7 Blockchain in the Construction Sector: A Socio-technical Systems Framework for the Construction Industry

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Abstract

Distributed ledger technologies (DLTs) including blockchain are increasingly being investigated as a potential solution to address many of the challenges hindering the construction industry's performance such as collaboration, information sharing and intellectual property rights. Existing studies addressing blockchain applications within construction and the built environment have ignored the interrelation of social and technological dimensions. To address this gap, this paper proposes a multi-dimensional emergent framework for DLT adoption within the construction sector. The framework was developed following a focus group discussion and took a socio-technical systems approach that encompasses three dimensions: political, social and technical. The framework was overlaid with an extensive set of construction-related challenges and opportunities and identified a number of associated agents across the dimensions. The structured and inter-connected dimensions provided by the framework can be used by field researchers as a point of departure to investigate a range of research questions from political, social or technical perspectives.

Keywords

Blockchain • Distributed ledger technology • Construction industry • Built environment • Socio-technical systems

7.1 Introduction

Technological advancements in the construction industry have been less effective in comparison with other industries such as logistics, automotive and mechanical engineering [1–5]. In the next 10 years, £600 billion will be spent on construction in the UK to improve infrastructure with efficiencies and productivity becoming strategic priorities in the sector for the UK Government [6]. Building Information Modelling (BIM) is the current expression of digital innovation in construction [7–9]. Blockchain is a possible enabler for ameliorating the issues of trust that often hinder collaboration and information sharing [8], both key to successful BIM projects. Blockchain is "*a peer-to-peer distributed ledger technology which records transactions, agreements, contracts, and sales*" [10].

The Blockchain, the first distributed ledger technology (DLT) introduced in 2008 alongside Bitcoin [11], is a verification tool for cryptocurrencies with the potential to be applied to other applications [12] and industries including, but not limited to health care [13], information sharing [14], information management, insurance, automated dispute resolution, real estate [15], crowdfunding [16], big data analytics [17], and education [18]. It has the "potential to benefit the economic, political, humanitarian, and legal sectors by reconfiguring the workings of society and operations" [13].

This paper aims to build on previous work by Li et al. [19] that explored the current level of research on DLT applications in the built environment through further development of its proposed emergent framework for DLT implementation. First, the paper explains key concepts underpinning DLT; second, an emergent multi-dimensional framework for DLT implementation in construction is presented; and third, the methodology for developing the framework is discussed.

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7.2 Distributed Ledger Technology (DLT): Key Concepts

A distributed ledger is simply a database of transactions. However, unlike those of a bank, which are processed and stored by one trusted, centralised organisation, transactions on DLT are processed and stored across many different (hence, decentralised) computers, known as nodes, replacing *trust* with *proof* [20]. Trust is built into the technology through its decentralised nature and basis of consensus representing a paradigm shift from trust to a "trust-free" society in which the need for trusted third-party substantiation becomes redundant [21]. Trust is transferred from people or intermediaries to computational code [22].

In a public network, anyone can access the ledger; in a private network, participants are granted access [23]. DLT operates across a decentralised P2P network and is immutable once chained. An algorithm ensures all nodes have the same version of the ledger. It uses a Proof-of-Work mechanism to validate transactions; in the case of Bitcoin this is a mathematical and deterministic currency issuance mechanism [15, 24]. Each user has a unique public key made up of an alphanumeric string of characters making it almost impossible to identify the individual it belongs to [25]. Secure by design, its cryptography and distributed consensus mechanism offers anonymity, persistence, auditability, resilience and fault tolerance [23].

Upon creation of a new transaction, the details are broadcast to the network for validation and verification [26]. If consensus is reached, the transactions in the block are considered valid, the block is appended to the blockchain and each node's copy of the blockchain is updated accordingly [27]. In a public blockchain, it is very difficult to change an existing block as all blocks thereafter must also be changed due to each block containing a hash of the one before it [28]. Moreover, this must be done in the time it takes to mine one block to the blockchain [29]. For changes to a private blockchain, all nodes on the network must agree by consensus and then modify the data. All blocks are linked back to the genesis block ensuring the blockchain's integrity [30]. Data privacy is stronger in a private blockchain due to access rights [23]. The blockchain architecture is constructed such that malicious attacks are difficult to achieve requiring significant computational power and simultaneous access to each node to be successful [1].

