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Designing a Blockchain Enabled Supply Chain

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Designing a Blockchain Enabled Supply Chain

Abstract:

While blockchain technologies are gaining momentum within supply chains, academic understanding of concrete, real-life design and implementation is still lagging, hence offering very limited insights into the true implications of blockchain technology on supply chains. This paper reports a two-year design science research (DSR) study of a smart contract initiative piloted by a consortium in the UK's construction sector. We seek answers to the research question, '*How should a blockchain enabled supply chain be designed?*' Guided by the theory of business model, we explore how a group of supply chain actors collectively designs and pilots a blockchain solution that addresses the supply chain transparency and provenance problem. Our research is one of the very few longitudinal empirical studies to offer in-depth evidence about how blockchain is deployed in complex multi-tier supply chain networks. In compliance with DSR research paradigm, we make contributions at three levels: designing and instantiating the blockchain architect and proving its utility in addressing the target problem; developing a set of design principles as a mid-range theory that can be applied and tested in different blockchain supply chain contexts; and refining and extending the kernel theory of business value at supply chain network level.

Keywords: blockchain, design science, supply chain, business model, design principles, longitudinal study

1. Introduction

Blockchain technology (or distributed ledger technology in general) is believed to have a profound impact on business and society (Tapscott and Tapscott, 2017; Iansiti and Lakhani, 2017). While blockchain technologies remain in their infancy, their application is gaining momentum within supply chains (Wang, Han and Beynon-Davies, 2019; Saberi, et al., 2019). Many proof-of-concepts (PoCs) or piloting schemes have been developed in recent years, particularly in 2017 and 2018, using blockchain technology. IBM alone is working with hundreds of enterprises on blockchain implementations (IBM, 2018). Application-specific implementations, such as Everledger for diamond tracking and Filament for IoT, have also commenced. However, academic understanding of concrete, real-life design and implementation is lagging behind, as with many other emerging technologies, providing us with very limited insight into the true implications of blockchain technology on supply chains and business model transformations (Saberi et al., 2019; Wang et al., 2019).

This paper responds to recent calls for empirical research to investigate the full implications of blockchain technology in the supply chain (Saberi, et al., 2019; Pournader et al., 2020). In particular, we try to fill an important gap identified by Cole, Stevenson and Aitken (2018) to 'evaluate the impact of blockchain on improving the transparency of multi-tier networks, potentially working alongside organisations as they begin to adopt the technology (p.21)'.

Via a two-year longitudinal participative study of a blockchain piloting initiative in a complex construction supply chain network in the UK, we address the following research question (RQ): *How should a blockchain enabled supply chain be designed?* Different from mainstream studies that tend to examine individual or organisational behaviours towards, and consequences of, technology adoption, we undertake a design science research (DSR) approach. We thus have the dual objectives: to design a blockchain system to solve a class of supply chain problems and to derive new theoretical and managerial insights that contribute to knowledge production.

In line with the requirement of the DSR research paradigm, we make contributions at three levels, namely: designing and instantiating the blockchain architect and proving its utility in addressing the target supply chain transparency problem (Level 1), developing a set of design principles as a mid-range theory that can be applied and tested in different blockchain supply chain contexts (Level 2), and refining and extending the kernel theory of business value at supply chain network level (Level 3). Our DSR approach also adds to the diversity of research paradigms in the operations and supply chain management (OSCM) field. We further contribute to Interorganisational System (IOS) studies in the supply chain literature by providing empirical insights on how blockchain may be adopted in complex multi-tier sub-supplier networks to increase visibility, transparency and auditability.

The rest of the paper is structured as follows. Section 2 discusses the literature and our theoretical underpinnings. Section 3 presents our research methodology detailing the case background and the design science approach, as well as the data collection and analysis methods. Section 4 then presents our research findings, reports pilot evaluation results and formalises our key learnings into design principles. Section 5 discusses both our theoretical and practical contributions, acknowledges research limitations, and suggests some future research directions.

2. Background literature

2.1 Blockchain for supply chains

Blockchain, in its essence, is an encoded digital ledger that is stored on multiple computers of a public or private network (Wright and De Filippi, 2015). It comprises data records, or 'blocks'. Once these blocks are combined in a 'chain', they cannot be changed or deleted by a single actor, and instead, are verified and managed using automation and shared governance protocols (Christidis and Devetsikiotis, 2016). Blockchain is a peer-to-peer network, so each node or participant maintains a replica of a shared ledger of digitally signed transactions (Swan, 2015). In a supply chain sense, it means that transactions between organisations are no longer taking place in a bilateral manner, for instance between a supplier and a manufacturer. A blockchain reduces the complex bilateral communications by providing a single, shared, tamper-evident ledger that records the transactions as they occur (Wang et al., 2019).

Transactions in a blockchain are typically confirmed by all participants via a consensus mechanism (Tapscott and Tapscott, 2017). Once validated and recorded in a blockchain, a transaction becomes permanent. No single participant, even a system administrator, is able to delete or change a transaction unilaterally, thus enabling perhaps the most popular use case so far in supply chains – product provenance (Hewett, Lehmacher and Wang, 2019). Different from centralised information systems where there is a single organisation controlling the database (hence it can be tampered with), blockchain enables supply chain actors to share control over access to – and evolution of – the data (Cole, Stevenson and Aitken, 2018). This distributed attribute reduces the risk of single point failure embedded in centralised databases.

Blockchain underpins cryptocurrencies such as Bitcoin and Ether, using a shared database that updates itself in real time and can process and settle transactions in minutes using computer algorithms (smart contract), with no need for third-party verification, such as those normally conducted by a bank (Swan, 2015). It may remove some traditional intermediaries in the supply chain, leading to the so-called 'disintermediation' (Wang, Han and Beynon-Davies, 2019).

Utilising its unique nature of disintermediation, transparency with pseudonymity and security and automation, various industries have started to explore its utility in supply chains, ranging from product provenance and traceability, international shipping and cross-border supply chains, trade finance, secure data exchange and recording, to smart contracts, anticorruption and humanitarian aid (Chang, Iakovou, and Shi, 2019; Pournader et al., 2020). Currently permissioned blockchains are the main type of blockchain being deployed in supply chains which give network members control over who can read the ledger and how nodes are connected (Wang, Han and Beynon-Davies, 2019).

Depending on the scope and operating context, a typical blockchain-based supply chain would include suppliers, customers, logistics service providers (e.g. warehouse operators, freight forwarders and carriers), port, airport and terminal operators as well customs (if cross border) and financial service providers such as banks. In practice, supply chain organisations tend to form consortia as vehicles to explore the potential of blockchain because collaboration as well as cost/risk sharing are needed to take advantage of a decentralised technology such as blockchain (Deloitte, 2019). Therefore, any type of blockchain supply chain study will inevitably be at network level (not just about the bilateral interorganisational collaboration many IOS studies tend to focus on), even though we may concentrate on a focal company that is part of the blockchain supply chain ecosystem. For a detailed exploration of the implications of blockchain for supply chains, one can refer to the works of Wang, Han and Beynon-Davies (2019), Bai and Sarkis (2020) and Kshetri (2018). For a more technical introduction of blockchain, one can refer to Swan (2015) and Zheng et al. (2017).

Blockchain's implementations are not without challenges. The anticipated challenges could be intra- or interorganisational barriers (such as lack of knowledge and expertise, financial constraints or collaborative and information sharing issues), regulatory uncertainties, energy consumption, unethical behaviours and technological interoperability etc. (Saberi et al., 2019; Queiroz and Wamba, 2019; Wang et al., 2019). Despite the increasing effort by scholars, empirical research exploring how organisations could design a blockchain enabled supply chain remains limited and evidences to support the claimed benefits are still lacking (Cole, Stevenson and Aitken, 2018; Koh, Dolgui and Sarkis 2020). This is largely due to the emerging and immature nature of the technology itself. For many scholars, access to early initiatives can be a big barrier. Our research fills this void as we managed to secure access to a blockchain initiative and co-create a blockchain use case with multiple stakeholders that addresses a pertinent supply chain problem in construction. Details about our approach are offered in Section 3.

2.2 Technology adoption in supply chains

The study of technology adoption in supply chains is inevitably cross disciplinary, as it concerns both the technology itself and its organisational and supply chain implications. We turn to our neighbouring discipline, information systems (IS), and our own OSCM discipline to provide a brief overview of the technology adoption literature.

In the IS discipline, most of the studies fall into the behavioural-science paradigm, which seeks to develop and verify theories that explain or predict human or organisational behaviour (Hevner et al., 2004). Popular theoretical lenses proposed by various authors focusing on individual behaviours include the Theory of Reasoned Action (TRA) (Ajzen and Fishbein, 1977), Theory of Planned Behaviour (TBP) (Ajzen, 1991), Technology Acceptance Model (TAM) (Davies, 1989), Task-Technology Fit Theory (Goodhue and Thompson, 1995), Diffusion of Innovations (DoI) (Rogers, 2010) and Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003).

In the context of interorganisational systems (IOS) study, the literature tends to address three primary issues: factors influencing organisational decisions to adopt IOS, the impact of IOS on governance over economic transactions, and the organisational consequences of IOS adoption (Robey, IM and Wareham, 2008). Earlier studies tend to focus on EDI initiatives, e-market and RFID, and popular theories adopted include transaction cost analysis (TCA) (Williamson, 1985) (for instance to debate the coordination costs of hierarchies vs market), relational exchange theory (Heide, 1994), network externalities (Katz and Shapiro, 1985). Later, more attention was paid to the latest technological developments such as IoT, artificial intelligence, cloud computing and online platforms and ecosystems (Schniederjans et al., 2020). More specifically, Treiblmaier (2018) suggested four specific theories that can be used to guide research into the impact of blockchain on supply chains: principal agent theory (PAT), TCA, resource-based view (RBV) and network theory (NT).Wong et. al. (2020) proved that the popular Unified Theory of Acceptance and Use of Technology (UTAUT) is an effective instrument to investigate the determinants of blockchain adoption in supply chain.

Studies of IOS consequences from both IS and OSCM disciplines use a broad array of theories (Büyüközkan, and Göçer 2018). These include the resource-based view of the firm (Barney, 1991), organisational information processing (Tushman and Nadler, 1978), resource dependence (Pfeffer and Salancik, 2003), social network theory (Powell, 1990), institutional theory (DiMaggio and Powell, 1983), and structuration theory (Giddens, 1984), to name only a few. Broadly speaking, these studies investigate the adoption of a particular type of technology or a bundle of technologies in strategic competitiveness, operational efficiency, and interorganisational relational structure and quality (Daneshvar Kakhki and Gargeya, 2019).

