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A CONCEPTUAL FRAMEWORK FOR LEAN CONSTRUCTION AND BLOCKCHAIN SYNERGY

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ABSTRACT

Blockchain is a distributed ledger technology referring to decentralized databases existing across multiple locations and participants, in which the need for intermediaries to process, validate or authenticate transactions is reduced or eliminated. Such transactions are synchronously held by computer nodes in distributed copies, with cryptographic signatures validated through consensus protocols and transparency achieved through peer-to-peer transactional access among the nodes. Blockchain-based applications can be preferred over centralized databases on the basis of high levels of trust, data security, immutability, transparency, and multi-user consensus protocols. There is growing interest in blockchain in the built environment, with a focus on procurement, the management of supply chain project-life cycle, smart cities, intelligent systems, sustainability, and decentralized organizations. However, there is little discussion on whether and how blockchain will affect the advances in lean construction (LC) and vice versa. This paper therefore proposes a framework that establishes interactions between blockchain and lean construction, which can potentially facilitate the implementation of both. It is based on a synthetic literature review. The results indicate that blockchain can facilitate the implementation of LC (e.g., recording and retrieving of Last Planner data), and vice versa (e.g., value stream mapping guiding the integration of blockchain with processes).

KEYWORDS

Lean construction, distributed ledger technology, blockchain, smart contracts, framework, synergy.

INTRODUCTION

Distributed ledger technology (DLT) refers to a database decentralized across multiple locations and participants, reducing or eliminating the need for a central authority to

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process, validate or authenticate transactions (i.e., data exchange between multiple parties for different purposes) (Li et al., 2019). Fundamentally, DLT transactions are synchronously held by computer nodes in distributed copies with cryptographic signatures validated through a consensus protocol, with peer-to-peer (P2P) transaction access (transparency) between the nodes (Li et al., 2019).

When high levels of trust, data security, immutability, transparency, and a multi-user consensus are sought, DLT applications can be preferred over centralized databases. Typical examples of these applications are smart (automated) contracts, or digital tokens denoting a value or ownership (Scott et al., 2021). A popular type of DLT is blockchain, introduced with the cryptocurrency Bitcoin by pseudonymous author Satoshi Nakamoto (2008) – where transactions are recorded as a chain of data blocks linked with one another. The cryptocurrency is the token used to keep the system running and does not equate to blockchain (Nakamoto 2008). Key blockchain features are: (i) decentralization across a P2P network of computers (nodes), (ii) data immutability once the blocks are chained, (iii) reliability due to all nodes having the same copy that is checked through an algorithm, and (iv) a proof-of-work procedure that is applied to authenticate the transaction and uses a mathematical currency (Bitcoin) to reward the miners (nodes) (Nakamoto 2008). Since the initial Bitcoin blockchain, other algorithmic procedures have also been developed to tackle the authentication issue such as the proof-of-work, proof-of-stake, proof-of-authority, ripple protocol consensus, delegated proof of stake, stellar consensus protocol, and proof-of-importance (Wadhwa 2022). Since around 2015, blockchain-based applications have been intensively discussed from the built environment (BE) perspective (Xu et al. 2022), including the following topics: contract management, information management, project-life cycle management, stakeholder management, integration with other technologies (e.g., BIM and Internet of Things (IoT)), procurement and supply chain management, smart cities, sustainability, and decentralized organizations.

Lean construction (LC) refers to managerial principles and techniques adapting lean management from automotive manufacturing into construction (Tzortzopoulos et al., 2020). This is guided by key principles (e.g., waste reduction, variability continuous flow), and facilitated by certain tools (e.g., the Last Planner System (LPS), visual management) and management and procurement practices (e.g., relational contracts) alongside digital technologies (e.g., BIM) (Tezel et al., 2018). LC research and application have been expanding through research and practitioner communities since coining the term in the early 1990s, the most active being the International Group for Lean Construction (IGLC).

