technology to build trust in the industry. Other normative trust-building strategies and amenable institution arrangements should also be devised to harness its power.

Disclosure statement

No potential conflict of interest was reported by the authors.

Data availability statement

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request (Blockchain prototype code).

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