BLOCKCHAIN ECOSYSTEM IN CONSTRUCTION: OPEN OR CLOSED INNOVATION?

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Blockchain technology has been considered a game-changer across many sectors and slowly gains traction in construction. Because of immutability and transparency, blockchain is seen as a solution to the fragmentation and distrust. Various industry players, government and policymakers are increasingly interested in co-creating ideas with this technology. This collective interest on blockchain implies the possibility for democratising it following an Open Innovation (OI) paradigm. We explore the feasibility of OI paradigm in construction using blockchain as an example and research setting. Through content analysis of semi-structured interviews with 24 experts we explore openness/closedness of blockchain innovation ecosystems. The data showed that OI is still in its infancy in construction. Whereas blockchain implies openness and transparency, construction focuses on closed blockchain ecosystems due to resistance in sharing data and research initiatives. This brings implications for government and construction clients who are deemed facilitators of digital revolution.

Keywords: information technology; innovation; partnering; technology transfer

INTRODUCTION

The emergence of blockchain technology has brought changes across sectors and attracted the attention of industrialists, practitioners, policy-makers and academics. Blockchain has a novel peer-to-peer controlled, distributed database structure, potentially affecting existing business transactions in construction through smart contracts, cryptocurrencies, and reliable asset tracking ((Wang *et al.,* 2017). Blockchain challenges existing views of innovation, which is primarily considered as the introduction of novel artefacts or processes (Abernathy and Clark, 1985). New logics in digital innovation emerge, as its implications spill across disciplines and their interactions become more distributed and less predefined (Lyytinen *et al.,* 2016). Blockchain meets all these characteristics and complexities of digital innovation.

Blockchain technology impacts various sectors, such as finance (Zamani and Giaglis, 2018), logistics (Qian and Papadonikolaki, 2020), healthcare variously, with some sectors been disrupted faster than others (Zamani and Giaglis, 2018). Among these

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sectors, construction is the most traditional and it has been known for not developing innovations but exploiting existing innovations previously developed in other sectors. As construction is transaction-heavy, it is ideal setting to explore the slowly changing landscape of blockchain ecosystem. Among innovations entering construction, blockchain has been seen as the next frontier (Li *et al.,* 2019). As an innovation, blockchain is highly pervasive affecting the ecosystem and not just isolated actors.

The construction sector undergoes digitalisation through innovations such as Building Information Modelling (BIM), Internet of Things (IoT) and big data analytics. Various countries attempt to regulate, standardise and mandate such technologies. For example, various institutions, e.g., government, policy, businesses, and industry consortia, actively developed BIM implementation processes and pushed its use. However, in the lower tiers of the construction supply chain, the democratisation of BIM was problematic and Small and Medium Enterprises (SMEs) lagged behind due to limited resources. This situation reveals a digital divide similar to the situation surrounding the BIM Level 2 agendas and has reinforced mistrust in improvement agendas (Dainty *et al.,* 2017). This paper problematises around this issue.

Disruptive innovations such as blockchain happen not only inside firms, but through numerous developments taking place simultaneously in interconnected ecosystems of firms (Chesbrough, 2003). The Open Innovation (OI) paradigm explains how firms use resources, such as knowledge, complementary assets and Intellectual Property (IP), outside their boundaries to create and commercialise innovation (Chesbrough, 2003). Innovators need orchestration capabilities to orchestrate these assets and ensure profitable innovation by exploiting external resources (Chesbrough, 2008). Through the lens of open innovation, this paper discusses how construction actors interact, either compete or collaborate in the blockchain ecosystem. We look at blockchain as an ecosystem and a meta-organisation, that is an organisation of organisations. Seeking to understand how blockchain influences organisational structures in construction, the study addressed the following research question (RQ):

"How open or closed is the blockchain innovation ecosystem in construction?"