There are some common themes in LC discussions such as improving trust between stakeholders (Howell, 1999), enabling process transparency as a key LC principle (Sacks et al., 2009), automating non-value adding activities (Akinci et al., 1998), instilling continuous improvement through effective record keeping (Koskela et al., 2019), BIM and LC integration (Sacks et al., 2010), and adopting prefabricated systems (Bjornfort and Sarden, 2006), which as discussed in this paper, could potentially be facilitated by DLT. With LC's increasing adoption, LC's potential impact on DLT implementations in the BE is also worth exploring.

Despite the surging interest in DLT in BE, there is scarcely any discussion on the synergies between DLT and LC. This paper therefore aims at proposing a framework of interactions between DLT (and specifically, blockchain) and LC, and outlining its synergistic elements as the initial outcome of a broader research effort aiming at mapping and expanding on those interactions. Similar conceptualizations in different technology domains have proven beneficial in the past in terms of setting the research agenda (e.g., see Sacks et al. (2010) for BIM, or Rosin et al. (2020) for Industry 4.0 technologies).

LITERATURE REVIEW

Blockchain-related research started being contextualized within the BE context in 2015 (Cardeira 2015). Ever since, there has been a surging research interest focusing on the role of blockchain applications in the BE. However, up until 2018, such studies were mostly speculative and mainly featured high-level conceptualizations (Xu et al. 2022). It is primarily since 2019 that relevant studies have become more concrete, featuring more detailed concepts, developed frameworks, prototypes (Kifokeris & Koch 2020; Tezel et al. 2021; Xu et al. 2022), and some rare use cases (Kifokeris & Koch 2021).

Based on that evolution, the literature review was limited to the period between 2019 and 2022, being focused almost exclusively on journal articles. Given those criteria and considering the categorizations offered by key publications in the field, the main foci of blockchain applications within the BE are on contract management, information management, project lifecycle management, stakeholder management, intelligent systems and integrating blockchain with other technologies (Xu et al. 2022), procurement and supply chain management (Kifokeris & Koch 2020; Scott et al. 2021; Tezel et al. 2021; Xu et al. 2022, Yoon & Pishdad-Bozorgi 2022), smart cities (Scott et al. 2021; Samuel et al. 2022), sustainability (Shojaei et al. 2019), and decentralized organizations (Scott et al. 2021, Tezel et al. 2022). Moreover, the industry report produced by Arup (Nguyen et al. 2019) divided the construction sector into five markets (cities, energy, property, transport, and water), and then presented the potential of blockchain in five subcategories in each market – e.g., smart cities integrated with the IoT (cities), energy microgrids (energy), sale and asset transactions (property), material passports (transport), and utility contracts and billing (water). In the same report, a technology readiness level for the development of blockchain applications corresponding to those subcategories was stated: almost all applications were at the level of concept or early prototype development, and commercialization were generally not thought to be achieved before 2025.

The common denominator of those studies is that the core properties of blockchain can add value to relevant business models, stakeholders' roles, organizations, and projects. These properties are: peer-to-peer transactions, process streamlining, and integration of the economic, material, and information flows through automation, smart contracts, record immutability, security through decentralization, consensus protocols, and reduction of the intermediaries' role (customized per case of implementation). Moreover, across the studies, the blockchain-related attributes are clustered around five epicenters: features (e.g., smart contracts), algorithms (e.g., proof-of-authority), permission levels (e.g., consortium), application fields (e.g., supply chain management), and technology integration (e.g., with BIM) – see Fig. 3. While concerns about the technology have been raised (e.g., its interoperability with other digital and cloud technologies, the available margins for a return on investment, long-term technology implications and needs, and a lack of legal and business frameworks) (Li et al., 2019), the potential of blockchain renders the predictions for commercialized systems for the BE feasible by 2025, with new implementation pilots reported at an increasing pace by practitioners and researchers.