Parallel to the behavioural-science paradigm is the paradigm of design science (DS), which is being increasingly recognised as equally important (Walls et al., 1992; Hevner et al., 2004; Peffers et al., 2007; Gregor and Hevner, 2013; Baskerville et al., 2018). Note that IS design science (i.e. reflection and guidance of artifact construction and evaluation processes) is different from IS design research (i.e. construction and evaluation of specific artifacts) (Winter, 2008). The design science paradigm in IS seeks to extend the boundaries of human and organisational capabilities by creating new and innovative artifacts[1] (Gregor and Hevner, 2013). Baskerville et al. (2015) argue that design science research (DSR) has a dual mandate, i.e. 1) the utilisation and application of knowledge for the creation of novel or innovative artifacts that engender change or improvement in existing situations or problem spaces, and 2) the generation of new knowledge. The new knowledge could be both design product knowledge and/or design process knowledge – about novel IT artifacts with practical utility (Iivari, 2020).

It is important to discuss the two distinctive paradigms here because they have different purposes of inquiry and hold different views on what constitutes as academic contributions. While behavioural IS research aims at 'truth', i.e. the exploration and validation of generic cause–effect relations, IS DSR aims at 'utility', i.e. the construction and evaluation of generic means – ends relations (Hevner et al., 2004). Our research is positioned as the latter.

Conceptions of the role of theory in DSR are quite diverse and scholars do not fully agree upon what constitutes as a theoretical or knowledge contribution. But there is generally a consensus that DSR does suggest theories, but of a different type (Iivari, 2020; Gregor and Hevner, 2013; Kuechler and Vaishnavi, 2008; Hevner et al., 2004). While the behavioural science paradigm typically uses 'kernel theories' (theories from natural or social sciences such as the ones mentioned above) for explanation and predication, theories in design science can be normative (i.e. for prescription and evaluation). Arazy et al. (2010) and Kuechler and Vaishnavi (2008) suggest that while the long-term DSR goal is to develop kernel theories, existing kernel theories

[1] Artifact is a term used widely in the IS discipline and refers to a thing that has, or can be transformed into, a material existence as an artificially made object or process. It may include construct, model, instantiation, hardware, software, method, design principles or technological rules. (Gregor and Hevner, 2013).

are not (necessarily) concrete enough to guide design, and so an intermediating theory is needed to bridge the gap. The intermediating theories are also discussed under the label of 'level 2 theories' by Gregor and Hevner (2013), 'mid-range theories' by Kuechler and Vaishnavi (2012), and 'substantive technology theories' by Iivari (2020). Kuechler and Vaishnavi (2012) further argue that mid-range theories can be used as a means of capturing design knowledge that would otherwise remain tacit in the design artifact. Though different terms are used, they nonetheless correspond mostly to the original description of mid-range theories proposed by Merton (1968), that they are explanatory theories of a restricted scope, and as such are more readily suggesting actions for specific efforts in applied fields. Iivari (2020) asserts that mid-range theories are design-oriented concretisations of abstract kernel theories. Therefore, kernel theories inform DSR efforts and can in turn be refined and developed by DSR (Kuechler and Vaishnavi, 2008). Formulating mid-range theories starts with accumulated knowledge about a phenomenon within a particular domain. This knowledge may stem not only from previous theory-based frameworks but also from inductive, qualitative observations of practice (Stank et al., 2017; Treblmaier, 2018).

Compared with the neighbouring IS discipline, DSR is less explored in the OSCM field. The notable efforts are from the Journal of Operations Management (JOM), which, although it has only published eight DSR papers as of May 2020, is actively encouraging the development of DSR. Interestingly a recent JOM editorial note by Chandrasekaran et al. (2020) advises that its DS department has changed its name to intervention-based research (IBR), though its mission remains the same as discussed in Van Aken et al. (2016, p.1) as 'to publish high quality research articles that derive new theoretical and managerial insights by engaging with practice and solving complex field problems'. They assert that IBR can be a path to interesting research and contribution, if an intervention deploys an abductive approach and either conforms the theories or generates surprising results and new knowledge that expands or recalibrates the original theories adopted. O'Keefe (2014) also argues for the case of design science as a research approach for operational research (OR) and asserts that design-oriented OR has a higher utility than narrow, problem-based OR. Research contributions from DS in OR are generated through the generalisation of methods, tools, or the entire artifact to other contexts. The author goes further to develop a DS methodology for design-oriented OR and proposes that scholars could use DS to contribute to what is referred to as Mode 2 research. Mode 2 research and knowledge production asserts that knowledge production occurs via collaborative inquiry between academics and practitioners in the context of application, as opposed to traditional 'Mode 1' where scholarly knowledge is generated as a result of an academic agenda (van Aken, 2005; Bartunek, 2007; Starkey and Madan, 2001; Starkey et al., 2009; Oliva, 2019).

Based on the latest thinking about DSR from IS, OM and OR disciplines, we establish that DSR can make three types of contribution (as summarised in Table 1). A specific DSR research project can produce artifacts on one or more of these levels ranging from specific instantiations at Level 1 in the form of products and processes, to more general (i.e. abstract) contributions at Level 2 in the form of mid-range theories (e.g. constructs, design principles) to well-developed theories about the phenomena under study at Level 3. Later in Section 5 we will discuss how we have made contributions to all the three types.

[Table 1 near here]

As discussed earlier in this section, there are a variety of theoretical lenses such as TAM, DOI and TCE in the behavioural research, which tends to explore antecedents as well as consequences of IOS adoption. However, our research purpose is to explore how we can design a blockchain enabled supply chain effectively, therefore those theories have their limitations in guiding our DSR research. The higher the generalisability of the theory, the less helpful it is to suggest directions for a design solution to a DSR problem.

In the following subsections we turn to the theory of business model which we chose as our guiding kernel theory. The theory of business model is useful for examining actual adoption and deployment, suggesting the meta requirements for the design process (Teece, 2010). However, its unit of analysis tends to be individual organisation, rather than a supply chain network. Therefore, in the next section, we attempt to refine and extend it to the context of blockchain supply chain and then use it to guide our DSR process.

2.3 Business model

The concept of business model is of critical importance because it translates and operationalises the vision and strategy of an organisation and provides a powerful way to understand, analyse, communicate and manage strategic-oriented choices (Al-Debei and Avison, 2010). As argued by Magretta (2002), a good business model answers the critical questions of 'Who is the customer? and 'What does the customer value?'. It should also answer the fundamental questions of 'How do we make money in this business?' and 'What is the underlying economic logic that explains how we deliver value to customers at an appropriate cost?'. Put simply, a business model articulates the design or architecture of the value creation, delivery and capture mechanisms employed by a firm (Teece, 2010). The term 'business model' can be traced back to 1960 but did not receive widespread use for decades until the early 2000s when disruptive technologies (e.g. the Internet) led to a number of new ways of doing business (DaSilva and Trkman, 2014; Johnson, Christensen and Kagermann, 2008). Despite the proliferation of literature on business model in the last decade and an explosion of the use of the term in practice, there is no universally agreed definition and conceptualisation of business model (for a summary of literature, please refer to the work of Peric, Durkin and Vitezic, 2017). Commonly agreed is that a business model centres around how it operates and creates value for its stakeholders (Casadesus-Masanell and Ricart, 2010; Al-Debei and Avison, 2010).

A business model is often examined at the individual firm level (e.g. Dubosson-Torbay, Osterwalder and Pigneur, 2002; Shafer, Smith and Linder, 2005; Teece, 2010; Wirtz et al., 2016), but it can also offer a network-oriented view and be used as part of a comprehensive framework for thinking about systemic change when technological innovation leads to structural changes in industries (Zott, Amit and Massa, 2011). A business model can be regarded as 'a new unit of analysis, offering a systemic perspective on how to "do business" encompassing boundary-spanning activities (performed by a focal firm and its partners, suppliers or customers) and focusing on value creation and value capture' (Zott, Amit and Massa, 2011, 1038). In parallel discussion with the concept of business model in the literature are the terms 'ecosystem' and 'platforms'. The ecosystem construct explicitly seeks to address the interconnectedness and interdependencies among supply chain partners, enablers (e.g. technology service providers and government agencies) and competitors (Viswanadham and Samvedi, 2013; Aarikka-Stenroos and Ritala, 2017). The concept of platform tends to be treated as a technological subsystem of a business ecosystem and a specific type of business model (Tsujimoto et al., 2018; Teece, 2018; Helfat and Raubitschek, 2018).

A common approach adopted in practice in exploring and exploiting the use of blockchain is to form a consortium where members may benefit from cost and risk sharing, accelerated learning as well as influencing standards and building critical mass for adoption (Deloitte, 2019). Even in blockchain initiatives that are largely led by a dominant player in practice such as Walmart's food provenance case (Hyperledger, 2019), there is still a strong need to include relevant supply chain actors (e.g. suppliers, distributors, logistics service providers, regulator bodies and technology service providers) into the blockchain system. The logic of blockchain is that information is shared, which requires cooperation between companies. Therefore, the concept of business model in our research goes beyond the narrow focus of an individual organisation and instead emphasises more on the collective act of a group of ecosystem players which utilises a blockchain platform to co-create value.

Al-Debei and Avison (2010) propose that the main elements or building blocks of a business model include *value proposition, value architecture, value network* and *value finance*, while others, such as Schon (2012) and Teece (2018), propose a similar approach under different terminologies that consists of *value proposition, revenue model* and *cost model*. The work of Al-Debei and Avison (2010) offers a broader perspective and fits well within the context of blockchain. This approach was also adopted by Chong et al. (2019) when examining five blockchain inspired business models in the financial sector, though they only focus on value creation logic, value capturing mechanisms and the challenges that may impact a business model's long-term viability. We adapt Al-Debei and Avison's four value dimensions in the context of a blockchain network and define them as follows:

- *Value creation proposition*: a way to demonstrate the business logic of creating value for customers and/or each party involved through offering products and services that satisfy the needs of their target segments.
- *Value network*: a way in which multiple firms are interconnected to coordinate and collaborate to co-create and acquire value.
- *Value delivery architecture*: a blockchain's structural capabilities to orchestrate and configure its network resources that allow the provisioning of products and services as well as related information flows.
- *Value appropriation*: a way in which blockchain network members manage issues relating to costs occurred and the capture and appropriation of value among members.

Although the four dimensions are useful in conceptualising a business model in the context of blockchain, they do not offer insights into *how* to design a business model that offers competitive advantages. Amit and Zott (2012) and Zott and Amit (2010) argue that a business model can be considered as an activity system, i.e. a bundle of specific activities conducted to satisfy the perceived needs of the market, along with the specification of which parties (a company or its partners) conduct which activities, and how these activities are linked to each other. This stream of arguments is largely in line with the value delivery architecture dimension discussed above. Amit and Zott (2012) go further to suggest three factors for consideration when designing a business model: a) content (the selection of activities to be performed); b) structure (how these activities are linked and in what sequence); and c) governance (who should perform them). They argue that business model innovation can occur in all three areas, i.e. by adding new activities, by linking activities in novel ways, and/or by changing one or more parties that perform any of the activities. Figure 1 captures the six questions systematically proposed by Amit and Zott (2012) and overlays them in the four dimensions of a business model discussed earlier based on Al-Debei and Avison (2010). We assert that these are the key parameters that need to be considered for business model design in the context of blockchain. Note that we have modified the original Question 6, '*What revenue models can be adopted to complement the business model?'*, by incorporating *cost sharing,* to reflect the co-creation and co-sharing nature of a blockchain network.

