Digital business model for large site building logistics

A generic approach to project-configured building logistics

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Digital affärsmodell för bygglogistik på stora byggplatser

Ett generiskt tillvägagångssätt för projektkonfigurerad bygglogistik

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Project ID: U5-2018-05

Granted in: Utlysning 5 – Inticament, risker och affärsmodeller 2018

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Gothenburg, Sweden

2021

FOREWORD

This was, to say the least, an interesting journey.

This project officially started in the summer of 2018, and eventually finished late in the spring of 2021. A lot of impactful local and global events happened within this period – not least the COVID-19 pandemic – which changed a series of societal conditions, including our own corner in the Swedish construction sector. It is within this context that digital business model development, building logistics, and blockchain technology, should be understood. As this project elaborates on the way a blockchain-powered solution for building logistics with integrated flows can be conceptualized, developed, tested and incorporated into a new digital business model for an independent building logistic consultant, we were thrilled to actively contribute to its progress.

The intersection of blockchain technology, digital business model development, and building logistics, is an emerging, cutting-edge field, gathering a lot of interest – in which the Swedish construction sector has the potential of being strongly positioned. We hope that our study will push research and development into that direction, as well as be an enabler of continued efforts towards a strong contextualization that will empower the Swedish construction industry – and society.

This effort forged a strong collaboration between us, setting the template for other collaboration contexts that have emerged since or will emerge in the future. But we were not alone in this. We want to extent our warm thanks to our main industry partner, namely the independent building logistics consultancy firm Prolog, for being actively with us throughout most of the project. Moreover, we are grateful for Urban Werner helping us immensely in the last stage of our study's empirical part, and for Magnus Dufwa facilitating the development and proof-of-concept of our prototype BLogCHAIN. Furthermore, we kindly appreciate the efforts of our colleagues Viktoria Sundquist, senior lecturer at Chalmers, and Stefan Gottlieb, senior researcher at Aalborg University (and previously, guest researcher at Chalmers), for their input in earlier stages of our project. In addition, the interesting insights offered by another independent building logistics consultancy firm, as well as the crucial role played by the contractor and the suppliers serving as the testers of BLogCHAIN in the context of a real construction site – all of which wished to remain anonymous – cannot be understated.

Last but not least, we warmly acknowledge Smart Built Environment (SBE) for funding this project, and for creating a platform within which we can pursue research and development towards the future of the construction sector in Sweden.

Dimosthenis Kifokeris and Christian Koch

Gothenburg, October 2021

EXECUTIVE SUMMARY

This project, funded by Smart Built Environment (SBE), aimed at investigating the way a site-specific solution for construction supply chains and logistics – where the information, material and economic flows are integrated and getting transparent through a blockchain-enabled solution – can be conceptualized, developed, tested and incorporated into a new digital business model for an independent building logistic consultant.

In a collaboration with such a consultant firm, Prolog, the insights, opportunities and shortcomings of blockchain as found in the current literature, were used to conceptualize a sociomaterial solution for construction logistics featuring blockchain for integrated flows, and embed this solution in the value proposition of a digital business model for independent logistics consultants. This, first, resulted in a generic digital business model for building logistics consultants as a business type, and then, in a Prolog-specific business model featuring a value proposition which focuses on facilitating logistics planning and flow integration. The Prolog-specific digital business model emphasizes consultancy over digitalization in its value proposition, focuses on the customer segment of public clients, and opts for an information flow integration system. Moreover, Prolog awaits further development of cryptocurrencies, before entering such economic flow-oriented solutions.

The conceptual sociomaterial solution emerged into a blockchain-supported flow integration from the issuing of purchasing orders until the completion of on-site deliveries. The development, tests, and evaluation of the solution prototype – named *Building Logistics BlockCHAIN (BLogCHAIN)* – involved the collaboration with a building site, the initial mapping of the prospective users' (and testers') experiences, and on-site testing (in two iterations) to inform both the first and the second version of the prototype.

The created value for the users and companies involved demonstrated the utility of blockchain in increasing integration and transparency, and prospectively reducing the number of transactions and facilitating value creation. The integration and transparency occurred among site managers supporting coordination. Reducing transactions and facilitating value creation remained as future options, since the system was tested as a stand-alone prototype. As such, the test context needed a system integration between planning, purchasing, and accounting, and a revision of existing purchasing contracts with regard to payment conditions. BLogCHAIN also highlighted the possibility of a more active and digitally supported role of the client, through enabling online monitoring of economic flows..

Recommendations for future work include preparing actual business cases via the conduct of larger-scale field tests, as well as innovation projects expanding on the potential of blockchain and digital systems' integration for building logistics. Blockchain, when further developed, can become a driver of digitalization in construction supply chains, but also other application fields in construction. It can complement well-established previous generation technologies such as BIM, but also cutting-edge technologies, such as IoT and machine learning. We hope that our study will push research and development in the direction of continued efforts of strong contextualization that will enable the competitiveness of the Swedish construction industry – and society.

SAMMANFATTNING

Detta projekt, finansierat av Smart Built Environment (SBE), syftar till att undersöka hur en platsspecifik lösning för byggvaruförsörjningskedjor och logistik - där information, material och ekonomiska flöden integreras och blir transparent genom en blockkedja (blockchain)-aktiverad lösning - kan bli konceptualiserad, utvecklad, testad och implementerad i en ny digital affärsmodell för en oberoende bygglogistikkonsult.

I ett samarbete med ett sådant konsultföretag, Prolog, användes insikter, möjligheter och brister som finns i den aktuella litteraturen om blockkedjor till att konceptualisera en sociomateriel lösning för bygglogistik med blockkedja för integrerade flöden och bädda in denna lösning i värdepropositionen i en digital affärsmodell för logistikkonsulter. Detta resulterade först i en generisk digital affärsmodell för logistikkonsulter som en affärstyp, och sedan i en Prolog-specifik affärsmodell med ett värdeförslag som fokuserar på att underlätta logistikplanering och flödesintegration. Den Prolog-specifika digitala affärsmodellen betonar rådgivning över digitalisering i sin värdeproposition, fokuserar på kundsegmentet för offentliga kunder och väljer ett informationsflödesintegrationssystem. Dessutom väntar Prolog på vidareutveckling av kryptovalutor innan man vill gå in i ekonomiska flödesorienterade lösningar.

Den konceptuella sociomateriella lösningen utvecklade sig till en blockkedja-stödd flödesintegration från utlösningen av inköpsorder till slutförandet av leveranser på plats. Utvecklingen, testerna och utvärderingen av lösningsprototypen – med namnet *Building Logistics BlockCHAIN (BLogCHAIN)* – involverade ett samarbeta med en byggplats, den första kartläggningen av de potentiella användarnas (och testarnas) erfarenheter och testning på plats (i två iterationer) för att utveckla både den första och den andra versionen av prototypen.

Det skapade värdet för de involverade användarna och företagen visade att blockkedja användes för att öka integrationen och öppenheten och potentiellt minska antalet transaktioner och underlätta värdeskapandet. Integrationen och transparensen inträffade bland platsledningen och underlättade samordningen. Att minska antalet transaktioner och underlätta värdeskapande var fortfarande framtida alternativ eftersom systemet testades som en fristående prototyp. Som sådan behövde testkontexten en systemintegration mellan planering, inköp och redovisning och en översyn av befintliga inköpskontrakt med avseende på betalningsvillkor. BLogCHAIN markerade också möjligheten till en mer aktiv och digitalt stödd beställarroll genom att möjliggöra onlineövervakning av ekonomiska flöden.

Rekommendationer för framtida arbete inkluderar att förbereda faktiska affärsfall via genomförande av större fälttest samt innovationsprojekt som utökar potentialen för blockchain och digital systemintegrering för bygglogistik. Blockchain, när det vidareutvecklas, kan bli en drivkraft för digitalisering i byggvaruförsörjningskedjor, men också andra applikationsområden inom bygg. Det kan komplettera väletablerade teknologier som BIM, men också banbrytande teknik, som IoT och maskininlärning. Vi hoppas att vår studie kommer att driva forskning och utveckling i riktning mot fortsatta insatser för stark kontextualisering som underlättar svensk byggindustri - och samhället.

CONTENTS

1 INTRODUCTION

Building sites involve complex, recurrent, and conflicting flows, consisting of processes such as material deliveries, subsystems, people from many different companies (e.g. supporting equipment), and more. It has become increasingly recurrent in Sweden to place a specific responsibility in site management or to employ a third-party firm to coordinate these flows. These firms, like FM management, Myloc, Prolog Bygglogistik, Svenskt Bygglogistik and others, are often small organizations that are given a central role in the flows (Kifokeris and Koch 2020). They embody a business model for improved building logistics that strengthens coordination across the supply chain, connecting the building client, transportation companies, main contractors, and sub-contractors.

Some of these small firms have, for some time, employed a digital business model involving technologies such as planning software, tracking systems, camera vision, and site access control systems – as well as centrally involving collaboration with the contributing parties on site. With the use of the blockchain digital technology, there is a potential to raise the efficiency and lower the cost in this collaborative digital business model. In the future, a coupling with the Internet of Things (IoT) will lever this potential further (McKinsey Global Institute 2017). However, developing and operating such digital business models comes at a risk (Bughin et al. 2018), and there is a need to develop and test solutions in a context-conscious manner, in order to enable a development towards sustainable digital models.

The integration of flows within construction supply chains has long been identified as crucial for the optimization of logistics and the overall success of construction projects (Palaneeswaran et al. 2000; Love et al. 2004). Titus and Bröchner (2005) had identified the information flow (the bidirectional flow of prompts and requirements received and released by a construction supply chain partner), material flow (the flow of physical goods), and financial flow (the flow of financial transactions), noting that their integration is critical for effective construction supply chain and logistics management. However, it can be considered that, when it comes to the latter flow, the term "financial" is not precise enough and only partially describes a flow that, in construction supply chains, is not only associated with financial and monetary exchanges, as well as the associated assets and cost entities; but rather, in conjunction to those, it also concerns transactions integrating data on prices, billing and invoices. Therefore, to encompass all of the aforementioned elements, we define such transactions as economic transactions, and the flow they belong to as the economic flow – which accompanies the material and information flows.

Given the aforementioned considerations, the overall research question and problem for the project and the current report is the following:

How could a solution for building logistics, in which the information, material and economic flows are integrated in an event-driven way via a suitable technology, be conceptualized and incorporated into a new digital business model for building logistics consultants – and what characteristics would this digital business model have?

The sub-aims and objectives of the project are:

- Carrying out a state-of-the-art literature study: Developing knowledge on digitalized building logistics, blockchain, distributed ledgers, smart contracts and IoT in construction sectors abroad, as well as other sectors (i.e. non-construction).
- Selecting a building site that carries out the ordering and purchasing of materials.
- Selecting a bounded area and timeframe within building logistics for development, i.e. a group of suppliers and a test period. This group of players are supposed to already cooperate on the building project and then asked to extend their collaboration into testing a blockchain prototype.
- Selecting a blockchain developer and technology.
- Developing and testing a software prototype, which is to be embedded in a blockchain-powered digital business model.
- Carrying out an impact and effect study using interviews, and data from the integrated flows.

The aim of this project report is therefore to address the research question, problem, sub-aims and objectives, by proposing a new digital business model supported by blockchain, which is dedicated to an independent logistics consultant within the Swedish construction context, i.e. Prolog. Such a digital business model will feature the conceptualization of a solution for integrated supply chain flows via the use of blockchain technology.

Delimitations

The project was at the outset delimited to the study of one building site and the involvement of a limited set of suppliers, which meant that subcontractors and a more comprehensive supplier network was excluded from the experimental set-up. This was decided in order to assure the feasibility of the project, given the limited project resources available. As the project progressed, several further delimitations had to be adopted.

Due to the COVID-19 pandemic restrictions, the preparatory interviews and the follow-up evaluation interviews were carried out over Skype and other virtual communication tools. The empirical material generated in this manner was interpreted as sufficient to fulfil the project goals - but it is believed that if researchers had been able to be present at the site during the preparatory work and the tests, it would have generated stronger research material.

Due to the focus of development resources on the blockchain prototype, it was decided not to directly involve cryptocurrencies or an integration with some kind (IoT) technology. It was possible to generate a test flow with a prototype having a narrower scope, which did not involve these two elements. Similarly, the building logistics consultancy company’s role was simplified into being identical to the client’s role in the blockchain prototype, appreciating a strategic client consultancy type of a digital business model. It should be noted that other building logistics companies sometimes use other business models that would require another blockchain design (see Kifokeris and Koch 2019a,2020).

2 DEFINITIONS AND FUNDAMENTALS

This section commences with presenting our overall theoretical understanding of digital technologies and business models being sociomaterial phenomena. The section then goes on to present our definition of *business models*, *digital business models*, *construction supply chain flows*, and the *blockchain* technology.

Sociomateriality

Sociomateriality is a sociotechnical approach which emphasizes the way technologies are co-shaped with practices (also applying to digital technologies) (Orlikowski and Scott 2008,2016). According to sociomateriality, the material and social aspects of digital technologies are inseparable and fused in practice (Orlikowski and Scott 2016). This is reflected upon the agency of the actors while they are utilizing the digital technology, since actions are considered to cease being exclusively human properties but are rather performed through interactions between humans and non-humans (Moura and Bispo, 2019). This sociomaterial co-shaping can affect the way in which the structure of an organization, or even a constellation of actors, is realized (Moura and Bispo 2019; Kohtamäki et al. 2020).

Important notions in understanding sociomateriality are the ones of entanglement and performativity (Orlikowski and Scott 2016). According to the notion of entanglement, the material and social aspects of a technology should not be merely realized as being progressively intertwined (which could foster an understanding that they initially exist separately), but actually understood as not having an independent, self-contained state (Barad 2007; Orlikowski and Scott 2008,2016). Performativity alludes to a world getting reshaped through ongoing reconfigurations (Barad 2007; Orlikowski and Scott 2016). This position strongly contrasts the more dominant one, which poses a world which is made up of self-standing entities with a priori properties (Orlikowski and Scott 2008,2016); sociomateriality rather poses that a technology's performativity emerges through social practices (Orlikowski and Scott 2008).

While Orlikowski and Scott (2008,2016) offer a central understanding of sociomateriality, there have also been other relevant theoretical approaches. Among those, Leonardi's (2013) understanding of sociomateriality departs significantly from the one by Orlikowski and Scott (2008,2016). Particularly, Leonardi (2013) considers that the material and social aspects of technologies are not isomorphic; as such, materiality is preconfigured and only gets gradually fused with the social aspect through imbrication over time. However, for the current project and report, we adopt Orlikowski's and Scott's (2008,2016) approach to formulate our understanding of a sociomaterial blockchain solution for building logistics, since we argue that the inseparable entanglement of the material and social aspects is particularly suitable to describe the reconfigurations of work practices induced by the introduction of a digital technology (Orlikowki and Scott, 2016).

Business models

A business model is a set of activities, processes and even innovations that create, deliver and capture value and revenue (Schneider and Spieth 2013). A crucial aspect of a business model is the value proposition, namely the creation of novel value for clients willing to purchase or reimburse it, thus converting it into company turnover and profit (Andreini and Bettinelli 2017).

Digital business models

A digital business model is a digitally supported set of processes to create, deliver and capture value (Schneider and Spieth 2013). A crucial aspect of a digital business model, as is the case for business models in general, is the value proposition – but when considering a digital support, this can in principle occur in any single element of the business model as long as a comprehensive digital architecture exists and fosters the covering and integrating of all business model elements.

Firms can actively respond to, or be forced to, incorporate new sources of value in their business models (Schneider and Spieth 2013). Such value may be indeed generated from new technologies; however, it might be difficult to use and exploit a new technology, and as such, the interested actors should re-evaluate and expand their business models in order to understand, frame and capture that value (Chesbrough 2010). When it comes to blockchain in particular, it is rational to start small, identify implementation objectives, take precautions, and consider issues of security and regulatory challenges (IBM Institute for Business Value 2017a). IBM Institute for Business Value (2017b) identified three basic concerns when deploying a digital business model utilizing blockchain: the involved project stakeholders need to receive some form of economic benefit, trust among them must be facilitated, and they should be among the early adopters of the technology. A number of studies have elaborated on these considerations and have presented value-adding benefits of blockchain implementation, drawing mainly from leveraging core capabilities of the technology. Indicatively, Dobrovnik et al. (2018) identified those benefits to be origin tracking, transaction cost reduction, advanced actor activity overview, process compatibility, reduction of transaction complexity, user-regulated participation, and information-sharing, and facilitated transaction observability. Moreover, O'Leary (2017), Scott et al. (2017), Wang et al. (2017), Dobrovnik et al. (2018), and Kshetri (2018) noted the value emanating from the streamlining of transparent and accountable processes, while Veuger (2018) focused on the facilitation of trust and collaboration among the actors in the blockchain network. Moreover, the shared digital ledger (which is a core component of blockchain) reduces the need to reconcile local ledgers, thus shortening confirmation times (Verhoeven et al., 2018).

Curiously, the culmination of these (and other) value-adding benefits into the actual value proposition of a digital business model is often not researched in the related literature (Risius and Spohrer 2017). A notable exception is the study by Chong et al. (2019), who map five Chinese companies implementing different digital business models featuring blockchain solutions. For each of the five cases, the value creation logic takes one of the following roles: platforming, disintermediating, mediating, transforming, and co-innovating (Chong et al., 2019). Note that this study concerns industry sectors that are not construction (Chong et al., 2019).