Notably, some studies (e.g., Li et al., 2019; Kifokeris & Koch 2020; Tezel et al., 2022) have indicated the importance of properly contextualizing blockchain for addressing key contemporary issues faced by the BE (e.g., sustainability, affordable housing, trust, transparency), as well as potentially integrating the technology with other frameworks and domains in order to meet long-standing industry needs. In this study, the context and potential for integration is set on the interactions with LC, which can act as a project management backbone in improving construction productivity, quality, and delivery of value to clients and end-users in the BE (Tzortzopoulos et al. 2020). However, studies on integrating blockchain and LC are scarce and fragmented. In that vein, Alonso et al. (2019) proposed a digital twin platform where smart contracts (automation of contract execution) could be used for reducing production time based on lean management concepts and principles. Dakhli et al. (2019) postulated that LC tenets can aid in precisely defining construction production tasks needed for the correct development of smart contracts. Di Giuda et al. (2020), and McNamara and Sepasgozar (2021) explored the use of blockchain for an LC-induced reduction of process fragmentation while executing contracts. Li et al. (2021a,b), designed a framework for a blockchain- and IoT-based smart product-service system tailored for prefabricated construction and off-site manufacturing. Sbiti et al. (2021) conceptualized a blockchain-streamlined information transaction within a framework integrating BIM and LPS. Finally, Bolpagni et al. (2022) mentioned that blockchain properties can be integrated with LC principles to aid nonlinear project management and integrated project delivery. To outline those connections, LC is conceptualized here over four dimensions (see Fig. 2 later): (i) principles, (ii) managerial practices, (iii) procurement practices, and (iv) tools and techniques.

RESEARCH METHOD

The literature on LC and blockchain in the BE was reviewed to synthesize a novel, conceptual LC-blockchain interaction framework (Webster & Watson 2002). The main concepts were "lean construction", "digital ledger technology", and "blockchain". Units of analysis emerged along the literature review, including, indicatively, "project lifecycle" and "construction supply chains". Filters and Boolean operators were applied to seek the search terms throughout each publication.

To develop the framework, the insights gained from the literature review were utilized according to the abductive reasoning of qualitative research, in which conceptualizations are developed iteratively between theory and data (in the current study, data as research content) (Bell et al. 2019). Through abduction, critical reflections and insights were gradually developed in a cyclic way (Bell et al. 2019). In the same vein, the authors evaluated the conceptual framework elements based on the expected benefits and return impact of an interaction point that can inform LC-blockchain applications in the future.

CONCEPTUALIZATION: INTERACTION FRAMEWORK

The framework of interactions between LC and blockchain (Fig. 1) combines LC elements (Fig. 2), and potential attributes of blockchain implementation in construction (Fig. 3), into a schema of interaction elements (Fig. 1 and Table 1). Fig. 1 shows the two-way (from LC to blockchain and vice versa) synergy framework dimensions.

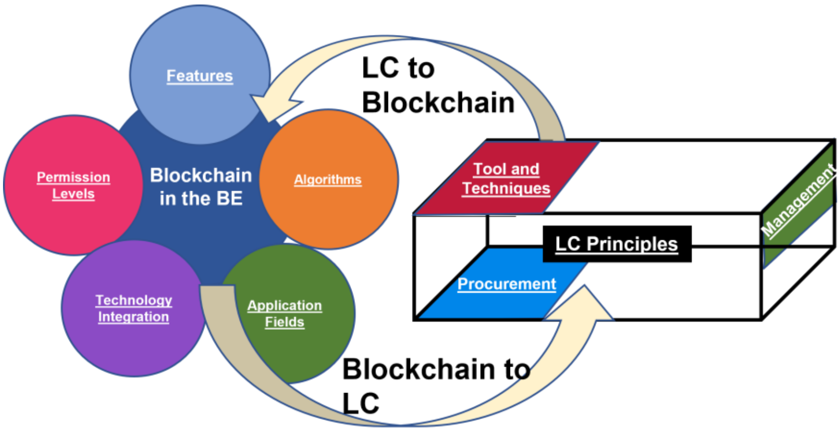

Figure 1: LC and blockchain synergy analysis framework

The cubic schema in Fig. 2 is expanded on and inspired by Thomsen et al. (2009). There are four types of elements, broadly covering the LC domain (Tzortzopoulos et al. 2020), having the LC principles in the middle surrounded by the supporting tools and techniques, managerial and procurement practices:

