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Blockchain innovation ecosystems orchestration in construction

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Abstract

Purpose – Rapid advancements in blockchain technology transform various sectors, attracting the attention of industrialists, practitioners, policymakers and academics, and profoundly affect construction businesses through smart contracts and crypto-economics. This paper explores the blockchain innovation ecosystem in construction.

Design/methodology/approach – Through a qualitative study of 23 diverse interviewees, the study explores how open or closed the blockchain innovation ecosystem in construction is and who its emerging orchestrators are.

Findings – The data showed that construction aims towards an open innovation blockchain ecosystem, although there are elements of hybridisation and closedness, each system pointing out to different orchestrators.

Practical implications – The study has implications for governments and large companies in construction, showing that open innovation initiatives need to be encouraged by policymakers through rules, regulations and government-sponsored demonstrator projects.

Social implications – The data showed that there is lack of readiness for business model change to support open innovation blockchain ecosystems in construction.

Originality/value – This is the first study applying the open innovation theory in the construction industry and sheds light into the phenomenon of blockchain, suggesting routes for further democratisation of the technology for policymakers and practitioners.

Keywords Blockchain, Building information modelling (BIM), Ecosystem, Innovation, Ecosystem orchestration

Paper type Research paper

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1. Introduction

The emergence of blockchain technology brings changes across various industries and attracts the attention of industrialists, practitioners, policymakers and academics. Blockchain offers a novel peer-to-peer controlled, distributed database structure and the potential to profoundly affect the business transactions in construction through smart contracts, cryptocurrencies and reliable asset tracking (Scott *et al.*, 2021). Blockchain challenges the existing views of innovation, primarily considered as introduction of novel artefacts or processes (Abernathy and Clark, 1985). Instead, new cross-disciplinary, unbounded and systemic logics in digital innovation emerge (Yoo *et al.*, 2010) with more distributed and less predefined interactions between individuals and organisations (Lyytinen *et al.*, 2016). Blockchain technology contains all these characteristics and complexities of digital innovation.

Blockchain impacts various industries, such as finance (Zamani and Giaglis, 2018), logistics (Shoaib *et al.*, 2020; Gupta *et al.*, 2020) and healthcare (Sharma *et al.*, 2019), with some industries been disrupted faster than others (Zamani and Giaglis, 2018). Among various industries that blockchain impacts, construction is the most traditional, and it has been notorious for its digital divide across the ecosystem (Dainty *et al.*, 2017). Discussions on blockchain in construction have accelerated after 2015, a decade after the first introduction of blockchain in 2008. As construction is very transaction-heavy, it offers an ideal setting for blockchain innovation as it becomes increasingly digitalised (Papadonikolaki *et al.*, 2022). Reports show the increasing popularity of blockchain that is touted as the next frontier in construction (Li *et al.*, 2019; Hunhevicz and Hall, 2020; Perera *et al.*, 2020). Key use cases of blockchain in construction include project bank accounts (PBAs) for fast payments, reverse auction-based tendering for bidding and asset tokenisation for project financing (Tezel *et al.*, 2021) and integrations with building information modelling (BIM) (Hunhevicz and Hall, 2020). Blockchain could be considered a systemic innovation showing a transactional nature, affecting the whole construction ecosystem holistically and not just isolated actors.

The construction industry undergoes digitalisation through innovations such as BIM, Internet of things (IoT) and big data analytics (Li and Kassem, 2021; Sacks *et al.*, 2020) to address many of its pathologies, e.g. trust, payments, fragmentation. Several countries attempt to regulate, standardise and mandate such technologies. Various institutions, for example, government, policy and industry consortia, actively developed BIM implementation processes and pushed its use. However, in low tiers of construction supply chain, the democratisation of BIM was problematic and suppliers' small and medium enterprises (SMEs) lagged behind due to limited resources and general lack of trust to the good will of tier-1 contractors, to whom they are based on for fast payments to retain their liquidity (Tezel *et al.*, 2021). To this end, construction is a project-based and very paper-based and transaction-heavy sector lacking trust (Qian and Papadonikolaki, 2020; Li *et al.*, 2019) as tier-1s act as payment gatekeepers (Li *et al.*, 2019). Blockchain is a transparent layer for immutable transactions, called the "Internet of trust", which is a network that captures real-world information, context and value through cryptographically assured transactions generating a "transparently validated consensus on truth" (Calcaterra and Kaal, 2020) that has the potential to reshape the construction ecosystem. This paper problematises around ecosystem leadership necessary for orchestrating blockchain innovation efforts in construction ecosystems.

Disruptive innovations such as blockchain happen not only inside firms, but through numerous developments taking place simultaneously in an interconnected ecosystem (Chesbrough, 2003). The open innovation (OI) paradigm explains how firms can use resources such as knowledge, complementary assets and intellectual property (IP) outside their boundaries to innovate and commercialise innovation (Chesbrough, 2003). OI is important for ecosystems, with players having limited resources, such as SMEs that can exploit open-source developments and collaborate with other tiers. Innovators need capabilities to orchestrate these assets and ensure profitable innovation by exploiting external resources

(Chesbrough, 2008). In innovation ecosystems, the ecosystem orchestrator becomes increasingly important, especially in collaborative and OI, as they orchestrate access to the ecosystem, the SMEs contributing to innovation efforts, the ecosystem relations, resources and social capital (Giudici *et al.*, 2018). Dhanaraj and Parkhe (2006) defined ecosystem orchestrator as a central player taking deliberate actions to create value by connecting firms, facilitating their interactions and setting governing rules.

As blockchain technology relates to open-source code and value co-creation from community members, it has meaningful links to the OI paradigm (Mu *et al.*, 2019). For this reason, the paper focuses on the blockchain innovation ecosystem in construction. Giudici *et al.* (2018) discussed open system orchestration, focusing more on pro-social interventions rather than profiting from innovation. In general, ecosystem orchestrators provide solutions to lead and bring consensus to the ecosystem and in the new and emerging blockchain ecosystem in construction, closed and open ecosystem orchestrators co-exist. Leadership in open collaborative innovation endeavours, such as in open-source blockchain projects, entails both relational and task-oriented leadership behaviours (Mu *et al.*, 2019), but the relationships are more prominent than task orientation. In the decentralised blockchain ecosystem, the role of ecosystem orchestrators becomes paramount, warranting further study.

This paper discusses how construction actors are organised in the blockchain ecosystem. Because blockchain technology can be conceptualised as a systemic innovation, a macro theory was selected as a sensitising lens to discuss its technological innovation in construction. Departing from other studies looking at the environment of blockchain (Clohessy and Acton, 2019; Badi *et al.*, 2021), we look at blockchain as a meta-organisational ecosystem (organisation of organisations). Seeking to understand to what extent blockchain influences the openness and closedness of innovation ecosystems in construction and how the blockchain ecosystem is orchestrated, the study addressed the research questions (RQ):

RQ1. How open or closed is the blockchain innovation ecosystem in construction?