As shown in the logic flow of Figure 1, the process of designing a particular business model usually starts by sensing the existence of customers with an unmet (or poorly met) need who are willing and able to pay for a potential product or service (For example, Netflix changes the way we (customers) consume traditional media by offering an online subscription service. Its business model is subscription based, as opposed to a model generating revenues at a specific title level, which addresses a poorly met need.). The next steps are to plan and configure the ecosystem activities performed by various members to deliver the proposed value, followed by a need to craft a revenue mechanism and to appropriately decide and agree upon cost and benefit sharing. The four value dimensions and the design elements outlined in Figure 1 serve as our theoretical framework and guidelines for our design science approach and our longitudinal engagement with the blockchain pilot.

[Figure 1 near hear]

3. Research methodology

3.1 Case background

In the UK, the construction industry is a major part of the UK economy, contributing to around 6% of GDP and 7% of the UK jobs total (Office for National Statistics, 2019). Yet it is a highly fragmented industry, and most businesses are SMEs, typically with a low level of digital capability. The built environment is also complex with many interactions between different stakeholders. Fragmentation and low digital capability were blamed for hindering productivity growth and the UK's competitiveness in the global market (Government, 2014). The UK government launched Digital Built Britain in 2016, aiming to, through digital technology, 'transform the way its construction industry and operations management professionals approach social and economic infrastructure'. Blockchain is seen as one of the strategic enabling technologies that supports this programme. The sector has since been actively exploring the potential value of blockchain in various areas (Lamb, 2018; Kinnaird et al., 2017).

It is within this context that a group of over 100 organisations, led by a specialist service provider (hereafter referred to as LeadCo) from the construction sector, started in 2017 to explore how blockchain, particularly smart contract, may help address some of the aforementioned problems in construction supply chains. The collective output objective of this group was not to act solely as an industry think tank, but as an enabler of change through the careful consideration of required distributed ledger technologies, and then facilitating the funding, building and open release of those technologies. The first step was to identify where distributed ledger technology can have the most impact on automating processes and improving outcomes in construction. The following step was to promote industry-wide implementation of blockchain, initially through pilot projects and then full rollout and scale-up.

It is worth noting that LeadCo, the group leader, had locked its attention on blockchain much earlier. As shown in Figure 2, since 2013 LeadCo had already noticed and sensed the value of Blockchain beyond cryptocurrency. It took LeadCo quite a few years for sensemaking (the process through which individuals work to understand novel, unexpected, or confusing events) internally, although it also built up an industrial network with domain experts from various organisations in the meantime. This has led to large-scale externalised sensemaking activities from 2017. Sensemaking is a crucial pre-adoption stage when senior executives diagnose the symptoms evident from blockchains and develop assumptions, expectations, and knowledge of the technology, which then shapes their future actions regarding its utilisation (Wang et al., 2019).

[Figure 2 near here]

A series of workshops were organised between June 2017 and May 2018 with a variety of industry subject matter experts from client organisations, main contractors, subcontractors, designing companies and law firms, to technology service providers and academics. This period is considered as the intensive 'collective sensemaking stage'. Supply chain actors started with questions such as 'will the technology work in construction supply chain?' and later evolved into how it may help address the productivity challenges facing the sector and what value it may create.

At the end of the collective sensemaking stage, a smaller group of core members decided in July 2018 to form a consortium to co-create and pilot a smart contract initiative in a permissioned blockchain. The identified problem to focus on was the lack of visibility and transparency in supply chains. Given the one-off, complex and highly fragmented nature of construction supply chains, it is often very difficult to track materials, plants (heavy machinery and equipment) and other resources and understand how a late or incorrect delivery impacts on program risk or how to make prompt payments for deliveries that are on schedule.

The goal was to complete a pilot PoC in a large government procured infrastructure project to show supply chain benefits in construction by using smart contract, targeting a subset of materials/plant to track delivery and quality of materials/plant against the contract terms and conditions. The supply chain transparency and audit trail of events provided by the blockchain system is expected to improve trust among all parties, facilitate and promote payment to suppliers, and allow the programme project management to be proactive and agile in risk management and mitigation.

The smart contract pilot officially started in September 2018 and finished at the end of December 2019. The pilot received a full buy-in from the target client in early 2020 and was deemed successful. The consortium includes nine core co-creation members (No.1-9 in Table 2) and two affiliate members (No. 10-11 in Table 2). Typically, each participating organisation in the consortium will name one (or two) individual(s), either its leader and/or a representative interlocutor, to represent that organisation in consortium meetings and working groups. Each organisation's roles in the pilot, as well as in the blockchain system, are also outlined in Table 2.

[Table 2 near here]

3.2 Design science research approach

This research adopts a qualitative, participative research approach and is particularly informed by design science research methodology (van Aken et al., 2016; Peffers, Tuunanen and Niehaves, 2018; Peffers et al., 2007). A typical design science approach follows the structure of problem identification, objective definition, design and development, final demonstration and evaluation (Holmström, Ketokivi and Hameri, 2009). A key role of the academic researcher in design science is to open up the possibility of multiple generative mechanisms as bases for achieving the goals of the design project at hand, for example by challenging and helping to expand the mental models of participants (Hodgkinson and Starkey, 2012).

The lead researcher sat in the Construction Smart Contract Committee as a panel expert, attending regular meetings and conducting numerous email exchanges and telephone conversations since early 2017, and has been closely involved in the smart contract pilot scheme since June 2017. She was appointed as one of the seven pilot governance members and a core co-creation actor among the consortium group, with a particular focus on supply chain processes and inter-firm connectivity. This engaged scholarship allowed her to seek involvement in and with the multiple stakeholders in the supply chain ecosystem, and to learn from their particular insights and perspectives. It hence affords her a greater understanding of the sensemaking process, the various issues multiple stakeholders encountered, and how a blockchain enabled supply chain solution was deliberated and developed in the problem space. Using the business model concept as a structure, she also actively contributed to the collective deliberation and development of the smart contract PoC. Engaged scholarship is well suited to this type of exploratory research design and pursues relevant theorisation and explanation for a specific situation, rather than universal generalisability (Wells and Nieuwenhuis, 2017; Evered and Louis, 1981).

3.2.1 Action design science research

A*ction design science research* (ADSR), as one of the popular research genres in DSR, reconciles and integrates the synergies between DSR and action research (Peffers et al., 2018). The intent of ADSR is not to solve the problem per se within a specific organisational context, but to generate knowledge that can be applied to *the class of problem* that the specific problem exemplifies (Sein et al., 2011). ADSR results in theory-ingrained artifacts. To be considered as an ADSR, Sein et al. (2011) argue that a) it requires a contribution in terms of design principles; b) these principles should address a class of problem (i.e. generalisation of the problem instance and the solution instance); and c) the outcome should be innovative. It is based on those criteria and in line with the theoretical DSR discussion in Section 2.2 that we design our research and claim our contributions.

We follow the logical stages of ADSR proposed by Sein et al. (2011) and Mullarkey and Hevner, 2019), and our research process consists of the following stages (see Figure 3):

- Problem formulation/planning: this involves identifying the relevant kernel design theories, any existing socio-technical artifacts, and the goals of the ADSR project.
- Artifact development and intervention: this contains a set of iterative co-creation activities over the search space of possible design candidates.
- Reflection and evaluation: reflection and evaluation should be ongoing and in concurrency with the decisions about designing, shaping and reshaping the ensemble artifact and work practices, therefore contributing to the refinement of the artifact and surfacing anticipated and unanticipated consequences.
- Formalisation of learning: this stage formalises the learning and moves conceptually from building a solution for a particular instance (specific-and-

unique) to applying that learning to a broader class of problems (generic-and-abstract).

[Figure 3 near here]

As with other ADSR projects, our research process frequently iterates between development/creation and evaluation phases rather than flowing linearly from one phase into the next. Given the complexities of the project, Table 3 summarises the main activities under each stage:

[Table 3 near here]

3.3 Data collection methods

The research data collection is quite intensive and covers from the sensemaking process at the pre-adoption stage to the development and piloting of the smart contract initiative for two years. Data was collected from a range of sources, for instance focus groups, working seminars, interviews, co-creation workshops and weekly project meetings. Milestone events such as focus groups were captured via a project log. Weekly project meetings for progress updates were written up as meeting minutes. The interviews with consortium members and related supply chain actors to understand their expectations and concerns were voice recorded and transcribed (please see Appendix 3 for an example of interview protocol). Co-creation workshops that developed the technical and operational architectures and defined detailed processes to be executed in the blockchain system were written up in detail and corroborated among participants. The details of our data collection activities and their rationale are summarised in Table 4.

One advantage of being a core member of the consortium is the access to all the related project documents and discussions (under a confidentiality agreement). Numerous email exchanges and the archival project documents further comprehend the data collection process. Different sources of data and the longitudinal nature of the research enhance data validity and robustness. These intensive data collection activities generate abundant data for the research in terms of amount (one meeting record transcription typically consists over 60 pages and about 16,000 words) and richness (views from a variety of key supply chain actors).

[Table 4 near here]

3.4 Data analysis

The data analysis was guided by our RQ, and by the business model framework developed. During the sensemaking pre-adoption phase, our primary concern was to understand how practitioners contextualised blockchain technology in the construction sector and how they collectively decided upon where blockchain would make the most impact on the supply chain. During the development and pilot phase, we focused on a smaller number of core members (see Table 2) and followed through the whole PoC development process.

Given the large amount of data we acquired, the first step we undertook was to create a data repository that records a list of data collected, from whom, where and when. A brief description was written about each set of data. Our logical step for coding and analysing the data was within-dataset analysis, followed by cross-dataset analysis.

We use the analysis of our interview dataset as an example to demonstrate our data analysis process here. When we analysed a particular interview transcript with a consortium member, our first order analysis was to develop our initial codes that capture the essence of each interview question in our interview protocol (Appendix 3), for example, *potential use cases, motivations, expected outcomes, concerns, perceived challenges/barriers, SME current digital capability, SME perception of blockchain.* We used those codes to code each of the interview transcripts manually. Coding was conducted by two academic researchers and then compared to check for consistency. Our second order analysis focused on identifying recurrent themes across all seven interviews and looked for differences and similarities. Following this, we tried to develop a sense of theoretical organisation of those themes into the four value dimensions from our business model framework, i.e. value proposition, value network delivery architecture and network, value appropriation. Consistency between researchers (or inter-rater reliability) and consistency over time with the same researcher improves coding reliability. For the former, both of the two academic researchers coded the same dataset independently and then compared to resolve any deviations in understanding. For the latter, the academic researchers would code a clean version of a dataset which she had previously coded, and then compared to see inconsistences. As time progresses, researchers' understanding of the phenomenon improves, there was often a need to revisit the data and revalidate earlier coded materials, and new codes were added in where necessary.

