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BLOCKCHAIN-ENABLED CONSTRUCTION CONTRACT ADMINISTRATION: A PRACTICE-ORIENTATED REVIEW

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ABSTRACT

Construction contract administration (CCA) is key to construction projects. Ineffective CCA is at the root cause of many of the industry's disputes. Blockchain may offer necessary features for improving CCA. However, no review of blockchain's potential against all functions of CCA exists. This study adopts a systematic review of relevant work, which is classified using a multifunctional approach to CCA. The findings reveal that existing research has focused on financial management whilst disregarding practice-based challenges. The study informs contracts policymakers and practitioners by showing how blockchain may revolutionise CCA, and establishes future research directions for researchers.

INTRODUCTION

The construction contract administration (CCA) process performs various functions across the contract life cycle to protect contractual rights and ensure the fulfilment of contractual obligations (Gunduz and Elsherbeny, 2020). Effective CCA is essential for achieving project success for contracting parties. However, ineffective CCA continues to be one of the biggest challenges encountered in the construction industry (McNamara and Sepasgozar, 2021).

The causes include: (1) misapplication of contractual provisions, and (2) deliberate negligence and refusal to operate contractual provisions (Peters et al., 2019), (3) ineffective communication and inaccurate documents (Abdul-Malak and Abdulhai, 2017), (4) inaccessibility to contemporary records (Ali et al., 2020), and (5) unclear roles and responsibilities (Khalef et al., 2021).

Blockchain technology is an emerging digital innovation that can offer the necessary features required for preventing or lessening the occurrence of these causes. Blockchain provides traceability, immutability, security, and decentralisation of digital records (Nawari and Ravindran, 2019a). Its resultant benefits to contracting parties include enhanced auditability, accountability, transparency, communication, and clearly defined roles and responsibilities (Li et al., 2019).

Recent research studies have demonstrated the potential of leveraging blockchain in tackling common challenges encountered in construction projects. For example, a blockchain-based document management framework to tackle document fragmentation was proposed by Das et al. (2022); an on-site quality management prototype to address problems arising from quality-related records was developed by Sheng et al. (2020); and a blockchain-based system demonstrated promising schedule performance monitoring was evaluated by Wang et al. (2020). To overcome payment-related issues in construction, several blockchain-enabled payment systems have been proposed (Ahmadisheykhsarmast and Sonmez, 2020; Chong and Diamantopoulos, 2020; Das et al., 2020; Hamledari and Fischer 2021a).

Another line of research has provided systematic reviews to consolidate individual research studies undertaken within the construction industry. For instance, studies conducted by Kiu et al. (2020) and Li and Kassem (2021) both identified that construction contract administration (CCA) could be improved by exploiting blockchain technology.

Despite the availability of these review studies and their contribution to the broad body of knowledge, there is a need for more focused work on specific blockchain applications; in this case, its contribution to improving CCA. Hence, the aim of this review study is to classify reported blockchain applications according to the multifunctional approach of construction contracts and discuss these classified studies from the perspective of challenges encountered in CCA practice.

CONCEPTUAL BACKGROUND

CCA functions

Contract clauses and provisions can be classified through a multifunctional analysis approach according to their functions (Gunduz and Elsherbeny, 2020). Construction contract administration (CCA) can be considered as serving three functions at an inter-organizational level (Chen et al., 2018) and eleven functions at a project level (Gunduz and Elsherbeny, 2020) as shown in Table 1.

Blockchain and smart contracts

Blockchain is the underlying distributed ledger technology (DLT) that underpins the operation of the Bitcoin cryptocurrency network (Nawari and Ravindran, 2019a). A blockchain records transactions and validates digital events (e.g., information) conducted in the network in the form of encrypted blocks and chains the entire recorded transactions chronology stored across multiple nodes (Das et al., 2020). Blockchain operates on three

core components: cryptography, consensus mechanisms, and decentralization (Li et al., 2021) that support: traceability of data transactions, immutability of data records, disintermediation to oversee transactions, and smart contracts execution. A smart contract is an automated protocol of coded instructions that self-execute upon the fulfilment of pre-determined conditions. The automated execution of conditions is enabled by rules-based operations (e.g., If/Then/Else/Otherwise) consistent with paper-based contractual rules (Mason, 2017).

Table 1: CCA functions

Inter-organizational Level	Project Level
Coordination-oriented functions	• Document and record management. • Communication and relationship management. • Team management. • Contract closeout management.
Control-enabled functions	• Financial management. • Performance monitoring and reporting. • Quality and acceptance management. • Project governance and start-up. • Changes and changes control management.
Adaptation-based functions	• Claims and disputes resolution management. • Contract risk management.