RQ2. Who are the emerging orchestrators of this innovation ecosystem?

The rest of the paper is organised as follows. The ensuing section presents the theoretical background of the work and relevant literature. In the third and fourth sections, the methodology and the data are presented, respectively. The paper concludes with a discussion of findings section, including theoretical contributions and practical implications, and concluding remarks.

2. Theoretical background

2.1 Innovation ecosystems

The current digital economy relies predominantly on innovative solutions using the power of data. Innovation typically refers to activities leading to the commercial introduction of something new. Novelty refers to new products or processes, radically departing from past practice (Abernathy and Clark, 1985). Novelty could also be based on new combinations of past practice, constructed within social networks (Schumpeter, 1982). Apart from novelty, innovation is firmly based on the premise of commercial deployment and profit from it (Teece, 1986). Therefore, the innovation generation skills are different from innovation value capturing skills, and both innovation generation and value capturing processes are equally important to innovation. Innovations fail when innovators fail to capture their returns, and it is often complementary assets outside/around the firm boundaries, such as marketing, sales or manufacturing capability, required to enable successful commercialisation of an innovative idea.

The Schumpeterian (1982) ideas of innovation as re-combination across and within social networks and systems become increasingly relevant. In business, "ecosystem" provides an attractive metaphor to describe a range of value, creating interactions and relationships between interconnected organisations, for example, business ecosystem (Moore, 2016). Ecosystem is a network of organisations linked to or operating around a focal firm or platform (Moore, 1993). Ecosystems are collaborative, dynamic, evolving and purposive constellations in which participants co-create value and include also policymakers, regulators and competitors, who are traditionally absent from network considerations and beyond the span of managerial control. Adner (2006) stressed the importance of innovation ecosystems in innovation strategy recognising that most breakthrough innovations fail in isolation, but instead need complementary innovation and critical supporting elements to attract customers and users.

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, creating and appropriating new value through innovation (Autio and Thomas, 2014). The ecosystem construct is distinguished from the value chain and supply chain constructs by its non-linear aspect, as it includes both vertical and horizontal relationships among actors. Typically, ecosystem boundaries are hard to define, especially in digital innovations that are unbounded (Yoo *et al.*, 2010) and interdisciplinary (Lyytinen *et al.*, 2016). Following the above, a blockchain innovation ecosystem can be defined as a network of interconnected organisations, connected to a focal blockchain platform, creating and appropriating new value through it. Especially in the construction sector, its innovation ecosystems are dominated by main contractors who control construction contracts, the multi-tiered supply chain (including designers, engineers and manufacturers) and the relation with the client or owner of assets. Importantly, in some countries, the government is the largest client, for example, the UK government is responsible for 40% of construction projects, whose strategic priorities shape the innovation scene. Although the construction industry structure is traditionally adversarial (e.g. competing on lowest price) and very hierarchical, there is a recent transition towards more innovative business models across the sector (Hall *et al.*, 2020; Papadonikolaki, 2018).

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 with proprietary systems that do not allow developing or using complementarities between systems. OI relates to innovation outside the firm boundaries, and its principles, explained by Chesbrough (2003), show that innovation may originate outside the firm boundaries, use external research and development (R&D) outputs such as patents, open-source code and create new business using both internal and external ideas and promote licensing of own IP to profit from others using it. Table 1 shows open and closed innovation principles. An OI ecosystem consists of: OI, innovation systems and business ecosystems (Chesbrough and Appleyard, 2007). Typically, a digital platform is essential to make a digital innovation ecosystem work as it aligns various actors to achieve a mutually beneficial purpose, and it can be used for both creating and capturing value. However, when the goals of ecosystem firms are divergent, OI is not uniformly superior to closed innovation (Almirall and Casadesus-Masanell, 2010). Therefore, understanding the roles of participants in innovation ecosystems becomes increasingly important.

2.2 Orchestration of innovation ecosystems

In innovation ecosystems, the control or coordination may reside with a single company, a collection of firms, a consortium or a not-for-profit organisation (Chesbrough and Appleyard, 2007). The interdependence among ecosystem participants challenges how ecosystems are

Table 1.
Principles of open and closed innovation

Categories of principles	Closed innovation principles	Open innovation (OI) principles
Human resources (HR)	The smart people in the field work for us	Not all the smart people work for us, so we must find and tap into the knowledge and 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 do not 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 do not 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

Source(s): Adapted from Chesbrough (2003)

coordinated and managed. This implies various ecosystem roles and associated activities and the importance of ecosystem orchestration. Chesbrough (2008) defined orchestrator as the role of those who orchestrate knowledge assets, complementary assets and IP to commercialise innovation. Dhanaraj and Parkhe (2006) defined orchestration as "deliberate actions" undertaken by a central hub firm, to ensure the creation and extraction of value. Key orchestration processes are managing (a) knowledge mobility, (b) innovation appropriability and (c) network stability (Dhanaraj and Parkhe, 2006). Knowledge mobility relates to maximising value creation by ensuring that specialised knowledge of each member is not locked within its organisational boundaries. Innovation appropriability relates to capturing profits generated by innovation (Teece, 1986), including the use of patents, copyrights and trademarks (Chesbrough, 2008). Network stability refers to dynamic stability with non-negative growth rate while allowing for entry and exit of network members.

Equally, the Dhanaraj and Parkhe (2006) view of ecosystem orchestration implies a sense of contractual control across the ecosystem relating more to closed innovation than to OI. Indeed, innovation may have formal management through ownership-based control devices or informal coordination mechanisms (Autio and Thomas, 2014). Reypens *et al.* (2019) described the Dhanaraj and Parkhe (2006) view of orchestration as "dominated" and enforced by contracts as opposed to consensus-based orchestration. They defined network orchestrator engaging in mainly three practices: connecting, facilitating and governing (Reypens *et al.*, 2019). Through "connecting", the orchestrator identifies potential members with desired capabilities and recruits them into the network, formally (through contracts and agreements) or informally. By "facilitating", the orchestrator provides a platform where the members interact with each other or combine their capabilities, ensuring that their goals and motivations of members are aligned. By "governing", the orchestrator puts appropriate governance arrangements in place, such as setting up collaborative structures, defining milestones and deliverables, to control and coordinate the activities in the ecosystem to ensure the achievement of desired outcomes.