We use the same rationale as demonstrated above to conduct data analysis with other datasets in our repository. Our cross-dataset analysis focuses on each of the four value dimensions first by consolidating insights gained across all datasets, we then move to analyse the causal relationship between the four dimensions, trying to explore answers to our research questions. Our synthesis of each dataset was shared with the consortium lead and related consortium members for further validation. Revisions were made where necessary following members' feedback. The whole data analysis was iterative, throughout the whole duration of the pilot, rather than following a linear fashion.

4. Research findings

4.1 Insights into how a blockchain enabled supply chain was designed (pilot stage)

To discuss how the supply chain actors in this case design a blockchain enabled supply chain, we utilise the concept of business model in this section. The disruptive impact of blockchain technology requires supply chain actors to rethink many aspects of the business model of the pilot.

4.1.1 Value proposition

A business model articulates the design or architecture of the value creation, delivery and capture mechanisms employed (Teece, 2010). For the case being studied, the starting point was to identify the 'pain' points in the existing supply chain. It took a considerable amount of time (12 months) and effort for the consortium to debate (via an iterative process) and decide the entry point to deploy the blockchain technology. A particular challenge was that supply chain actors need to identify an area where value could be co-created and benefits co-shared/captured by multiple players. Different consortium members tend to have different priorities and sometime conflicting goals due to the nature of their businesses and their relative 'location' in a supply chain network.

The pre-adoption sensemaking process has helped a great deal to bring the members into a consolidated understanding of technological developments and knowhow. However, a good understanding of blockchain technicality and intention to adopt does not automatically lead to a justified business case and business success. A business model is needed to translate innovation into a viable commercial success. Articulating a business model inevitably forces the consortium to select a network orchestrator/community leader to coordinate the various activities and ensure concerted efforts towards the goal. As a result, LeadCo became the consortium coordinator/leader. This is an interesting outcome because if one refers to the network orchestration literature, the hub/pivotal firm tends to be a core supply chain actor e.g. a manufacturer or a retailer who has sufficient power to undertake deliberate purposeful actions and draw together multiple supply chain actors for value co-creation (Paquin and Howard-Grenville, 2013). In the case of the construction sector, the most powerful supply chain actor tends to be the main contractor or the client. The orchestrator in this case is an IT solutions provider (specialising in providing costing calculation and estimation software to clients and main contractors). LeadCo is not a primary supply chain actor (instead is an enabler and service provider) but was the driving force that brought various supply chain actors together. It might be because LeadCo was in a relatively neutral position in the supply chain and therefore received less resistance from those major supply chain actors in the consortium which often have conflicts in interests. But more interestingly, as one of the consortium members (MainCo operations director) pointed out:

> *You've [got], to integrate between the client, main contractor and everybody else… So, this (pilot) project control sits with somebody who is not the client and is not the contractor. He's almost the arbitrator between everybody, filtering data and stripping data out. Almost, this could be a new role in the industry.*

Our longitudinal observation reveals that LeadCo undertook a range of activities that steered the development of the pilot initiative: configuring the network (i.e. building the blockchain ecosystem), bundling up and mobilising the resources from across different supply chain actors, legitimising the participating members, and trying to create a governance mechanism for the consortium.

The consortium decided to focus on the supply chain transparency and provenance issue. This was the area where they saw blockchain enabled smart contract and asset tracking would bring not only commercial but also social and environmental benefits to the construction sector e.g. by supporting the concept of whole lifecycle asset management and circular economy. They also intended to share the lessons learnt at the industry level. Therefore, unlike what Teece (2010) has emphasised, that the commercial value and 'mechanisms to block imitation' are the predominant element of a business model, the ecosystem approach in this case stresses the importance of improving the competitiveness of the whole sector instead.

The consortium also decided to 'keep things simple' to start with, and thus the pilot would primarily focus on following the life cycle of a batch of a specific type of construction materials (that are to be used for an infrastructure project) from design to manufacturing, delivery and build. The blockchain was used to record critical events and data. The evidences recorded in the blockchain will then trigger automatic payments to related parties. During the three value co-creation workshops led by ITCo, the blockchain solution provider, business values were articulated and iterated many times among participants and mapped to individual supply chain stakeholders, which we summarise and codify in Table 5.

[Table 5 near here]

4.1.2 Value delivery architecture and network

The value proposition discussed earlier defines the benefits the consortium will deliver to customers and various stakeholders. The next step is to decide how it will organise the supply chain network to do so (*value delivery architecture and network*), and how it will capture a portion of the value that it delivers (*value appropriation*). Value delivery architecture and network dictate the process, relational and technological configurations between participating companies. It is therefore the generative mechanism that will operationalise the value proposition. Under this dimension, we are primarily concerned with a) how the consortium should be configured; and b) who should conduct what activities and how those activities should be linked. Major decisions regarding both a) and b) were made in an iterative manner, again during the co-creation workshops and the follow-up weekly project meetings.

The first round of analysis relates to the set of stakeholders in scope and how the set of relationships among them are arranged (this arrangement is known in the pilot as 'business configuration'). This was explored at the first co-creation workshop where participants were asked to identify the relevant parties that are needed for the smart contract pilot. A whiteboard exercise was organised where participants listed a range of organisations that may directly and indirectly involve in the pilot. These are categorised broadly into:

1) Main collaborating parties: sponsor, client, design professional services, main contractor/subcontractors, suppliers (incl. SMEs).

2) Supporting services and departments: project management office, legal, value engineering[2] and change management, procurement.

A further elaboration of the main collaborating parties was conducted afterwards via a weekly teleconference which lead to a clear description of the roles of each party in a blockchain supply chain network (see Appendix 1).

Once the business configuration was completed, participants from the main parties were asked in the second round of the whiteboard exercise (i.e. the 2nd co-creation workshop) to list as many as possible what problems they were trying to use the smart contract pilot to solve. This exercise aimed to corroborate the expected benefits and value proposition developed earlier, but more importantly to identify exactly what the specific problems there were in the existing supply chain that the pilot could address. The discussions were quite lengthy and in total 31

[2] Value engineering is the change management process within a program where products are changed, upgraded, or enhanced to adapt to the build specification.

business challenges were identified (Appendix 2), which were categorised into five clusters: liability, behaviour, transparency, tracking and tracing, and value. Due to the page limit, we would discuss them only briefly here.

The liability issue in construction was widely recognised by the consortium members. It is often challenging to pinpoint exactly who should be held responsible if things go wrong. Typical behaviours in the supply chain are ignorance and shifting blame to other parties. Transactions logged into blockchain are timestamped, immutable, and verified by all related parties. This improved visibility and transparency provides robust evidence of who conduct what activities at which point, reducing the finger-pointing and blaming behaviours typically observed in practice. The immutable records can be used for audit purposes to understand whether the products installed on-site are in line with the specifications of the designing company, mitigating potential 'value engineering' misconducts from contractors and ensuring product provenance. The tracking and tracing utility afforded by the extended visibility across supply chain actors offers a helicopter view of critical supply chain events logged into blockchain to the consortium members, therefore helping various parties to understand where potential risks are located and promoting proactive rather than reactive actions. Similarly, clients or main contractors could utilise the data from blockchain to monitor and manage performances and benchmark suppliers and sub-suppliers against each other. Finally, smart contract will automatically execute payment once the contractual terms and conditions are met. This does not only reduce the administrative cost of payment, but more importantly helps SMEs with their cash flows as any late payment could be detrimental to their operation, or even survival, in the marketplace. Consortium members also reckoned that automated payment would lead to a reduction in fraud and money laundering as each task can be mapped to a contract and cost account to ensure that the correct suppliers are paid.

In order to decide who should conduct what activities and how those activities should be linked, the first step the consortium undertook was to use a structured storyboard developed by ITCo to map out the detailed processes of the pilot. In total, 13 processes were identified and sequenced. Each process was then further broken down into specific tasks (sub-processes) to be conducted by various members being outlined for each process. A high level of the process flow is summarised in Figure 4. Note that this detailed process map is of critical importance. Not only did it dictate who does what at which point, it also served as a technical blueprint for ITCo to develop a bespoke blockchain solution in order to execute those activities correctly in a blockchain. Therefore a large part of the activities in co-creation fell within this category, as pointed out by the ITCo senior product architect that the consortia needed to '*walk the process again and again until it can be walked blind*'. The granular level of detail and attention to nuances regarding the processes were scrutinised and delineated in many rounds of discussions via emails and weekly teleconferences among the consortium members until every detail was agreed on by all in the 3rd round of co-creation workshops in terms of what task was to be done by which supply chain actor and when.

[Figure 4 near here]

In parallel with this stream of process mapping activities, the consortium had to work out and agree on detailed attributes of various datasets that needed to be appended into the blockchain. For example, the component (material) attributes should include product master data (e.g. width, length, depth, fire resistance, unit weight, acoustic rating, external finish colour and international finish colour), environment product declarations (EPD), and ethical data (e.g. origin/source of the product). Those different attributes to be recorded by the blockchain were largely determined by the expected benefits discussed in the previous section. For instance, the reason why DesignCo required EPD data to be recorded was because of their vested interest in the circular economy, and in trying to evaluate contractors' deviations from the specifications during the tendering and construction stages.

> *We would like very much for the blockchain to measure the performance of a digital specification over the lifespan of a project... why is this different from any other (non-blockchain) project? I would say that it is because learnings were gained. If we know how it performed over its lifecycle, we can then use that information and learning to go back to the next specification making better designs. So this pilot is not just about product provenance (tracking the materials/components) and the automated payment, but also the digital specification*s *(DesignCo senior director)*.

Finally coupled with process flow and information flow defined for the blockchain was the flow of cash. A cost account structure was created. Within the blockchain programme, each activity was assigned to a cost account. By having careful control of the cost account codes the client in this case could track all works and payments correctly. This was key for the project management office team and the finance department and affords the improved monitoring and control of project spending. A RAG (red/green/amber) dashboard was created to indicate project status and how well a project was performing. This way, the project management team had better visibility of the programme and had trust in the source of the status.

4.1.3 Value appropriation

Value distribution clarifies how the value should be distributed among the consortium members. At the PoC stage, every consortium member covered their own costs and time. A co-creation agreement was developed and signed by the members, including the lead researcher from an academic institute, which covers a range of issues but mainly lays out clearly the terms and conditions on intellectual property. Guided by a broad vision of taking inefficiencies out of the existing supply chain, the consortium spent more efforts in discussing the investments that are needed to pilot the project, i.e. on *value creation*, and were less concerned with how value needs to be devised. This was because most members would like to use this pilot as a learning experience to get to know the technology better, and economic benefits were not high on their agenda for the pilot. Though via the pilot, they expected to test out exactly what kind of benefits a blockchain enabled smart contract might bring to the ecosystem participants. At this stage, detailed roles and responsibilities were assigned between the members, for instance a 'swimming lane' was established depicting who would drop what kind of data at which point into a blockchain. Issues were intensively explored on data integrity (particular prior to entry to the blockchain system), remediation (when bad data gets input into a blockchain), security, ownership and privacy. Measures to mitigate such issues were developed collectively with the support of the blockchain platform provider (ITCo). A protocol was proposed regarding how each company could 'plug in' to ITCo's on-demand blockchain as a service platform.