Related work and point of departure

Within the construction research domain three systematic reviews have been undertaken to consider individual blockchain-based solutions. Table 2 summarizes these and identifies the limitations of each within the context of the present study. These studies focused on the broad application of blockchain in improving the performance of various processes (including CCA) associated with construction and the built environment at large. However, a conceptual understanding of how blockchain may improve CCA does not exist. Hence, this review study attempts to bridge this knowledge gap, thereby contributing to revolutionizing construction contract administration through blockchain-enabled digitalization. To achieve this, the following research question (RQ) is proposed:

RQ: How can the state-of-the-art of blockchain-based applications be leveraged to improve construction contract administration?

RESEARCH METHODOLOGY

The multistage approach to a systematic literature review (SLR) (Kitchenham et al., 2009) was chosen for this study (Figure 1). Scopus and the American Society of Civil Engineers (ASCE) Library were chosen as two of the largest databases of scientific research available. The search strings used are shown in Table 3. Applying the inclusion and exclusion criteria (Table 4) resulted in the classification of 21 studies, which are presented and discussed in the next section.

Table 2: Previous relevant systematic review studies

Author/Year	Focus of Study	Limitation
(Kiu et al., 2020)	Identifying potential areas in construction that can leverage blockchain applications.	• Contract administration was identified as a potential application from a trust and payment lens. • The study suggested blockchain application in simple relational contracts.
(Scott et al., 2021)	Investigating evolvement of blockchain-related studies in the built environment across various areas.	• No reference to possible blockchain-enabled contract administration during the construction phase. • Blockchain-enabled payment was classified under procurement and supply chain.
(Li and Kassem, 2021)	Classifying existing blockchain-based studies specifically to the construction sector.	• Contract administration was identified as a potential area that could leverage blockchain capabilities; however, this was not sufficiently covered.

Table 3: Search strings for selection of papers

SCOPUS: TITLE-ABS-KEY (((blockchain OR dlt OR "distributed ledger" OR "hyperledger fabric" OR "smart contract*" OR chaincode*) AND (bim OR "building information model*" OR "building information manage*" OR "built environment" OR "construction procurement" OR "construction project*" OR "construction stage" OR "construction phase" OR "construction industry" OR "construction sector" OR aec OR "contract administration" OR "contract management" OR "construction manage*" OR "project manage*" OR "project lifecycle" OR "infrastructure project*" OR "civil engineering")))

ASCE: (“blockchain” OR smart AND contract*” AND “construction industry”)

Table 4: Inclusion and exclusion criteria

Inclusion Criteria	Exclusion Criteria
1. Academic journal studies published from emergence of the topic in 2016 to date. 2. English language studies. 3. Studies that focus on the construction phase or performance of the built asset regarding defects. 4. Studies that have proposed at least a framework, and/or proof-of-concept simulation.	1. Academic review and conference studies. 2. Studies that are irrelevant to construction contracts. 3. Studies that explore how blockchain may address BIM limitations (e.g., security and interoperability). 4. Qualitative studies without proposing at least a framework. 5. Replicated studies the ideas of which are published by the same authors in different journals. 6. Studies where blockchain is discussed only in the conclusion.