From the spectrum of "dominated" to "consensus-based orchestration", Reypens *et al.* (2019) propose the idea of hybrid orchestration as orchestrators switch from one mode to the other responding to emergent network challenges. When studied longitudinally, orchestrators were found to change their behaviours from "engagement" to "connection", and "co-development" to "progress", from simply assembling members to create value and achieve strategic growth (Paquin and Howard-Grenville, 2013). Evolving orchestration behaviours suggest a hybrid approach, as orchestrators' role and innovation continuously evolve. Apart from evolving orchestration behaviours in innovation ecosystems, roles also evolve and beyond the traditional roles of hub firms, members and intermediaries, for example, business incubators and venture associations (Dutt *et al.*, 2016; Giudici *et al.*, 2018), emerge. Table 2 summarises key roles and characteristics of open, hybrid and closed ecosystems.

2.3 Blockchain innovation ecosystem in construction

Blockchain technology has been thought as the most important invention since the Internet (Tapscott and Tapscott, 2016). However, inventions are different from innovation, in terms of the need of the latter to carry value. Blockchain applications struggle to be considered valuable 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. Contrary 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 (Nawari and Ravindran, 2019; Hunhevicz and Hall, 2020). Blockchain also allows transactional data to be recorded chronologically in a chain of data blocks using cryptographic hash codes (Perera *et al.*, 2020). When a transaction is registered on blockchain, the transaction is packed with other transactions in a block, and the validator nodes or miners – computers nodes connected over a specific blockchain network – analyse the transaction and validate the block via a predefined consensus protocol.

Due to of the ability to store immutable data and verify transactions, blockchain is an attempt in addressing the global decrease in trusting the Internet and the underdeveloped trust in decentralised technological solutions (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 high level of trust increases efficiency in business relations. Therefore, interorganisational relations and

	Closed innovation ecosystem	Hybrid innovation ecosystem	Open innovation ecosystem
Relations	Contractually dependent or semi-independent firms	Semi-independent and independent firms	Independent firms
Orchestrator type	Hub firms	Hub firms or intermediaries	Intermediaries, e.g. business incubators and accelerators, venture associations
Orchestrator size	Large corporations (for profit)	Varying sizes	Varying sizes (including non-profit)
Member relations	Member firms, partners, supply chains	Member firms, partners, supply chains	Member firms
Member size	Varying sizes	Small and medium enterprises (SMEs)	Small and medium enterprises (SMEs)
End goal	Collective innovation goal	Innovation goal and independent business opportunities	Independent search and pursuit of business opportunities
Key references	Dhanaraj and Parkhe (2006)	Reypens *et al.* (2019), Paquin and Howard-Grenville (2013)	Dutt *et al.* (2016), Giudici *et al.* (2018)

Table 2. Composition of closed, hybrid and open innovation ecosystems

constellations, such as supply chains and ecosystems, are often considered key application areas for blockchain. Because blockchain as a distributed technology shapes and is shaped by various participants such as accessors, participants, miners and regulators, developers/start-ups, large companies trialing blockchain-based operations, think-tanks, non-profit consortia, research organisations and others, it is associated with interorganisational constellations. Blockchain is considered key enabler of digitalisation of supply chains and logistics (Gupta *et al.*, 2020) as many supply chain theories can be adapted for blockchain technology (Treiblmaier, 2018). Treiblmaier (2018) demonstrated the shortcomings of neoclassical economic theories such as principal agent theory (PAT), transaction cost analysis (TCA) in addressing human behaviour, resources and dynamic relationships over theories such as resource-based view (RBV) and network theory (NT). Qian and Papadonikolaki (2020) have demonstrated how blockchain-based smart-contracts change the nature of trust in construction supply chains from relational to technological trust.

Blockchain is an important technology in construction as it complements BIM and IoT with various applications across the project life cycle across cities, energy, property, transport and water sectors (Scott *et al.*, 2021; Elghaish *et al.*, 2021; Sacks *et al.*, 2020). The fragmented nature of construction procurement shows that main contractors take ownership of innovative solutions, and SMEs struggle to address skills shortages and financial liquidity. Nevertheless, blockchain in construction has been used in the digitisation of material flows to complete material information of a built asset, for example, in material passports (Li and Kassem, 2021). Blockchain has demonstrably been applied in project bank accounts (PBAs) to ensure fast payments for SMEs, hence bypassing the dominance of contractor in delaying payments and allowing liquidity to SMEs and asset tokenisation for supporting project financing through crowdfunding for raising funds for shared ownership (Tezel *et al.*, 2021). These changes show a transition towards a less paper-based and more trusting sector. Alongside private organisations and their pilot projects with blockchain, blockchain consortia emerge for different industries globally (Barima, 2017), governments across the world trail trial blockchain for public funds (Anjum *et al.*, 2017) and multinational organisations like the North Atlantic Treaty Organisation (NATO) and European Union (EU) show interest in it (Houben and Snyers, 2018).

Blockchain protocols are classified over two dimensions, anonymity (public/private) and consensus (permissionless/permissioned), with advantages and disadvantages (Tezel *et al.*, 2020). Public ledgers allow anyone to read a ledger, whereas private ledgers allow only specific members to access transactions. Permissionless nodes allow anyone to set up a node and interact with the ledger, for example, by adding transactions or participating in the consensus mechanism. Public and permissionless DLT are more decentralised. Mu *et al.* (2019) challenged the role of online leadership in open collaborative innovation in public versus private blockchain solutions and concluded that relation-focused leadership embedded in social capital prominently supports open collaborative innovation success. Moreover, they discovered that the joint effects of technical contributions, internal social capital and open community commitment positively impact open collaborative innovation success (Mu *et al.*, 2019). However, simultaneously, Mu *et al.* (2019) explained that openness not only encourages wide participation, but also constrains the commercialisation of blockchain open-source projects and thus threatens the innovativeness of blockchain. This paper discusses the openness or closedness of blockchain innovation ecosystem and how its orchestration can support industry change.

2.4 Research gap

This study aims to clarify the extent of the openness or closedness of blockchain innovation ecosystem in construction, factoring in its nature (private/public), consensus mechanisms and industry structure. On the one hand, well-known initiatives such as cryptocurrencies, Bitcoin and Ethereum are open ecosystems, governed by public permissioned blockchains. On the other hand, Treiblmaier (2020) suggested that private permissioned blockchains governed by private consortia imply closed ecosystems and are better described as centralised, seen in initiatives such as IBM, Hyperledger, R3 Corda and Tezos. In construction, various large companies and SMEs explore the blockchain space and consider its adoption to reap benefits mainly related to transparency, trust and traceability of assets. Large companies are more likely to adopt blockchain and lead R&D activities (Clohessy and Acton, 2019). Equally, Clohessy and Acton (2019) explained that technological aspects, organisational setting and blockchain environment are important for blockchain adoption, but regulation is top factor overpassing others, followed by market dynamics. Similarly, around smart contracts in construction, Badi *et al.* (2021) discovered that the environmental setting is significant. Therefore, the existing construction industry dynamics, dominated by large companies and government regulation, are key determinants of the blockchain innovation ecosystem and warrant further investigation.