This usual lack of explicitly identifying the value proposition of blockchain for digital business models, is also apparent in the case of building logistics. However, it has been shown that when developing digital business models for construction logistics, a simultaneously integrated and agile approach is needed (Thunberg and Fredriksson, 2018). The digitalization of (or enhancement of already digitized) business models through blockchain, can optimize their efficiency and lower costs (McKinsey Global Institute 2017). Blockchain properties also align with the recognition of such digital business models in an inter-organizational supply chain context (Vendrell-Herrero et al. 2018).

Construction supply chain flows

The flows in construction supply chains are threefold: the material flow (the most visible), the information flow, and the economic flow. The material flow is constituted by the flow of physical goods (Titus and Bröchner 2005). The information flow is bidirectional and involves prompts and requirements received from and released by construction supply chain partners (Titus and Bröchner 2005). The financial flow or flow of financial transactions is primarily associated with the exchange of assets (Titus and Bröchner 2005) and entities like operational cost (Panova and Hilletofth 2018). Moreover, such a flow has also been termed “cash flow” (Pryke 2009; Lundesjö 2015), regarding cash transactions, and “money flow” (O’Brien et al. 2009), reflecting monetary exchanges. However, it can be considered that using the aforementioned terms (“financial”, “cash” and “money”) is not precise enough and leads to only a partial description of a flow that, in construction supply chains, does not have to be carried out in cash (as in the case of Sweden), and is not only associated with assets, cost entities and monetary exchanges; but rather, in addition to those, it also concerns transactions containing integrated data on prices, billing and invoices (e.g. of materials). Therefore, to encompass all of the above, we define such transactions as economic transactions, and the flow they represent as the economic flow – which complements the material and information flows.

Throughout the years, there have been studies exploring the ways a single flow can be realized (e.g. the information flow in Obonyo and Anumba (2011)), but also partially considering the possibility of flow integration. Such studies have investigated the integration of the information flow (emanating from tracking technologies) with the material flow in order to increase the overall visibility of the supply chain network (Ikonen et al. 2013), the utilization of building information models (BIM) and geographic information systems (GIS) in order to integrate the material and information flows within the construction site and connected remote areas (Deng et al. 2019), and a network design formulation integrating the material and information flows in order to choose the best installment location of on-site temporary facilities (Golpîra 2020). However, the integration of the economic flow (as understood in the manner described previously) has not been investigated as rigorously. Studies such as the aforementioned are examples of a general focus on the integration of just the material and information flows. Nonetheless, it can be envisioned that the integration of all three flows could be event-driven; such “events” can include the release of invoices and payments to the associated actors (e.g. suppliers, transporters) via direct peer-to-peer information exchange after successfully concluded material deliveries, correct on-site component placement, and completion of related work packages (Wang et al. 2017). However, the actual benefits, framework, appropriate technology, and implications of such an integration, have not been adequately explored. In addition, the associated value proposition – realized through a new digital business model for the specific actors that could propagate such an integration – has not been investigated. Nonetheless, with the work conducted in the current research project, both of these largely unresolved issues are addressed, albeit for a specific context.

Blockchain

Blockchain is often described as a digital ledger technology for peer-to-peer transactions, which are kept in a historical record that is updated through consensus (Singhal et al. 2018). Beyond this general description, there have been different definitions of blockchain in the literature, according to the research orientation of each study (Wamba et al. 2020). On the one hand, there are definitions that could be described as economic flow-oriented, which are focusing on the digital ledger aspect of blockchain (Lamb 2018). On the other hand, there are definitions that could be described as information flow-oriented, which are focusing on the data exchange properties of blockchain (Verhoeven et al. 2018). These approaches are analyzed in, correspondingly, the following two paragraphs. It should be noted that, in some studies attempting to define blockchain, those foci can be mixed (e.g. see Dobrovnik et al. (2018), and Li et al. (2019)).

Considering what is described in the economic flow-oriented definitions, the peer-to-peer system for value transaction is central to the blockchain technology (through a shared and decentralized digital ledger replicated across different nodes) (Lamb 2018). The need for in-between transactional verification, security, and settlement through trusted third-party intermediaries, is claimed to be partially or completely redundant (Dannen 2017; Singhal et al. 2018); or, as Chong (2019) terms it, disintermediating. This is an important feature compared to present day accounting processes, saturated with checking and double-checking. The digital ledger databases of blockchains are append-only (Gausdal et al. 2018); every entry is permanent and immutable, with the new ones reflected on all database replicants hosted in the nodes (Singhal et al. 2018). The way such nodes are set up can result in different digital ledger architectures, in accordance with the privacy settings in the blockchain - which can range from public permissionless systems, to private permissioned ones (Chong et al. 2019). In permissionless blockchains, network nodes can be set up without oversight and anonymously (Chong et al. 2019). On the contrary, permissioned blockchains are operated by a central authority; authorization is required for setting up the network nodes, which are selected according to predefined compliance criteria (Chong et al. 2019). In some studies, even when the term "digital ledger" is not explicitly mentioned, the focus on the economic flow is accentuated by noting the use of blockchain in economic transactions involving tokens and cryptocurrencies (e.g. in Barima 2017).

Described in a more information flow-oriented manner, blockchain is a technology to store and access information in a decentralized and transparent way, by facilitating data transactions kept sequentially in a historical record (Verhoeven et al. 2018). Each "block" of this historical record stores finite data; then each block is connected to the previous and the next one in a fixed order or "chain" (Verhoeven et al. 2018). Thus, by determining the dataset through following the chain and resolving the block transactions, the blockchain not only keeps the present transactional information, but also the complete transaction history (Verhoeven et al. 2018). Throughout the nodes, such a history is shared and can only be updated through consensus via certain validation methods, such as "proof-of-work", "proof-of-stake" and "proof-of-authority" algorithms (O'Leary 2017;

Verhoeven et al. 2018; Rossi et al. 2019). Such an information flow-oriented approach can reflect more diverse blockchain uses than just economic transactions (Scott et al. 2017; Kshetri 2018), such as quality control (Chen et al. 2017) and data integrity (Lemeš and Lemeš 2020).

The above presented diversity when it comes to the definitions of blockchain, along with its potential application-wise versatility, can be partly attributed to it being an emergent general-purpose technology (Filippova, 2019). While blockchain was initially introduced to support the cryptocurrency known as Bitcoin – as described in Nakamoto (2008) – its application potential has grown extremely (Konstantinidis et al. 2018). Within such versatile potential, there have been studies on construction supply chains and building logistics in particular, which have so far focused on the streamlining of a single flow (e.g. the information flow in Nanayakkara et al. (2019)), or on the integration of the material and information flows (e.g. see in Lanko et al. (2018), and Wang et al. (2020)). The utilization of blockchain for the integration of all logistics flows (also corresponding to the general lack of research on the integration of all three flows within building logistics, as mentioned earlier), is another issue addressed in the current research project.

Summary – a sociomaterial understanding of blockchain within construction supply chain and logistics with integrated flows

In this project we adopt a sociomaterial take on blockchain as a solution for construction logistics, with a key element being the integration of all flows. Sociomaterial understandings of blockchain are relatively few, but/and give the following insights:

- Blockchain is intertwined with the social world in both its protocol and application levels (Rossi et al. 2019). Thus, the stakeholders' actions and issues of governance are critical, not only with regard to the consensus mechanisms of the operation protocols (e.g. smart contracts, permission regulation etc.), but also the framing and constraints of the technology in its application (Rossi et al. 2019). This framing also shapes the understanding of trust, information privacy, scalability, security, user behaviordubois, disintermediation, and environmental sustainability, among the actors in the blockchain constellation (Rossi et al. 2019). It can also lead to blockchains with different privacy settings (Rossi et al. 2019).
- Blockchain can facilitate a complex sociomaterial system among actors, by digitizing the value chain, integrating various flows, shifting routines and capabilities, and reconfiguring existing sociotechnical infrastructure (Kohtamäki et al. 2020).

Building on a combination of the economic flow- and information flow-oriented definitions of blockchain, as well as the aforementioned sociomaterial postulations, we sociomaterially define blockchain for building logistics with integrated flows as a permissioned private digital ledger for partially decentralized peer-to-peer information and economic transactions across a project-specific network/constellation of supply chain actors (e.g. clients, contractors, logistics consultants, and suppliers). The database within its digital ledger is append-only, permanent, stored and accessed in a historical record updated through consensus, and shared across all network nodes reflecting the stakeholders of the constellation. As a permissioned system, it features a reduced but existing need for in-between verification, security and settlement of the transactions, and the consensus updates are based on a proof-of-authority algorithm - where consensus features identity as a stake and is agreed between the authorized participants (Verhoeven et al. 2018). In addition, it creates power shifts within the constellation, in line with the sociomaterial autonomy-control paradox (Bader and Kaiser 2017). The economic transactions are event-driven and event-inducing, i.e. they are triggered when certain events in the information flow (e.g. sending purchasing orders) and/or the material flow (e.g. concluded on-site material delivery) take place, and can trigger themselves other events (e.g. issuing invoices when transactions are completed). Thus, the economic, material and information flows become integrated.

Through this sociomaterial understanding, a blockchain solution for building logistics with integrated flows can be the central value-adding aspect for a new digital business model implemented by the suitable actors. In the course of the current project and report, we argue that such actors can be the independent logistics consultants in the Swedish context.

3 RESEARCH METHOD

The design of the research method is aiming at responding to the research question and aims presented in the Introduction. Following the conceptual preparation above, this study unfolds methodologically through:

- A targeted literature review for the selection of research material according to certain criteria.
- The collection of empirical data about business models operated by building logistics consultants.
- The development of the digital business model.
- Design criteria for the blockchain solution prototype, including finding an appropriate building project and site that would fit the test iterations.
- Development (in iterations) of the blockchain solution prototype.
- Testing (in iterations) of the blockchain solution prototype, including in-between interviews and developmental updates of the blockchain solution prototype.
- After-test evaluation of the blockchain solution prototype, including follow-up interviews and a final workshop.
- The analysis and reporting of our results.
- Documenting the delimitations of our study.

In the following subsections, each of these points will be elaborated on.

Literature review

Due to the fact that blockchain-related research is developing very quickly, our literature review has been a continuous process for almost two years and was iterated three times between November 2018 and October 2020; more precisely, the iterations took place in the autumn of 2018, the autumn of 2019, and the spring and summer of 2020. For the literature review, the concept-centric framework augmented by units of analysis was used (Webster and Watson 2002) - in which, the units of analysis emerged during the iterations of the review. This iterative revision followed the abductive reasoning of qualitative research (Bell et al. 2019). Moreover, we implemented the references-of-references and "snowballing" techniques (Greenhalgh and Peacock, 2005), as well as the conduct of a comprehensive search to avoid a narrow sample (MacLure, 2005).

Specifically, within the first, second, and especially the third iteration of the literature review (also published in Kifokeris and Koch 2020), the following steps were followed and abductively iterated:

1. Source selection (e.g. books, journal articles, consultancy reports, conference papers, and theses).
2. Identification of broad keywords fitting the research aims (e.g. blockchain, supply chain, logistics, logistic flows, sociomateriality, business models, and value creation). The search was conducted on a number of library engines covering a range of publishers active in related fields. After filtering out the results in terms of relevance, a total of 188 literature sources were kept. 23 of them were chosen as the current

study's backbone in the background, theory and research methodology. The remaining 165 sources were treated as described in steps 3 and 4.

3. Identification of targeted keywords fitting the research aims (e.g. sociomaterial blockchain, construction supply chain, construction logistics, construction logistic flows, smart contracts, cryptocurrencies, decentralization, digital business models, value proposition, independent logistics consultants, Swedish construction context). The corresponding sources amounted to 100 out of 165, with the ones finally selected for inclusion being 53.
4. Inclusion of studies not directly related to construction, but with the potential to offer insights suitable for construction, as they elaborated on topics tangentially relevant and/or applicable to the research aims. The corresponding sources amounted to 65 out of 165, with the ones finally selected for inclusion being 19.

It should be noted that while the literature sources were broadly categorized as previously, there can be found contextual overlaps among them. The exclusion and inclusion criteria (Dundar and Fleeman 2017) applied for finally selecting the 23+53+19=95 references, were the sources' particular relevance, high quality (with regard to the impact factor of their publication contexts, as well as the number of their cross-references), methodological rigorousness, clarity of results, and sound basing on previous research output.

Empirical material collection

When it comes to the collection and elaboration of field qualitative data to couple the results of the literature review, the co-authors focused on the Swedish construction sector context; this methodological choice was made in order to account for the national institutional and socioeconomic forces impacting and making each industry unique (even if it can share similarities or interfaces with others). In the particular context of Sweden, at least until the recent COVID-19 pandemic outbreak, an intense urbanization had been taking place, despite a very uneven density distribution of urban and countryside areas. Such an activity and the complex processes associated with it, especially within densely populated places, can result in supply chain- and logistics-related issues (e.g. delayed deliveries, complicated flow coordination, and low productivity) (Dubois et al. 2019). One Swedish business practice to counter such issues has to do with clients employing independent logistics consultant firms, in order to coordinate and handle complex, recurrent and conflicting flows (e.g. deliveries of materials and arrival of incoming goods) (Gustavsson 2018). Such firms facilitate such coordination across the supply chain by suitably connecting the related actors (e.g. clients, material suppliers, main contractors, and sub-contractors) (Gustavsson, 2018). This business practice is particularly emerging in the case of public clients in central urbanization projects.

In this context, we collected our empirical material by combining the following sociomaterial qualitative techniques described in Moura and Bispo (2019): observations, interviews, participant mapping, and photo elicitation. These techniques were implemented (in various combinations) during the following three sessions:

1. The introductory study (December 2018 to July 2019), which consisted of two substeps. The first one was identifying sociomaterial constellations of construction supply chains and building logistics within the Swedish context, studying the way the flows (and especially the economic one) were realized in each, envisioning the way a

blockchain solution could offer some kind of flow facilitation, and finally focusing on the case of the independent logistics consultants (as one of the identified sociomaterial constellations). The second substep zoomed in on studying seven firms offering independent logistics consultancy exclusively or in combination with other services (LogTrade, Myloc, Prolog Bygglogistic, Servistik, Bygg Dialog, Svenskt Bygglogistic, and FM Management). The sampling of these companies followed their characterization as prominent in their field by Swedish construction periodicals (e.g. Byggindustrin, Byggvärlden), as well as the field expertise of one of the co-authors as an observer of such firms' business activity in the Swedish construction sector since 2013.

2. The in-depth collaboration with Prolog was arranged as regular meetings from autumn 2018 to summer 2020. Another independent logistics consultancy firm was also visited but wished to remain anonymous. The selection of these two companies occurred before applying for funding for the project and was furtherly consolidated after the co-authors' personal communication with them. The premises of Prolog were visited by one of the researchers three times: twice in Stockholm (in December 2018 and January 2019), and once in Malmö (in January 2019); the offices in Malmö were visited again by both co-authors in February 2021. In these visits, the company's operation processes were observed, while discussions were held with the consultants with regard to their respective roles – resulting in the design of a participant mapping in early 2019, which was then disseminated to all relevant colleagues. Moreover, from November 2018 to March 2020, we held regular (almost biweekly) Skype meetings with Prolog; these meetings were not recorded, but each time notes were taken and then disseminated to participants. During most of 2020, those meetings became the primary channel of collaboration with Prolog, due to the COVID-19 pandemic. In the case of the anonymous firm, and apart from the construction site visits (see next step), one of the co-authors held a number of telephone conversations with one of the company's founders in October 2019; notes from these conversations were taken and used as a preparation for the interviews described in the following.
3. Visits to three construction sites where the anonymous firm operated; one featuring the expansion of a hospital in a town in Sweden, and two (for which the firm wished the non-disclosure of project information) in Denmark. Both co-authors and a research colleague visited the Swedish town in October 2019, and interviewed the anonymous company's founder and partner, as well as another of the partners, for about four hours. This semi-structured interview, first taking place in the on-site firm's premises and then at the construction site itself, was recorded and transcribed. The two sites in Denmark were both covered in a single visit (December 2019). In the first site, one of the co-authors interviewed the company's founder and partner for about two hours. In the second site, both co-authors continued interviewing the same interviewee for about three hours. This two-part semi-structured interview was recorded, and its most useful parts were transcribed and codified. In both cases, the interviews took place in the firm's respective on-site premises, and then at the construction sites themselves. During the interviews, we also observed the company's consultancy processes and took notes. Moreover, the interviewee introduced the participating researchers to on-site partners, which then helped us design a participant mapping for each visited site. Furthermore, in all three site visits (in Sweden and Denmark), photographs from the company's workflow charts, as well as their actual on-site coordination, were taken. All of the interview transcriptions, notes,

observations, and site photographs were summarized into a short compilation, which was then disseminated to all participants. Although this summary and the items included in it are non-disclosed after the company's request, the results most relevant to our research that emanate from it, have been anonymously included in this report.

The sum of this material was used to inform all empirical findings in Chapters 5, 6,7, 8, and 9. Also, ethical considerations about data and corporate confidentiality were accounted for; only the information allowed by all involved actors is disclosed in this study.

Business model development

Two conceptual digital business models were developed until the autumn of 2020, using the business model canvas tool by Osterwalder and Pigneur (2010). The first one was conceived for independent logistics consultants and featured a blockchain solution with integrated flows for construction logistics. The conception of this model was mainly based on the knowledge gained through the results of the literature review and the collection of our empirical material. The second one was conceived with direct involvement of Prolog and featured the particularization and customization of the first model into the specific business case of Prolog. The business model canvas tool by Osterwalder and Pigneur (2010) was also used in the final workshop taking place in Prolog's premises at Malmö in January 2021, where both researchers, as well as Prolog's consultants, participated.