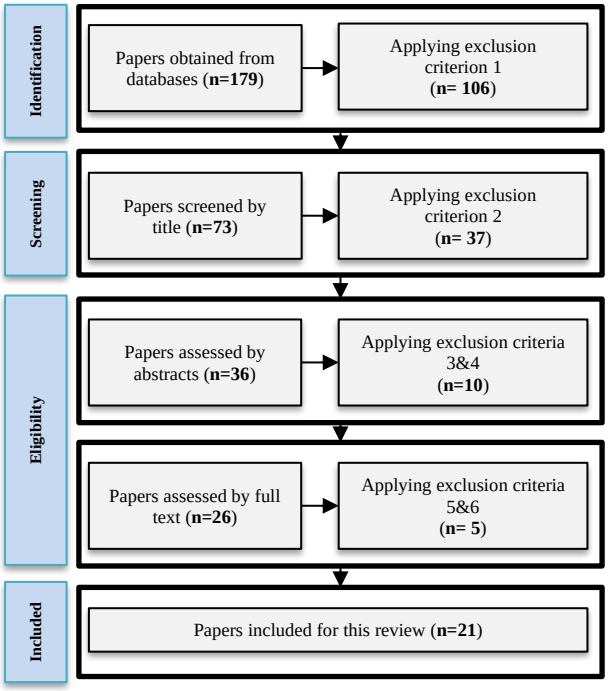

Figure 1: SLR process

BLOCKCHAIN STUIDES ACROSS CCA FUNCTIONS

This section classifies and describes the outcomes of the resulting 21 studies according to the CCA functions identified in Table 1. A brief description of the challenges associated with each of these functions is introduced. Then, the outcomes of the included relevant blockchain studies are described. If no direct application/study could be mapped to a given CCA function, other relevant studies are referred to. Finally, the applicability of the studies is discussed as appropriate under each function.

Classifying blockchain applications across coordination-oriented functions

Document and record management

Construction projects are widely recognized to suffer from the unstructured nature of and unavailability of documents and records. Four blockchain-related studies addressed this issue. Ciotta et al. (2021) developed a proof-of-concept (PoC) for structural system-related documents of building projects stored across multiple fragmented stakeholders to prevent the exchange of incorrect file versions. Erri Pradeep et al. (2021) developed and evaluated a prototype to facilitate traceability of design information exchange concerning request for information (RFI)-related documents and defect-related responsibility. To overcome the challenge of blockchain's limited capacity to store large files, Tao et al. (2021) integrated blockchain with the Interplanetary File System (IPFS). Das et al. (2022) demonstrated a blockchain-based decentralized document management prototype was able to prevent alterability, accessibility denial, and incorrect revision history of documents.

From these studies, it can be inferred that blockchain could improve this CCA function both during and post construction. For example, blockchain addresses the issue of separate documents (e.g., emails, minutes of meetings, confirmation of verbal instructions) involved to conclude a response to an RFI and its subsequent execution. It also reliably facilitates information retrieval and document relocation without the need for reverification.

Communication and relationship management

Communication breakdown and poor working relationship management are widely recognized as problems in construction (Jelodar et al., 2016). Two studies demonstrated blockchain-based systems' ability to address this problem. Yang et al. (2020) employed a permissioned blockchain in a cladding material approval process for a building project. Their study demonstrated transparent communications among stakeholders as a result of immutable and accessible records to all stakeholders. Lee et al. (2021) reported enhanced efficiency of communicating decisions for essential actions among dispersed project participants.

Both studies reveal that blockchain-based platforms streamline stakeholder management and remove communication barriers at both inter-organizational and project levels. Blockchain-enabled smart contracts receive, verify, update, and record information in the form of immutable and transparent transactions. In turn, the recorded transactions are directly and automatically communicated to all stakeholders registered on the blockchain network according to pre-defined communication protocols.

Gaps in coordination-oriented functions

There were no papers identified for *team management* nor *contract closeout management*. Team management is an essential function of successful CCA to, for example, assign accountability and define roles and responsibilities; blockchain-based systems are believed to address both (Hunhevicz and Hall, 2020).

At the closeout phase, contracting parties perform a series of tasks to ensure that the project has achieved its intended purpose (e.g., the contractor carries out tests upon completion; the employer's personnel inspect the completed works to prepare for takeover). The associated contractual and practical tasks involve a high volume of documentation concurrent with coordination with key staff decoupled from the project. Implementing a blockchain-governed CCA would arguably contribute to a more successful contract closeout.

Classifying blockchain applications across control-enabled functions

Financial management

This CCA function serves and performs the contractual payment-related provisions dealing with the respective rights and obligations of both parties (Abdul-Malak et al., 2019). However, both parties often tend to misinterpret, misapply, deliberately neglect, or refuse to operate associated mechanisms and provisions to improve their financial position (Peters et al., 2019). Despite the availability of legal frameworks to enforce and manage

payments in construction, the issue persists (Hamledari and Fischer 2021a; Motawa and Kaka, 2009). Eight studies were identified proposing blockchain-based solutions with the aim of improving financial management and securing timely payment to contractors and the supply chain.

Das et al. (2020) argued that a blockchain-based framework could facilitate an interim payment cycle and secure timely payment. Ahmadisheykhsarmast and Sonmez (2020) evaluated a smart contract-based system to automatically transfer booked cryptocurrency from the employer's wallet to the contractor and subcontractors' wallets according to agreed terms. Their evaluation, based on practitioners' perceptions, revealed that current concerns about delayed payment may decrease but employer's direct payment to subcontractors may result in a loss of control over the supply chain. These perceptions align with findings reported by Tezel et al. (2021) who translated the payment mechanism governed by a Project Bank Account arrangement into a blockchain prototype and assessed its viability by a focus group that suggested employing BIM.