Theoretical Background

Open and closed innovation ecosystems

The current digital economy relies predominantly on innovative solutions using the power of data. Innovation is novelty in new products or processes (Abernathy and Clark, 1985) but can also be based on new combinations of past practice (Schumpeter, 1982) (value creation). Innovation should also be commercially deployed so that firms can profit from it (Teece, 1986) (value capture). Innovations fail when innovators fail to exploit the innovation. The Schumpeterian ideas of innovation as re-combination across social networks become increasingly relevant to innovation (Schumpeter, 1982), which implies systems thinking. In business, the term 'ecosystem' provides an attractive metaphor to describe a range of value creating interactions and relationships between sets of interconnected organisations, e.g., business ecosystem (Moore, 2016). In management research, the term 'ecosystem' usually refers to a network of interconnected organisations that are linked to or operate around a focal firm or a platform. Ecosystems are collaborative arrangements, dynamic, evolving and purposive networks in which participants co-create value including policy-makers, regulators and competitors, who are traditionally absent from networks and beyond the span of managerial control.

Innovation ecosystems are important as most breakthrough innovations fail in isolation and instead need complementary systems of support (Adner, 2006). An innovation ecosystem is a network of interconnected organisations, connected to a focal firm or a platform, that incorporates both production and use side participants and creates and appropriates new value through innovation (Autio and Thomas, 2014). Consistent to ecosystem thinking, there are two main types of innovation: closed and open, linked to the proliferation of open-source code (West, 2003). Closed innovation relates to proprietary systems that do not allow developing or using complementarities between systems. OI relates to innovation outside firm boundaries and its principles by Chesbrough (2003) show that innovation may originate outside the boundaries of firms, use external Research and Development (R&D) outputs such as patents, forces to create new business models and uses both internal and external ideas and promotes licensing of own Intellectual Property (IP) to profit from others using it.

Table 1: Principles of open and closed innovation adapted from (Chesbrough, 2003).

Areas of principles	Closed Innovation Principles	Open Innovation Principles
Human resources (HR)	The smart people in the field work for us.	Not all the smart people work for us, so we must tap into the expertise of bright individuals outside our company.
Research and Development (R&D)	To profit from R&D, we must discover it, develop it, and ship it ourselves.	External R&D can create significant value: internal R&D is needed to claim some portion of that value.
Commercialisation	If we discover it ourselves, we will get it to the market first.	We don't have to originate the research to profit from it.
Business models	The company that gets an innovation to the market first will win.	Building a better business model is better than getting to the market first.
Idea creation	If we create the most and the best ideas in the industry, we will win.	If we make the best use of internal and external ideas, we will win.
Intellectual Property (IP)	We should control our intellectual property (IP) so that our competitors don't profit from our ideas	We should profit from others' use of our IP, and we should buy others' IP whenever it advances our business model.

Chesbrough and Appleyard (2007) define an OI ecosystem as: OI, innovation systems and business ecosystems. Value creation and capturing in innovation ecosystem are constituents of innovation ecosystem and OI (Chesbrough *et al.,* 2018). The outcome of OI ecosystem contributes to product innovation (Xie and Wang, 2020). The dynamics of the entrepreneurial cycle of OI in developing network relationships between companies and giving value to cooperation between individuals lead to enhancement of dynamic capabilities for accomplishing greater performance and maximizing profits in SMEs (Valdez-Juárez and Castillo-Vergara, 2021). A platform is essential to making a digital innovation ecosystem work by aligning various actors to achieve a mutually beneficial purpose and it can be used for both creating and capturing value. However, when the goals of the ecosystem firms are divergent, OI is not uniformly superior to closed innovation (Almirall and Casadesus-Masanell, 2010).

Blockchain technology

Blockchain technology has been thought as the most important invention since the Internet (Tapscott and Tapscott, 2016). Blockchain solutions are still struggling to be

considered profitable innovations, despite the hype (Hunhevicz and Hall, 2020, Perera *et al.,* 2020). Blockchain is a form of distributed ledger technologies (DLTs) (Li *et al.,* 2019), a database that exists across several locations or among multiple participants. As opposed to centralised databases on fixed locations, a distributed ledger is decentralised and reduces the need for a central authority or intermediary to process, validate or authenticate transactions (Hunhevicz and Hall, 2020). Apart from surpassing the need for intermediaries, blockchain also allows transactional data to be recorded chronologically in a chain of data blocks using cryptographic hash codes (Wang *et al.,* 2017, Perera *et al.,* 2020) and transactions can be validated by nodes or miners - computers nodes connected over a specific blockchain network - over a predefined consensus protocol.