Options such as using a membership fee to cover the ongoing cost of the pilot have been proposed but yet to be agreed upon. For the set-up cost, it is likely that whoever is going to benefit 'most' will invest more than other members in the consortium. It has been largely agreed between the consortium members that the setup cost of a real deployment in a specific project would need client's investment. The consortium lead, LeadCo, together with the participating members, has been actively exploring potential buy-in from potential clients in order to move from PoC to a pilot deployment. In addition, PoC demonstration and walk-throughs as well as project briefs have been circulated to a range of government agencies (which look after large rail, road, water, and air infrastructures) in order to obtain a wide support from various agencies. This has been a challenging task, but the consortium has made some positive progress at the time of writing and has secured a client's support to start the pilot in a large rail infrastructure project. The setup of a private blockchain consortium in many aspects resembles the setup of an internet-enabled supply chain network (for a consortium example, one can refer to Wang et al., 2011). If the investment is heavily skewed towards a particular group of supply chain actors and benefits are not fairly distributed, there is a great danger that the consortium network would collapse. We have witnessed many such failures in the past, for example Covisint (automotive), Elemica (chemical) and Global Transportation Network (maritime shipping). All of the failure cases changed their business models, e.g. they became independent marketplaces or other.

Another important issue at the core of the pilot was the governance issue. Due to the decentralised nature of blockchain, many would assume that decision making in a blockchain enabled supply chain will be decentralised too. This is not necessarily the case, particularly in a permissioned blockchain network. Although each participating organisation has a stake in how the blockchain supply chain should be configured and managed, we observe the significant influence by the network orchestrator LeadCo and the large corporate members e.g. DesignCo and SupplierT2. Decision rights, accountability and incentives are the core components of IT governance (Beck, Muller-Bloch and King, 2018). At the design stage, there was a high degree of centralised decision making, which enabled centralised control later on. Rules, liabilities and responsibilities in a smart contract were designed in a centralised manner; whereas the control and execution of the contractual terms would be decentralised later. Because there were a range of legal issues to deal with, lawyers were heavily consulted at this stage to determine how participating members should interact with each other and how to resolve potential disputes among members. In a private blockchain network, it is not necessary that all nodes validate each single transaction. Therefore there was also a need to define who would be validating the transactions and how codes could capture the right business logic. A lengthy legal document was proposed by a law firm in order to dictate how consortium members should interact, how commercially sensitive information should be protected, and how IP issues should be resolved. Incentives for technical consensus, system development and maintenance, and for users were scrutinised via an extensive process among members.

4.2 Evaluation, key lessons learnt and design principles

As indicated in Section 3.2, the evaluation and reflection phases of our ADSR are continuous and interwoven with the co-creation activities during the pilot. A summative evaluation at the end of the pilot is essential as it moves us to the formalised learning phase. What we aim to achieve in this session is to firstly evaluate the utility of the artifact designed (i.e. the blockchain system), and then move conceptually from the building of the blockchain platform for the use case to derive the key learnings (in our case, a set of design principles) that guide a more generic deployment of blockchain in supply chain. Those design principles can be considered as mid-range theories (as discussed in Section 2.2 and Table 1) that are much more readily adoptable into future blockchain supply chain projects.

4.2.1 Pilot evaluation

Earlier in Section - 4.1.1, we discussed the expected value by the consortium members of the blockchain pilot. At the end of the pilot, we mapped out the actualised value against the expected for different supply chain members, as highlighted in Table 5. As shown in Table 5,not all expected value was realised and there were also unexpected items that were revealed during the pilot. The consortium was also able to quantify substantial cost saving benefits but, due to commercial reasons, we will not disclose those here. As can be seen from Table 3, benefits from a blockchain solution are not homogenous across the supply chain.

For client organisations, the main value they derive from using the blockchain system lies in the visibility of title/ownership transfer between supply chain actors and near real-time tracking of resources (e.g. financial and material) along the supply chain. This greatly enhances its ability of programme management and monitoring, knowing who should be accountable for what kind of activities in the supply chain. Another benefit is that as the owner of large infrastructures, client organisations are responsible for the ongoing operation and maintenance of the infrastructures once built. The blockchain system encourages supply chain data integration from the start of a construction project all the way through to handover. It offers a secured record of critical data and transactions that bridges information gaps and supports whole lifecycle asset management. On the contrary, traditionally critical building related data are often incomplete or inaccurate, and sometimes get lost along the supply chain. Offering secured, untampered data at the handover stage to the client powers important concepts such as total predictive maintenance and circular economy. Main contractor and subcontractor (tier 1 supplier) share the value of protecting data loss, real-time transparency and visibility of ownership/title transfers with client organisation. They also enjoy the additional benefits of item/material-level tracking and traceability as the risks associated with a critical component/material could have a costly impact on the project.

For a design services company, the blockchain system proves the provenance of materials and provides design clarity between what was initially designed and what was installed. The environmental and performance data of materials stored in the blockchain will allow the assessment and reuse of materials and supports new circular economy business models such as leasing rather than buying a product from a manufacturer.

For manufacturers (tier 2 supplier in this case), they need to produce products based on the specifications of a design services company, therefore they share the value of being able to track the whole life material performance specification, and the opportunities brought about by circular economy (e.g. lease vs purchase mode of its products). They also enjoy the benefit of item/material level tracking as with main contractor. For tier 3 suppliers (many are SMEs), the blockchain system assists prompt automated payment processing based on a trusted audit trail and provides much needed cashflow certainty.

Across the consortium at supply network level, the blockchain system engenders trust between supply chain parties and helps with the liability challenges facing large complex construction programmes. It improves productivity via automated execution of critical activities. The use of blockchain also builds the digital capability throughout the supply chain, and particularly improves SMEs digital uptake by offering easy access and upload/download of data via mobile apps/websites. Blockchain requires supply chain actors to participate and maintain the records of transactions collectively, hence it reduces the silo effect and enforces and improves supply chain integration within the fragmented sector. Integrating with other technologies such as the Internet of Things and ERP systems would further enhance the diffusion of technological innovations within the sector and improves the competitiveness of the whole sector.

4.2.2 Formalised learning and design principles

As our DSR study is in the substantive context of blockchain adoption in large complex construction programmes, the specific case problem can be cast as an instance of a class of problems, i.e. lack of supply chain transparency and provenance. In this section, we derive design principles (DPs) for this class of problem and embed our DPs within the business model design framework we developed in Section 2.3.

Our study shows that collective sensemaking among the supply chain actors plays a critical role in managing the ambiguity and uncertainty caused by the emergence of blockchains. It influences the strategic options supply chain actors use to form their future actions and reaching the consensus on which areas to pilot blockchain initiatives. Through the collective sensemaking, a mutual understanding can be built among the consortium members, therefore a shared vision and value proposition to solve a common problem can be developed. There could be multiple scenarios (entry points) where blockchain could provide a good fit and create value. The scenarios to start with should be those that will provide the most benefit and are the simplest - one of the key lessons learnt from our DSR study. Correspondingly we propose:

DP1: Collective sensemaking among supply chain actors is essential in order to decide the blockchain's best entry point to a supply chain.

It is evident as discussed in Section 4.1.1 that a blockchain system must deliver multiple benefits and create value that resonates with all supply chain actors in the ecosystem, though the exact value will likely differ for each member. If the investment is heavily skewed towards a particular group of supply chain actors and benefits are not distributed fairly, there is a great danger that the consortium network will collapse. For a blockchain initiative to succeed, each participating organisation will need to contribute data and resources that are beneficial to the others because each participant's success is dependent on the success of the group. It is unlikely that anyone will participate if such participation creates additional work for them without clear benefits. It thus calls for a clearly defined value proposition that reflects the sharing of value among all participants. The inclusivity of value proposition will likely attract more participants and enables the scaling up of a blockchain supply chain network – the scale-up problem is a challenge currently facing many blockchain initiatives (Deloitte, 2019). The value proposition also determines how the network will be funded and dictates the network operation model (revenue/cost) and its core activities (Wang et al., 2019). Therefore, we propose DP2:

DP2: Blockchain should be deployed in areas where it adds value to ALL its supply chain ecosystem actors and its value proposition needs to be clearly articulated.

The consortium arrangement often forms organically with a few companies who get together in a working group to explore blockchain technology further. Once they decide to pilot the use of technology to address a particular supply chain problem, a more formal relationship is required. Not all group members will join the formal consortium, but there is a need to outline the minimum number of members required to establish a viable ecosystem to support and drive future activities. One of the key learnings from our DSR project is that having larger companies as anchor participants can act as a springboard to give greater confidence and encourage additional key member participation. They bring industry credibility and provide financial, human, physical, and intellectual resources to the network. The founding network can evolve and expand to allow other organisations to join the network once the blockchain platform goes into production and becomes widely adopted. It is also possible that ownership may also change. Regardless of how the network may evolve, building network legitimacy is most critical at different stages (from discovery, design and development to pilot and industrialisation) of network evolution (Provan, Fish and Sydow, 2007). Continued reinforcement of the rationale and goals of the group was critical to keep participants engaged and to ensure that the network operates within the boundaries of the stated objectives. We propose DP3 accordingly:

> *DP3: A viable blockchain ecosystem needs to have a minimal number of supply chain actors as its core members in order to establish its legitimacy and utility.*

More importantly, a supply chain orchestrator is required from the early stages to bundle and mobilise resources, configure and legitimise network participants, and to provide the new consortium with an initial neutral space to collaborate. A blockchain supply chain network will not run itself and it requires active management to make it work. Without such an orchestrator it is difficult to manage and balance sometimes conflicting and competing interests from different members. Many of the unique benefits of a blockchain network could be lost or expected outcomes could not be achieved. The strategic role of an orchestrator was well articulated by Dhanaraj and Parkhe (2006) who propose that hub firms orchestrate via three primary tasks in a knowledge-intensive innovation network: managing knowledge mobility, innovation appropriability and network stability. Here we propose:

> *DP4: A supply chain network orchestrator is needed to coordinate the formation of a blockchain consortium, bundle, structure and leverage network resources, and to draw together multiple supply chain actors for value co-creation.*