- LC principles, i.e., the core tenets and fundamental properties of LC. Those include a focus on customer value and the technology adding such value, reduction of waste, variability, batch size, cycle-time, and inventory, a push/pull-based control, increased transparency and flexibility, continuous improvement, standardized work, and others (Sacks et al. 2010).
- LC implications for construction management, incl. a modular and prefabricated systems strategy, supply chain management practices, engagement and investment in LC, Gemba walks, and Hoshin management (Dombrowski & Mielke, 2013).
- LC implications for procurement, incl. integrated project delivery, long-term relations, relational contracts, team- and trust-building and others (Ghassemi & Becerik-Gerber, 2011).
- LC tools and techniques, incl. LPS, visual management, 5S, TQM, BIM, Just-in-Time production, location- and Takt-based planning, PCDA and A3, value stream mapping, choosing by advantages, set-based design, and others (Tezel et al. 2018).

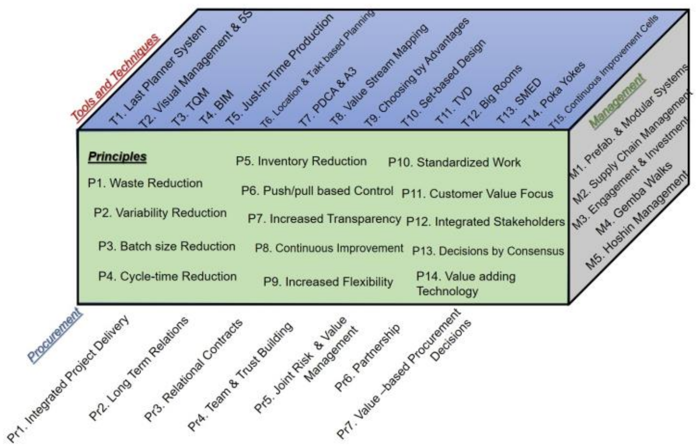

Figure 2: Cubic conceptualization of LC over Principles, Tools and Techniques, Management, and Procurement

Accordingly, the mapping in Fig. 3 is based on the content and insights offered by the reviewed blockchain-related studies. The potential attributes of blockchain implementation in construction are clustered around the following epicenters:

- Features, i.e., the core attributes of the technology. Those include digital distributed ledgers, crypto assets (incl. cryptocurrencies), throughput (processing rate), data storage and sequencing, interoperability and application programming interfaces (APIs), non-fungible tokens (NFTs), smart contracts and others.
- The algorithmic structure of the consensus protocols. Those include the proof-of-work, proof-of-stake, delegated proof of stake, proof-of-authority, proof-of-importance, ripple protocol consensus, and stellar consensus protocol algorithms.
- The permission levels indicating the blockchain's privacy settings. Sorted from the most open to the most demarcated systems, those include public, consortium, hybrid, and private blockchains.
- The construction sector fields where blockchain can be applied, including the management of contracts, information, design, production, project lifecycle, stakeholders, procurement and supply chains, energy, and water and others.
- Technologies that can be potentially integrated with blockchain such as BIM, IoT, intelligent systems, digital twin, digital building logbooks (DBL) and others.