Design criteria for the blockchain prototype

As stated in the Introduction, one of the goals of the project was to develop a configurable blockchain solution prototype, contextualized in the case of a construction site. As such, establishing the design criteria preceding the development of this prototype, entailed that the construction site would have to be found beforehand.

The search for a construction site suitable for the project was a long process (starting in the autumn of 2018 and ending in the summer of 2020) and was done in a collaboration with Prolog and while addressing municipalities (clients) and contractors. One particular municipality, being one of Prolog's clients and developing a new district in the area, has been considered a candidate for a long time, but eventually decided to delay the district development. In early September 2020, a suitable construction site was found (a school building), and the collaboration with this specific site and the associated actors (i.e. suppliers and the contractor's operatives and site managers) willing to test our prospective prototype app there, commenced.

Seven semi-structured interviews were carried out in September 2020 and provided material regarding the supply chain and logistics work practices of the specific actors at the specific construction site (e.g. the existence of other IT solutions, and different degrees of systemic integration between the contractor and each supplier).

Development of the blockchain prototype

The results from the aforementioned interviews in September 2020, as well as our previous conceptualizations, constituted the platform for the development of the blockchain prototype - but also introduced constraints and alterations in the development, eventually leading its design, functionality, and user interface to depart (in certain respects) from the initial conceptual vision (see chapters 6, 7, 8, as well as Kifokeris and Koch 2020).

This platform informed the 1st iteration of the development of the blockchain prototype app (before the 1st iteration of the field testing). This development of the app took place roughly between September and early November 2020 and started before the last round of the preliminary interviews was finished. The developed proof-of-concept was based on the conceptualized solution presented in chapters 6 and 7 (and in Kifokeris and Koch 2020) but modified according to the practitioners' input acquired in this and the previous stage. At the end of this first iteration of development, the name of the prototype was also decided: *Building Logistics BlockCHAIN*, abbreviated as *BLogCHAIN*.

In the 2nd iteration of the development of BLogCHAIN (before the 2nd iteration of the field testing), evaluation results after the 1st iteration of the field testing were considered (see next section). As such, three main improvements were included and followed through in the subsequent development: the conditional re-involvement of the roles of the client and the logistics consultants, the deployment of a notification function for the transporters as they approach the construction site, and making provisions to accommodate the different roles of managing the sales and issuing the invoices that can exist within the same supplier company. This development was done in January 2021.

Testing of the blockchain prototype

The test was carried out in two steps, the second one resulting from the relatively limited results of the first round of tests. When the first test round was planned in August 2020, it was hoped that we could conduct on-site introductory training, observations, and interviews. However, all these had to be carried out online through Microsoft Teams, due to COVID-19-related restrictions that were still ongoing as of the second half of 2020 and the first half of 2021. In the first iteration of field testing for BLogCHAIN, a series of meetings were conducted with the testers over the span of two weeks, in order to assist them in its installation and guide them through its functionality and interface. Afterwards, the tests took place through the rest of November and December, having designated the end-of-year vacation period as the stopping point of the tests. The tests consisted of the collaborating suppliers and contractor's operatives carrying out supply chain transactions through BLogCHAIN. In order to not disturb the everyday work at the construction site, we agreed with the testers that the implementation of BLogCHAIN would run in parallel to the established way in which the supply chain transactions were already taking place – and not in replacement of those practices. During the tests, we conducted semi-structured and unstructured interviews with the testers, and engaged in observations as they used the application.

The feedback after the 1st iteration of field testing was conducted as semi-structured interviews with all the testers, in order to record their user experiences. This amounted to four interviews with supplier representatives and one group interview with four representatives of the contractor's site management team. Wishes for improvement were articulated, such as enabling transport companies (åkerier) to notify the construction site of the arrival, and integration of accounting representatives at the material suppliers (not only including sellers). These wishes informed the improvements introduced in the 2nd iteration of development, as described in the previous subsection.

The 2nd iteration of field testing for BLogCHAIN was carried out in February 2021. Some new suppliers served as the testers, and more transactions occurred in this second testing period. The feedback after the 2nd iteration of field testing was also organized as a series of interviews with site management and suppliers. Moreover, there was an attempt to include interviewees from transport companies, but this was hampered by practical barriers.

Evaluation

All of the empirical material collected through our field studies before the development and testing of BLogCHAIN, the interviews and observations during the design and the two development and testing iterations of the blockchain prototype, the post-test feedback interviews, and the final workshop with Prolog, formed the platform for the evaluation analysis.

As mentioned before, parts of the material were initially combined to inform the actual development of the application – beyond the initial conceptualization discussed in chapters 7 and 8 (and in Kifokeris and Koch 2020).

The evaluation then aimed at understanding the potential alterations in the work practices that can be realized through BLogCHAIN, check which of the previously envisioned benefits and drawbacks of the blockchain solution did or did not materialize, and document the delimitations and shortcomings of the pilot, while simultaneously gathering recommendations for its improvement and expansion. For this, the literature review and the sociomaterial framework were used - and more particularly, the study framework by Moura and Bispo (2020), and the ten-step decision path to determine when to use blockchain technologies by Pedersen et al. (2019).

Final workshop with Prolog - digital business model development

All of our field data insights were combined with the understanding of the previously sketched digital business model canvas that was customized for and verified by Prolog. This combined material was used to inform and serve as the basis for the final digital business model workshop held with Prolog (Malmö, February 2021). The setup of this workshop, in which the aforementioned material was utilized, was framed under the auspices of the "BeeBusiness" systematic business model development framework and equipment (BeeBusiness 2021). The method was adapted to this project and supported the final evaluation of the prototype and the digital business model development with two main tools: the Beeboard and Beestar (a special type of table). First, the updated version of the BLogCHAIN prototype (after incorporating the improvements suggested between the two test iterations), was presented. Then, the Beeboard was used to evaluate the development and readiness degree of the prototype. Finally, the Beestar was used to support the subsequent business model development dialogue among three representatives from Prolog and the two researchers.

The workshop was recorded in audio and in pictures. The audio recording was subsequently transcribed. Note that four participants attended the workshop physically, and one through a videolink.

Analysis and reporting

The literature review findings and the field data were combined to realize the sociomaterial understanding of blockchain for integrated flows in construction logistics, conceptualize the blockchain solution, understand its value creation for a new digital business model, select the independent logistics consultants in Sweden as a suitable candidate for the implementation of this digital business model, and conceptualize such a digital business model. For these, the sociomaterial study framework by Moura and Bispo (2019), the ten-step decision path to determine when to use blockchain technologies by Pedersen et al. (2019), and the business model canvas tool by Osterwalder and Pigneur (2010), were used. Finally, for the verification of the digital business model, a case study was conducted with Prolog. The firm particularized the previously formulated conceptual digital business model canvas in its own context. The use of case studies for verifying conceptualizations in a sociomaterial context is exemplified in Rossi et al. (2019) and Moura and Bispo (2019).

Also, it should be noted that considering data confidentiality, only the information allowed by all involved actors is disclosed in this report.

Limitations

A digital business model for a small consultant company like Prolog would often include networking and partnering with other companies, in order to provide customer specific solutions. As such, Prolog often collaborates with a technology partner. This partner was however not involved in the present project, excluding the possibility of embedding the blockchain solution with the IT infrastructure that the technology partner could potentially offer.

From the outset, it was planned to interact with a limited set of suppliers and transporters. The amount of such partners was further reduced when focusing on an early phase of a building project, which resulted in two suppliers for the 1st test iteration, and six suppliers for the second test iteration. This subsequently reduced the input concerning improvements for the app. Another aspect of this, is that the testing of the prototype in an early phase of a building project made, on the one hand, the number of participants and corresponding transaction more manageable, but on the other hand, tended to simplify the test. An additional test iteration in a later (and more complex) phase of the building prject was originally planned, but this proved impossible to follow through.

It should be noted that the conceptual development, the prototype, and the testing came to be focused on the supply chain processes until delivery at the site gate, whereas processes inside the building site were not prioritized. This a future potential for focusing on a horizontal integration in the logistics processes.

The developed blockchain prototype emerged as a stand -alone system that was tested in parallel to the economic flow and the other flows of construction supply chains and logistics. This clearly limits the test results, as a tighter integration with the ordering and accounting systems (and the respective flows) would have strengthened the test participants' understanding of the blockchain potential.

4 LITERATURE REVIEW

Blockchain in construction - research in the international and Swedish contexts

Before the advent of blockchain in the construction context, there had already been research noting the need for transparency in the access and management of information in construction supply chains (e.g. in Čuš-Babič et al., 2014), as well as new approaches to procurement (e.g. in Eriksson and Lind, 2016). Since these aspects can be coupled with the capabilities of blockchain (described in chapter 2), it can be considered that they have paved the way for investigating blockchain solutions for the construction sector.

It has been claimed that, while possibly overhyped, blockchain has indeed a credible potential within construction (Perera et al. 2020) – despite concerns regarding its applicational immaturity, the possible inertia of the sector in adopting it (Perera et al. 2020), and generally considering the technology as more fitting in a process-based, rather than the dominant project-based, approach within construction (Sharma and Kumar 2020). Regarded to be among the enablers of Construction 4.0 (Maciel 2020), blockchain for construction is still in the very early stages of technological readiness and commercialization (Gerber and Nguyen 2019; Nguyen et al. 2019), and the corresponding research output has been relatively limited. However, such an output is constantly growing, and can be broadly categorized into studies approaching the potential for blockchain implementation within construction more holistically, and studies with a differentiated scope, which distinguish and focus on specific niches and/or processes of the sector.

First, the studies with the more holistic approach will be elaborated on. Having a wider focus, these efforts have tried to provide overarching insights.

Specifically, Barima (2017) brought attention to leveraging the basic Bitcoin blockchain for transactions in construction, and then proceeded to also investigate the potential of altchains, sidechains, and cryplets. Barima (2017) also noted that using cryptocurrencies can alleviate currency fluctuations across borders, thus streamlining exchanges pertaining to international construction projects. Li et al. (2019) introduced a sociotechnical framework for implementing blockchain in construction, which mainly focused on the digital ledger aspect of the technology and featured conceptual models that considered the dimensions of technical architecture, process management, social impact, and policy. Hunhevicz and Hall (2020) also focused on the digital ledger aspect of blockchains, and proposed a framework to decide whether there is a need for one, determine its design (public or private, permissionless or permissioned), and note the associated use constraints (e.g. throughput, data storage, interoperability, privacy, and cost structure). Perera et al. (2020) extrapolated the insights gained by the implementation of blockchain in other industries (e.g. financing, identity protection, agriculture, and healthcare) to construction, and concluded that blockchain can be especially useful for industry-wide processes, such as file sharing and property and document management. Finally, Yang et al. (2020) explored the potential of public and private blockchains within construction, pointing to challenges emanating from business variations, node identity issues, cost and complexity of adoption, and system scalability, vulnerability, and security.

Following, the studies with the differentiated scope will be presented. Having a focus on specific niches and/or processes of the construction sector, these efforts aimed at offering more targeted insights. As will be shown, some studies focused on one niche (e.g. Mason (2017)), while others investigated two or more niches (e.g. Penzes (2018), and Gerber and Nguyen (2019)).

Specifically, Cardeira (2015), Lamb (2018), Penzes (2018), Das et al. (2020), and Hamledari and Fischer (2020) emphasized the use of smart contracts (namely, computer protocols for facilitating, verifying, or enforcing clauses (Cuccuru 2017)), as well as the peer-to-peer transactional properties of blockchain, for the automation and facilitation of contractual agreements (including progress and interim payments). Mason (2017) looked into smart contracts for commercial bargains between construction stakeholders. Piraquive et al. (2017) focused on implementing blockchain in the knowledge management of construction projects. Heiskanen (2017) and Kochovski and Stankovski (2018) researched the integration of blockchain and IoT for the enhancement of construction productivity and performance during production, claiming that such an integration can expedite processes, simplify data flows, and reduce issues of messy and untrustworthy data (due to multiple sources and formats). Graglia and Mellon (2018) explored the utilization of blockchain for strategic innovation in real estate management. Klyukin et al. (2018) emphasized the potential of distributed digital ledgers for the purposes of urban planning. Lemeš and Lemeš (2020) postulated that the integration of blockchain with Computer Aided Design (CAD) can facilitate the distribution and validation of digital designs. Integrating blockchain with BIM (Penzes 2018; Hargaden et al. 2019; Di Giuda et al. 2020) – sometimes also using IoT network data as input for BIM (Arthur et al. 2018) – has been claimed to facilitate stakeholder trust, tackle data-related issues (e.g. data confidentiality, provenance tracking, disintermediation, non-repudiation, multiparty aggregation, traceability, inter-organizational record-keeping, change tracing, data ownership) (Turk and Klinc 2017), mitigate workflow bottlenecks through increased visibility and predictability (Woodhead et al. 2018; Nawari and Navindran 2019), and scaling collaboration to multiple agents through smart contracts (Dounas et al. 2020). Ghaffarianhoseini et al. (2017), though, have criticized the integration of blockchain and BIM, considering blockchain as being useful only as a tool for automated document handling and auto-invoices. Gerber and Nguyen (2019) and Nguyen et al. (2019) have discretized the construction sector into five markets (cities, energy, property, transport, and water), and then presented blockchain visions and prototypes for five subcategories in each market, like, indicatively, circular economy (in the market of cities), renewable certificate tracking and trading (in the market of energy), lease agreements and automated payments (in the market of property), freight tracking (in the market of transport), and utility contracts and billing (in the market of water). For each subcategory, Gerber and Nguyen (2019) and Nguyen et al. (2019) focused on specific blockchain attributes that were correspondingly deemed more suitable - and, primarily, digital distributed ledgers and smart contracts. Elghaish et al. (2020) developed a blockchain framework to facilitate integrated project delivery (IPD) by automatically executing financial transactions among the members of the core project team; as such, they coded functions such as reimbursed costs, profits, and cost savings, within the IPD smart contracts. Fu and Zhu (2020) showed the applicability of public blockchains as a potential infrastructure for trusted data networks in the context of smart cities. In the questionnaire survey by Kim et al. (2020), which focused on the applicability and anticipated impact of the technology, blockchain was deemed suitable for project cost and change management, contract bidding and formation, and procurement evaluation. A literature review by Kiu et al. (2020) showed that leveraging core blockchain properties points to several potential areas of application within construction, such as construction supply chain management, facilitation of BIM, contract management, electronic document management, real estate management, and funding management. Finally, Zhong et al. (2020) showed the potential of smart contracts for quality management, through the facilitation of compliance checking to regulation requirements of construction products.

Naturally, of particular interest for the current project and report are the efforts with a differentiated scope focusing specifically on the potential of blockchain for construction supply chains and logistics. Within that focus, Cardeira (2015) noted that digital distributed ledgers can mitigate the disorder due to changes in the construction supply chain strategy, thus reducing the suppliers' uneasiness connected to withheld payments or other insolvencies. Wang et al. (2017,2020) and Nanayakkara et al. (2019) posed that the information flow in downstream supply chain segments can be improved through the transparency and traceability brought by blockchain. Lanko et al. (2018) have studied the improvement of on-site logistics through the integration of blockchain with on-site RFID sensor data. Penzes (2018) claimed that transactions through a blockchain network can result in dynamic and instant payments for suppliers, transporters, and subcontractors, as well as better communication with the main contractor. Moreover, the visibility of the complete transactional history across the supply chain, as well as the consensus requirement for the block updates, are positively noted for tackling the tampering with past logistics data (Penzes 2018) and productivity and efficiency issues (Shemov et al. 2020). Furthermore, blockchain is envisioned to reduce administrative rework (e.g. matching data among different supplier ledgers for multiple deliveries) and data errors and outages across the supply chain, thus leading to time and cost savings, better change management, better planning, and quick (even instant) delivery notice for the contractors (Penzes 2018). Ma (2020) identified three key legal issues when implementing blockchain in construction supply chains, namely the restricted use of smart contracts to prescribed outcomes, the shared data access and ownership, and multi-jurisdiction concerns related to governing regulations and laws. Rodrigo et al. (2020) explored the utility of blockchain in estimating the embodied carbon emissions along construction supply chains, by making the relevant data transactions transparent and immutable. Tezel et al. (2020) emphasized, through a SWOT analysis, that preparing construction supply chains to accommodate blockchain would require the conceptualization and development of operational processes that align with the roles and responsibilities of the supply chain actors. Qian and Papadonikolaki (2020) have postulated that blockchain, by tackling issues of data tracking and contracting and transferring resources, can mitigate the opportunistic behaviors of supply chain actors - thus shifting the trust from relational to system- and cognition-based. Finally, Tezel et al. (2021) developed and collected feedback for three blockchain-based models, namely project bank accounts for payments, reverse auction-based tendering for bidding, and asset tokenization for project financing; among their key findings, they especially highlighted the need to upscale the legacy IT systems, and facilitate regulatory compliance.