7.3 Emergent Framework

In this section, an emergent framework is proposed to form the basis of implementing DLT in the context of the built environment and specifically, the construction industry. The framework was developed using a socio-technical systems approach to ensure both social and technical elements are considered. A *political* dimension is introduced to address the political and legal environment concerning the use of DLT in construction given that this is a key area of focus for any technological system to thrive. Justification for adding this dimension stems from the challenges highlighted by a number of authors [31–34], and discussed in the review by Li et al. [19], that underlines the need for regulation, laws and governance around DLT for it to be successful in all sectors and across all applications. Lack of these elements leaves the door open for challenges to the international economic order [35] and the potential to descend into an anarchic state [22].

One of the aims of the review by Li et al. [19] was to identify challenges and opportunities facing the built environment with regards implementation of DLT. The framework combines three interconnected dimensions—technical, social and political—with overlaps across dimensions that represent the real-world environment where one characteristic rarely sits within just one dimension. A number of agents have been identified such that, when considering a challenge or opportunity, the specific agents that have influence on (or should be involved in) the corresponding solutions will be highlighted. Laying the challenges and opportunities onto this framework will ensure that each relevant element and its associated group of users is considered when addressing each challenge and exploiting each opportunity. The framework is presented in Fig. 7.1 along with the identified agents for each dimension. Challenges and opportunities may sit within one dimension, across two, or at the point of convergence of all three in the centre. Figure 7.2 demonstrates how the framework can be overlaid with the challenges and opportunities facing DLT applications in construction. Each of the dimensions is detailed in the following paragraphs and is explained in the context of the socio-technical system.

The **technical** dimension deals with the implementation of the technical architecture of DLT. Many challenges highlighted at this stage in the technology's development (e.g. throughput, latency, interoperability) are likely to be addressed over time with either updates of existing technologies or the development of new products. For example, NEO [36] is one of the newest smart contract platforms in development proposing to provide solutions to throughput and latency, interoperability and resistance to quantum attacks. In this context, following Szabo [37], a smart contract is defined as a computerized

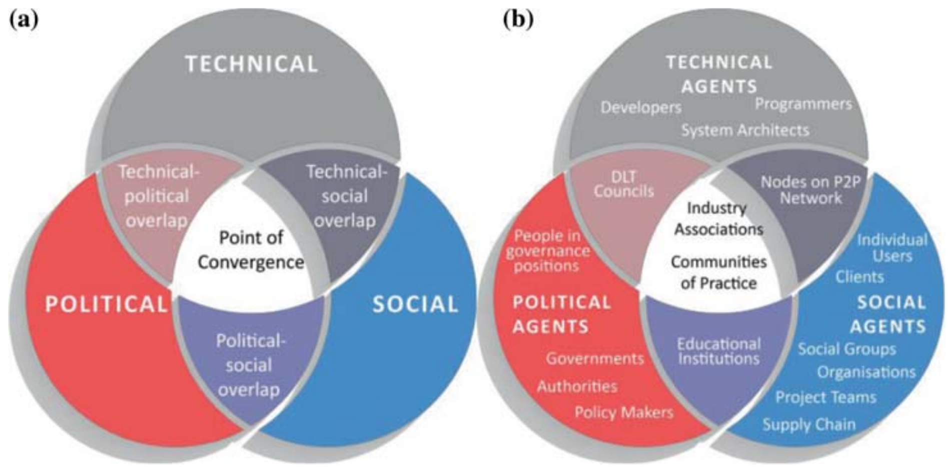

Fig. 7.1 **a** Emergent framework; **b** identified agents

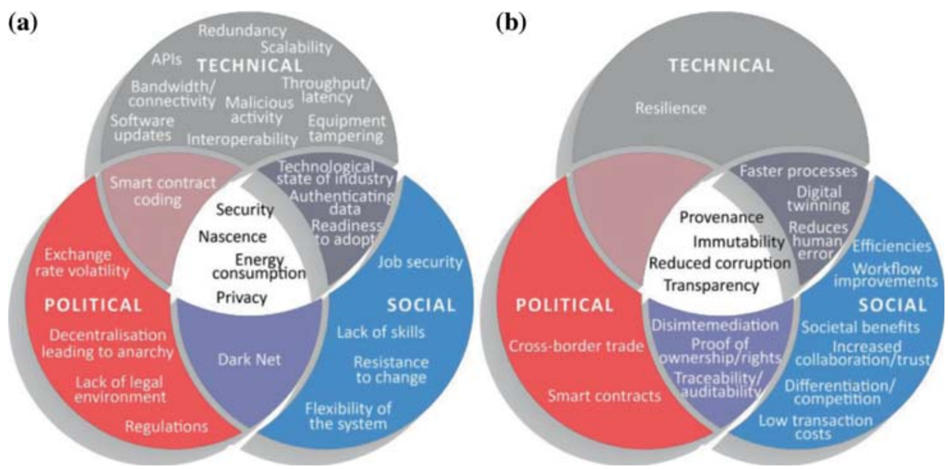

Fig. 7.2 **a** Framework overlaid with challenges; **b** framework overlaid with opportunities