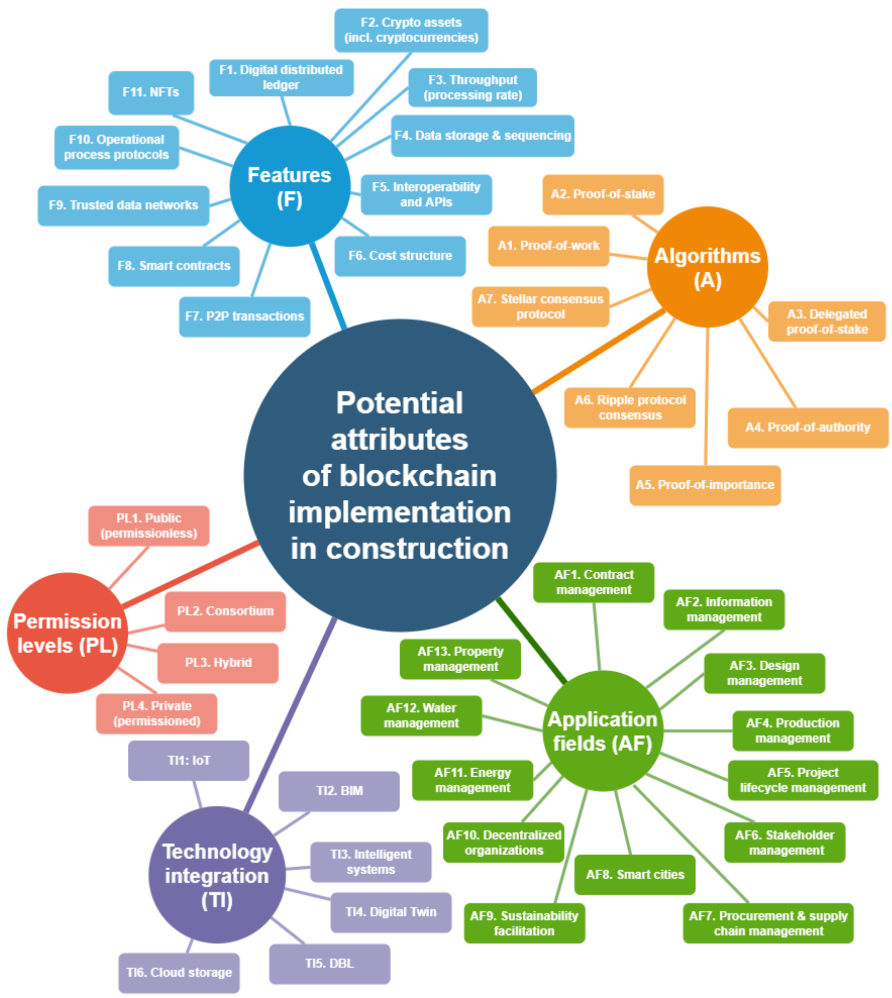

Figure 3: Potential attributes of blockchain implementation in construction

Table 1 explains the interaction between blockchain, and LC shown in Fig. 1, based on the alphanumeric coding used in Figs. 2 and 3. There are two main sections in the table; blockchain's potential contributions to LC, and LC's potential impact on blockchain. Some elements map against specific components (e.g., AF1) on Figs. 2 and 3, and some more general attributes (e.g., AF) covering all the corresponding subcomponents. Color coding was used to display the envisioned impact potential with explanations.