Large organisations willing to spearhead blockchain in construction tend to adopt more controlled/permissioned type of blockchain arrangements, which may be limiting and risk underachieving the sectoral change expected with blockchain (e.g. autonomous organisations, improved collaboration) in the long run (Tezel *et al.*, 2020, 2021). This is because the more controlled/permissioned a blockchain arrangement, the more akin it is to a distributed database controlled by a select few. This will also create technology gatekeepers with implications on project management, project governance, project financing, SMEs and other sector players, as the gatekeepers retain their position and the status quo. For a "healthy" unfolding of blockchain in construction, and to reap its envisioned and rather revolutionary benefits fully (admittedly comes with embracing also the less controlled and more public arrangements), it is important to understand how this innovation ecosystem works and what it is composed of. Previous studies have emphasised the importance of human behaviour, resources and dynamic relationships for understanding blockchain technology from a distributed view, as various members such as accessors, participants, miners and regulators are involved (Treiblmaier, 2018). In this distributed ecosystem, various actors step up and play different roles, either as leaders or ordinary members, and there are a few contenders about the potential orchestrator of this innovation ecosystem. The originality of this paper is on focusing on the much-needed view of the ecosystem level and its orchestration. Following these views, theories of OI and ecosystem orchestration are used to analyse the empirical fieldwork. To sum up, the paper discusses the paradigm of blockchain by considering it as an ecosystem and concludes with propositions for rethinking the role of construction actors in leading change for digital construction.

3. Research methodology

3.1 Methodological underpinnings

This study follows Saunders *et al.* 's (2007) "research onion" approach to demonstrate how research philosophy was operationalised into appropriate methodological options. First, in terms of research philosophy, and as ecosystems concern actions and interactions among various actors, this study sets off 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 for various actors (Teece, 1986), we adopt interpretivist epistemology to understand how the value of blockchain innovation ecosystems is perceived by the said actors. Second, regarding theory development, the theoretical framework has been inspired by the OI and ecosystem orchestration theories, and the research employs inductive reasoning to move from fieldwork to emerging patterns of tentative propositions (Arthur, 1994), seeking consistent set of mental models from expert informants on the topic.

3.2 Data collection

The study is based on a mono-method qualitative approach, with data collected through interviews. Because the second research question is on the roles of emerging orchestrators in blockchain innovation ecosystems, qualitative data were deemed more appropriate, as there is little archival data on the topic and a general lack of quantitative data from businesses and such ecosystems. Data were collected by asking questions orally to individual interviewees (DiCicco-Bloom and Crabtree, 2006). To allow for researchers' freedom and the emergence of patterns in data, the interviews were semi-structured. This flexibility allowed researchers to adjust pace and interview content to topics that the interviewees were better-versed in.

The interview protocol included briefing the interviewees about research aims, important keywords related to the study and the nature of the interview questions. There were only eleven questions, and the interviews lasted 22 min–72 min, depending on the interviewees' replying pace of. The questions were about the professional background and experience of the interviewee, about how blockchain technology was affecting the openness/closedness of the ecosystem and the emerging roles of orchestrators in the innovation ecosystem. Appendix shows the full list of interview questions. Data collection took place between November 2018 and May 2019. Most interviews (n = 23) were conducted face-to-face in the university or organisations, and some (n = 12) were conducted online. Following the study's ethical considerations and confidentiality policy, all interviewees were informed that they and their organisations would be pseudonymised. All interviews were audio recorded with the express consent of the interviewees and then transcribed.

The interviewee selection criteria were crucial. The interviewees were from a global sample with experts from the United Kingdom (UK), Sweden, United States of America (USA), Germany, France and Spain. In total, 23 subject experts participated, initially through purposeful sampling of individuals active in blockchain implementation and research, and then snowballing to expand the number of interviewees. The initial interviewees who were recruited from the authors' professional networks helped identify other potential interviewees meeting the sampling criteria. Depending on their professional background, experts were selected for their high (a) familiarity with blockchain, (b) engagement with digital technologies in construction and (c) professional experience in construction or technology space. Table 3 describes their profiles.

3.3 Data processing and analysis

To respond to RQ1 regarding nuances between openness and closeness of the blockchain innovation ecosystem in construction, a more deductive data analysis method was followed. Using the OI principles shown in Table 1 of HR, R&D, commercialisation, business models, idea creation and IP as deductive or top-down codes, the data were analysed searching for patterns to fit the codes. RQ2 refers to roles of the various members in the innovation ecosystem, seeking to understand who are the emerging orchestrators of OI ecosystems, and the data were analysed in an inductive qualitative manner through inductive and *in vivo* coding. 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 (Bazeley, 2013;

ID	Position	Organisation	Industry	Location	Interview type*	Interview duration**
1	Director	BIM consultancy	Construction	UK	F2F	38
2	Director	Entrepreneur	Technology	UK	F2F	35
3	Founder	Client	Construction	USA	F2F	50
4	Principal	Architecture and Law Consultancy	Construction	UK	F2F	42
5	BIM leader	Design and Engineering (D&E) Consultancy	Construction	UK	F2F	30
6	Reader	University	Higher education	UK	F2F	75
7	Consultant	D&E consultancy	Construction	Germany	F2F	52
8	Consultant	D&E consultancy	Construction	UK	F2F	58
9	Consultant	D&E consultancy	Construction	UK	F2F	60
10	Director	Law consultancy	Construction	UK	F2F	43
11	Senior consultant	D&E consultancy	Engineering and construction	UK	OM	38
12	Director	Blockchain development	Construction	France	OM	42
13	Vice-president	Blockchain foundation	Construction	USA	OM	36
14	CEO	Blockchain technology company	Construction	UK	OM	37
15	Senior tesearcher	Research institute	ICT	Sweden	OM	67
16	Head of VDC infrastructure	Client	Construction	Sweden	F2F	30
17	Sustainable development responsible	Client	Construction	Sweden	OM	22
18	Head of DLT	Innovation Centre/ Institute	Multi/ICT	UK	OM	45
19	CEO	DLT service provider	ICT	UK	OM	40
20	Director of research and development	D&E consultancy	Construction	USA	OM	45
21	Business and technology analyst	D&E consultancy	Construction	USA	OM	35
22	Business consulting and innovation partner	D&E consultancy	Construction	Spain	OM	20
23	Senior associate	Management Consultancy	Construction	UK	OM	55

Note(s): *F2F: Face-to-face, OM: Online meeting, ** in minutes

Table 3. Identifiers (ID) and profiles of interviewees and interview details

Saldanã, 2009). The interview data were coded into themes using both inductive (emerging from the data) and deductive (emerging from the theoretical background) or *a priori* codes (Saldanã, 2009). The inductive codes focused on comparing and contrasting the data to discern patterns of interpretations (Bazeley, 2013). The deductive codes were used to assign the pieces of data to codes (Saldanã, 2009). The combination of these approaches provided interpretative flexibility to the research.