In line with this suggestion, BIM has been proposed to provide progress data of installed construction elements to the blockchain network by triggering smart contract-based payments to subcontractors (Chong and Diamantopoulos, 2020). The effectiveness of integrating blockchain with BIM was further demonstrated in real-life project-based research studies undertaken by Hamledari and Fischer (2021a; 2021b). In the same vein of integrating BIM as a digital oracle to feed the blockchain network with data for payment purposes, Sigalov et al. (2021) demonstrated a semi-automated model processed by connecting BIM containers with blockchain-based smart contracts for payment from employers to contractors. Unlike earlier-described studies that disregarded procurement routes, Elghaish et al. (2020) developed a permissioned blockchain-based financial framework specifically for construction projects procured through integrated project delivery (IPD).

The approaches reported here are believed to revolutionize current payment practices in the construction industry and improve the financial management function of CCA. For example, negligence to process and certify a subcontractor's payment will likely be visible since the blockchain system provides transparent and accessible information concerning responsiveness.

Performance monitoring and reporting management

Performing this CCA function efficiently and effectively is challenging when it is conducted manually, but digital technologies overcome this challenge (Elghaish and Abrishami, 2020). Although BIM-based project performance monitoring tools have been introduced to the industry, their fully intended benefits with regard to this CCA function have remained unrealized (Hamledari et al., 2017). This is due to reluctance to share information and frequent discrepancies of chronological records. Three blockchain-based studies considered how to tackle these issues.

A blockchain-based information model demonstrated an accessible and a traceable comparison between planned and actual progress of precast operations and delivery (Wang et al., 2020). As a response to both resistance to information sharing due to data privacy and inefficient performance reporting for off-site modular housing production, Li et al. (2021) developed a Two-layer Adaptive Blockchain-based Supervision (TABS) model using on-chain and off-chain networks. The model allowed each stakeholder to access traceable and immutable records relevant to monitoring and reporting while data irrelevant to the project were kept unshared. A recent study leveraged the potential of blockchain-based smart contracts to serve this CCA function post-construction (Hunhevicz et al., 2022). Accordingly, a use case was employed to a performance-based procured building project to monitor the thermal performance levels stipulated in the contract.

The above studies could be extended to perform this CCA function by leveraging blockchain capabilities for on-site construction activities, thereby eliminating the need to wait for the monthly progress reports to detect a performance-related problem.

Quality and acceptance management

To prevent or lessen the severity of defects due to substandard execution of work, contracts place obligations on contractors to conform with contract specifications. If a nonconformance occurs, contracts give rights to employers to reject completed work and issue a nonconformance report (NCR). However, recording and documentation of quality-related issues have been consistently reported as a problem on construction projects (Love et al., 2018). Two studies were identified that could improve this function.

Wu et al. (2021) presented a blockchain-based conceptual framework to secure and automate quality inspection records respectively through the immutability of blockchain and its smart contracts. In contrast, Sheng et al. (2020) deployed a prototype for a project quality management information system for the inspection of a cast-in-situ bored pile on a real-world project. The validation of the prototype demonstrated blockchain tackled fragmentation inherent in the information flow of quality acceptance and associated NCRs.

Both studies provide initial evidence to demonstrate that blockchain could be applied in construction projects to enhance the quality management function of CCA.

Project governance and start-up

During the project initiation phase, this function legally connects a given construction project with its ecosystem. For example, this connection is achieved through obtaining building permits prior to executing the contract plans on site. Nawari and Ravindran (2019b) proposed a blockchain-based conceptual framework for building permit application from local authorities. Such frameworks are believed to accelerate administrative

processes on new projects while providing timely notifications of necessary technical requirements demanded by relevant authorities.

Gaps in control-enabled functions

While no studies related to *changes and changes control management* were identified within the scope of this review study, it is important for both the employer and the contractor to control changes so they have minimal impacts on cost, time and quality of the project (Love et al., 2019). A blockchain-based system can streamline the process of a contractual change procedure which generally describes the mechanisms to manage changes. Since changes and accepted change orders rely on documents and communication, it can be argued that the studies identified earlier under these respective functions can be indirectly mapped to this CCA function.