Table 1. Interaction between LC and blockchain

	Blockchain to Lean Construction		
No	***Explanation***	***Blockchain element***	***LC element***
1	Multi-attribute and multi-stakeholder contractual agreements supporting LC, such as IPD, relational contracts, and partnerships, can be facilitated through a trusted and decentralized blockchain network.	F1; F5; F7; F8; F9; A4; A7; PL2; PL3; PL4; AF1; AF6; AF7; AF10	Pr1; Pr3; Pr5; Pr6; P7; P12; P13
2	Blockchain can streamline platform processes in industrialized and modular construction, which feature a mode of production supporting LC. Prefab. material logistics, provenance, certification, manufacturing and sourcing related data could be recorded on blockchain	F4; F10; A2; PL4; AF2; AF3; AF4; AF7; TI3; TI6	M1
3	A blockchain-powered network of relevant stakeholders can be implemented across the supply chain, helping in its streamlining and waste reduction. Supplier certification, performance, guarantees, payment, approvals, and contract data could be recorded	F1; F4; F5; F7; F8; F9; F11; A2; A4; PL3; PL4; AF7; TI1; TI6	M2
4	Key hoshin targets and performance metrics for departments and teams could be recorded on blockchain.	F9; A3; PL4; AF2; AF5; AF10; TI3; TI5; TI6	M5
5	Key Last Planner data (e.g., PPC, constraint logs, phase, lookahead and weekly plan) for critical projects with multiple parties could be recorded on blockchain.	F1; F4; F5; F9; A4; A5; PL3; PL4; AF2; AF3; AF4; AF5; AF6; TI6	T1
6	Quality logs, documentation, certificates, and performance data for critical projects with multiple parties could be recorded on blockchain.	F4; F8; F9; A4; PL4; AF2; AF6; AF13; TI5	T3
7	BIM is an important enabler for LC. Some BIM management data (e.g., clash records, approval history, handover data, ownership, IoT sensor data and IFC code) could be recorded on blockchain.	F4; F5; A4; A6; AF2; AF3; AF4; TI1; TI2; TI4; TI5	T4
8	Data for logistic scheduled dates, responsibilities and material/component manufacturers could be recorded on blockchain for key materials/components.	F4; F5; F9; F10; A4; A5; PL3; PL4; AF4; AF5; AF7; TI1; TI3	T5
9	Continuous improvement data, such as responsibilities and targets for important efforts, could be immutably recorded on a blockchain.	F4; F5; F9; A5; PL4; AF2; AF5; TI3	T7; T15; P8
10	Critical CbA options and decisions could be recorded on a blockchain.	F4; F5; F9; A5; PL4; AF2; TI3	T9
11	Set-based-design development progress and decision-making points could be recorded on a blockchain.	F4; F5; F9; A5; PL4; AF2; AF3; TI3	T10
12	Adopting smart contracts on blockchain will partially automate contract execution, reducing mistakes, waste, and cycle times in those activities.	F8; A4; PL4; AF1; AF2; AF6; TI6	P1; P2; P4; T14
	Lean Construction to Blockchain		
No	***Explanation***	***LC element***	***Blockchain element***
1	Core LC principles and procurement-related tenets can inform the development of smart contracts, for an optimized value delivery to the contracted stakeholders.	P7; P9; P11; P12; P13; P14; Pr3; Pr4; Pr5; Pr6; Pr7; T5	F8
2	Core LC principles and procurement-related tenets can set a benchmark for data trust requirements when designing the blockchain framework.	P7; P13; M3; Pr2; Pr4	F9
3	Core LC principles and procurement-related tenets can inform the customization of the consensus algorithms, which will most probably support (quasi-) permissioned architectures.	P13; M3; Pr6; Pr7	A4; A5; PL3; PL4
4	Core LC principles and procurement-related tenets can inform a blockchain-powered contract management (e.g., in the consensus privileges held by the stakeholders in the network).	P12; Pr1; Pr2; Pr3; Pr4; Pr5; Pr6; Pr7	AF1
5	LC-inspired tools and techniques for design optimization can inform a blockchain-powered design management (e.g., on the choice of the design data to be stored in the blockchain).	T2; T4; T10; T11; T12	AF3
6	LC-inspired tools and techniques for production optimization can inform a blockchain-powered production management (e.g., on the choice of the production data to be stored in the blockchain).	T1; T5; T6; T8; T11; T15; P1; P2; P3; P4; P5; P6; P7; P8; P9; P10; P11; P12; P13; P14	AF4
7	Core LC principles and procurement-related tenets can inform a blockchain-powered stakeholder management (e.g., on the choice of the permission levels and implemented data security protocols in the blockchain architecture).	P11; P12; P13; M5; Pr2; Pr4; Pr6; Pr7	AF6
8	Core LC principles, procurement-related tenets, and procurement and supply chain-related tools and techniques, can inform a blockchain-powered procurement and supply chain management (e.g., when writing smart contract clauses).	T5; T9; P3; P4; P5; P6; P11; M2; Pr1; Pr2; Pr3; Pr4; Pr5; Pr6; Pr7	AF7
9	VSM could facilitate an effective blockchain technology and application integration with existing processes.	T8	TI; AF
10	CbA could be adopted to select blockchain technology integration, application, and permission levels for a project	T9	TI; AF; PL