4. Findings

4.1 Blockchain innovation ecosystems in construction

The data showed varying degrees of applicability of the OI principles by Chesbrough (2003). Following a deductive coding approach, this OI theoretical framework was used to evaluate the openness and closeness of the ecosystem, responding to a theoretically informed questions. Overall, whereas some principles such as 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. Table 4 presents the applicability of the OI principles to blockchain in construction and shows how many interviewees aligned with each principle. In the next paragraphs, quotations from the interviewees are given and attributed as "*Int-ID*" (based on IDs shown on Table 3).

4.1.1 Human resources (HR). Almost all interviewees recognised that new skills are crucial for blockchain technology and that firms need to tap into the expertise of bright individuals outside their boundaries. The findings supported the argument of finding and training the best skills for OI. Some interviewees focused more on soft skills needed and necessary mental shift accompanying new introduction of the technology. As Int-12 stated: *"It is not about skills, it's about mentality having people open to work together on new topic and also test. There is a pioneer's spirit about blockchain"*, supported by Int-14: *"I think it's more of a mindset than a skillset, actually"*. Similarly, Int-16 recognised that due to silos in the industry, there is a *"need to get everybody in the same area and really collaborate"*. Following a more socio-technical and pure OI approach, Int-7 explained:

> You need people that first of all understand these new technologies and new paradigms, for large companies it totally makes sense to have those people in-house, and combine this knowledge with a good understanding of the challenges of the construction industry. (. . .). And you could also hire people and you could buy this knowledge from external parties.

4.1.2 Research and development (R&D). Most interviewees recognised that OI requires the combination of internal and external R&D, and they aligned with various open-source

Table 4.
Applicability of open innovation principles (see Table 2) to blockchain in construction

Categories of principles	Closed innovation (CI) principles	Open innovation (OI) principles	Indicative interviewee arguments in support of CI	Indicative interviewee arguments in support of OI
Human resources (HR)	1	22	Not a huge difference from how we manage it today	We need to find and train the best skills
Research and development (R&D)	3	20	We have our own dedicated R&D departments	We take advantage of developments from open consortia
Commercialisation	3	20	Government needs to help us internalise these initiatives	Blockchain ecosystems are useful in the pre-competitive stage
Business models	9	14	Construction firm protect existing business models	Businesses need to align with technology
Idea creation	0	23	N/A	We take advantage of ideas around blockchain
Intellectual property (IP)	11	12	Construction does not have the culture of sharing data	Blockchain needs companies sharing their data
Total interviewees	23	23	N/A	N/A

Note(s): N/A: Not Applicable

initiatives such as Ethereum or even hybrid solutions such as Hyperledger. Some focused on developing new ideas in-house by aligning to existing closed and proprietary systems, such as Autodesk around BIM: *"we integrate the blockchain within the current ecosystem of the software, namely Autodesk Revit user community"* (Int-12). Int-20 agreed that *"the biggest changes that needs to happen to the industry (. . .) is (. . .) to start approaching this [R&D] from a collaborative mindset (. . .) as a team"*.

4.1.3 Commercialisation. Most interviewees resonated with the ideas of OI for profiting from innovation in a pre-competitive stage through OI ecosystems. Int-2 stated that: *"the pre-competitive model is, 'Hey, there are a bunch of things that we all need to collaborate on; without those things we cannot do the competitive things'. So, building that pre-competitive model and ecosystem is primary to making this work"*. The potential of OI was seen as enabling sustainable practices and allowing *"feasibility studies and predevelopment work for sustainable global infrastructure projects (. . .) to get kick started off the ground. This helps public communities around the globe, raises standards of living and makes life easier for people that are living in large metropolitan areas"* (Int-13). Others focused more on the existing competitive practices of firms protecting their innovations, hoping to profit more when they were ready to market. As Int-3 explained:

> It's a zero-sum game, always, in the US. If you have a project, I'm losing a project. If you're having new technology, I'm losing a new technology, where (. . .) in many other areas there are opportunities happening right now to get further integrated through more of an idea of cooperation versus competition. Competition is necessary, but at what end?

4.1.4 Business models. The data around business model change for blockchain innovation ecosystems were mixed. Only half of the interviewees indicated that business model change was needed to engage in OI blockchain ecosystems. This was demonstrated by the statement that blockchain solutions should focus on reducing costs in the existing closed industry structure (Int-18) rather than rethinking the traditional procurement system. Int-12 stated that *"construction is less innovative than banking and like them they want to protect their business model"*. Equally, Int-2 stated that *"defining those business cases where it's not just about an isolated one company doing it, it's saying, 'Well, if we did this across a particular group of companies, that's when the benefit comes.' (. . .) They're not interested in the ecosystem; they're interested in their own business case"*. According to Int-2: "*Part of the challenge of blockchain, it's not about blockchain. It's really more about where are the business problems right now that you can solve"*. Some concrete solutions focused on: "*the potential for subcontractors to get paid faster which helps small businesses with their cash flow and keeps them engaged in the project to finish project faster"* (Int-13).

Contrariwise, the interviewees recognised how OI in blockchain could allow for shorter supply chains (Int-17) and removing intermediaries (Int-14): "*allowing smaller actors to work together in the project not being so dependent on the huge companies that hold everything together like the risk and public management. (. . .) It's another thing if could ever be realized. Because there is probably a threat that could be to current business models"* (Int-17). Int-14 added:

> By using smart-contracts, payments could be milestone-based. Companies will be able to hold supplier payments funds in escrow using smart-contracts – once a certain parameter has been achieved, the payment is automatically released to the supplier. Therefore, introduction of smart-contract-dependent protocol could completely revolutionise how the entire process is managed.

4.1.5 Idea creation. All interviewees agreed that to succeed in blockchain innovation ecosystems – whether closed or open – they need to make the best use of 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: "*You need to get everybody in the same area and really* *collaborate"* (Int-16). Int- 13 explained that idea creation in blockchain space is more difficult than in other traditional developing frameworks: "*If an organisation is going to be looking at blockchain, there is going to be looking from development perspective and new skills sets in terms of development platform while working with blockchain developers and technical people will start looking at*". According to Int-8, as a solution to this challenge, the appropriate blockchain innovation ecosystem could look like:

> . . . an ICO or some sort of Cloud fund, blockchain-based one where you have lots of smaller companies, small to medium companies are the funders, so maybe they collaborate together to bed down a project and they kind of share the resources and they all kind of go for that project . . ..