When it comes to construction logistics in the Swedish context, subsequent studies by Kifokeris and Koch (2019a,b,c; 2020) have gradually investigated the integration of the material, economic and information flows along the supply chain, through a blockchain solution forming part of the value proposition in independent logistic consultants' business models within the Swedish context. In particular, Kifokeris and Koch (2019a) investigated the suitability of Swedish construction supply chains and logistics for the accommodation of a blockchain solution integrating the logistics flows, involving independent logistics consultants (usually hired by public clients in building projects) that can incorporate such a solution in their digital business model; the study then proceeded with a preliminary mapping of such consultancies operating in Sweden. In Kifokeris and Koch (2019b), the perspective of sociomateriality was introduced in relation to a potential blockchain solution for integrated logistics flows, and the power shifts that such a solution would bring in constellations of supply chain actors in the Swedish context, was discussed. These constellations included the typical case of large contractors internalizing logistics services, the atypical case of using independent logistics consultants, and the emergent case of third-party actors offering dedicated digital building logistics services (Kifokeris and Koch 2019b). In Kifokeris and Koch (2019c), sociomateriality was used to map potential benefits and threats related to blockchain visions and prototypes for construction (documented mainly in industry reports), and discuss the way those can be extrapolated to a solution for integrated supply chain and logistics flows in the Swedish context. Finally, Kifokeris and Koch (2020) offered a sociomaterial conceptualization of such a solution, mapped the ways in which such a solution can transform a generic logistics setup, planted the solution in a conceptual digital business model canvas for independent logistics consultants, and customized the canvas on the business case of a specific consultant company (with the input of the company's representatives themselves).

Early findings on blockchain visions and prototypes for construction

As argued earlier in this report, integrating the economic, information and material flows through blockchain can bring about a holistic overview of the construction supply chain and logistics processes, through the fostering of stakeholder trust, transactional transparency and traceability, enhancing the deliverables' quality appraisal, facilitating stakeholders collaboration, and ultimately, creating value for the supply chain actors. Trying to investigate the hands-on realization of such benefits and value creation, we follow up the comprehensive literature review of the previous section by focusing on some blockchain-related visions and prototypes for the construction sector and analyzing them through a sociomaterial lens.

It has already been mentioned that at the vision level, Gerber and Nguyen (2019), and Nguyen et al. (2019), have identified the following market areas (and their associated technologies), which can be integrated with blockchain solutions for project facilitation and value creation for the relative actors:

- Cities – the associated technologies are utilized for the procurement and supply chain management, and the IoT-integrated smart city.
- Energy – the associated technologies are utilized for energy microgrids, electric vehicles' power sharing, smart meter billing, clean energy sources, and renewable certificate tracking and trading.

- Property – the associated technologies are utilized for smart contracts for real estate, title records, lease agreements and automated payments, and property data management.
- Transportation – the associated technologies are utilized for ride hailing, car sharing payments systems, material passports, and biometrics to enable gateless borders.
- Water - the associated technologies are utilized for water quality, water trading, water treatment, utility contracts and billing, and access to water for developing countries.

In Penzes (2018), there have also been identified areas and relative technologies that can potentially accommodate integrated blockchain solutions. Some of them, like procurement and supply chain management, correspond to the ones mentioned above; others, include maintenance survey, site management record keeping, smart contract-governed site working hours register and payment systems, smart contract-governed design package submissions, on-site health and safety incident registration, and material tracking for improved sustainability. In addition, in Li et al. (2019a), a systematic literature review has been conducted on conceptual models and practical use cases regarding blockchain and digital ledger solutions in the built environment, discretized in the areas of smart energy, smart cities and shared economy, smart government, smart homes, intelligent transport, BIM in construction management, business models, and organizational structures.

Apart from those cases of visions, there are also certain examples for construction sector-related blockchain solutions that have reached the point of prototype, thus offering a richer understanding on the actual realization of such systems. Notable among such prototypes are the following:

- BIMCHAIN (Mathews et al. 2017; Penzes 2018; Gerber and Nguyen 2019; Nguyen et al. 2019): This prototype is within the market area of cities, and the application areas of BIM coordination and smart asset management. It is argued that BIMCHAIN can facilitate security, liability, transferability and live data collection, acting as a digital immutable ledger in BIM-supported processes. It allows the project to be mapped and tracked at every stage, thus establishing ownership of models and tracking incremental updates and improvements during the design stage. The related data can be internally and externally controlled and relied upon, increasing transparency and trust, and reducing corruption, system inefficiencies, and contractual disputes. For the realization of such benefits, BIMCHAIN can act as a legally binding tool, aiming at high-quality and accountable BIM products. Within BIMCHAIN, smart contracts can be drawn up and payments are automated, in order to ensure that the related actors are committed to achieving their stated outcomes. As of the second half of 2020, BIMCHAIN is still on its beta testing stage (Pradeep et al. 2020).
- Circularise (Gerber and Nguyen 2019; Nguyen et al. 2019): This prototype is within the market area of cities, and the application area of circular economy. Through Circularize, blockchain can allow the effective and reliable tracking of materials and components along the supply chain. Considering the reusability of materials and components as part of their lifecycle, such blockchain-enabled tracking can continue in perpetuity and contribute to circular economy. Manufacturers, recycling agencies, and clients, can consistently monitor the circularity of their products. In this vein, Circularise, an open and distributed communications protocol, offers an open-source distributed communications protocol for circularity, thus allowing information

exchange along the supply chain and facilitating transparency around product and material histories and destinations.

- SiteSense® (Gerber and Nguyen 2019; Nguyen et al. 2019): This prototype is within the market area of cities, and the application area of cash flow construction management. Blockchain has the ability to connect all project stakeholders, allowing each actor to track progress and automate payments according to completed work packages. Thus, construction progress can be more effectively monitored, and any cash flow problems mitigated. As such, SiteSense® utilizes blockchain in a cloud-based project site field tool setting to monitor, categorize and maintain relevant resources and documentation. The list of transactions is stored in a private permissioned blockchain accessed only by the related stakeholders.
- Blockchain tool for real estate transactions and mortgage deeds (Gerber and Nguyen 2019; Nguyen et al. 2019): This prototype is within the market area of property, and the application area of sale and asset transactions. This tool is piloted by Sweden's Land Registry Authority (Lantmäteriet) and other partners. It connects sellers with real estate agents and buyers and integrates the available information on land registry and bank accounts. Demonstrations of the tool done as early as 2019, included identifying verification processes, approving, and executing digital agreements, and exporting finalized legal contracts. Thus, signing the purchase agreement through the registration of the sale can be facilitated to last only a few days or even hours, instead of four to six months.
- Shipment tracking solution by Maersk and IBM (Gerber and Nguyen 2019; and Nguyen et al. 2019): This prototype is within the market area of transportation, and the application area of freight tracking and logistics. Such a solution aims to digitize trading workflows and end-to-end shipment tracking. Within the system, each stakeholder can track the progress of items along the supply chain, and check customs documents, bills of lading, and other freight data. In this solution, the role of blockchain is to ensure a secure, well-documented data exchange and transparent repository, and reduce the cost of bottlenecks due to manual paperwork.

The lessons-learned of these visions and prototypes for the potential of blockchain-enabled construction supply chains and logistics with integrated flows, approached from a sociomaterial angle, informed the conceptualizations and development processes described in chapters 6, 7 and 8.

Literature review summary and insights

The literature review on blockchain-related research, visions and prototypes for construction, shows that while some blockchain studies approach the construction industry with a bird's eye view, most focus on specific niches and processes of the sector. In each case, there are conceptualizations, visions and some prototypes of blockchain solutions, but no actual use cases yet. On another note, core properties of blockchain, such as peer-to-peer transactions, record immutability and a degree of decentralization, are generally described as beneficial for construction, and generate the majority of the stated added value. Most studies elaborating on these properties and benefits, approach blockchain in a blended economic flow- and information flow-oriented manner, although there are efforts (e.g. the ones about integrating blockchain with BIM) where the information flow is more pronounced. Regarding specific blockchain aspects, the digital ledgers and smart contracts are generally the ones considered to have the biggest potential for construction, and they are investigated across various blockchain visions and prototypes.

The studies particularly focusing on construction logistics, largely adopt the previously discussed themes as well, i.e. investigation on a largely conceptual level, a blended economic flow- and information flow-oriented approach, potential for added value mainly emanating from the core blockchain properties, and a focus on digital ledgers and smart contracts. Nevertheless, Tezel et al. (2020, 2021) and Qian and Papadonikolaki (2020) have also considered social issues, such as the facilitation of trust across the supply chain. However, no construction logistics-related studies elaborate explicitly on the simultaneous integration of the information, material, and economic flows. In addition, no such studies adopted sociomateriality. Notably, Li et al. (2019) have used a sociotechnical approach; however, they did not explicitly focus on construction supply chains and logistics, and as their approach did not build on the co-shaping of the technology with its practical implementation, it is not considered sociomaterial. However, the studies pertaining to the Swedish context do introduce sociomateriality for a deeper consideration of the transformation of work practices that could be realized through the implementation of a blockchain solution and bring attention to the issue of flow integration. However, while their context-specific approach can be considered methodologically strong due to considering institutional particularities, it also makes their conceptualizations (especially in Kifokeris and Koch (2020)) vulnerable to any departure from that particular context. As described in the development of the prototype app elsewhere in this report, this vulnerability actually materialized, since the absence and/or inactivity of certain supply chain actors initially considered in the conceptualized solution (the logistics consultants and clients, respectively), forced the development and testing of a proof-of-concept that was reduced in comparison to the initial vision.

Finally, the potential constraints and security issues regarding the implementation of blockchain, two topics that are quite widely researched outside the field of construction, are only limitedly considered in a few construction-related studies (e.g. in Barima 2017; Perera et al. 2020; Sharma and Kumar 2020; Shemov et al. 2020; and Yang et al. 2020). To expand this limited consideration, we investigated blockchain-related studies within other industry sectors. Regarding implementation constraints, Kshetri (2018) wrote that for supply chains and logistics, blockchain should only be adopted if it leads to the achievement of strategic objectives, such as cost, quality, speed, dependability, risk reduction, sustainability and flexibility. Furthermore, Verhoeven et al. (2018) identified strategic factors that can impede the adoption of blockchain for logistics, which included a limited engagement with the technology, limited seeking of technological novelty, limited context awareness, limited cognizance of alternative technologies, and anticipation of technological alteration. Considering security, a number of studies (e.g. Underwood 2018; Veuger 2018; Chong et al. 2019; Rossi et al. 2019) highlight two common denominators. The first is a presumptive mistrust in the potential of blockchain as a viable technological investment. The second is an anticipated abuse of the properties of blockchain; the anonymity of the distributed node network could lead to illicit activities, the use of cryptocurrencies to losing grasp of the actual value of fiat currencies, and the inflexibility of the automated transactions to potentially emerging tensions among the actors in the blockchain network.

5 DIGITAL BUSINESS MODEL FOR INDEPENDENT BUILDING LOGISTICS CONSULTANTS IN SWEDEN

Constellations of supply chain and building logistics actors in Sweden

As stated in the Research Method section, the first step of our introductory empirical study (taken place from December 2018 to July 2019), featured the identification of sociomaterial constellations of actors within construction supply chains and building logistics settings in the Swedish context. During this identification, we noted the primary proponents of the constellations, focused especially on the way the economic flow was realized in each, and envisioned the way a blockchain solution could offer some kind of flow facilitation and value creation within relevant digital business models. With this process, at least three such constellations were identified in the Swedish context:

1. The typical case of large contractors that integrate building logistics competences internally, to overcome transactional challenges and maintain power over business-critical processes of the material and information supply chain flows, along with their reflection on the economic flow.
2. The emergent case of third-party players such as construction equipment suppliers and/or industrialized house building firms, which have entered the field of supply chain and logistics management by offering digital building logistics solutions.
3. The atypical case of small independent logistics consultant firms, which are employed by the (usually public) clients; those firms can appear as independent conveyors of different interests in the supply chain and logistics setup.

The identification of and targeted focus on these three constellations was supported by findings during our literature review (see also chapter 4), and the input of practitioners working within organizations that constitute typical examples of each of the three constellations. Such input consisted of statements, descriptions, and procedural documents, was solicited through unstructured interviews, was compared with the aforementioned literature review results, and was critically scrutinized through the sociomaterial perspective. As a result, a sociomaterial analysis of each of the constellations is respectively featured in the following three subsections. It should be noted that these constellations are not the only ones that can be found in the Swedish context - however, they do appear to be the most dominant. Nonetheless, even among those three, the cases featuring the typical practice of large contractors internalizing logistics competences vastly outnumber the cases featuring either of the other two investigated constellations. Moreover, project governance, and institutional and cultural context, can also be considered as potentially impactful factors for the business model of each constellation.

The typical case of large contractors internalizing building logistics

Large construction sites in Sweden often rely on the interaction of a range of actors - mainly contractors, purchasers, subcontractors, retailers and other material suppliers, and transporters (Sundquist et al. 2018). Especially in heavily urbanized areas, a network of material and equipment storage places, local offices, retailer facilities and other infrastructure, is permanently in place in the vicinity of a newly specified construction site, in order to support it. For example, this was the initial state of the site for the project Urban Escape, namely a currently built district in Stockholm (Juhlin 2018); the way this initial state was changed by the operation of third-party actors offering digital building logistics services, is described in the next subsection.

In such an environment, most operating contractors have chosen to integrate the corresponding supply chain and building logistics competences and services internally. That way, they attempt to overcome transactional challenges (which would have been prevalent in the case such services were delegated elsewhere) and maintain power over business-critical processes of not only the material and information supply chain flows themselves, but also their reflection on the economic flow. An aspect of this reflection are the co-called working costs - namely, all costs incurred at the construction site but not directly included in production (e.g. costs connected to work management, machines, workstations, sanitation, and construction lifts (Juhlin 2018)). This approach can be characterized as relying on existing supply nodes and routes; order release, incoming transport, on-site material placement, and even subsequent payments, are largely organized by many actors in parallel, each relying on their own supply setup, with little coordination before on-site arrival. This can lead to occasional congestion and bottlenecks in incoming flows, e.g. in the case a single road provides site access, or a single main gate has to be passed by all incoming transport.

The economic flow in this constellation passes certain human-information system nodes, such as the client's and the main contractor's accountants - each usually utilizing different accounting systems. The corresponding ledgers are organized according to each actor's business practice, and they are rarely structured commonly along general standards. Observing the corporate-level function even within the large contractor companies themselves, there can even be a discrepancy in the way the economic flow is realized and disseminated among the different business units.

In such a situation, transitioning to a digital business model utilizing blockchain for building logistics with integrated flows, would mean that a generalized, decentralized and common digital ledger would be used by all actors in the constellation - thus significantly mitigating the discrepancy in the utilization of different accounting systems. While there can be varying levels of blockchain integration within the economic flow-related aspects of the existing business model, a potential process normalization and record immutability brought about by blockchain, would give a certain impetus to at least adopt a basic level of decentralization in the relative processes.

The emergent case of third-party players offering dedicated digital building logistics services

An emergent practice is the placement of tasks, as well as the organization and management of supply chains and building logistics via unique and/or out-of-the-box solutions and digital services offered by third-party actors. Among these, Juhlin (2018) reports the case of the equipment supplier Ramirent.

Ramirent normally leases machines and other equipment to construction sites. But in the case of the large site for the aforementioned multi-building project Urban Escape, they offered a comprehensive concept for facilitating the site's supply chain and logistics (Juhlin 2018). The client and developer needed a logistics solution for a congested site with many operating stakeholders and main contractors, as well as a concept for what was termed as the “temporary factory”. Ramirent changed their ordinary business model and engaged in providing the entire logistics concept, including site access technologies. The site was split in six major zones, split among the three major contractors (Skanska, NCC and Zengun). These six zones featured different access points and transportation routes and are shown in Fig. 5.1.

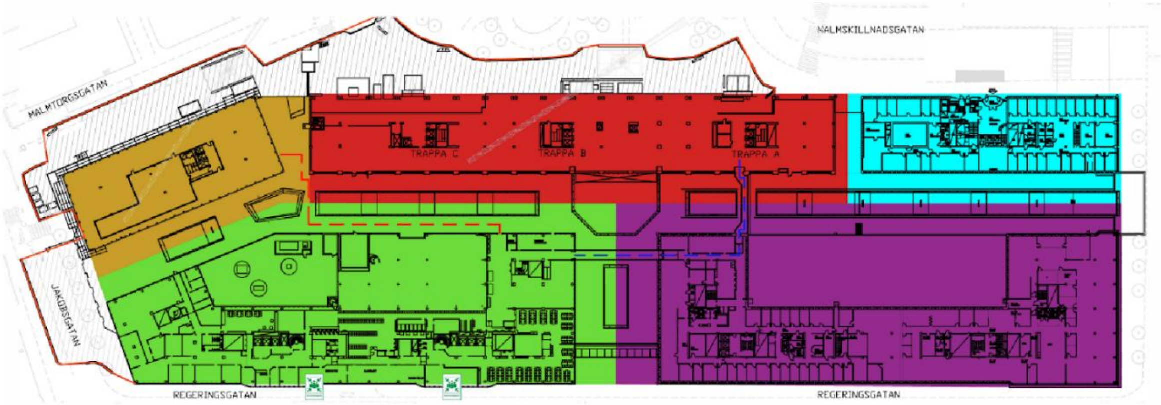


Fig. 5.1. Picture of Urban Escape (adapted from Juhlin 2018). Green and purple areas - Skanska, brown and blue areas, garage and Gallerian - Zengun, red area - NCC.

The “temporary factory” was a hybrid framework drawing from the contractors' way of realizing building production, along with new concepts introduced by Ramirent (Juhlin 2018). The function of this temporary factory was translated into a new way of planning, organizing, visualizing, performing, and invoicing temporary facilities that do not directly concern the construction of permanent buildings - such as taking up the responsibility for common areas and functions (e.g. reception, changing and dining rooms, cleaning), visualization of processes in time and space with the help of BIM, development of logistics plans, construction of temporary infrastructure (e.g. auxiliary buildings, elevators, electricity network, scaffolding), waste management activities, rental of machinery, development of new digital support tools, growth of new competencies, and provision of enclosures and guards. Ramirent outsourced the individual tasks to external partners, including a BIM-competent company. This enabled the active use of visualization in the design of the temporary factory, as well as the integration of design and production planning in 4D BIM. The temporary factory also involved an on-site machine rental center, which all participating contractors were supposed to use.