Classifying blockchain applications to adaptation-based functions

Claims and disputes resolution management

As a given claim arises and evolves, the biggest associated challenge facing contracting parties is reported to be ineffective construction claim management (Abdul-Malak and Abdulhai, 2017). Therefore, a system that addresses this challenge is a dire need in construction contracts. Only one recent study has considered blockchain in the context of the claim management and resolution of disputes.

Saygili et al. (2022) offered a blockchain system as an alternative method for managing payment-related dispute resolution process transparently. This construction-specific system was reported to facilitate the assessment of dispute cases by people who understand construction workflow.

Blockchain-enabled claim and dispute management can support contracting parties in various ways. For instance, contemporary records required to substantiate a claim can be chronologically and immutably recorded on a blockchain-platform. Furthermore, the traceability feature of blockchain technology can assist forensic schedule delay analysis to a great extent. As a result, quantification of an extension of time claim can be achieved within a shorter period compared to the current conventional manual process. At the extreme level, the recorded documents and chain of evidence can serve dispute resolution boards and expert witnesses without the need to re-verify the dispute-related documents.

Contract risk management

Risks are identified and allocated between the employer and the contractor via the conditions of contract agreed upon between parties. This identification and allocation lays the foundation for an appropriate response as soon as a given risk materializes during the contract period (Fawzy et al., 2018). This CCA function can be indirectly mapped to other studies reviewed under *communication and relationship management* and *document and record management* functions and, therefore, it can leverage the same reported benefits offered by blockchain.

DISCUSSION

This study aimed to answer the following research question: *How can the state-of-the-art of blockchain-based applications be leveraged to improve construction contract administration?* A classification of the state-of-the-art of blockchain applications according to the CCA functions was created using a narrow SLR approach. The review revealed that only seven of the 11 project-related CCA functions (Table 1) have received attention in blockchain applications within the construction research domain.

With a desired incremental progression toward a digitally-based CCA centred on optimizing construction contractual mechanisms, enhancing contractual control and increasing CCA efficiency (McNamara and Sepasgozar, 2021), it is easy to observe how the unique characteristics of blockchain presented in the reviewed applications prevent or lessen the likelihood of the occurrence of ineffective CCA causes. Given that CCA functions synergistically intersect with one other to holistically serve effective CCA, a complete integration of these scattered reported applications will likely result in realizing a digitally-based CCA, the core of which is formed by blockchain technology. For instance, the studies described under the *communication and relationship management* and *document and record management* functions, can be indirectly linked to the *claims and dispute management* function, which received attention only in one recent study that concerned payment-related disputes. Given the fact that this function operates by reliance on documented evidence and verified chronological records coupled with multilayer communication, a blockchain-based platform oriented towards claims and disputes resolution management is believed to improve this function. However, this is complicated by the fact that various claim types demand different documents and records in addition to multilayer communication among the actors involved.

Given that blockchain is still in its exploration stage within the construction research domain, the valuable and insightful contributions presented in the reviewed studies will likely face challenges. The following offers seven common challenges viewed through a practical lens.

First, ‘cash farming’ is a challenge that was disregarded in the line of research concerning blockchain-enabled payment studies. Kenley (1999) describes ‘cash farming’ as a cashflow management practice adopted by main contractors that enables them to utilize the supply chain’s money. This practice is made contractually binding by stipulating prolonged payment terms in signed agreements. Supply chain actors tend (willingly or unwillingly) to accept this practice to maintain their business relations with main contractors. As a result, main contractors are likely to resist employing alternative systems. This challenge could be partially overcome by adopting a payment methodology that balances the required working capital needs of all actors (Motawa and Kaka, 2009).

Second, malfunction of the blockchain system can result in adverse contractual consequences to all parties. For example, it may lead to delayed payment to the contractor and delayed retrieval of records required by the employer. A corrective measure might be to revert to the conventional paper-based processing mechanism on a temporary basis. However, how the actions completed through this temporary measure would be subsequently incorporated into the blockchain system after solving the digital malfunction remains an area to be explored.

Third, the blockchain system and its smart contract lifecycle have been ignored in the reviewed studies given the embryonic nature of this research domain. The availability of records on the blockchain and the executability of smart contracts during defects liability periods seem to be a challenge. This challenge will likely be pronounced where off-chain and on-chain intersect. A future research direction to tackle this challenge is needed.

Fourth, converting the logic of contractual provisions into a self-executing smart contract is likely to be the most pronounced challenge. Contractual provisions forming a specific mechanism are generally scattered across the contract documents. Such scattering can be found in the payment-related provisions stipulated in FIDIC contracts where provisions interact and complement each other. Thus, ensuring that the encoded smart contracts would produce the exact contractual outcomes over the whole payment cycle (from the advance payment to the final payment) is essential, but as yet, unresearched.