4.1.6 Intellectual property (IP). The feedback from the interviewees about IP and its role in blockchain innovation ecosystems was mixed. On the one hand, the interviewees did not see the need to open and share their IP for developing blockchain-enabled solutions as Int-15 stated: "*I do not actually believe that the construction industry understands what the blockchains are without sharing data"*. Similarly, Int-1 mentioned that with blockchain, "*it will be easier to protect intellectual property*". Int-8 shared that the relation between blockchain and IP may have legal implications and that "*access to right on a particular blockchain-based address might be limited to certain people who are trustees maybe, I image that would be a case to avoid any legal issues*". On the other hand, others supported an "*open-source solution personality rather than let's make it proprietary, put it in our closet and never let any other firm*" (Int-20). There were suggestions of "*federated blockchain where companies share data. The traditional design and build contract system is pretty outdated*" (Int-19). Similarly, Int-2 explained key ideas of sharing IP across blockchain innovation ecosystems:

> So there are a bunch of characteristics around ecosystems that need to be put into place; one big one is that you have to build a bunch of open-source protocols, and they have to be open-source, you have to build a bunch of open-source data standards and collaborate with them. You have to build an ecosystem where you get participants to contribute to building the ecosystem and the network rather than thinking about proprietary stuff.

4.2 Orchestration of blockchain innovation ecosystems

From above, Table 4 showed mixed results in terms of how open or closed blockchain innovation ecosystems in construction are. The data showed three main types of blockchain innovation ecosystems: (1) open, (2) hybrid and (3) closed. For each of these innovation ecosystems, there were different technological principles used, value created and preferred orchestrators. Regarding technological principles, there exist prominent blockchain platforms with different characteristics (public/private – permissioned/permissionless) whose features apply to all sectors adopting blockchain, including construction. Table 5 summarises key characteristics of the three emerging blockchain innovation ecosystems and their orchestration.

Regarding the orchestrator of blockchain innovation ecosystems, there were two main patterns revealed. First, with regards to open and hybrid innovation ecosystems, consortia were mentioned as potential orchestrators. On the one hand, Int-18 stressed how consortia need to take over this new role as the existing business model is based on competition and transactional focus only: "*Yes, so actually it's outside the construction industry, it's not transformation inside the construction industry (. . .), because at the moment there's this winner takes all approach that if you use in my Blockchain I'm going to keep adding value, I'm just going to charge you per transaction and I'm going to make billions. (. . .) instead, it has to be built as a consortium effort with the industry hand in hand*" (Int-18). On the other hand, Int-2 explained examples from other industries where consortia were not productive in orchestrating the new innovation ecosystem:

Innovation ecosystem	Business ecosystem	Preferred orchestrator
Open innovation ecosystem, e.g. public blockchain platforms such as Ethereum	Business model: non-profit Business case example: blockchain for tracking accountability in design provenance New value created • Collective/community goals* (9)	• Open-source consortia (4) • Large companies (3) • Owners and maintenance (2)
Hybrid innovation ecosystem, e.g. permissioned blockchain such as R3 Corda	Business model: Non-profit or for-profit Business case example: Blockchain-based BIM platforms New value created • Collective/community goals* (3) • Individual/commercial goals** (3)	• Software vendors (1) • Insurance firms (1) • Communities (1) • SMEs (1) • Contractor (1) • New organisations formed (1)
Closed innovation ecosystem, e.g. Hyperledger Fabric private and permissioned blockchain (also known as enterprise blockchain)	Business model: For profit Business case example: Blockchain-based platform for streamlining real estate transactions New value created • Individual/commercial goals** (5) • Collective/community goals* (2)	• Contractor (5) • Tech companies (1) • Owners and Mmaintenance (1)

Note(s): *Collective goals in value creation relate to how more than one member of the ecosystem will be benefitted
**Individual goals in value creation relate to how only one member of the ecosystem will be benefitted commercially
In brackets, the number of interviewees supporting the idea is shown

Table 5. Emerging blockchain innovation ecosystems, their orchestrators and roadmap to change

> If you're trying to do things by committee, one of the biggest problems is, if you've got banks paying, in this case, for R3, banks are paying a lot of money, they want their pound of flesh; they want, 'I put $2m in, I want to be on the steering committee and I want to drive the direction'. So, when you try and get a bunch of guys who are all equal who all want what they want in a room. (. . .) They're all saying, 'Well, I want my requirements, I want my requirements', and so what you get is a lowest common denominator of requirements.

The second trend was related to closed innovation ecosystems, where traditional actors were considered as appropriate for leading them. Int-4 explained that contractors would be appropriate to orchestrate them as they stand to gain more: "*Contractors work under very small margins. So, anything that makes it more efficient, things can happen quicker, you can find out things quicker, it's definitely going to be win-win for them. (. . .) Because as I've said, for them, they're the ones who actually apply things on site. (. . .) I would say they're the ones who would benefit, not necessarily control it*". Int-16 shared that clients needed to orchestrate these new ecosystems and drive them: "*I think it will be harder because they probably do not see the same value. If the clients do not initiate this, it will never happen. We are relying on the clients especially on the smaller projects*". Whereas Int-7 shared that "*Blockchain cannot be looked at separately, it has to interact with a number of existing technological initiatives within construction. Remobilising resources. So, I think the government really, the industry, need to do something about it*".

The dominant orchestrating role of contractors was also mentioned in conjunction with hybrid innovation ecosystems. The hybrid approach contained varying responses around the orchestrators, and the orchestration approach was vague. Int-19 suggested that new digital-savvy organisations would be formed to replace the traditional role of contractors.

4.3 Emerging relations

Many of the interviewees (Int-1, 4, 7, 9, 11, 12, 16, 21, 23) believed that new business models are not needed for blockchain. These same respondents indicated contractors and large companies as their preferred orchestrators. This may be due to the perception that these organisations generally have better exposure to and control over the whole supply chain with a higher capacity of creating networks and interaction in the extant business models. Being the more powerful actors in project delivery, whose priorities often shape the decision-making, those interviewees see the client as dominant. The blockchain use case expectation of those interviewees is also frequently operational at a project level, and project and supply chain management focused (e.g. payments, smart contracts, logistics and supply chain tracing).

Contrariwise, the interviewees who supported the need for new business models expected a comparatively broader set of blockchain drivers such as governments, consortia, financiers or large companies with a sectoral and cross-sectoral reach. Aligning with new business models, their views on orchestrators are also more varied involving open-consortia, new organisation types to be formed, communities, SMEs and technology companies. Regarding use cases, they often referred to a generic "blockchainification" of data beyond operational and project management focused applications.