transaction protocol that executes the terms of a contract. The agents involved in this dimension include, but are not limited to: developers, system architects and nodes (computers running the P2P Network). When developing blockchain-based systems for the construction sector, consideration needs to be given to whether public or private access is required. Once this decision has been made, consideration then needs to be given to scalability, data frequency requirements, security and integration with hardware (e.g. sensors) and software (e.g. BIM, interoperability, Application Programming Interfaces (APIs), networking).

The **social** dimension is associated with the impact DLT will have on society; it is broad-reaching in terms of the agents associated. These include, but are not limited to: individual users, social groups, educational institutions, industry associations, communities of practice, organisations operating within the built environment generally and construction projects specifically. This dimension addresses how the technology will integrate into the real world, represents the social system where benefits of DLT adoption will occur, and identifies the agents who will benefit from and influence its adoption. At this early stage of framework development, a holistic social dimension is adopted as the focus is on exploring the opportunities and challenges for the entire built environment and the construction sector. During technological development, attention should be given to how data is presented and stored on the blockchain, particularly where personally identifiable data is generated, to ensure privacy is maintained, especially in the wake of data scandals such as that involving Cambridge Analytica [38]. Consideration of environmental sustainability should be inherent in any new technology, particularly given the currently high levels of energy required to run blockchains.

Overlap with the technical dimension with regards usability (interoperability, appropriate APIs etc.) will ensure technical solutions also meet social requirements. Finally, any solution should be developed with a view to promote information sharing, without compromising on privacy, which will assist in promoting collaboration and development of DLT applications for good uses.

The **political** dimension represents the environment in which DLT will be established and the interactions/influences that agents from the political field exert on DLT adoption. This includes establishing robust regulations, laws and compliance for implementation of DLT in the built environment and the construction industry. Agents for this dimension include, but are not limited to: governments, authorities, policy makers, DLT councils (those with the power over how DLTs function) and other organisations/individuals in governance positions. For example, as smart cities are a goal for many governments, they have a responsibility to ensure appropriate infrastructure is put in place to support the development of DLT to allow it to thrive in the long-term and integrate fully with smart technologies. To promote the integration of services and overcome interoperability, robust regulations and a manageable system in which DLT applications can function without inhibiting innovation are needed. Government strategies should incorporate plans to educate the general public of the benefits and operation of DLT to be successful as the system relies on user-led data and are user-run. In addition, robust succession planning to train sufficiently skilled personnel to run the system is required such that resourcing does not become a barrier to implementation.

In light of the three dimensions and current stage of development, the attentive scoping of DLTs is key to ensure what is designed offers a solution to the construction industry that succeeds in solving its challenges and allows it to assimilate with technologies like BIM. In particular, the solution must be everlasting and tolerant of updates and future advancements as DLT provides an everlasting ledger of information.

The framework will help in answering a number of questions related to DLT that must be dealt with during development including: is the construction sector ready for DLT? What needs to be put in place to ensure it will be ready in the near future? Who bears the initial implementation costs? How can stakeholders from across the dimensions be encouraged to work together? What needs to be done to ensure integration with existing technologies (e.g. BIM, Internet of Things)? Addressing these questions along with the extensive challenges and opportunities identified in the earlier paper by Li et al. [19] will ensure the technology matures in line with the socio-technical environment.

In the next stage of development of this framework a fourth dimension will be proposed to encompass *processes* which, at present, are inherently embedded into the social dimension. This will allow the framework to take a more industry-specific and project-oriented approach for application to the construction industry.

7.4 Methodology

DLT is nascent technology and its coverage in the built environment literature is recent, with no prevalent theoretical considerations of its implementation. The research conducted for this paper was inductive in nature where theories are borne out of observations and/or findings, typically from qualitative research. Qualitative research is important for research of socio-technical systems [39]. This study encompassed a systematic literature review (SLR) informed by a socio-technical approach and a focus group session.