Thus, Ramirent created a market for itself and can leverage a better capital investment, as a type of a blue ocean strategy (Juhlin 2018), despite expanding to an area of lower profitability. It can be considered that the company even presents an approach to logistics solutions which echoes the business models of Swedish firms offering miscellaneous construction services (e.g. Buildsafe, Loop Rocks, Ene Golv, and Edvirt). This approach can potentially be strengthened by introducing blockchain to the respective digital business model, by streamlining the decentralized economic flow of on-site planning (already "flattened" to mitigate on-site congestion), along with the multiple material and information flows connected to the differently designated site areas and access points.

The atypical case of independent building logistics consultants

To ameliorate issues connected to construction supply chain and logistics, as well as facilitate all associated services (especially in response to the typical case of large contractors internalizing logistics), an atypical business practice is the employment of independent logistics consultancy firms (such as LogTrade, Myloc, Prolog Bygglogistic, Servistik, Bygg Dialog, Svenskt Bygglogistic, and FM Management). These firms coordinate and handle complex, recurrent and conflicting flows consisting of deliveries of materials, arrival of incoming goods, payments for deliveries and services, bi-directional information exchanges, and other subsystems. These firms are often small organizations; they embody a business model for improved construction logistics, strengthening the coordination across the supply chain by connecting the client, the material and equipment suppliers and transporters, the contractors, and the subcontractors (Gustavsson 2018). Prominent independent building logistics consultants in Sweden are featured in Table 5.1.

Table 5.1. Most prominent independent logistics consultancy firms in Sweden as of October 2021 (all financial and corporate data taken from the firms' websites and allabolag.se).

Name	Latest available turnover	Staff no.	Industry	Main clients	Approach	Digital solution?
LogTrade	≈ 33 MSEK (12-2019)	10	Construction, manufacturing, retail, transportation	Contractors, suppliers, distributors, retailers, transporters	Digitalization Automation	Yes, in-house
Myloc	≈ 20.5 MSEK (12-2019)	11	Construction, real estate, inventories, manufacturing	Contractors, suppliers, distributors, manufacturers	Digitalization Automation	Yes, in-house
Prolog Bygglogistik	≈ 12 MSEK (12-2020)	12	Construction, real estate	Contractors, suppliers, distributors, transporters	Strategic consultancy Facilitation Digitalization	Yes, with external partner
Servistik	≈ 17 MSEK (04-2020)	13	Construction, manufacturing, waste management	Contractors, suppliers, distributors, manufacturers, transporters	Facilitation Digitalization Automation	Yes, in-house
Bygg Dialog	≈ 2300 MSEK (12-2020)	203	Construction, real estate	Contractors, suppliers, manufacturers	Facilitation Digitalization Automation	Yes, in-house
Svensk Bygglogistik	≈ 34 MSEK (12-2019)	27	Construction, real estate, transportation	Contractors, suppliers, distributors, transporters	Facilitation Digitalization Automation	Yes, in-house
FM Management	≈ 20 MSEK (06-2020)	7	Construction, real estate, transportation	Contractors, suppliers, distributors, transporters	Facilitation Digitalization	Yes, with external partner

When it comes to business practice, there are variations in the approach and level of digitalization for the coordination procedures the logistics consultants carry out. Their use of IT support (such as planning software, site gate control systems, and tracking applications) varies and is reflected on the firms' different business models. For example, firms like Prolog outsource their digital solutions to specialized IT consultants, which can differ in each project; and firms like LogTrade and Myloc deploy an in-house IT infrastructure. However, while all approaches entail that the independent logistics consultants collaborate interactively with on-site contributing parties and key suppliers, evidently no approach features blockchain. Nonetheless, this collaborative aspect is important to the value proposition of the business model of such firms.

It was found that a common practice by independent logistics consultants (as well as other practitioners) in Sweden, is the implementation of area disposition plans (namely, drawing-based material and storage management plans (Cooke, 2015)). Such plans have often been claimed to be dynamic but are practically rather static. They are rarely translated to an uninterrupted on-site space usage for provisional storage, and scarcely exhibit a continuous integration between the logistics planning, its included information and material flow control system, and the material registration, placement and installation. In some cases, there is also a difficulty in efficiently regulating the delivery entries at the construction site, as a suitable gate control system may be either absent, or disintegrated with the information flow (e.g. when deliveries are manually assigned in a ledger, and then communicated to the logistics consultants via phone calls). Moreover, on-site physical placement is rarely tied to any implemented digital solutions facilitating information exchange. However, even in the presence of such ties (depending on the digital systems used), the economic flow remains disintegrated with the information and material flows. This is evident in the decoupling among the deliveries and transportation services, the corresponding payments, and the fees released for the implemented logistics solutions. Consultants are usually burdened with justifying the value-for-money for their services (commonly paid on an hourly wage), as the communication of their results to the clients is mainly done in parallel to the actual construction supply chain and logistics setup, and the clients do not participate in the information flow too actively. Independent logistics consultants strive to solve such problems while tackling delivery failures, imprecise data retrieval, time delays, withheld payments, and inefficient intra-systemic flows and data transfers. Even more crucially, the economic flow brought about by these consultants is still ambiguous; their coordination of the invoices to be paid after any successful deliveries and/or finished works has not fully eliminated issues of delay and complacency. This may even result in a parallel economic flow, often organized similarly to the one featured in the typical case of the first constellation.

To confront these issues, a viable solution might be to digitize the consultants' business models through blockchain - thus optimizing their efficiency (McKinsey Global Institute 2017). Blockchain properties align with viewing such digital business models as inter-organizational, rather than single-company, efforts (Vendrell-Herrero et al. 2018) – as is the case when partnering with those firms. In such a context, this digital business model could even involve partnerships between incumbent product-oriented firms and digitally capable newcomers, in order to foster the agility of supply chains (Vendrell-Herrero et al. 2018), as well as benefit from a simultaneously integrated and agile approach (Thunberg and Fredriksson 2018). A blockchain solution integrating the economic, information and material flows, could facilitate such agility (O'Leary 2017).

The employment of these independent logistics consultants is not common. While there are clients asking for them (e.g. the public clients of the whole district development in the area of Järfälla, Stockholm), in most cases the construction projects are either contracted to actors already internalizing logistics services, or the dedicated services of third-party players are derived. Nonetheless, our analysis so far shows that when it comes to the operation and challenges of the independent logistics consultants, the Swedish sector presents a fertile and suitable sociomaterial context to accommodate a digital business model for construction logistics with integrated flows through blockchain - and it is within this context that we pursued the development of a blockchain solution and new digital business model. However, and in accordance with the autonomy-control paradox (Bader and Kaiser 2017), the logistics consultants have also to consider the power shifts among the supply chain actors as soon as the integrated flows (and particularly the economic flow) change with the implementation of blockchain. Through our collaboration with the logistics consultants (and especially Prolog), we have found that the main contractors, already losing some of their control over the supply chain when the client hires independent logistics consultants, are not very keen to relinquish more of their power in a setting that gets even more decentralized due to blockchain.

A blockchain-powered digital business model for independent logistics consultants

Following the supply chain flow analysis and the sociomaterial understanding of a related blockchain solution in chapter 2, the insights from blockchain visions and prototypes for construction logistics in chapter 4, and the analysis of the previous subsection in the current chapter, we can conceptualize an event-driven blockchain-induced flow integration across all phases of the related processes (i.e. from the issuing of purchasing orders until the completion of the on-site deliveries), as a feasible solution for logistics consultants. Envisaged value-adding aspects of this integration can include the holistic overview of the supply chain, an increased value-for-money perception via tightened work-payment coupling (even when the consultants are paid on an hourly wage), the fostering of transactional trust, transparency and traceability, the offer of quicker and more efficient services, the quicker collaboration with the main contractor, and the leveraging of process automation in order to commit fewer human and material resources on the more tedious parts of the logistics plan (thus being more useful to the client by focusing on more convoluted issues). Notably, while some of these value-adding aspects (e.g. offering quicker and more efficient services) can be considered as services already offered by centralized IT systems (already developed and/or implemented by some of the independent logistics consultants) working in conjunction with each other, there is currently no solution that can address them simultaneously in the way a blockchain solution could do. In addition, all other current IT solutions require some form of third-party intervention, while a blockchain solution can facilitate the direct peer-to-peer interaction of the participants in the blockchain network, and furtherly reduce time and resource waste.

As such, by using a sociomaterial lens to combine the aforementioned theoretical and empirical results and findings, a new digital business model for independent logistics consultants can be conceptualized. This conceptualization, based on the tool by Osterwalder and Pigneur (2010), is provided in Fig. 5.2 (see next page)

The proposed conceptual digital business model involves all the known elements of a business model canvas. The value proposition emanates from the embedding of a blockchain solution based on a combination of the literature insights regarding the potential of blockchain for construction logistics, and the benefits envisaged during our empirical study. In the key resources, the blockchain system is added as a digital asset that can be offered by the logistics consultant as an IT solution. As mentioned above, a key aspect of this digital asset is that it can be a single system and not a bundle of IT solutions working in conjunction. Customer relationships are also altered due to the transactional properties of blockchain. More specifically, the direct peer-to-peer transactions can offer more transparency and traceability, make payments more dynamic, and expedite the consultants' collaboration with the clients and on-site partners.

<table>
<tr>
<td rowspan="2"><u>Key partners</u>

- Other consultants
- Material and equipment suppliers
- Transporters
- Subcontractors
- Professional associations
- Academia
- Specialized IT consultants (optional)</td>
<td><u>Key activities</u>

- Coordination of complex, recurrent and conflicting flows
- Coordination across the supply chain by connecting the main stakeholders
- Interactive collaboration with on-site contributing parties and key suppliers</td>
<td rowspan="2" colspan="2"><u>Value proposition</u>

- Offered services: quicker, more efficient, and upgraded in terms of project overview
- Justified value-for-money and increased productivity
- Acceptance of the new professional role by the clients
- Automation and improvement of traditionally cumbersome logistics processes
- Smoother communication and collaboration with the main contractor
- Commitment of less human and material resources in the more tedious parts of the logistics planning
- Crude switches between different supply chain strategies during the project production can be smoothened out, or mitigated
- Economic friction points within the logistics process can be minimized</td>
<td><u>Customer relationships</u>

- Interactive collaboration with on-site contributing parties and key suppliers
- Automated-dynamic transactions using cryptocurrency
- Peer-to-peer transactions</td>
<td rowspan="2"><u>Customer segments</u>

- Project owners / clients
- Main contractors and developers: accounting, purchasing, project planning, services related to the work of suppliers / transporters / retailers
- Project managers (e.g. structural, facilities, HVAC)
- Representatives of the suppliers
- Representatives of the transporters
- Representatives of the subcontractors</td>
</tr>
<tr>
<td><u>Key resources</u>

- Monetary: fees paid by the client
- Human: logistics consultants
- Human: specialized IT consultants (optional)
- Digital assets: blockchain system
- Material assets: offices and on-site working facilities (e.g. as parts of a logistics consolidation center)</td>
<td><u>Channels</u>

- Business reputation (new and potentially disruptive solution offered)
- Customers
- Social media
- Industry events</td>
</tr>
<tr>
<td colspan="3"><u>Cost structure</u>

- Service cost paid by the client (included in the logistics fees)
- Business and asset costs
- Reduction of interaction and accounting costs (economic data)
- Less rework with the accounting figures</td>
<td colspan="3"><u>Revenue streams</u>

- As created by the operation of the blockchain nodes
- Decentralized, secure, transparent, resulting through instant transactions
- Initial utilization of cryprocurrency → then translation into fiat currency depending on the system used</td>
</tr>
</table>

Fig. 5.2. Digital business model canvas for logistics consultants: blockchain solution with integrated flows for construction logistics (see also Kifokeris and Koch 2020).

Notably, a permissioned private blockchain can allow for the retainment of the aforementioned benefits, while still keeping the solution accessible only to project-specific actors – which, according to our empirical insights, was a security requirement by all project stakeholders willing to accept a blockchain solution offered by independent logistic consultants. In that sense, the permissioned private system would allow for a better positioning of the logistics consultants as the sole providers of a solution avoiding the possible jeopardies of permissionless public systems. In the cost structure, the positive impact of blockchain on the accounting processes is mainly reflected on the reduction of interaction costs and accounting rework, mainly due to a shared ledger structure – instead of multiple actors' ledgers which the logistic consultants would need to align. The revenue streams are integrated with the blockchain network – also due to the possible use of cryptocurrencies – and are both facilitated and expedited due to direct peer-to-peer transactions. The key partners, key activities, channels, and customer segments remain largely unchanged in comparison to the current situation of logistics consultants, since during our literature review and empirical study we found no indication that these business elements would alter in case the consultants would start implementing a blockchain solution.

6 DIGITAL BUSINESS MODEL DEVELOPMENT FOR PROLOG

The conceptual digital business model canvas presented in the previous chapter, corresponded to a generic case of an independent logistics consultancy firm envisaged through our empirical investigations. However, this project seeked to develop a digital business model for a specific firm, namely Prolog - and as such, a corresponding case study had to be performed.

Prolog was founded in 2001, is staffed by 12 employees as of October 2021, and currently has an active business in Malmö and Stockholm. During its years of work, it has consulted around 400 clients, and has successfully offered its services in around 1560 projects, including ones situated in Norra Djurgården and the Jarfälla municipality in Stockholm. Within our 21-month-long collaboration with Prolog, its consultants were able to verify and customize the generic conceptual digital business model canvas shown in Fig. 5.2, into one especially befitting Prolog (shown in Fig. 6.1).

<table>
<tr>
<td rowspan="2"><u>Key partners</u>

- Other consultants (e.g. Svensk Bygglogistik)
- Material and equipment suppliers
- Transporters
- Subcontractors
- Specialized IT consultants
- Associations (e.g. Byggherrarna)
- Academia (e.g. universities and students)</td>
<td><u>Key activities</u>

- Coordination of complex, recurrent and conflicting flows (incl. managing processes and change)
- Coordination across the supply chain by connecting the main stakeholders
- Interactive collaboration with on-site contributing parties and key suppliers (e.g. through workshops, analyses, and competence development)</td>
<td rowspan="2"><u>Value proposition</u>

- Efficiency development
- Unique facilitation of the logistics planning and integration of flows
- Improved situational leadership
- Improved change management
- Improved process management
- Effective digitalization and streamlining of processes
- Increased productivity</td>
<td><u>Customer relationships</u>

- Interactive long- and short-term collaborations
- Peer-to-peer transactions
- One-time deliveries</td>
<td rowspan="2"><u>Customer segments</u>

- Project owners / clients, like municipalities (e.g. Järfälla Kommun, Stockholms Stad)
- Facilities (e.g. VA Syd, Traffikverket)
- Developers / contractors (e.g. JVAB, Skanska, NCC, Veidekke, Bravida, Assemblin)
- Facility managers (e.g. Riksbyggen)</td>
</tr>
<tr>
<td><u>Key resources</u>

- Reference projects
- Monetary: fees paid by the client
- Human: logistics consultancy employees
- Innovative assets: blockchain system
- Material assets: offices and on-site working facilities (e.g. as parts of a logistics consolidation center)</td>
<td><u>Channels</u>

- Present and former customers
- Word-of-mouth
- Social media
- Industry events</td>
</tr>
<tr>
<td colspan="3"><u>Cost structure</u>

- Fees paid by the client through the blockchain system
- Staff salaries (e.g. consultants, project leaders, salespeople)
- Office rent
- Reduction of interaction and accounting costs
- Less rework with the accounting figures</td>
<td colspan="2"><u>Revenue streams</u>

- Fixed-priced consultant service fees payment throught the blockchain system
- Variable-priced consultant service fees payment throught the blockchain system</td>
</tr>
</table>

Fig. 6.1. Particularization of the conceptualized digital business model canvas to specifically fit Prolog.

It can be observed that the elements constituting the partitions of the customized canvas, are either similar to, or particularizations of the ones featured in the initial conceptual canvas (as e.g. in the case of the value proposition). As such, most of the expected benefits in the key resources, the customer relationships, the cost structure, and the revenue streams, can be carried over in the specific case of Prolog. However, some aspects of the digital business model partitions were deleted during the customization (e.g. within value proposition and customer segments), which was to be expected, since the conceptual canvas was developed to be as generic as possible for the general case of independent logistics consultants.

In more detail, the Prolog-specific canvas in Fig. 6.1 features a central value proposition consisting of the facilitation of logistics planning and the integration of the economic, information and material flows. This value proposition mirrors the actual business positioning of Prolog, which emphasizes consultancy over automation. Another interesting departure of the Prolog-specific canvas from the generic one presented in the previous chapter, is found in the customer segments section. While the facilitation of construction logistics with blockchain can address many customer segments, Prolog focuses more on the project clients, who in the Swedish context are typically public. When it comes to key resources, the “digital asset” in Fig. 5.2, is addressed as an “innovative asset” in the case of Prolog. This can reflect not only Prolog’s opportunity to position itself as a possible innovation leader in the field of building logistics, but also as a statement of evolving their business practices (from currently outsourcing digital solutions to offering an integral, in-house system). Finally, in the revenue streams, Prolog has rejected the use of cryptocurrencies, opting for a crypto-free system. This might show caution and prudence, as from our interviews with Prolog we have understood that the company deems current sociomaterial constellations in Swedish construction logistics to be too inert to adopt cryptotransactions.