Blockchain governance is widely recognised in both academia and practice to be one of the most important design considerations and a key indicator of a well-functioning consortium (Beck, Muller-Bloch and King, 2018; Bradley et al., 2019). By design, a blockchain ecosystem is a distributed network which creates added complexities to traditional network governance in terms of decision rights, accountability and incentives (Beck, Muller-Bloch and King, 2018). Note that we focus on the establishment of governance within a consortium here. Based on both the business and regulatory requirements, a consortium blockchain network can be governed in two ways: a) off-chain governance using a pre-agreed policy; b) on-chain governance e.g. through algorithm and/or a set of tokens. Policy-based approaches require a set of rules agreed upon upfront by key stakeholders, such as consortium members and regulators. Consortia governance setups tend to lean heavily towards off-chain governance, relying on standard business practices and agreements (EU Report, 2020). The rules can be wide reaching and might, for example, describe strategy, incentives for cooperation, intellectual property (IP) management, membership management, liabilities and responsibilities. On-chain governance deals with operational level governance often including participants on-boarding/off-boarding, consensus mechanism, data sharing and storing. Note that although it is not the case in our DSR project, some blockchains use tokens to govern behaviour, for example the public Ethereum blockchain uses its cryptocurrency Ether to determine one entity's smart contract processing capacity. While early business blockchains have typically been governed through policy, there is an increasing number of business blockchains that have been augmented with token systems as a means to encourage behaviour within the network (Bradley et al., 2019). As the network grows, the governance model may need to change and adopt accordingly. We propose DP5:

> *DP5: A blockchain governance model should be established at both off-chain and on-chain levels. A well-designed, adaptable, and fair governance of a consortium is a prerequisite to the successful operation and maintenance of a blockchain solution.*

Another important design decision that closely relates to the governance issue is the permissioning level of a blockchain system. As discussed earlier in Section 2.1, most data found in supply chain transactions today is commercially sensitive, therefore blockchain solutions for supply chains tend to favour a permissioned/private blockchain which limits its access to only those organisations that have been admitted into the network, as was the case for our DSR project. Within a private blockchain, access tend to vary among supply chain actors. Depending on their network roles, different types of permissions can be granted to different supply chain actors based on three parameters:

Read: Who can access the ledger and see transactions

Write: Who can generate transactions and send to the network

Commit: Who can update the state of ledger

Private blockchain is not the only option though. Even if a supply chain network decides to use a public chain, there are still ways to protect critical data. For example, one can store the hash (a cryptographic algorithm that takes a text input of any size of data and creates an output of fixed length. The output is called a hash and is irreversible) of the data on-chain and the original data off-chain in its proprietary information systems. This hashing function is often deployed in a private blockchain too. As evidenced in our study, storing only the hash information improves the system performance (the speed with which transactions are written to the blockchain). A key lesson learnt from our study is that the choice of private or public or hybrid blockchain should be determined by the strategic objectives of supply chain use cases and take into account the factors of system performance, interoperability, cost, personal data protection, as well as governance model. Hence we propose DP6:

DP6: Sensitive data on key actors and their products should always be protected. A degree of permissioning is required in a blockchain enabled supply chain depending on supply chain use cases.

Supply chain provenance requires consistent data on the identity of the items being tracked. In a complex supply chain network, different supply chain actors would have different demands in terms of what data should be appended to the blockchain and what specific attributes are needed that serve to identify and monitor that specific item being tracked. What data should be on-chain vs off-chain also needs clear deliberation as there may be unintended consequences and risks. Regulations such as the European Union's General Data Protection Regulation (GDPR) and the 'right to be forgotten' means that you need to avoid storing any personal data on a blockchain for legal compliance purposes. As a blockchain is a peer-to-peer network, data in the form of transactions is shared and replicated across the network to different peers. Although the boundary of our pilot case is domestic, it is important to consider what data is stored and where because the network can span multiple jurisdictions (as is often the case when supply chains are global). Correspondingly we propose DP7:

DP7: Sharing product data on the blockchain is key to establishing transparency and tracking provenance; what data should be on-chain requires careful consideration.

Finally, a blockchain often uses smart contract to code and automate business processes that can be shared and executed among multiple supply chain actors. This automatic execution increases trust and reliability in the process and can lead to significant gains in efficiency and cost reduction, as demonstrated by our pilot case. Smart contract can also be used to hard code agreements between parties involving value and other types of asset transfer and can even create decentralised autonomous organisations (DAOs) and tokenisation of tangible or intangible assets (Dolgui et al., 2020). Despite the innovative impact brought about by blockchain and smart contracts, the unique characteristics of decentralisation, pseudonymity/anonymity, immutability and automation of blockchain may expose supply chain participants to legal and regulatory uncertainties and make it difficult to reconcile with existing legal and regulatory norms. For example, in large-scale permissionless blockchain networks, it can be difficult to ascertain who the actors in the network are, where they are located and what exactly their actions have been. That can make it challenging to assign responsibility or determine jurisdiction in the case of dispute and what law is applicable in a particular situation. It is equally challenging to ascertain who 'owns' the network and its data, and therefore legally responsible for it in a decentralised digital environment. Therefore, when establishing and building a blockchain network, it is necessary to consider the legal concerns per network participant. Different actors in a blockchain network will have different legal concerns regarding matters such as limitation of liabilities, ownership and use of IP. We propose DP8:

DP8: It is crucial to establish clear legal and regulatory documentation when *setting up a blockchain network to ensure supply chain participants have clarity over the functioning of the blockchain network.*

5. Discussion and conclusions

The paper reports a two-year research with a consortium in the UK's construction sector that piloted a smart contract initiative with blockchain technology. Via the longitudinal study, this paper searches for answers to the research question, 'How should a blockchain enabled supply chain be designed?'. We used the DSR approach in combination with the theoretical lens of business model to actively shape the deployment of blockchain. Design science enables us to have a deep engagement with the field problem and practitioners, while the business model allows us a generic design of blockchain deployment, while testing this generic approach in a given context, i.e. the smart contract pilot. A formal evaluation of the pilot evidences the values created to multiple supply chain actors by the blockchain solution. From the formalised learning, we were then able to derive a set of design principles that are applicable to a general class of supply chain provenance and transparency problem in supply chains. Given the infancy nature of blockchain and limited existing understanding of how blockchain may be deployed in supply chains (Wang et al., 2019; Wang, Han and Beynon-Davies 2019; Chang, Iakovou and Shi, 2019; Pournader et al., 2020), this research offers valuable insights into how consortium members design a blockchain enabled supply chain and tackle the various issues they have encountered.

5.1 Theoretical contribution

As suggested in Section 2.2, DSR can make contributions at three levels: in designing and instantiating the architect (Level 1), developing mid-range theories (Level 2) and refining or extending existing kernel theories (Level 3). We will discuss our contributions at the three levels accordingly.

Level 1 contribution. Peffers et al. (2018) pointed out that while there has been much research published about DSR with a great number of guidelines, rules and frameworks, there has not been much research that actually applies the DSR research paradigm to IS research. Studies that apply DSR in the OSCM field are even scarcer. Our study represents one of the early efforts that attempts to fill this void. Via our ADSR, a blockchain platform that addresses a pertinent supply chain problem in a large complex multi-tier construction supply chain was designed and piloted successfully. The blockchain solution created business value for all participating supply chain actors as well as demonstrated positive impact at the network and industry levels. This developed artifact i.e. the blockchain platform, represents a solution that addresses a common problem facing supply chain management: supply chain transparency and provenance. Hence our research is not just about solving a specific supply chain problem in a specific context, it contributes to the knowhow for developing a blockchain solution that addresses a class of problem common in practice.

Level 2 contribution arises from the set of design principles we abstracted and formalised from our research. These principles can be considered as a mid-range theory that can be operationalised in future DSR blockchain supply chain projects and as design propositions to be tested in a number of unstudied contexts. The nature of different research paradigms i.e. natural and behavioural science vs design science makes it unlikely that theory from outside design science will be readily adaptable to artifact construction (Kuechier and Vaishnavi, 2008). Although having less generalisability compared with kernel theories, these design principles, as mid-range theory, have more utility in explaining and enhancing our understanding of blockchain adoption in supply chains, and guiding design and action. They are an effective means of capturing design knowledge that would otherwise remain tacit in the design artifact.

Level 3 contribution is that through our research, we have refined and extended the business model theory in the context of a blockchain supply chain network. Our research suggests that business model is a valid system-level theoretical framework and can act as a generative mechanism that shows how supply actors coordinate and combine activities to create value from emerging technologies - blockchain in our case. The business model approach provides a systematic structure in shaping people's attention, deliberation and decision making about blockchain, as well as framing the collaborative efforts between the consortium members towards the joint pursuit of a common objective and value creation – before our intervention, the efforts were rather fragmented. Business model has successfully operationalised the collective vision among consortium members, and its development has been a co-creation and iterative process.

We extend the business model literature by examining the business model at the network level. The majority of existing studies have focused on a single actor, a focal firm (Zott, Amit and Massa, 2011), rather than exploring how value is created by the collective action of the key supply chain actors. Our study also supports the argument of Palo and Tahtinen (2013) that business model can be regarded as a dynamic device to be used in both planning and conducting future business.

The key dimensions of the business model, i.e. value creation proposition, value network, value delivery architecture and value appropriation, can be translated into key supply chain design decisions in building a viable blockchain supply chain ecosystem. Used in combination with design principles, they form the building blocks that provide answers to our RQ – i.e. *how a blockchain enabled supply chain should be designed*.

Finally, our study also enriches IOS studies in the supply chain literature. While behavioural science research focuses on developing and verifying theories that explain or predict human or organisational behavioural in technology adoption, we undertook an action design science research approach to develop theoretical insights into how blockchain should be adopted in supply chains. We thus add to the diversity of research paradigms in the OM field. Our research is one of the very few longitudinal empirical studies to offer in-depth evidence about how blockchain is deployed in complex multi-tier supply chain networks. Our research thereby offers valuable insights to SCM and OM researchers, laying a foundation to aid their understanding and to motivate them to explore this emerging technology further.

5.2 Practical implication

As organisations start to understand the disruptive potential of blockchain to supply chains, they need to find a way that suits their own context to take advantage of the benefits blockchain has to offer. As demonstrated by our case, the deployment of blockchain is a complex process. It requires change in mindset and behaviours, as well as new technological, relational and process configurations among multiple organisations in a decentralised environment. Some of these organisations may not have traditionally worked directly with one another. Therefore, a clear understanding of the requirements and issues across all participating supply chain actors are critical to the success of blockchain deployment. Our research offers a structured way (i.e. the business model approach) to designing a blockchain enabled supply chain. The four dimensions of the business model can be used to guide organisations' key decision makings along the blockchain deployment journey. The design principles we proposed can be used as guidelines for organisations to navigate the complexities, identify potential use cases and think through the critical issues such as value proposition, governance model, information sharing, legal and regulatory compliance early on. For design science researchers, they can be used to inform the development, delivery, and evaluation of interventions.