A summary of the findings is illustrated in Figure 1. In the construction industry, large companies as orchestrators need to find and train the best skills regarding blockchain technology for OI. Concerning R&D approaches, companies should take advantage of developments from open-source initiatives. As for commercialisation ideas, companies profit from innovation in the pre-competitive stage through OI ecosystems by utilising open-source solutions. Regarding business models, OI in blockchain can allow for shorter supply chains and remove intermediaries by using smart contracts. Regarding idea creation, companies nurture new skills in terms of platform development by taking advantage of ideas around blockchain from the ecosystem. Concerning sharing IP, companies can build open-source protocols and standards and collaborate over them. In OI for blockchain as meta-organisational ecosystem, legitimisation and deployment strategy, guidance to SMEs, endorsing blockchain by trial and pilot projects, legalisation of cryptocurrency, support of research, legislation, contracts, standards and incentives concerning stronger government involvement are the examples of needed policy change.

5. Discussion

5.1 Open innovation ecosystems in construction

Digital technologies such as blockchain gain traction in construction. This study focused on the emergence of blockchain innovation ecosystems. This study set out to explore how open or closed is the blockchain innovation ecosystem in construction (RQ1) and who are the emerging orchestrators of this innovation ecosystem (RQ2). By using the OI principles by Chesbrough (2003) as a deductive set of codes and an analytical lens, the study revealed the six OI principles were not addressed to the same extent in the data from the expert interviewees (answer to RQ1). To this end, although some conditions exist for OI blockchain ecosystems, not all principles are recognised.

There were four OI principles supported in the data. Firstly, in terms of HR, the findings were consistent with previous studies (Valdez-Juárez and Castillo-Vergara, 2021; Unalan and Ozcan, 2020) supporting the argument that for OI, firms need to find and train the best skills (Table 4, $n = 22$). Secondly, with regards to R&D, the findings were congruent with OI in requiring a combination of internal and external R&D aligned with various initiatives such as Ethereum or perhaps Hyperledger. This aligns with the literature, that companies take advantage of developments from open consortia (Unalan and Ozcan, 2020).

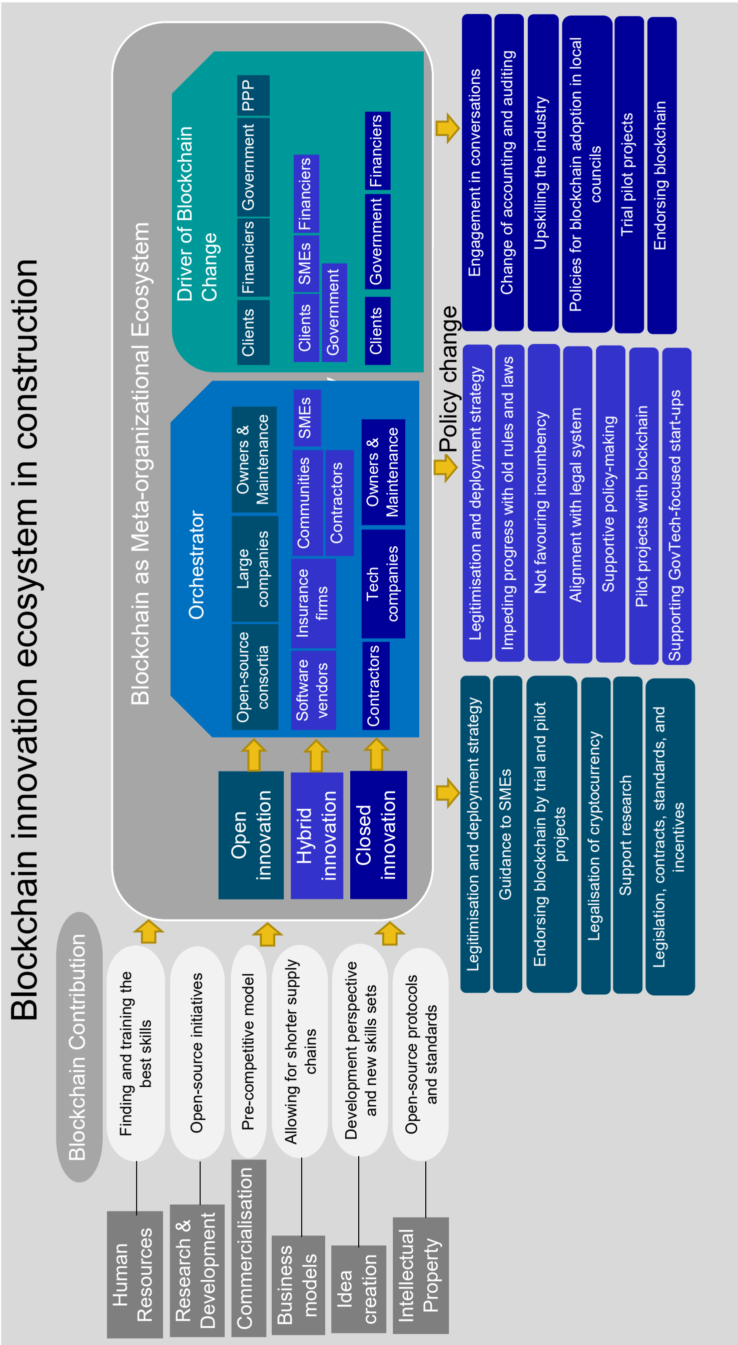

Figure 1.
Blockchain innovation ecosystem in construction based on the data analysed from interviews

Thirdly, commercialisation ideas of profiting from innovation in the pre-competitive stage through OI ecosystems also emerged from the data (Table 4, $n = 20$), and the interviewees echoed ideas of firms looking at open-source solutions as ways to profit from new developments outside the boundaries of their firm. However, the data also showed firms focused more on protecting their innovations to profit more when they were ready to market due to constraints in the commercialisation of blockchain (Mu *et al.*, 2019). Fourthly, the data showed a clear resonance to the OI principles of joint idea creation, making the best use of internal and external ideas. Construction firms are open to aligning with OI projects such as Ethereum and use open-source solutions in their innovations, as highlighted in the literature (Li *et al.*, 2019) – that companies take advantage of ideas around blockchain.

There were also two OI principles that were only partially supported by the interviewees, showing a clear division in the understanding and implementation of open ecosystems. On the one hand, the data displayed that a significant proportion of the interviewees overlooked the need for aligning their business models with blockchain technology but instead focused on the existing ways of doing things in accompanying participation in blockchain ecosystems (Table 4, $n = 9$). This was demonstrated by using blockchain solutions to focus on reducing costs in the existing industry structure (Int-18), rather than rethinking the traditional procurement system that could allow for shorter chains (Int-17) and removing intermediaries (Int-14), as emphasised in the literature – that businesses need to align with technology (Unalan and Ozcan, 2020; Chong *et al.*, 2019). On the other hand, 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 their 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 the literature – that blockchain needs companies sharing their data, and construction does not have the culture of sharing data (Mačiulienė and Skaržauskienė, 2021).