As mentioned in chapter 3 (Research Method), the understanding of this Prolog-specific digital business model canvas was combined with all of our field data in order to inform and serve as the basis for the final digital business model workshop held with Prolog (Malmö, February 2021). The setup of this workshop, in which the Prolog-specific digital business model canvas was featured prominently, was framed under the auspices of the “BeeBusiness” systematic business model development framework and equipment (BeeBusiness 2021). The method was adapted to this project and supported the final evaluation of the development of the digital business model (and also the BLogCHAIN prototype), with two main tools: the Beeboard and Beestar (a special type of table). Particularly for the digital business model, the Beeboard was used to evaluate the development and readiness degree of the prototype as part of the model; and the Beestar was used to support the subsequent business model development dialogue. This dialogue also informed the evaluation of the Prolog-specific digital business model, as well as the developed blockchain prototype, as described in chapter 9.

7 DESIGN CRITERIA FOR THE BLOCKCHAIN PROTOTYPE

Initial concept

The design for our blockchain prototype was conceived from the outset as a means to realize the value proposition (and the rest of the canvas segments) of the digital business model presented in chapter 6. As such, by combining – through a sociomaterial lens – insights from our theoretical basis, our conducted literature review, and our empirical findings, the blockchain solution can be conceptualized into being implemented on the logistics consultant-facilitated economic flow involving the client, the main contractor, and suppliers. This implementation is coupled with events on the material flow (e.g., successful on-site deliveries) and the respective data exchanges on the information flow. It should be noted that the suppliers can be interchangeable with transporters and/or subcontractors – or can be different entities altogether; in the case of our initial example (as well as many real projects), those are one entity.

As a preparation, in Fig. 7.1 we present a swim lane process flow diagram depicting in a simplified way the situation before implementing the blockchain solution - i.e., the initial form of the construction supply chain and logistics setup segment which the independent logistics consultants are hired to facilitate.

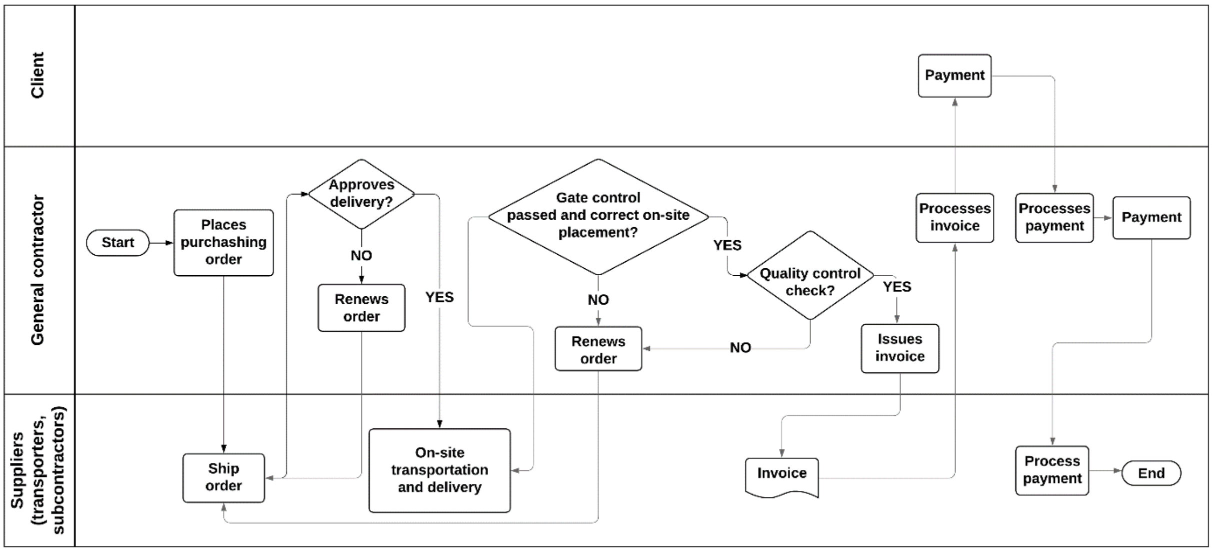


Fig. 7.1. Swimlane process flow diagram depicting the construction supply chain and logistics setup segment which is facilitated by the independent logistics consultants (see also Kifokeris and Koch (2020))

This supply chain segment is usually preceded by many other steps (e.g. supplier specification by the clients or architects, obtainment of the supplier quotes by the general contractor, approval of the supplier submittals, etc.). However, in the generic case, the facilitation offered by the independent logistics consultants usually starts when the suppliers have already been chosen, and the purchasing department of the contractor issues the respective purchasing order (economic flow). Then, the ship order is issued by the suppliers and is supposed to prompt the contractor's approval of the delivery (information flow). If this approval is denied, the order is renewed (information flow); if accepted, there is a clearance for the on-site transportation and delivery to take place (information flow). Then, the transportation and delivery are actually realized (material flow). As soon as the goods are delivered on site, a series of checks is performed (gate control of incoming traffic, on-site placement of goods, quality control); if those checks fail, the orders can be renewed (information flow), and if they succeed, the issuing of the invoice is prompted (information flow). The invoice is sent to the suppliers and then processed by the contractor's accounting division, which prompts the payment by the client (economic flow). Finally, after its final processing by the contractor's accountants, the payment is released to and processed by the suppliers (economic flow).

In this supply chain segment, the independent logistics consultants strive to facilitate, accelerate and coordinate the recurrent and conflicting flows, connect the client, the general contractor and the suppliers, and confront the decoupling of the delivery and transportation services with the corresponding payments. However, the currently described setup makes such a facilitation difficult. The general contractor seems to retain power over most business-critical supply chain aspects, and large parts of all three supply chain flows remain separated and disintegrated – thus making the client and the suppliers more "passive", especially along the economic flow. Moreover, the on-site checks upon the deliveries and the physical placement of goods are sometimes not implemented, or are done with distance in time - thus separating the information and material flows. Furthermore, the information communicated to the client is not shown in the diagram, as it is only weakly connected to this setup. It rather runs in parallel, thus accentuating the burden of the independent logistics consultants to justify the value-for-money for their services.

In Fig. 7.2 (see next page), we present a swim lane process flow diagram conceptualizing in a simplified way the situation after the independent logistics consultants implement the envisioned sociomaterial blockchain solution (as described in the final subsection of chapter 2).

Specifically, such an implementation is shown to simplify and integrate the flows, thus accelerating processes and countering issues of delivery failures, imprecise data retrieval, time delays, withheld payments, multiple ledger structures, and faulty intra-systemic data transfers. Moreover, the transparency and traceability of the whole setup is enhanced through the active involvement of all actors in the consensus checks of the smart contracts – even the ones that, in the pre-blockchain setup, were mostly passive. In particular, the placement, approval and renewal of the orders (economic + information flows) can be done directly through the blockchain system itself (e.g. with the storing of hashes of files pertaining to each of these transactions), and subsequently trigger the on-site transportation and delivery (economic + information + material flows). Finally, through the blockchain, the successful on-site checks of the deliveries are codified and stored as smart contracts (information + material flows), the issuing of the invoices is event-triggered within smart contract clauses (economic + information + material flows), and the payments are released in a way predefined, again, through smart contracts (economic + information flows).

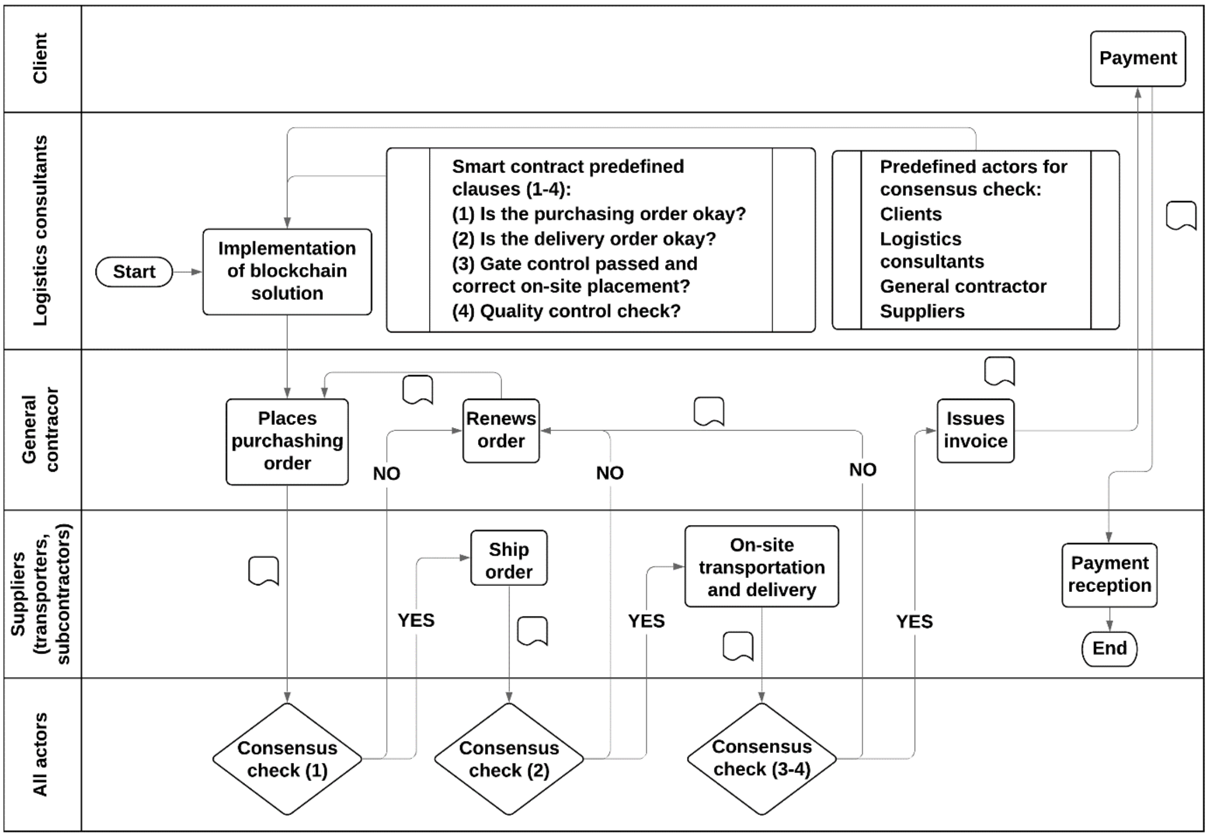


Fig. 7.2. Swim lane process flow diagram conceptualizing of the construction supply chain and logistics setup with the sociomaterial facilitation offered by the blockchain solution (see also Kifokeris and Koch (2020))

In this setup, the client and the suppliers are centrally involved in shaping all three flows, thus assuming a much more active role. This can allow them to have a more detailed and transparent overview of the construction supply chain and logistics. Moreover, the independent logistics consultants do not simply facilitate the various flows at the behest of the client "in parallel"; on the contrary, they too participate in the active shaping of the flows by implementing the solution, fostering accountability through the consensus checks, and justifying their offered services' value-for-money as a measure of the solution's performance. However, it should also be noted that in line with the sociomaterial autonomy-control paradox (Bader and Kaiser 2017), the general contractor may lose a lot of their centralized power over the supply chain – as this power would be diffused, through the consensus checks and the automated processes of the blockchain, to the client, the suppliers, and the logistics consultants themselves.

Updating the concept through the initial preparatory on-site feedback

The site elected to host the field tests of BLogCHAIN was a school building project. Within that testing ground, a series of preparatory semi-structured interviews was conducted, leading to a number of updated design inputs for our project-specific blockchain prototype.

In particular, the findings from our preparatory interviews showed that the development of the blockchain application would have to depart from the conceptualization in Fig. 7.2 (and in Kifokeris and Koch (2020)) – and lead to a proof-of-concept that would be in places simplified and/or altered. More specifically, the only actors left to enact transactions through the application, as well as participate in its consensus checks, would be the site management of the contractor, the sales representatives of the suppliers, and (conditionally) the transporters. The design of the prototype was updated to reflect that the stream of the material, economic and information flows on which the BLogCHAIN was to be implemented and attempt the flow integration, would start when the supplier issued the confirmation of the order already placed by the contractor, and would finish with the contractor accepting (or not) the supplier's invoice (issued after the material delivery had taken place). As such, the steps before (e.g. the contractor issuing the order) and after (e.g. the payment of the supplier) this segment, as described previously (and in Kifokeris and Koch 2020)), were left out to make the size of the test prototype possibly to develop and test. An updated version of the process steps put forward in the new design of our prototype is shown, in English and Swedish, in Figs. 7.3 and 7.4, respectively.

```
1 - SUPPLIER - CREATE NEW ORDER
2 - SUPPLIER - UPLOAD DOCUMENTS - MULTIPLE VERSIONS FLOW
3 - CONTRACTOR - ACCEPT ORDER (NOT POSSIBLE TO UPLOAD NEW VERSIONS AFTER THIS)
4 - CONTRACTOR - MARKS ARRIVAL OF DELIVERY
5 - TRANSPORTER OR/AND CONTRACTOR - PERFORM CHECK 1-3
6 - TRANSPORTER OR/AND CONTRACTOR OR/AND SUPPLIER - PERFORM CHECK 4
7 - SUPPLIER - UPLOAD INVOICE - MULTIPLE VERSIONS FLOW
8 - CONTRACTOR - ACCEPTS INVOICE
```

Fig. 7.3. Updated process flow after initial preparatory interviews.

```
# process overview (version 3)

1 - SUPPLIER – LADDA UPP ORDERBEKRÄFTELSE
2 - SUPPLIER – LADDA UPP DOKUMENT - MULTIPLE VERSIONS FLOW
3 - CONTRACTOR - ACCEPTERA ORDERBEKRÄFTELSE (NOT POSSIBLE TO UPLOAD NEW VERSIONS AFTER THIS)
4 - CONTRACTOR – BEKRÄFTA LEVERANSMOTTAGANDE MARKS ARRIVAL OF DELIVERY
5 - TRANSPORTER OR/AND CONTRACTOR - PERFORM CHECK 1-3
    CHECK 1 – KONTAKTADE TRANSPORTÖREN BYGGET ENLIGT ÖVERENSKOMMELSE?
    CHECK 2 – LEVERERAT PÅ RÄTT PLATS?
    CHECK 3 – STÄMMER UPPMÄRKNING OCH KVANTITETER ENLIGT ORDERBEKRÄFTELSE?
6 - TRANSPORTER OR/AND CONTRACTOR OR/AND SUPPLIER - PERFORM CHECK 4
    CHECK 4 – ÄR EMBALAGET / LEVERANSENS YTTRE HELT?
7 - SUPPLIER - UPLOAD INVOICE - MULTIPLE VERSIONS FLOW LADDA UPP FAKTURA
8 - CONTRACTOR - ACCEPTS INVOICE ACCEPTERA FAKTURA
```

Fig. 7.4. Updated process flow after initial preparatory interviews (in Swedish)

Following this updated process flow, the new concept of the blockchain solution, which was finally used for the 1st development iteration of BLogCHAIN described in the following chapter, is summarily depicted in Fig. 7.5.

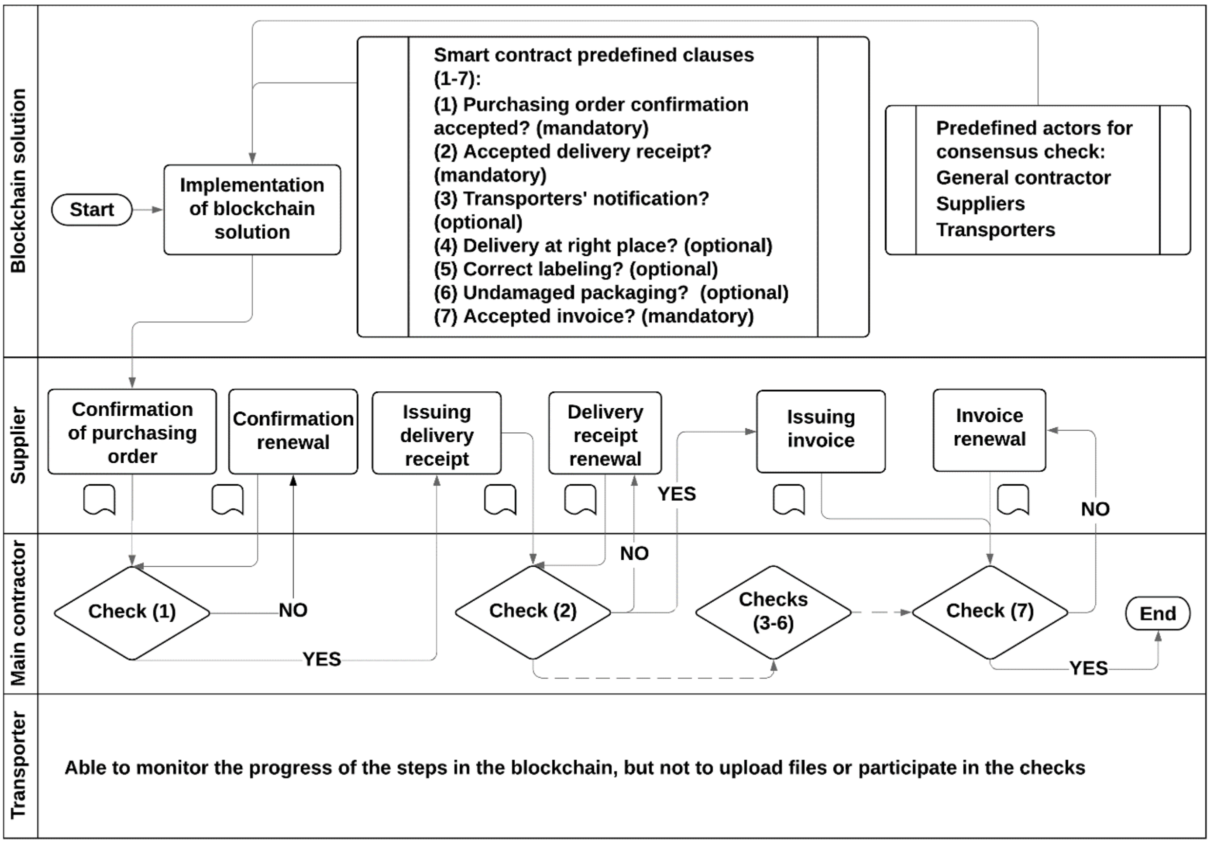


Figure 7.5. Updated concept of the blockchain solution (also in Kifokeris and Koch (fo.b))

As shown in Fig. 7.5, the smart contract clauses and checks depicted in Fig. 7.2 were replaced with the following partially different statements:

1. Is the purchasing order confirmation accepted? (mandatory)
2. Is the delivery receipt accepted? (mandatory)
3. Did the transporters of the delivery notify the construction before their arrival (if such an action had been agreed upon beforehand)? (optional check)
4. Was the material delivered at the right place? (optional check)
5. Was the labeling and the quantities of the delivery correct? (optional check)
6. Is the packaging (when applicable) of the delivery undamaged? (optional check)
7. Is the invoice accepted? (mandatory)

The difference between the mandatory clauses and the ones pertaining to the optional checks, reflects their ability (or inability, respectively) to block the process in case of non-satisfaction. Non-satisfaction of the mandatory clauses prevents the transaction from being completed, while non-satisfaction of the optional clauses shows stumbles in the process but does not prevent initiation of the next step. The clauses were respectively deemed mandatory or optional according to the overall interpretation of the interviewees collective input. Moreover, the setting of the sociomaterial constellation of actors led to a setup where, within the proof-of-authority algorithm, the consensus checks were to be replaced by checks performed by the contractor, and the transporters assumed a passive observant role.