5.3 Limitation and future research directions

This research examines one smart contract pilot initiative over two years. Though offering valuable insights and demonstrating the utility of the developed architect for a common supply chain problem, our theoretical base (both the design principles derived and the refined business model theory) needs to be further tested in various settings. We need to caution that the generalisability of mid-range theories such as the proposed design principles in our research are delimited in their area of application, therefore the contexts to test our proposed theory should be confined within supply chains. Future empirical research should explore how smart contract and blockchain could be further scaled up in supply chains, taking into consideration its potential business, legal, ethical and social complications. Current efforts in this space are still largely conceptual (e.g. Chang, Chen and Lu, 2019) or analytical (Dolgui et al., 2020). It would be valuable to explore the potential negative impact a smart contract initiative may have upon supply chains, for instance the potential exclusion of certain types of supply chain actors.

Research opportunities are abundant given the emerging nature of blockchain. For instance, research in examining the critical role of the blockchain supply chain network orchestrators is well worthwhile, as evidenced by our research, they play a significant role in shaping the direction of blockchain deployment, mobilising resources, configuring networks and ensuring objectives and actions are aligned among members. Blockchain cannot be used in isolation. Research investigating how the integrative use of blockchain with enterprise systems, IoT and artificial intelligence and their transformative impact on supply chains would be very worthwhile. Future research could also examine how blockchain systems interact with centralised systems such as web-based platforms and how they may enhance information flows within and between supply chain actors. The various socio-technical issues identified in this research reflect the uncertainties and ambiguities caused by blockchain's emerging and unsettled technological development, and supports the call for close observation and a better understanding of its potential diffusion path (Wamba et al., 2018).

Finally, DSR in the OSCM discipline is still in its infancy. Unlike its presence in the engineering and IS disciplines, its potential is yet to be fully recognised in our field. Our research showcases that DSR could be a complementary research diagram that can generate significant theoretical contributions whilst making an impact on real practice. We call for more researchers to explore the use of DSR research paradigm and derive new theoretical and managerial insights by engaging with practice and solving complex field problems. Both behavioural science and DS paradigms are needed to ensure the relevance and effectiveness of our research.

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Figures

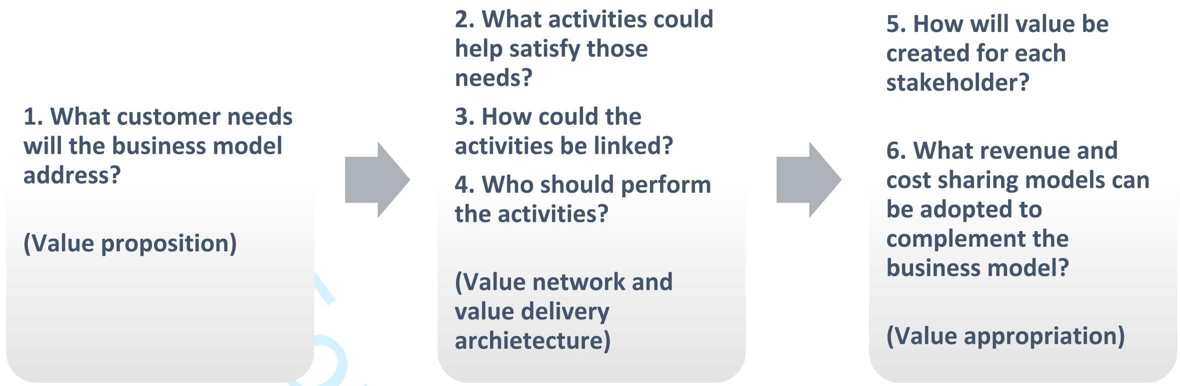

Figure 1: A business model design framework for blockchain enabled supply chain (adapted from Raphael and Zott [2012]).

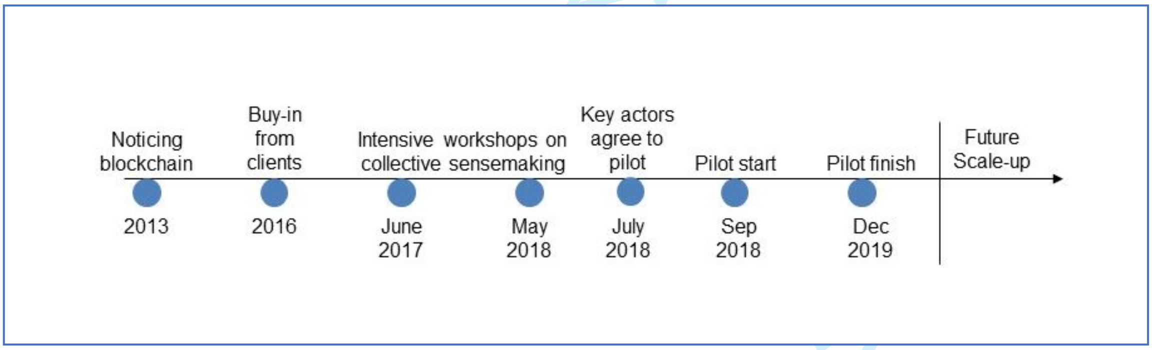

Figure 2: The case blockchain pilot timeline

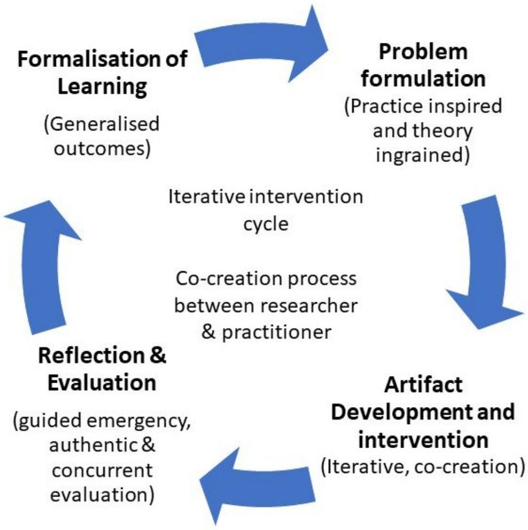

Figure 3: The action design science research cycle (adapted from Mullarkey & Hevner [2019] and Sein et al.[2011]).

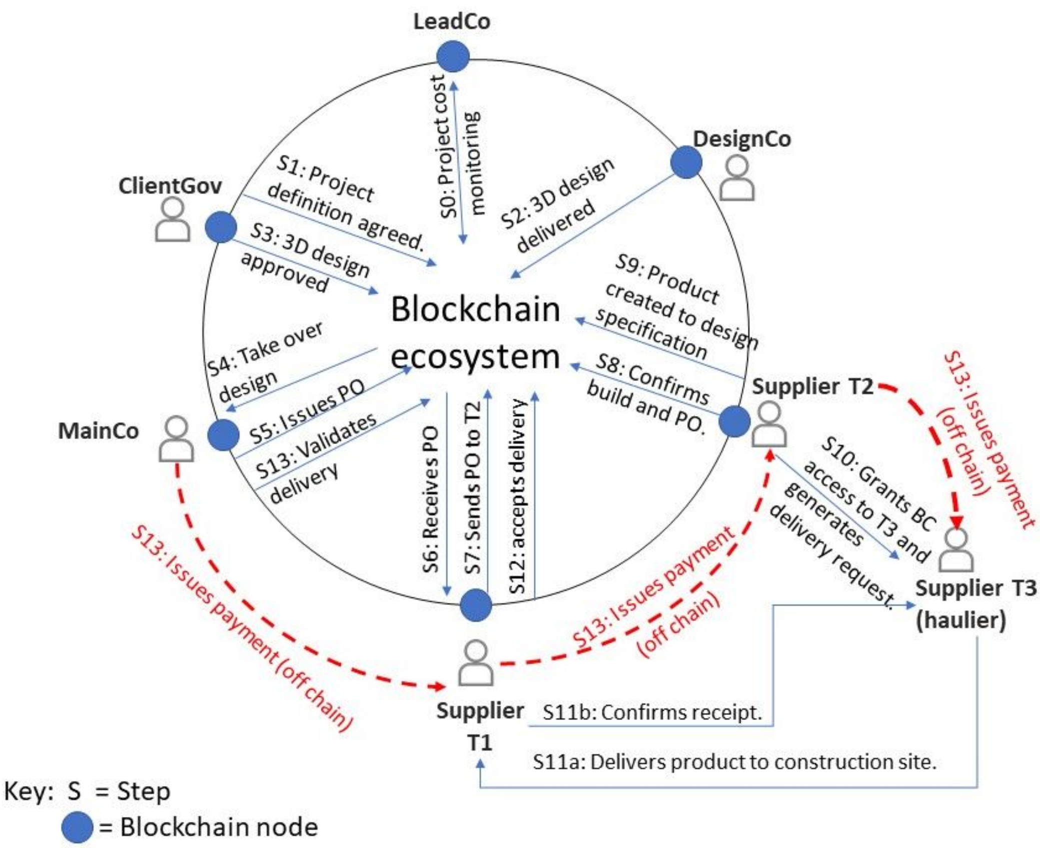

Figure 4: A high level process map of the pilot

Tables

Table 1: Type of DSR contributions

	DSR Contribution type	Examples
More abstract, complete, and mature knowledge	Level 3. Well-developed abstract scientific theory (i.e. kernel theory) about embedded phenomena	Confirming, refining or extending existing theory or generating new surprising knowledge
⇳ ⇳ ⇳ ⇳	Level 2. Mid-range theory – knowledge as operational principles/architecture (that applies to a specific class of problem situation)	Operational principles or architecture including constructs, methods, models, design principles, technological rules
More specific, limited, and less mature knowledge	Level 1. Situated implementation of artifact and practical contribution	Instantiations and situated artifacts (software products or implemented processes)

(Source: developed by the authors based on Kuechler and Vaishnavi, 2008; Gregor and Hevner, 2013; Baskerville et al., 2015; Iivari, 2020; and Chandrasekaran et al., 2020)

Table 2: Consortium members of the pilot initiative

No.	Organisation (anonymised)	Type of supply chain actor	Roles in the pilot	Blockchain system level designations
1	LeadCo	Supply chain consortium lead and costing estimation solution provider	Project lead, BC node operator	Data owner/user
2	DesignCo.	Architectural designing company, large multinational company	Core member, BC node operator	Data owner/user/provider/validator
3	ClientGov	Client organisation, large government agency on transport infrastructure	Project sponsor, BC node operator	Data owner/user/provider/validator
4	MainCo	Main contractor, large multinational company	Core member, BC node operator	Data owner/user/provider/validator
5	SupplierT1	Tier 1 supplier (heavy/civil construction, large multinational company)	Core member, BC node operator	Data owner/user/provider/validator
6	SupplierT2	Tier 2 supplier (large multinational manufacturing company)	Core member, BC node operator	Data owner/user/provider/validator
7	Supplier T3	Tier 3 supplier (a haulier)	Non-core member	Data providers/users
8	ITCo	Blockchain technology service provider, large multinational company	Blockchain platform provider	N/A
9	ConCo	Independent consultant (project governance and management specialist)	Core member (advisory)	N/A
10	Academic researcher	knowledge transfer and academic advisor in supply chain digitisation	Core member (advisory)	N/A
11	LawCo	Law firm	Non-core member, legal advisory	N/A
12	TA	Trade association	Non-core member, industry advisory	N/A

Table 3: Summary of the ADSR process in the case project

Research stages	Summary of activities
Stage 1: Problem formulation	Research was driven by the need in the construction supply chain for improved supply chain transparency and audit trail.
	The theory used was the sensemaking theory for pre-adoption and business model for actual deployment.
	Problem was formulated based on the intensive sensemaking activities.
Stage 2: Artifact development and intervention	The ADSR team included researchers and practitioners which form the core of the consortium. Collaborative intervention with co-creation activities was critical to design and develop the blockchain system to solve the given problem.
	The process model and technical architecture of the blockchain system was developed based on multiple rounds of elaboration and iteration.
Stage 3: Reflection and evaluation	During the ongoing reflection and evaluation, important issues were discovered, reflected, and acted upon during the pilot, such as decisions about what data and related attributes should be appended, and the issue of how to reduce the participating barriers for small and medium-sized enterprises.
	The final evaluation confirmed the utility and effectiveness of the blockchain system and captured a number of benefits to different type of supply chain stakeholders. Economic value (e.g. cost saving) was quantified. Potential risks were identified, and mitigation measures developed.
Stage 4: Formalisation of learning	A set of design principles was articulated, positioning the case problem as an instance of a class of supply chain transparency problem.