5.2 Emerging orchestrators of construction innovation ecosystem

Based on the aforementioned OI principles, the study showed that there were (1) open, (2) hybrid and (3) closed blockchain innovation ecosystems. For each of these innovation ecosystems, there were different emerging orchestrators (answer to RQ2). Project leadership is very important in blockchain, as Mu *et al.* (2019), focusing on collaborative innovation research around blockchain, highlighted the roles of project leaders rather than only ordinary members and provided evidence that leaders do exist and play a highly influential role. They suggested that OI project leaders are pivotal when members choose to target open collaborative innovation projects with their contributions (Mu *et al.*, 2019). Equally, in blockchain innovation ecosystems, the role of orchestrators is crucial for shaping the governance mechanisms that form them. Especially in the open and closed innovation ecosystems, there are clear orchestrators identified. In the former, open-source consortia are the preferred orchestrators;, in the latter, contractors are the preferred orchestrators.

5.3 Theoretical contribution

The main theoretical contribution of this work is that – to the best of the authors' knowledge – this is the first OI study in the construction industry. The OI paradigm has found many applications in the information technology (Chesbrough, 2003), hardware and software (West, 2003), power and energy (Greco *et al.*, 2017) and life sciences sectors (Chesbrough and Appleyard, 2007). An unexpected finding of the study was that by applying the OI theory to the construction industry, we can identify challenges in applying the theory, especially with regards to business model innovation, as the interviews did not show any concrete direction in transforming the existing business models to align with novel technologies such as blockchain.

This unexpected finding shows further research avenues. Nevertheless, the data from the interviewees resonate with the ideas of Adner (2006) on the importance of complementary innovations in innovation ecosystems that was confirmed by linkages between blockchain and BIM technologies in construction.

Business models are an important vehicle for innovation and may be also a source of innovation in and of itself (Massa and Tucci, 2013). To this end, it is surprising that whereas blockchain is a key technology based on openness and transparency in construction, this is seen as a mostly closed rather than open system due to the competitive and contentious culture, resistant to business model innovation, so as to align to new technology and not utilising the developments made available from public blockchains such as Bitcoin and Ethereum. Resistance to sharing data shows persistent mistrust and lack of a business mindset, as according to Chesbrough (2007), "a better BM will beat a better idea or technology".

5.4 Practical implications

The work puts forward a number of practical implications. First, the data showed strong implications for policymakers and governments. Especially the UK-based interviewees expressed that blockchain OI initiatives need to be encouraged and regulated by policymakers and the government, according to the data shown in Figure 1. Second, in government-sponsored demonstrator projects, the public client is expected to enforce blockchain-compliant commercial solutions and ensure transparency in financing projects. This was especially supported for financing complicated global infrastructure projects (Int-13). Third, open-source consortia and communities were seen as the potential orchestrators of such blockchain innovation ecosystems, in the open and hybrid (but not in the closed) innovation paradigm, and policymakers and the government were seen as the enablers of such ecosystems (Int-6 and Figure 1). These findings can guide policy development around blockchain and used as basis of regulatory frameworks for open or closed innovation ecosystems to leverage the full potential of the technology. Especially in construction, these ideas could unlock the sector's adversarial nature.

Finally, in both open and closed innovation scenarios, almost all interviewees concurred that the SMEs stand to gain more from blockchain innovation ecosystems as they will be protected, paid in time and gain visibility across the supply chain, even compete with larger players due to better liquidity. National programmes for the development of blockchain skills can be initiated by governments to support the SMEs. The OI approach will remove conventional R&D limitations and create a regulated system to infiltrate external ideas and breakthroughs to company's boundaries. Governments could stimulate commercialisation, expedite digital revolution and support emerging business change. Integrating blockchain with the existing digital delivery models involving BIM could resolve IP challenges and legal responsibility for sustainable building design coordination and collaboration throughout the life cycle phases (Li and Kassem, 2021; Scott *et al.*, 2021). This shows the potential of blockchain for supporting incremental changes and slow transition of the existing business models.

6. Conclusion

This study sought out to understand how open or closed the blockchain innovation ecosystems in construction are, following OI as a theoretical and analytical lens. Blockchain technology, due to its transparency, traceability and immutability properties, presents an ideal context for studying OI, as a lot of developments in this domain come from open-source initiatives and a growing community base. The data showed that construction is primarily headed towards an OI blockchain ecosystem ($n = 9$), although there are elements of hybridisation ($n = 6$) and closed ecosystems ($n = 7$), such as hierarchical forms of orchestration and pursuing of individual business goals. To this end, the OI paradigm in construction is largely misunderstood and not fully leveraged. Still, there was a consensus on the regulation needed for blockchain in construction and especially aligning with the existing delivery methods (Table 5).

The data showed a traditional or hierarchical approach to ecosystem orchestration, as contractors were predominantly seen to fulfil this role for the closed innovation paradigm, followed by asset owners (Table 5). At the same time, the study showed clear indications of potential orchestrators of OI blockchain ecosystems through open-source consortia. The government and large clients are seen as drivers of technological change. Paradoxically, data showed that technological change and innovation are limited by the traditional business models in the industry that do not allow for "*knowledge spillover*" effects (see Table 4). In both open and closed innovation scenarios, the data showed that the SMEs stand to gain more from blockchain innovation ecosystems as they will be more protected and gain visibility across the supply chain, which is the first step in transforming construction's business model.

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Appendix

Interview questions:

(1) What is your current industry and how would you describe your background, experience and current role?

(2) How would you describe your current level of knowledge, expertise and experience with blockchain technology?

(3) What is the potential of blockchain technology in construction and could it become or is it a disruptive innovation? Do you reckon it is a true potential or hype/fad?

(4) What would be the greatest benefit of blockchain technology in construction and how could it revolutionise it?

(5) How can blockchain support or improve the use of other technology-oriented processes in construction (e.g. BIM)?

(6) What transformations, for example in skills, procurement (financial), legal and business models are needed to harness the potential of blockchain technology in construction?

(7) How could blockchain technology change the trust in the construction ecosystem?

(8) Could blockchain help smaller organisations in construction in some ways to democratise construction supply chains, for example facilitate their access to financial instruments without having to go through third-party companies?

(9) What is the role of the following actors in controlling or democratising the blockchain innovation ecosystem in construction? Who will be the potential orchestrator of the blockchain innovation ecosystem? Who are the most important actors from the below:

- Government
- Clients
- Financiers
- Owners/operators
- Consultants
- Contractors
- Suppliers
- Manufacturers
- Users
- Are there any other actors not considered in this list crucial to innovation?

(10) What applications of blockchain technology in construction do you first see maturing first and becoming mainstream?

(11) What should be the policymakers' response to the increasing popularity of blockchain technology in construction? And what should be their immediate steps to be taken?

About the authors

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