Synergy Impact	***Higher***	***Medium***	***Lower***

DISCUSSION

The literature on LC is mature and diverse, and the academic output is also supported by information and accounts of best practices that are featured in, e.g., the Lean Construction Institute (LCI) websites or practitioner events around the world. As such, the content of the referred studies was aligned with the dimensions of the cubic LC framework (Fig. 2) in the most concise manner possible. By contrast, the literature on blockchain for the BE is nascent (though rapidly expanding, especially after 2019), and several related perspectives and aspects have not been fully investigated yet – let alone in connection to LC. Thus, while the blockchain mapping framework attempts to crosscut through the relevant studies by showing the connection between the depicted elements, it is evident that most attributes revolve around technological aspects that may only influence the BE tangentially – which indicates that the direction of blockchain research for the BE, which is presently technology-focused, should take a more pronounced sociotechnical, and even sociomaterial, turn.

When it comes to the interaction framework, it can be observed that its two mirrored dimensions (from blockchain to LC, and from LC to blockchain) are quite heterogeneous in terms of the quantity, content, and interconnections of the synergistic elements.

Considering quantity, there are quite a few recurring elements in both dimensions of the framework. Core LC principles and procurement tenets, blockchain features of data storage and retrieval, blockchain algorithms and permission levels pointing to more private (but still partially decentralized) structures with an established level of control, and a technology integration with more commercialized (e.g., BIM, IoT), rather than nascent (e.g., DBL), technologies are found in most instances of the interaction framework. This shows that the synergy between LC and blockchain can have specific elements in its core. As such, non-recurring elements that appear only on specific instances show a particularization of the two-way LC-blockchain interaction. Nonetheless, it is evident that more blockchain elements are generally matched to the respective LC elements in the "Blockchain to LC" dimension, rather than LC elements matched to blockchain elements in the inverse case. This may show a certain contextual "flexibility" of the blockchain elements, as well as their "materiality" as technology components, in their potential to facilitate LC. In comparison, the LC elements have a higher specificity.

Moving on from quantity, the analysis of the content of the synergies shows that blockchain can inform and facilitate LC on a largely technical basis – i.e., streamlining, digitizing, and decentralizing LC-supported tools, techniques, tasks, and processes in procurement, contract, and supply chain management in particular. As such, the theoretical and methodological contribution of blockchain to LC seems to be minimal, with the challenge placed mostly on properly fitting LC elements into specific blockchain architectures. On the other hand, LC can inform blockchain with the provision of core principles and tenets (mostly related to procurement), and in aspects such as design, customization, and appropriation of the blockchain attributes. This insight is aligned with the understanding of blockchain as a general-purpose technology (Kifokeris & Koch 2020) and its characterization as a contextually "empty cup" that needs to be filled – also in connection with construction. It is shown that some LC tools, such as CbA and VSM, can be practically used for, respectively, decision making and the integration of blockchain elements in existing processes.

Regarding the interconnections of the synergistic elements, it can be observed that some are bilateral (e.g., core LC principles, permissioned blockchain algorithms structures, and blockchain features mainly connected to data provenance, storage, and retrieval), while others are connected one-way. This shows that not all points of interaction between LC and blockchain are fully unambiguous and is probably connected to the aforementioned content analysis of the synergy – the nature of the elements' interaction is necessarily influenced by the content of their synergy.