Being able to store immutable data and verify transactions, blockchain is called the "internet of trust" (Calcaterra and Kaal, 2020). Trust is a ubiquitous concept in psychology, sociology, philosophy and business. In business, trust influences corporate activity and interaction (Gulati and Nickerson, 2008) and a higher level of trust increases efficiency in business. Inter-organisational relations and constellations, such as supply chains are considered key blockchain application areas. Because of its distributed network of accessors, participants, miners and regulators, blockchain technology is associated with inter-firm settings and ecosystems. Blockchain is a "mainstream technology for OI ecosystems" (Chen, 2018) and can stimulate OI as it allows for gain of value created by community members (Unalan and Ozcan, 2020). A System of Innovation (SI) demonstrates flows of knowledge, involving technology and information among innovation actors such as universities, private firms and governmental institutions (Unalan and Ozcan, 2020). SIs evolve from centralised to decentralised networks, enabling active collaboration among innovation actors (Unalan and Ozcan, 2020).

Efficient collaboration in OI initiatives with blockchain technology is relevant to firms of all sizes. Value appropriation in blockchain-enabled business models affects the entire ecosystem (i.e., platform), conventional value chains (i.e., disintermediator and mediator), and individual companies (i.e., transformer and co-innovator) (Chong *et al.,* 2019). Larger companies can consider improving their business models to face the increased competition caused by blockchain-enabled OI. To enhance their national competitiveness, governmental institutions must establish innovation policies to maximise OI initiatives and connect to national innovation strategies (Unalan and Ozcan, 2020). A blockchain-based product service system that complies with a company's strategy can stimulate further commercialisation business and accelerate industrial transformation and upgrading (Xuan *et al.,* 2020). The deployment of blockchain technology could reduce the problems of trust and the adoption of IP in the context of co-creation and OI (Mačiulienė and Skaržauskienė, 2021).

Research setting

Being transactional-heavy, construction is an ideal setting for blockchain applications. In construction, blockchain is an important technology in construction as it links BIM and IoT and has various applications across project lifecycle. The fragmented nature of construction procurement showed that main contractors take ownership of blockchain solutions and SMEs struggle to address skills shortages and implement them. Government bodies negotiate blockchain standards with technology players, trial blockchain for public funds and blockchain consortiums emerge for different sectors across the world and multi-national organizations like the European Union (EU) are showing interest (Houben and Snyers, 2018).

Blockchain protocols are classified over two dimensions; anonymity (public/private) and consensus (permissionless/permissioned) with their advantages and challenges (Tezel *et al.,* 2020). Public ledgers allow anyone to read a ledger, whereas private allow only specific members to access transactions. Permissionless nodes allow anyone to set up a node and interact with the ledger, e.g., by adding transactions or consensus participation. Public and permissionless DLT are more decentralised and joint effects of technical contributions, internal social capital and open community commitment positively impact OI collaborative success (Mu *et al.,* 2019). Yet, openness not only encourages wide participation but also stiffles commercialisation and thus threatens the innovativeness of blockchain (Mu *et al.,* 2019). Blockchain applications have shown a shift in the conception of trust from relational to system- and cognition-based (Qian and Papadonikolaki, 2020). Nevertheless, there is need to define how open or closed are the blockchain innovation ecosystems in construction.

METHODOLOGY

Methodological Underpinnings

As ecosystems concern actions and interactions among various actors, this study sets of from a constructivist ontology, considering ecosystems as value-creating interactions and relationships among interconnected organisations (Moore, 2016). Additionally, given that blockchain as an innovation concerns creativity, invention, but also value creation from various actors (Teece, 1986), we use interpretivist epistemology to understand how the value of blockchain innovation ecosystems is perceived by them. As the theoretical framework has been formulated from theories of OI, the research employs deduction to move from fieldwork to emerging propositions seeking a consistent set of mental models from expert informants on the topic.

Data Collection

The study is based on qualitative data from interviews. Because the key RQ is on emerging blockchain innovation ecosystems, qualitative data was appropriate, as there is little archival data on the topic and a general lack of quantitative data from businesses and OI ecosystems. Data was collected through interviews asking semi-structured questions orally for research freedom and emergence of patterns in the data. The interview protocol included a briefing about the research aims, keywords related to the study and the nature of the interview questions. There were only eleven questions and the interviews lasted 22-72 minutes, depending on the speaking pace of the interviewees. The questions were about the interviewees' professional background and blockchain experience and about blockchain technology ecosystem. Interviews were audio recorded, transcribed, and data was pseudonymised.