Based on the updated concept of Figure 7.5, the 1st iteration of the development of our application commenced (see the following chapter).

Updating the concept through the feedback after the 1st testing iteration

As will also be shown in the following chapter, the users of BLogCHAIN provided feedback after the 1st testing iteration, which included proposals for improving the prototype. To furtherly update the concept and inform the 2nd iteration of the application's development (see the following chapter), the three most important of these proposals were used:

1. The conditional re-involvement of the roles of the client and the logistics consultants.
2. Deploying a notification function for the transporters as they approach the construction site.
3. Making provisions to accommodate the different roles of managing the sales and issuing the invoices that can exist within the same supplier company.

In more detail, the roles of the clients and the logistics consultants were proposed to be re-involved, under the condition that they would have an overarching but strictly observatory role, i.e. not being able to participate in the consensus checks, but only have a full overview of all conducted transactions. Moreover, the notification function for the transporters was included in smart contract clause (3) of the concept shown in Fig. 7.5. Finally, the provisions to accommodate the different roles within the same supplier company, were facilitated through the functionality of the software extension upon which our prototype was developed (namely MetaMask - see next chapter). As such, there was no need to actively update the concept in order to address this proposal - but rather be more precise in the instructions given to the testers for the 2nd testing iteration.

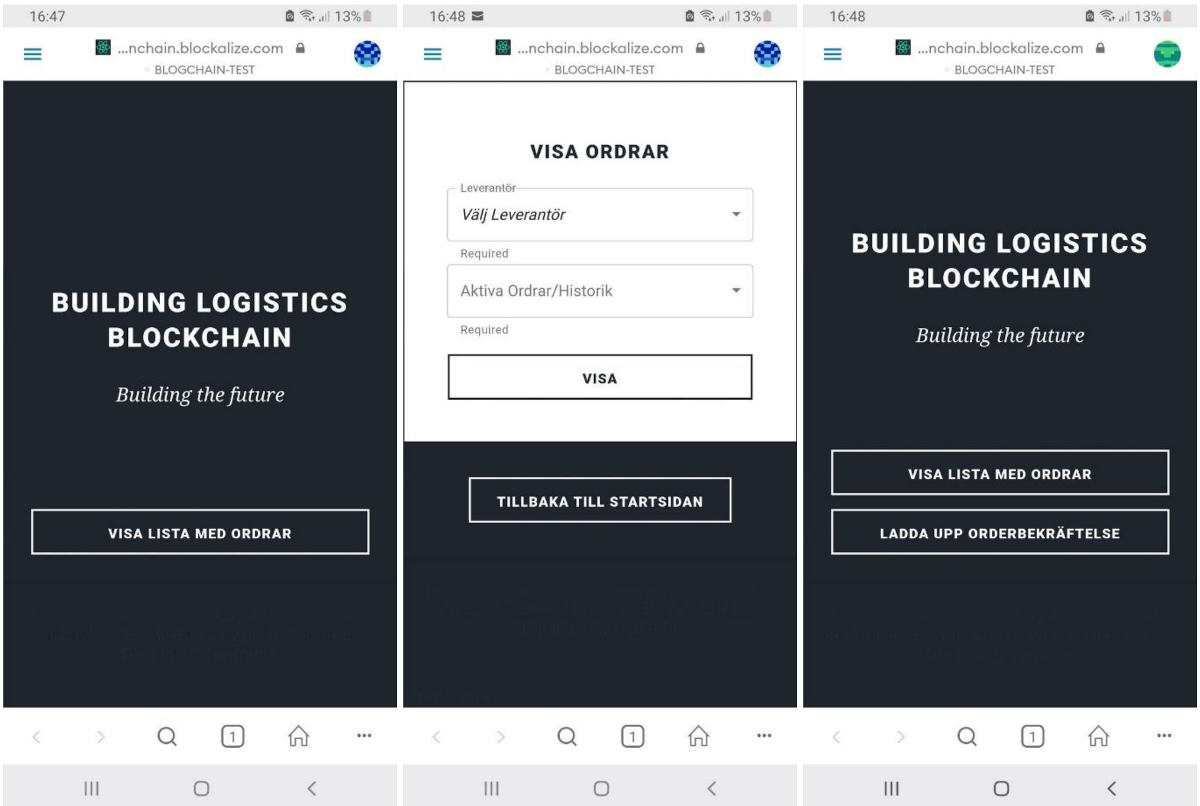
As can be understood, the accommodation of the three central proposals after the 1st iteration updated the concept only slightly, and in a way that did not actually alter the process flow in Fig. 7.5. The proposals (and especially the 2nd and the 3rd one) were of a rather functional nature. As such, there was no need to produce a third process flow diagram.

8 DEVELOPMENT AND TESTING OF BLogCHAIN

Development of BLogCHAIN – 1st iteration

BLogCHAIN was developed as an online application. Its user interface is suitable for both desktop computers and smartphones, and is in Swedish. The blockchain infrastructure of BLogCHAIN utilizes the open source Hyperledger framework, and can be accessed through MetaMask, a crypto-wallet and gateway to blockchain applications. MetaMask functions as an extension for Google Chrome, an application in Google Play, and an application in the App Store (for desktop computers, smartphones, and iPhones, respectively). The files to be uploaded on the online repository connected to BLogCHAIN (e.g. invoices) should be in PDF format, and they are encrypted in Microsoft Azure. The URL of BLogCHAIN is https://constructionchain.blockalize.com/ – however, without an active MetaMask account, the website cannot be accessed.

Indicatively, the following seven screenshots show the user interface (UI) of the first iteration of BLogCHAIN (smartphone version). It should be noted that the UI can be differentiated according to the role of the respective user (contractor-entreprenör, supplier-leverantör, and transporter-transportör).



(From left to right): **Figure 8.1.** Starting screen for (contractor, transporter); **Figure 8.2.** Order lists (contractor, supplier, transporter); **Figure 8.3.** Starting screen (supplier)

The first three screenshots show the initial interface offered by the app for the different user roles. In Figure 8.1 the starting screen for the users having the role of contractors or transporters is depicted. By tapping on the "Visa lista med ordrar" ("Show order list") , the user can advance on the order list menu (Figure 8.2), where they can navigate through drop-down menus to, respectively, choose the supplier and then the active and/or already finished orders they need to oversee.

It should be noted that while a contractor can see all suppliers and all orders, a transporter can see only the suppliers (and their respective orders) with which they are affiliated. In Figure 8.3, the starting screen for the users having the role of suppliers is depicted. By tapping on the "Visa lista med ordrar", the user can advance on the order list menu, which for suppliers looks exactly the same as the one for contractors and transporters, depicted in Figures 8.4, 8.5 and 8.6. However, in the case of the suppliers, they can only oversee their own orders, by picking themselves from the "Välj leverantör" drop-down menu. Otherwise, the suppliers can initiate a new blockchain transaction, by tapping the "Ladda upp orderbekräftelse" button, which will lead them (and the contractors) to the processes shown in the following four screenshots.

(From left to right): **Figure 8.4.** Order confirmation upload screen (supplier); **Figure 8.5.** Order processing 1 (contractor, supplier, transporter); **Figure 8.6.** Order processing 2 (supplier, transporter)

Figure 8.4 shows the screen where the suppliers can initiate a new blockchain transaction by following through the ensuing steps: uploading an order confirmation (in PDF format); choosing the transporter affiliated to them ("Välj transportör") and the contractor to whom they are going to deliver ("Välj entreprenör"); giving an ID to the order (in alphanumeric characters); and confirming the initiation of the transaction by tapping on the "Bekräfta" button (not shown in the figure). After such a confirmation, the first block of the blockchain connected to this order is created. It should be noted that while the app was developed in Swedish, some generic buttons (like "Choose file to upload") may appear in the default language of each user's smartphone interface; therefore, the button "Επιλογή αρχείου" (which means "Choose file to upload") appears in Greek within the screenshot, i.e. the default language of the researcher's smartphone, where this screenshot was taken.

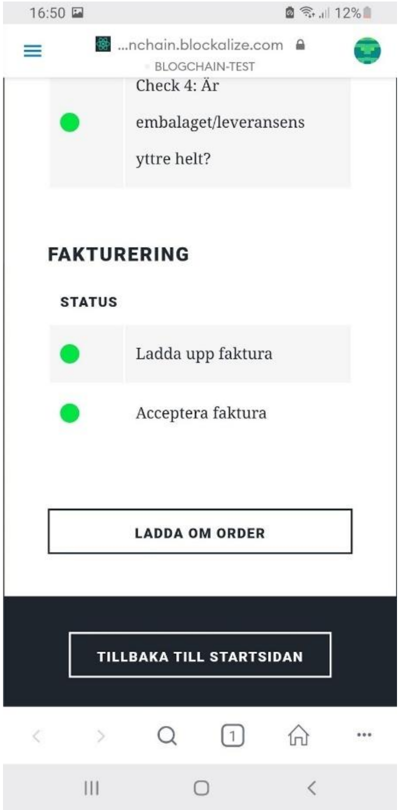


Figure 8.7. Order processing 3 (supplier, transporter)

Figures 8.5-8.7 show the process flow from the supplier's and transporter's perspective and refer back to the process flow and numbered steps in chapter 7 (shown in Figs 7.3 and 7.4), as well as the updated concept in Fig. 7.5 (also in Kifokeris and Koch (fo.b)). The status of each of the three mandatory ((1-2) and (7)), and optional ((3-6)) smart contract clauses, is colour-coded: green for an accepted clause, yellow for a tentative/unchecked clause, red for rejected clause. In the indicative screenshots (Figures 8.5-8.7), the three mandatory clauses are green, namely:

1. The acceptance of the order confirmation ("Orderbekräftelse är accepterad).
2. The acceptance of the delivery receipt ("Mottagandet är accepterad").
7. The acceptance of the invoice ("Acceptera faktura"), which was previously uploaded by the supplier ("Ladda upp faktura").

When it comes to the optional checks, the following are shown:

3. Check 1: Did the transporters notify the construction site of their arrival ("Check 1: Kontaktade transportören bygget innan leverans enligt överenskommelse?" This is shown as red.
4. Check 2: Were the orders delivered at the right place? ("Check 2: Levererat på rätt plats?"). This is shown as green.
5. Check 3: Were the deliveries' labels correct? ("Check 3: Stämmer uppmärkning och kvantiteter?"). This is shown as green.
6. Check 4: Was the deliveries' packaging undamaged? ("Check 4: Är emballaget/leveransens yttre helt?"). This is shown as green.

It should be noted that the UI from the contractor's side is almost identical; however, all mandatory clauses have a "Yes" ("Ja") and a "No" ("Nej") button (by tapping them, the contractor signals a green or red notification, respectively), and all optional clauses have "Yes", "No" and "No agreement" ("Ej överenskommelse"), with the latter signaling a yellow notification.

Testing of BLogCHAIN – 1st iteration

Right after developing the 1st iteration of BLogCHAIN, a series of in-house tests was conducted to check the stability and utility of the alpha version. The developers created dummy contractor, supplier and transporter accounts and conducted test transactions. This process lasted for about a week, in which various minor bugs and UI issues were identified and dealt with. Afterwards, a series of remote meetings were held with the actual testers, in order to introduce and train them with installing and using the application. In some cases, short subsequent meetings were held for clarifications. And further support function was also offered.

The tests themselves consisted of transactions between the contractor and two out of the three suppliers that were contacted. One supplier was responsible for delivering concrete and aggregates of a varying granulometric gradation, and the other delivering an assortment of less heavy materials, and primarily wood. These transactions were infrequent and spread during the testing period of late November and into December 2020. As a result, only a handful of transactions were recorded on BLogCHAIN by the end of the testing period, initiated by the concrete and aggregate suppliers. This infrequency and sparseness had to do with the construction phase, which mostly entailed a few bulk deliveries of heavy materials, as well as the COVID-19 pandemic crisis, which detained (to a certain degree) the supply chain and logistics processes.

The third supplier (delivering the reinforcement steel) had been present in the preparatory stage and had also installed BLogCHAIN after its development, but they ended up not using the application at all. Shortly after the installation, this supplier informed us that their company already deployed an automated digital system for handling the flows between them and the contractor (e.g. the issuing of the invoices). This system was deemed by the supplier to be as optimized as needed for the company's business model, and therefore the supplier declined participating in testing it even in parallel to their established work practices.

It should be noted that during the tests, the developers maintained dummy accounts within BLogCHAIN for technical and functional reasons. Moreover, several informal correspondences and communications were held with the testers, in order to monitor their testing attempts on a hands-on basis and offer continuous technical support.

Insights and feedback after 1st test iteration

After the completion of the first testing period, a series of semi-structured interviews were held with the testers, in order to record their experiences from implementing BLogCHAIN. The interviews covered issues of participating actors, aspects and process of the test. The aspects included integration, efficiency, value creation, collaboration and work environment (including UI).

By comparing their established supply chain and logistics practices to the test transactions conducted through BLogCHAIN in parallel, the interviewees indicated a number of envisioned benefits in the implementation of the application: tampering with past data was avoided; and the integration of the logistics flows led to a streamlining of the process, along with fostering a somewhat higher degree of trust among the testers. However, the test did confirm a barrier related to the practitioners' almost absent previous engagement with blockchain. This made it more difficult for the testers to experience the technology's potential.

The interviewees also provided proposals for improving BLogCHAIN, which were implemented in a second iteration of the tests conducted in February 2021. For this topic, even the supplier not participating in the tests offered some feedback, even though they did not have a user experience with BLogCHAIN. Central among those proposals were:

1. The conditional re-involvement of the roles of the client and the logistics consultants.
2. Deploying a notification function for the transporters as they approach the construction site.
3. Making provisions to accommodate the different roles of managing the sales and issuing the invoices that can exist within the same supplier company.

As mentioned in a more detailed manner in the previous chapter, the roles of the clients and the logistics consultants were proposed to be re-involved, under the condition that they would have an overarching but strictly observatory role, i.e. not being able to participate in the consensus checks, but only have a full overview of all conducted transactions. Moreover, the notification function for the transporters was included in smart contract clause (3) of the concept shown in Fig. 7.5. Finally, the provisions to accommodate the different roles within the same supplier company, were facilitated through the integral functionality of MetaMask. Other proposals, like the system checking of the clients' creditworthiness on behalf of the suppliers, were deemed interesting but out of the scope of this pilot; so, they were categorized as recommendations for future work.

Development of BLogCHAIN – 2nd iteration

The 2nd iteration of the development of BLogCHAIN followed the collection and processing of the aforementioned feedback after the 1st iteration. It was conducted between late December 2020 and late January 2020. The previously used alpha version of the app was modified according to the feedback after the 1st iteration, and the system was reinforced with additional features to address the aforementioned proposals 1-3. An indicative screenshot is offered in Figure 8.8 (next page), where the newly added transporter notification function is shown.

Testing of BLogCHAIN – 2nd iteration

The second round of tests featured both more suppliers and more transactions than the first round. In particular, four suppliers now acted as testers (compared to the two suppliers in the first iteration of the tests), who conducted, in total, more than double the transactions of the first iteration. The tests were conducted during the two middle weeks of February 2021. The initial plan was to use only one week of the tests, but utilitarian issues forced some of the deliveries to be spread over a second week, so that was included in the testing period as well.