Table 4: Summary of data collection activities

Phases	Data collection activity	Description	Time (total hours)
Phase 1 – Pre-adoption	Focus group with 32 participants from different organisations (4 hours).	This is referred to by the consortium as the 'Genesis of the PoC', which marks the start of the collective sensemaking progress, on blockchain introduction, early use cases and its implications for construction.	4
	11 group working seminars (typically 3-4 hours per session).	A series of sensemaking activities, theme-based on governance, data standards and classification, integration with enterprise applications, public/private and cross chain interoperability, integration with other technologies such as augmented reality and machine learning etc.	**38**
Phase 2 - Pilot	Seven interviews with the smart contract pilot consortium members (each interview lasted 60-90 minutes and was voice recorded).	Semi-structured interviews were conducted with consortium members (No 1-7 in Table 1) to understand the motivations and expectations from different consortium members of the pilot. (Please see Appendix 3 for an interview protocol).	**8.5**
	Three co-creation and design thinking workshops (11 attendees covering all related supply chain actors in the supply chain) (each workshop lasted a minimum of 5 hours).	These workshops were led by ITCo1, where storyboards were created to capture business challenges, supply chain and process configurations. The focus is on functional and technical aspects of the PoC, including process orchestration, integration with backend systems and overall architecture.	**15**
	28 weekly teleconferences on project updates (1 hour/per conference).	These were the checkpoints periodically scheduled with the co-innovation participants to share progress, status, and review. The PoC created via the workshops was reiterated, refined and developed along the time. The main outcomes include: 1) a list of data attributes specified to be included in the transaction; 2) a step-by-step process and data transaction map that captures all the main interactions between different supply chain nodes (actors); and 3) the building of a blockchain technical architecture that executes the smart contract coded.	**28**
Total			**93.5**

Table 5: A summary of business values identified for different stakeholders (both expected and actualised) (source: developed by the authors)

Role	**Organisation (anonymised)**	**Business Value (BV)**
Client	ClientGov	**BV1: Real-time transparency of the overall programme**. Project management status dashboard linked to the programme. ➔ ***Change to: Near real-time transparency of resources*** BV2: Ability to see problems early to allow proactive actions to correct. BV3: Engenders trust between parties and helps with the liability challenge with complex construction programmes. BV4: Assists prompt and efficient payment processing to SMEs and other parties with less administrative burden. **BV11: Clear transfer of material title/ownership of materials during construction.** **BV12: Protection against loss of data held in supply chains.** BV13: Asset tracking and maintenance linked to source suppliers' data.
		Additional ones identified (post pilot) ***BV18: Supply chain data integration with fragmented sector.*** ***BV19: Smart contracts demonstrating micro execution against main contract obligations.***
Design Services	DesignCo	**BV5: Circular economy** – prove the provenance of material and the ability to reuse material. **BV6: Whole life material performance specification -** design clarity between what was initially designed and what was installed across environmental data and performance data. Easier tracking of gold thread digital specification information from source to asset management.
Manufacturer / Supplier	SupplierT2	BV2: Ability to see problems early to allow proactive actions to correct. **BV4:** Assists prompt and efficient payment processing to SMEs and other parties with less administrative burden. ➔ ***Change to: Automated payment authorisations on verified task completion.*** **BV5: Circular economy** – prove the provenance of material and the ability to reuse material. **BV6: Whole life material performance specification -** Design clarity between what was initially designed and what was installed across environmental data and performance data. Easier tracking of gold thread digital specification information from source to asset management. BV10: Understanding of how and when material is being used in the overall program. When is the material/component actually installed?
		Additional ones identified (post pilot) ***BV11: Clear transfer of material title/ownership of materials during construction.*** ***BV18: Supply chain data integration with fragmented sector.***

		BV20: Near real-time transparency and tracking of materials, plant and equipment.
Contractor / Sub-contractor	MainCo/ SupplierT1	BV1: Real-time transparency of the overall programme from a client and main contractor point of view. Project management status dashboard linked to the programme. ➔ ***Change to: Near real-time transparency of resources*** BV2: Ability to see problems early to allow proactive actions to correct. BV3: Engenders trust between parties and helps with the liability challenge with complex construction programmes. BV4: Assists prompt and efficient payment processing to SMEs and other parties with less administrative burden. ➔ ***Change to: Automated payment authorisations on verified task completion*** BV8: More efficient management of SMEs. **BV11: Clear transfer of material title/ownership of materials during construction.**
		Additional ones identified (post pilot) ***BV12: Protection against loss of data held in supply chains.*** ***BV20: Near real-time transparency and tracking of materials, plant and equipment.*** ***BV19: Smart contracts demonstrating micro execution against main contract obligations.*** ***BV18: Supply chain data integration with fragmented sector.***
SMEs (e.g. a Logistics Service Provider)	----	BV7: Ease of participation to interact with complex programme through providing mobile apps/websites to track tasks and progress. BV9: Transparency of the overall programme from an SME point of view. How soon will I get paid? Prompt transparent payment of SMEs on completion of agreed tasks.
		Additional one identified (post pilot) ***BV4: Automated payment authorisations on verified task completion.***
Industry	Government and all Stakeholders	**BV3: Engenders trust between parties** and helps with the liability challenge with complex construction programmes. **BV14: Increase in digital uptake throughout supply chain** and improved productivity. BV15: Enhanced auditability, immutability and provenance the system provides to all stakeholders. BV16: Enhanced security of the smart contract and payment process. **BV17: The traceability and interoperability to link technologies**, like IoT sensors, to verify physical progress in the production or logistics cycle, e.g. RFID tags.
Note: • **The actualised business values (post-pilot) are highlighted in bold;** • ***The additional business values identified (post-pilot) were added in a separate row and highlighted in bold and italic.***		

Appendix 1: Definition of main parties involved in the pilot

- Sponsor: defines the need and liaises with the client
- Client: translate the needs to requirements, and responsible for managing procurement, legal, issuing contracts, finance.
- Design professional services: create the 3D design, track the design through the lens of circular economy (reuse), environmental factors (carbon footprint), ergonomics, cost, etc.
- Main Contractor: takes over the running on the program once the Technical digital specification has been completed. Engages the sub-contractors for different phases and tasks
- Subcontractor: Tiers 1-4 in a hierarchy for more and more detailed and specialised tasks in the construction project
- Suppliers: Manufacturers and suppliers of the component parts and materials:
- SMEs: make up the major of entities in the construction industry, including transportation

Appendix 2: Business pain points and challenges the smart contract may help to address (source: articulated by the consortium).

Challenges	***Description***
Liability	*1. Liability* *2. Act of Nature delaying project – who's fault is it* *3. Unforeseen events causing delays or cancelled contracts* *4. Cancellation of contracts* *5. Ignorance is bliss – if we don't know then it is not our problem*
Behaviour	*1. Social evaluations – ethical sourcing* *2. Digital maturity, especially of SMEs* *3. Artificial barriers* *4. Environmental evaluations – monitoring carbon footprints* *5. Optimising incentives to drive behaviour* *6. Risk understanding where risk is allocated* *7. Compensation Event (CE) and Early Warning Notices (EWN) trends in dealing with disputes*
Transparency	*1. Blame game* *2. Expectation that my data is my IP* *3. Configuration control* *4. IP – Intellectual property (counter to sharing information)* *5. Misalignment of decision makers* *6. Value engineering –different product installed on site to the one specified by the designer* *7. Benchmarking of contractors against each other* *8. Re-usability of estimates*
Tracking and Tracing	*1. Provenance – source or origin* *2. Performance data* *3. Accountability* *4. Achieving fast approvals for deliveries, commissions, justification etc..* *5. Mass / Haul / Traffic management* *6. Anti-money laundering*
Value	*1. Unaware of known and especially unknown knowns – where is the value hidden* *2. Standardisation of assets* *3. Profitability* *4. Automatic cost allocations* *5. Asset structure management*

Appendix 3: Interview Research Protocol

Part I: General questions

1. What is your role and responsibility within your organization?
2. How do you become involved in this smart contract pilot in built environment?
3. What role do you see your organisation play in this initiative?
4. What are the expected outcomes from your perspective?

Part II: Interview questions to consortium members (architect, main contractor, client, manufacturer, technology service provider, legal service provider, etc.)

1. In your opinion, what potential application scenarios blockchain will have in construction industry?
2. Why would your organization be interested in this pilot initiative?
3. What do you think would be the impact of this smart contract initiative on supply chain?
4. In addition to automated payment, (how) do you think blockchain may improve the transparency and overall efficiency of the supply chain?
5. How do you think suppliers (in particular SMEs) will react to this initiative?
6. Do you foresee any challenges/barriers in implementing this initiative?
7. What actions could be taken to promote the deployment of smart contract in construction industry?

Part III: Interview questions to SME suppliers

1. Can you please give us a brief introduction about your company?
2. How important is digitalisation (the use of digital tools/software) to your business?
3. What digital software is your company using e.g. BIM? What are the purposes of these software?
4. To your opinion, what are the opportunities and challenges of digitalization in your business?
5. Have you ever heard about blockchain and what is your perception of this technology? Have you or your company been involved in any related pilot initiative?
6. What is your opinion on the potential application of smart contract in your business operation? Do you welcome the fast-automated payment that based on smart contracts from your perspective?
7. What are the barriers for your business to get involved in smart contracts initiative? How keen are you to get involved?
8. If smart contracts could be successfully applied in the automated payment to SMEs, do you think it will encourage the diffusion of digitalization in construction SMEs?