7.4.1 Socio-Technical Systems

Socio-technical systems design (STSD) methods are an approach to design that considers human, social and organisational factors, as well as technical factors in the design of organisational systems [40]. Neglecting to consider social and technical factors, particularly when developing new systems, will often result in failure of the system due to meeting technical requirements but missing social ones [40]. Geels [41] discusses three aspects of socio-technical systems as "production, diffusion and use of technology" highlighting the importance of looking at the relationship between innovation *and* users to ensure societal needs are fulfilled. Regulation sits at the centre as the element that produces trust and intercepts with each of the three aspects. Lack of regulation currently represents a significant gap in development of DLTs [42, 43].

7.4.2 Systematic Literature Review

A systematic literature review was used to identify where current research lies on blockchain applications in the built environment and to compile a list of challenges and opportunities with regards its implementation in the sector. More detailed results from the SLR can be seen in an earlier review providing an extensive description of current applications, challenges and opportunities regarding DLT in the built environment [19]. In summary, a review was made of 53 papers to discover the current body of research focused on seven applications of DLT: (i) smart energy; (ii) smart cities and the sharing economy; (iii) smart government; (iv) smart homes; (v) intelligent transport; (vi) BIM and construction management; and (vii) business models and organisational structures.

The most widely-researched application to date is *smart energy* focusing on microgrids and energy trading, where the blockchain is opening up markets and promoting prosumer behaviour. *Smart cities* and the *sharing economy* focuses on improving communication and data sharing between citizens and governments for mutual benefit, promoted by the IoT. *Smart government* is looking to move some services onto the blockchain such as land registries, tax collections, identity management, government records [31], voting, and patents [44]. *Smart homes* (and smart districts [45]) focuses on developing better places for people to live, work and interact day-to-day. There are overlaps with regards applications (ii)–(iv) where security and privacy of data are key concerns along with interoperability, longevity, accessibility and balance of power [22, 46]. Blockchain is transforming *intelligent transport* by allowing people to monetise their idle vehicles by offering rides to people travelling in the same direction [47] and providing alternatives for charging electric vehicles [48]. In (vi), many use cases are identified that benefit areas such as the supply chain, payments, equipment leasing, facilities management, data management, collaboration, information sharing and intellectual property rights [3, 8, 15, 49]. However, the research lacks empirical data to support the use cases and there is consensus that BIM needs to advance from its current level of implementation (i.e. BIM Level 2) before any benefits can be realised [9, 16, 50]. Finally, blockchain will introduce new business roles (e.g. smart contract mediator [51]), new organisational structures such as decentralised autonomous organisations [24, 31] and many tasks and activities will become semi- and fully automated [31].

7.4.3 Focus Group Discussion

A focus group was held on the premises of a UK university with eight participants: five academics, one industry practitioner and two Ph.D. students all involved in BIM and digital construction innovation. The purpose of the session was to canvas views on blockchain and its potential benefits for construction with a focus on potential benefits and challenges to implementation. The one-hour session consisted of a brief presentation of DLT and applications currently investigating its use followed by semi-structured questions.

Participant comments supported the framework development, particularly that DLT "*must be considered as a socio-technical system*". Another commented that, "*it has the potential to address one of the biggest challenges in the construction industry, which is trust*". Other considerations that emerged from the discussions centred on: whether a decentralised system is required or whether the industry, projects or organisations would still benefit from centralised blockchains; what are the transactions that take place throughout a construction project lifecycle, and whether blockchain can improve current practices; how the problem of data authenticity is solved as blockchain alone will not solve the problem (garbage in, garbage remains and is immutable); and how data and transaction frequency requirements will impact on choice of technology.

This initial focus group helped direct development of the framework presented in this paper. It was not intended to be an exhaustive session and will be followed up with further sessions and different agent groups as the research progresses. This paper does not intend to answer the concerns raised; they are highlighted to support other researchers' investigating the use of DLT in the built environment and the construction industry.

7.5 Conclusions

This paper aimed to further expand on an emergent framework [19] based on identified challenges and opportunities associated with the adoption of DLT in the built environment. Based on initial focus group discussions a socio-technical systems methodology has been proposed. An inductive research approach underpinned the inquiry process and culminated with the development of an emergent multi-dimensional framework.

The framework combines three interconnected dimensions—political, social and technical. It is overlaid with an extensive set of challenges and opportunities facing the implementation of DLT in the built environment and represents an important baseline for its adoption. Field researchers can utilize the framework as a point of departure for a wide range of investigations from political, social, and technical perspectives.

It is the authors' intention to add a fourth dimension to the framework to encompass *process* to improve its applicability to project environments, particularly those related to the construction industry. The revised framework will be validated with academics and industry practitioners and subsequently applied to a construction-related project to demonstrate Proof-of-Concept.

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