The interviewee selection criteria were from a global sample with experts from the United Kingdom (UK), Sweden, United States of America (USA), Germany, Spain and France. In total 24 experts participated, after purposeful sampling. Experts were selected for their high: (a) blockchain familiarity, (b) engagement with digital construction, (c) professional experience in construction or technology. From the interviewees, half of them (n=12) had hands-on experience in blockchain applications, such as coding smart contracts and the rest (n=12) had other coding experience and were either researchers in digital technology space (in digital construction) or policy advisors in the area of blockchain technology. Table 2 describes these interviewees.

Table 2: Interviewee profiles (referred to in text as Int-ID).

ID	Position	Organization	Industry	Country
1	Director	BIM consultancy	Construction	UK
2	Director	Entrepreneur	Technology	UK
3	Founder	Non-profit	Construction	USA
4	Principal	Architecture and Law	Construction	UK
5	BIM Leader	AEC Consultancy	Construction	UK
6	Reader	University	Higher Education	UK
7	Consultant	AEC Consultancy	Construction	Germany
8	Consultant	AEC Consultancy	Construction	UK
9	Consultant	AEC Consultancy	Construction	UK
10	Director	Law Consultancy	Construction	UK
11	Senior Consultant	Design and Consulting firm	Construction	UK
12	Director	Blockchain Development	Construction	France
13	Vice President	Blockchain Foundation	Construction	USA
14	CEO	Blockchain Start-up	Construction	UK
15	Senior Researcher	Research Institute	Technology	Sweden
16	Head of VDC	Infrastructure	Construction	Sweden
17	Sustainability Leader	Project development	Construction	Sweden
18	Head of DLT	Innovation Centre/Institute	Technology	UK
19	CEO	Blockchain Start-up	Technology	UK
20	Director of R&D	AEC Consultancy	Construction	USA
21	Business Consulting	AEC Consultancy	Construction	Spain
22	Business Analyst	AEC Consultancy	Construction	USA
23	Business Consulting	AEC Consultancy	Construction	Spain
24	Senior Associate	AEC Consultancy	Construction	UK

Data Analysis

To respond to the research question regarding the nuances between openness and closeness, a systematic data analysis method was followed. Qualitative Content Analysis (QCA) was used to systematically describe the meaning of qualitative data (Hsieh and Shannon, 2005). QCA was done through analysing with coding, a systematic approach to manage, store, identify, and sort data interpretations (Saldanā, 2009). The interview data after transcription was coded into themes using deductive, a priori codes (Saldanā, 2009) emerging from theory on OI principles in Table 1 to analyse the data as to openness/closeness of the blockchain ecosystems.

FINDINGS

The data showed varying degrees of applicability of OI principles by Chesbrough (2003). Overall, whereas some principles, e.g., HR and idea creation are widely understood, others such as creating new business models for OI and profiting from external IP are still in their infancy and closed. Table 3 presents applicability of OI areas to blockchain in construction, giving pointers to interviewees' data as 'Int-ID'.

Table 3: Applicability of open innovation (OI) principles to blockchain in construction.

Areas of open OI principles	Agreement among interviewees about OI principle applicability	Indicative interviewee arguments in support of the principle	Indicative interviewee arguments in against the principle
Human resources (HR)	100%	We need to find and train the best skills	N/A
Research and Development (R&D)	~86%	We take advantage of developments from open consortia	We have our own dedicated R&D departments
Commercialisation	~86%	Government needs to help internalise these initiatives	Blockchain needed in pre-competitive stage
Business models	~57%	Businesses need to align with technology	Construction protects its business model
Idea creation	100%	Re-using blockchain ideas	N/A
Intellectual Property (IP)	~48%	Blockchain needs firms sharing their data	Construction lacks a data sharing culture

Human resources (HR)

All interviewees recognised that skills are crucial for blockchain technology and that firms need to tap into the expertise of bright individuals outside firm boundaries. This resonates with previous studies (Unalan and Ozcan, 2020, Valdez-Juárez and Castillo-Vergara, 2021) supporting the argument of finding and training the best talent.