Fifth, in the reviewed blockchain-based studies there was a notable disregard for common procurement routes and contractual frameworks. With the exception of the publication (Elghaish et al., 2020), no study identified or defined a procurement route and contractual framework. To overcome this challenge, exploration of how to align blockchain-based applications with existing procurement routes and standard forms of contracts is suggested. This can be achieved by considering the role played by contracts policymakers in the adoption of such innovative solutions in future research efforts. Such research direction is likely to increase the usability of blockchain applications in practice as construction projects are generally governed by conditions of contract (for example, FIDIC or NEC) that have been drafted and developed over time by contracts policymakers.

Sixth, since a contractor is expected to execute the work items in line with employer's requirements stipulated in contracts by allocating resources and taking performance-related risks, the acceptance of implementing a blockchain-based platform needs to be obtained from this party. This is a challenge as blockchain is still in its exploration stage in the construction research domain. To accelerate acceptance of this party with a focus on subsequent adoption and implementation, contractors need to be consulted and involved in the development of such systems. Among the 21 reviewed studies, only two studies reported on evaluating the acceptance of practitioners, including contractors, on the developed blockchain-based prototypes (Ahmadisheykhsarmast and Sonmez, 2020; Tezel et al., 2021) while other studies evaluated the proposed prototypes in controlled environments. Thus, involving and valuing the contractors' roles in future research efforts will likely overcome the acceptance challenge in the adoption stage.

Seventh, the accessibility mechanism of blockchain-based systems to dispute resolution boards (e.g., arbitration tribunals and courts) was overlooked in the proposed applications. Therefore, a blockchain protocol encompassing this coupled with the admissibility of the blockchain records without further verification needs to be unearthed in future research efforts.

The above elaboration provides a narrowed yet new perspective on the likely challenges that may decelerate the adoption of blockchain-based CCA. These narrowed challenges resonate with the challenges identified from a broader perspective by (Hamledari and Fischer, 2021a; Li and Kassem, 2021; Tezel et al., 2021; Wu et al., 2021).

CONCLUSIONS

A systematic review was conducted to establish how the state-of-the-art of blockchain-based applications can be leveraged to improve construction contract administration. To achieve this, blockchain research studies were mapped across the multifunctional approach of CCA from a practice perspective. The review revealed most studies have been focused on the security of payment aspect of the financial management function of CCA while document and performance management functions, for example, received comparatively less attention. Various blockchain frameworks and PoC simulations have been developed that can prevent or lessen the occurrence of causes behind ineffective CCA through exploiting the blockchain unique characteristics of immutability, traceability, and smart contracts. Despite the significant efforts observed in the last two years, the full potential of blockchain technology for enabling digital CCA in construction projects is yet to be realized.

Penetrating these classified research efforts while reflecting on practice resulted in the identification of future research directions to address several challenges. Of note is that protocols should be developed to include temporary corrective measures to respond to malfunctioning and define the smart contract lifecycle.

This study carries implications for contracts policymakers (e.g., FIDIC Task Groups) and practitioners by raising awareness of the applicability of blockchain in addressing a specific issue arising from a given CCA function. In practical terms, the study provides an up-to-date reference point for enhancing knowledge of contracts policymakers and practitioners.

Contribution to the academic body of knowledge was realized in two ways. First, classification of blockchain applications according to the multifunctional approach of CCA serves as a response to calls by McNamara and Sepasgozar (2021) to enable incremental progression towards a digital CCA. Second, it established a relationship between the scattered research efforts and the

CCA functions to demonstrate that causes of ineffective CCA can be addressed with the outcomes of these efforts.

Given the initial evidence demonstrated by this review, it can be inferred that the way forward with blockchain-enabled CCA can start with demonstrating blockchain capabilities to improve claim management and accelerate claim determination. The need to improve this function of CCA lies at the heart of both the employer and the contractor's interests.

Future research on blockchain-based CCA should be extended to address procurement routes (e.g., design-bid-build, design-build). This study can serve as a point of departure for these future investigations.

Finally, this study has highlighted that the roles played by policymakers of standard forms of contract and main contractors had been ignored in the reviewed blockchain-based applications. It is therefore suggested to include perspectives of such parties in future research efforts. This would arguably drive adoption by helping to ensure balanced benefits for all actors involved in shaping the construction industry while improving the operationalization of procurement and contractual frameworks devised by policymakers.

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