For a more tangible LC and blockchain interaction discussion, a more dedicated contextual focus should be sought. Considering the global challenges that point to more resource-economic perspectives, such a contextual focus could be placed on the facilitation of circular construction – i.e., the contextualization of the circular economy concept towards sustainable construction (Ogunmakinde et al. 2022). This contextualization must address the key contemporary issues of the sector, while also accounting for meeting long-standing industry needs. As such, the circularity context can be provided by the UN sustainable development goals and the relevant problematization on how construction can become more circular (Ogunmakinde et al. 2022). As such, while the potential for interaction between blockchain and LC can be conceived to act as a fundamental factor in improving construction productivity, quality, and delivery of value to clients and end-users of the BE (Tzortzopoulos et al. 2020), this can also be taken up a notch by considering sustainability and circularity through a resource-economic lens.

The discrepancy between the maturity of LC research and implementation, and the nascency of blockchain perspectives and application for the BE, cannot be overstated. For a more streamlined synergy with LC, concerns, issues, hindrances, and barriers faced by blockchain implementation within the BE should be tackled – including its interoperability with other digital and cloud technologies, the available margins for a return on investment, and a lack of legal and business frameworks. In line with this, it is advised that the suitability of the opportunities identified in this paper should be justified by using a DLT decision-making framework – for example the framework developed by the World Economic Forum (WEF) (Mulligan et al., 2018) to avoid unnecessary implementations.

CONCLUSIONS

In simple terms, blockchain is a decentralized database and a form of DLT existing across multiple locations and participants, reducing the need for a central authority or intermediary to process, validate or authenticate transactions. The interest in blockchain in the BE has been soaring with many application opportunities identified recently. However, despite such an interest, to the authors' knowledge, there is no specific discussion of its potential interaction with LC. The objective of this paper was therefore to present and outline an initial effort for creating a detailed conceptual interaction framework between blockchain and LC.

Alongside the automation-related process benefits where necessary non-value activities such as contract control and execution, payment arrangements, validation of transactions and data records by external parties, blockchain holds the potential to support the required trust and transparency in LC applications in multiparty arrangements (e.g., IPD), which in the current narrative are more relational through contractual and social dynamics, with technology-induced trust and transparency. This does not however mean that it should replace the social and relational aspects of LC arrangements. LC on the other hand will help the technology to become more relevant for the needs of project management in the BE by shaping its features.

More specifically, the interaction framework shows that its two mirrored dimensions are quite heterogeneous in terms of the quantity, content, and interconnections of the synergistic elements. With the materiality of being a disruptive technology, it is evident that more blockchain elements are matched to the respective LC elements as facilitators. On the other hand, with respect to the content, LC can shape the blockchain elements by its principles, management and procurement dimensions and tools. Moreover, the interconnections of blockchain and LC in the framework of interaction show that not all synergy points are fully unambiguous with some being two-way and some one-way. To strengthen and operationalize the synergy between the two concepts, it is deemed useful to frame this synergy within a key contemporary challenge facing the BE. Sustainability, with a narrow definition around environmental sustainability or a broader definition containing social and economic elements, seems to be a suitable candidate for future efforts in that regard. Nevertheless, it is deemed necessary to further define and explore the two-way synergy between DLTs/blockchain and LC for the sake of Lean Construction 4.0, in which DLTs can be an important data recording layer.

This study's limitations are connected to its highly targeted rather than extended review of the literature, and the nature of the framework's conceptualization, which at this point is based only on the authors' understanding and synthesis. As such, recommendations for future work can include conducting a more detailed literature review, involving expert practitioners in not only expanding and updating the interaction framework empirically – but also in validating the framework itself through surveys and case studies. Moreover, we recommend commencing the development of blockchain architectures informed by LC, as well as LC implementation cases that include the utilization of blockchain. Establishing priorities among the multiple interactions on Table 1 presents another research opportunity. Exploring the LC-blockchain interactions from a TFV (Transformation-Flow-Value) perspective will be also useful.

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