Research and Development (R&D)

Most interviewees recognised that OI requires the combination of internal and external R&D and they aligned with various initiatives such as Ethereum or even Hyperledger. The findings are congruent with the literature (Unalan and Ozcan, 2020, Xie and Wang, 2020) that firms take advantage of developments from OI consortia. Instead data showed that some firms focus on developing R&D themselves (Int-12) or even aligning to more closed and proprietary systems, such as AutoDesk around BIM.

Commercialisation

Whereas most interviewees resonated with the idea of profiting from innovation in the pre-competitive stage through OI ecosystems (Int-2) reinforcing the literature (Xuan *et al.,* 2020), others focused more on protecting their innovation to profit when ready to market due to constraints in commercialisation of blockchain (Mu *et al.,* (2019).

Business models

Almost half the interviewees indicated that they overlooked the necessary business model transformation needed to engage in OI in blockchain ecosystems. This was shown by using blockchain to focus on reducing costs in existing industry structure (Int-18), rather than rethinking traditional procurement systems to allow for shorter chains (Int-17) and remove intermediaries (Int-14) as seen in literature that businesses need to align with technology (Chong *et al.,* 2019, Unalan and Ozcan, 2020).

Idea creation
All interviewees agreed that to succeed in blockchain OI ecosystems, they need to leverage internal and external ideas. They were open to align with OI projects such as Ethereum and use open-source solutions (Int-2) in their innovations (Li *et al.,* 2019).

Intellectual Property (IP)
Less than half of the interviewees did not see the need to open and share their IP for developing blockchain-enabled solutions. Thus, they sought to protect and close their IP to competitors (Int-1) and also did not use external IP in their solutions (Almirall and Casadesus-Masanell, 2010), even if that could advance their own business model as pointed out in literature that blockchain needs firms sharing their data and that construction lacks the culture of sharing data (Mačiulienė and Skaržauskienė, 2021).

The main theoretical contribution of this work is that - to the best of our knowledge - this is the first OI study in construction. OI paradigm has found a lot of applications in information technology (Chesbrough, 2003), hardware and software (West, 2003) and life sciences sectors (Chesbrough and Appleyard, 2007). By researching the OI's applicability to construction, we can map shortcomings and how to overcome them. It is surprising that whereas blockchain is a key technology based on openness and transparency, aiming to be the "internet of trust" (Calcaterra and Kaal, 2020), in construction, this is seen as a closed rather than open system, not utilising developments made available from public blockchains such as Bitcoin and Ethereum. Resistance to sharing data shows persistent mistrust.

The work puts forward a number of practical implications. First, the implications for policy-makers and government are bifold. Especially UK-based interviewees stated that blockchain OI needs to be encouraged and perhaps regulated by policy-makers and government. Second, in government-sponsored projects, the public client is expected to enforce blockchain solutions for transparency in project financing, in particular for complex global infrastructure projects (Int-13). Third, government and policy-makers were seen as potential orchestrators of blockchain ecosystems, in the OI paradigm (Int-6), whereas large contractors were seen as orchestrators of closed innovation ecosystems (Int-7). Finally, in both OI and closed scenarios, almost all interviewees concurred that SMEs stand to gain more from blockchain innovation ecosystems as they will be protected, paid in time and visible across the supply chain.

National programs for developing blockchain skills are needed. An OI approach will remove conventional R&D limitations. Governments could expedite digitalisation and stimulate commercialisation. Companies could align with the technology to establish digital business models by participating in blockchain ecosystems for potential value creation. Integrating blockchain with BIM could resolve IP and legal challenges for sustainable building design coordination across lifecycle phases. Further research will adopt quantitative research methods to analyse the data. This will help understand hindrances to shared R&D and IP and boost commercialisation to transform business models for OI and in particularly blockchain-based construction.

CONCLUSIONS

We sought out to understand innovation ecosystems in construction and explore how open or closed is the blockchain innovation ecosystem, using OI as a theoretical lens. Blockchain, due to transparency, traceability and immutability is ideal context for studying OI, due to relevant developments coming from open-source initiatives and a large community base. Yet, data showed that OI in construction is misunderstood and

the sector is organised in closed innovation. This is limited by traditional business models that do not allow for 'knowledge spillover' effects (see Table 3). Crucial in transforming construction's business model, is the improved, protected role of SMEs and government or large contractors playing orchestrator roles in closed innovation.

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