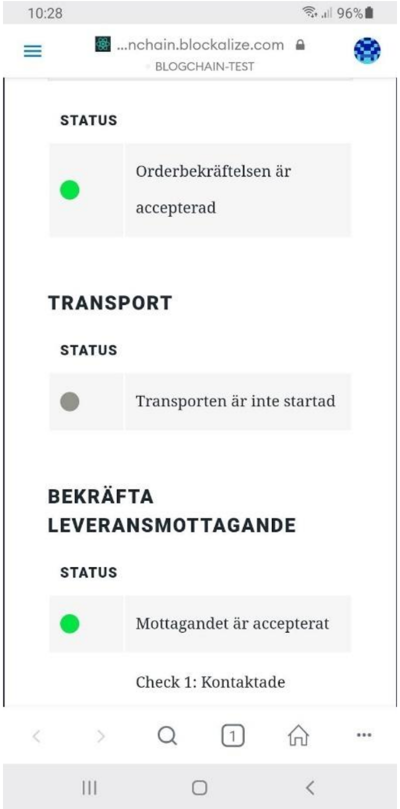


Figure 8.8. UI of BLogCHAIN's 2nd iteration - transporter notification function added

This second testing period, in which the functionality of the second version (beta) of BLogCHAIN was monitored, was the final one.

Insights and feedback after 2nd iteration

The feedback after the 2nd (and last) iteration of the tests for BLogCHAIN was acquired through one interview with each of the supplies, and one with the contractor's site management representatives. Overall, the feedback consisted of mainly positive and constructive comments. With regard to the positive comments, it was mentioned that BLogCHAIN creates a clear connection between the supplier and the contractor, while the confirmation function in the app allows this connection to be documented and available for different roles in the supply chain (and not just individuals). Moreover, its ability to bring together and connect the supply chain actors was highlighted as an improvement over practice as “in current practices, e.g. e-mails between individuals, they cannot do the same thing, as the individual can disappear, and the information can disappear or get mixed up among different people, or it is even difficult to access/follow it up”. It can possibly be understood that this comment mainly referred to the information flow. Furthermore, BLogCHAIN creates a ready-made platform where everyone can join, as “the key is that everyone in the industry must gather around a common interface” (according to one interviewee). It was also noted that even though there might be no major problems with invoices and approvals today, planned meetings for clarifications (e.g. at the end of the month) were needed - and the app, through the overview it offers, could potentially reduce the need for such meetings. Finally, the app was praised for making it possible to quickly satisfy requests of finding and showing the right order confirmation - through BLogCHAIN, it is possible to quickly get details out of the purchase, know exactly what the customer previously bought (and of which they now want to buy more, or on which they now want to make a complaint on).

When it comes to the constructive comments, it should be mentioned that there was not a really critical feedback in this iteration. However, not all testers felt that any substantial value was generated for them by using BLogCHAIN. Specifically, one company shared that they are in the process of developing a system with similar functions, although not based on blockchain; it remains to be seen how another base technology can lead to “similar functions”. The benefits, costs and risks of handling payments via a common blockchain solution instead of the parties' current systems, were considered to not be self-evident, as well as impossible to calculate. The cost of internal administration at each party is not clear and there are probably more aspects that need to be highlighted. Another supplier declared that apart from a visible approval of the order confirmation, no major benefit was generated for them, as they already have a functioning system. The same company highlights that there are different issues depending on the material to be delivered, and therefore the app is too generic to be of real interest. However, the same company highlighted that they distrust the industry's ability to adapt to new technologies (in principle regardless of what such a technology may be). This last comment can be interpreted as emanating mostly from a concern on the institutional aspects of the industry (“slow to adapt”), rather than the app in itself.

Summary, final insights, and proposals for further development

Although substantial time and resources were invested in the initial concept of BLogCHAIN (see previous chapter), updates and remarks that came late into the process (right before the start of the development itself), were also important - as those latter updates were very specific to the context of the construction site that served as the testing ground of our proof-of-concept. Even little conceptual and preparatory changes had a far-reaching effect in the development process itself.

A set of interesting insights regarding late invoice payments and in connection to them possibly being ameliorated through blockchain, emerged from the final round of interviews. Specifically, it was discussed that there are different driving forces for those delays, such as the client having difficulties paying due to financial problems, consciously paying late (either to make capital gains, or due to uncertainties about the deal), and even withholding the entire payment in case of ambiguity of parts of the delivery. Suppliers tend to avoid clients with financial difficulties, but the issue of consciously payling late appears mainly in serious and repeat clients. There is a consensus among suppliers and clients that both parties contribute to this situation and it is not the respective company's internal payment routines per se that are the problem. As no interviewed party had a clear picture of the cost of internal administration of complaints/disputes regarding invoices, the actual problems seem to arise during the validation of the received goods and getting the correct information in the invoice. As such, late payments by "serious customers" seem to be largely due to deficiencies in the contractor's delivery receipt control, which are only discovered when it is the time for the contractors to administer the payment.

Both iterations of the development were very much affected by the in-between professional relationships of the participating testing parties. The resulting simplification of the concept, and as such the developmental process itself, led to the choice of widely used and relatively standard development tools in the field of blockchain and smart contracts (i.e. Hyperledger, MetaMask, and Microsoft Azure). The absence of more “exotic” choices did not harm the development of our proof-of-concept, but rather the opposite - it facilitated a streamlined development process, and a relatively simple, understandable functionality and UI in the prototype itself, which helped the testers grasp it quickly and easily. Streamlining, quickness and easiness were essential for the testers, as this meant fewer disruptions in their normal day-to-day tasks. Such a reduced disruption was also facilitated by running the tests in parallel to the business-as-usual transactions between the contractor and the suppliers - after a bilateral agreement with the testers, the transactions done through the app did not replace the standard-business transactions, but were done alongside the standard ones.

When it comes to proposals for the future development and/or improvement of the app, it was highlighted that it needs to be integrated with the respective supplier's own ledger system, so that the order confirmation and invoice can enter the app automatically. Expansions in its utility, like the coupling with a scanning function upon receipt of incoming goods, enacting payments (which would probably require cryptocurrencies), connecting the information in the app with future additional sales from e.g. the end customer, and using it as an interface between the parties' internal business systems for coherent information flows, were discussed. The development of the app in order to facilitate partial invoice payments (e.g. when a defect is found in a part of the delivered goods), as well as to regulate transactional disputes within the contractor firm itself, were suggested. Finally, a major proposal constituted in creating an aftermarket case in the app; interestingly, to illustrate the need for this case, a piece of the received feedback by an interviewee went thus: “If a part of the invoice is questioned, the supplier can accept or reject the complaint; the contractor can then withhold payment for the disputed part - but pay the rest of the invoice. Today it is common for the contractor to withhold the entire amount. To make things clearer, let’s say that a supplier delivers with a 30-day payment time. Receipt is approved. The material is assembled after 15 days, and after assembly a defect is found in the material. The contractor then withholds the entire invoice. It then becomes a dispute where the supplier "must" subsequently prove that the material now complained upon, was formerly received and approved by the contractor”.

9 EVALUATION

The evaluation of the results and outcomes of this project consists of three parts. The first part relates to the evaluation of the way the potential of blockchain is realized for building logistics within the context of this project. This part includes the dimensions of integration, reduction of transactions, transparency, and value creation. The second part regards the evaluation of the way the potential of blockchain is realized within the digital business model for independent building logistics consultants. Finally, the third part elaborates on the implementation of the technology.

Evaluation of the potential of blockchain in building logistics

The conceptualization collectively carried out in chapters 2, 4, 5, and 6, pointed to at least four main characteristic potentials for blockchain in building logistics within the Swedish context:

- Integration.
- Reduction of transactions.
- Transparency.
- Value creation.

In the following, these will be further elaborated on.

Integration

Currently, the flow of building materials is adversely affected by a lack of joint planning, a risk of parallel orders and other processes, and disorientation among actors active in the pursuit of integrating and defragmenting parallel material flows and logistics.

The tests of the prototype showed the way site management could perform a more integrated management of received goods, by using the blockchain app as a common tool with a single common user. The tests also showed that stronger integration between, on the one hand, sellers and their information systems and, on the other hand, accountants and their ledger systems in the organization of the material supplier organisation, is an attractive potential.

Reduction of transactions

Nowadays, the information and economic flows in construction supply chains and logistics require constant checking and rechecking by a series of professionals who take over an item. These needed controls and checks thus imply constant human intermediation. The potential disintermediation, i.e. the reduction of the number of needed human interventions, has a large potential for generating surplus for the involved companies (Chong et al. 2019; Rossi 2019).

The test of the prototype did not directly show a realization of this potential. The prototype operated as a standalone application, and as such it increased rather than decreased the number of needed intermediations in the process. Moreover, the longerterm possibilities of overseeing e.g. monthly transactions have not been tested in this project.

Transparency

Blockchain, when employed along the information and economic flows across a construction supply chain, can be characterized as a trust-based technology: it requires trust amongst the stakeholders in the supply chain, but can also develop new trust because of its transparency. Public permissionless blockchains (such as the ones based on proof-of-work algorithms, like the Bitcoin blockchain), do constitute open systems accessible for all. Such transparency is believed to be paired with the irreversibility of the conducted transactions, which is seen to assure that the system cannot be tampered with.

The prototype however deployed a permissioned system, only allowing actual members of the supply chain as users (Pedersen et al. 2019). This type of limited trust, higher security and partial information privacy appears to have worked well in the tests and did not receive any comments. It actually appeared to have been taken for granted, as Pedersen et al. (2019) also expected in blockchain applications.

Another potential use of blockchain is related to an active client. If blockchain is supposed to support a more client-oriented constellation (i.e. a constellation with clients that are more active, either by themselves, or through a logistics consultant), then it is more suitable in an atypical ("more egalitarian") constellation, e.g. a partnering project where mutual trust ("opening one's books") is declared.

Value creation

Presently, building logistics are hampered by continuous tensions about payments. Disagreements on what is delivered, and how and when the payment is to occur, are recurrent. Intrum (2019) shows that in 2019, Swedish companies paid their bills on an average of 33 days after receiving them - even if standard conditions clearly delimit this span to 28 days. Moreover, conscious late payment is viewed as accounting for 50% of the total payments. Therefore, the potential for agreeing on an automated payment is huge. The creditor can realise direct monetary advantages when receiving payment just 3-5 days earlier than the present average practice, and the debitor can avoid constant attention on paying at a particular (late time), thus reducing human intermediation. It should therefore be possible to create a joint value creation - a win-win situation- with smart contracts.

Moreover, smart contracts can support purchasing agreements common to the construction industry. These agreements specify agreed-upon annual purchasing volumes, delivery and quality conditions, and set prices. If all parties in the agreement are interested in trading on these values, smart contracts can administer this. However, it is likely that a function where it is possible to deviate from the clauses of a smart contract at a later stage will be welcomed, as site managers are quite often able to negotiate better conditions than the initial (and by convention, immutable) clauses prescribed in the smart contract. In other words, there is a risk related to smart contracts, where they become a top-down instrument for management, to the detriment of the company.

A smart contract was built in the prototype tested, and its clauses pertained to all the transactions that the app could facilitate within its scope. To address the aforementioned risk of a too rigid smart contract, we introduced optional checks as a type of flexible clauses. These were, on the one hand, received well by the suppliers, but on the other hand, treated with some skepticism by the site management representatives of the contractor. However, it remains to be seen if such simple solutions can account for a larger scale implementation of a blockchain prototype within construction supply chains and logistics, where numerous conflicting flows and hundreds of transactions might have to be performed simultaneously.

Evaluation of the potential of blockchain within the digital business model for independent building logistics consultants

A question that emerges through the evaluation analysis is connected to which actor should be the “carrier” of a blockchain solution. In this project, the independent logistics consultants were initially elected, following a specific analysis, argumentation, and context. However, the potential inter-organizational aspect of the network operated through blockchain might mean that the identity of such a carrier cannot always be clear. The client option might not always be obvious or suitable, as it is not neutral enough in some contexts.

Interestingly, Pedersen et al. (2019) point to the possibility of substituting a trusted third party with a blockchain solution. The implication here is that the building logistics consultants themselves, embodying a form of a third-party consultant, might be substituted with a system. However, it is here suggested that a building logistics consult in tandem with a blockchain solution might be superior to a pure technical solution (like a centralized IT system), as a sociomaterial constellation of human and non-human elements (the consultants and the blockchain) probably is the better-performing solution.

The test of the blockchain prototype came to focus on the interaction between the main contractor and the material suppliers, partly because of the disinterested clients, and the absence of the building logistics consultants in the context of the specific building project within which the test iterations were conducted. Nevertheless, the tests showed indirectly that integration does not occur by itself by merely employing a blockchain solution. On the contrary, a number of integrative human planning and decision acts came to be missing during the tests, even if site management did integrate some processes. Therefore, the potential of a joint constellation of blockchain with independent building logistics consultants is maintained, even if the tests did not directly demonstrate this potential.

When connecting the test results with the digital business model development for Prolog (as was done in the final workshop), it became clear that more developmental work was needed, both for the technological solution and the digital business model. Prolog evaluated the prototype as too simple and is at the moment ambivalent about adopting it directly in their business. One possibility that was not tested in the project, was the option for Prolog to engage in a partnership with a dedicated technology supplier willing to supplement other digital technologies for building logistics with a blockchain solution. Then, whenever Prolog would have a customer interested in a technology-based solution, this partnership could be activated.

In the current situation, Prolog has positioned themselves as a strategic consultant for clients, which implies that a digital technology such as blockchain does not automatically fit comfortably within Prolog’s strategy - but the technology partner perspective appears attractive.

Implementation

The sociomaterial focus on the intertwinement of human and non-human elements is constant throughout the current study, framing a mutual intermediation as artefacts and objects interact with humans. However, the strong embedding of the prototype in human practice was prevented by its stand-alone character. BLogCHAIN would need several application interfaces (APIs) to become smoothly integrated in the information system architecture, which is required to obtain reduced and/or changed human intermediation.

The sociomaterial perspective would also emphasize the way blockchain would be intertwined with changes of practices. A strong implementation concept is needed to obtain this practical embedding in practices, a strong implementation concept is needed. In the case of the current project, such an implementation encompassed introductory meetings when starting up preparatory interviews, introduction meetings when the prototype was ready for testing, and one-to-one sessions with each user setting up their account for BLogCHAIN. During the test a continuous online support was offered. The start-up was a typical example of a common implementation process of digitalization; first time users struggling with the basic function of the MetaMask shell and the entries in the blockchain itself. But these “early symptoms” were overcome relatively quickly. A more thorough embedding would extend beyond the two testing periods, and a crucial moment for future adoption would be when the use of the system goes beyond a single case and becomes standard software for the central users - first and foremost the building logistics consultants, and then the client and the main contractor.

As a perspective for future development it is maintained that blockchain can bring about a complex sociomaterial system among actors, by digitizing the value chain, integrating various flows, shifting routines and capabilities, and reconfiguring existing sociotechnical infrastructure (Kohtamäki et al. 2020). But this requires roughly at least five more years, as pointed out by Arup in their technology forecast for blockchain in the built environment (Gerber and Nguyen 2019; Nguyen et al. 2019). They predict that the period of 2023-2028 is needed for the emergence of a similar blockchain solution to the one studied in this project.

10 DISCUSSION

The discussion goes through the arguments and analysis made throughout our study, which has proposed a new digital business model for independent logistics consultants, which utilizes a sociomaterial conceptualization of a blockchain solution for the integration of the information, material and economic flows within construction logistics. It commences with an elaboration on the literature reviews (including our insights regarding our choice of sociomateriality), goes on to offer insights on the digital business model development, and continues with deliberating the development, test and evaluation of the blockchain prototype. These elements are then followed by a further perspective taken on blockchain as a general-purpose sociomaterial technology, which also draws attention to the barriers for adopting a construction logistics solution with blockchain.

Literature review and choice of sociomateriality

The three iterations of our literature review on blockchain for the construction sector show that the core properties of blockchain, such as peer-to-peer transactions, record immutability and a degree of decentralization, are generally expected to generate the majority of the potential value-adding benefits – but little implementation experiences exist yet, as well as no actual business cases. Nonetheless, the associated research literature is growing quickly. Within such literature, while some blockchain-related studies approach the construction industry as a whole, most differentiate by focusing on specific niches and/or processes of the sector. In both approaches there are developed conceptualizations, visions, and some prototypes of blockchain systems.

Also informed by the insights of our literature review, the choice of sociomateriality for our own conceptualization reflects not only our theoretical considerations on the way blockchain, a general-purpose technology, can be properly contextualized within construction supply chain and logistics setups in Sweden – but also our empirical understanding of the real-life function of such setups. Rather than viewing the respective actions as technical choices among rationally discernible operational models, which is recurrent in the approaches of operations management and business economics, we interpret them as different sociotechnical solutions involving characteristic distributions of power. This evidently means that the investigated operational framework is not limited to knowledge exchange (Gustavsson 2018), but also constitutes a political game which is co-shaped along the utilized technological frameworks. Moreover, the sociomaterial approach leads to the understanding of mutual trust as a crucial issue of security in blockchain implementation (see also in Woodhead et al. (2018)). Since large urban building sites can suffer from theft and shrinkage in material supplies, at least internal trust among the actors in a (partially) decentralized blockchain network, should be cultivated. However, supporting an outright permissionless setup can be difficult. Thus, a permissioned private system (like BLogCHAIN or one that BLogCHAIN can evolve into) that can establish procedures to protect the blockchain network both from external threat and internal instabilities, is informed by existing sociomaterial conditions. Furthermore, deeply integrating the new technology evidently involves technical interoperability issues, as well as changes in the work practices, social setups and organizational structure of the participating companies. Through our sociomaterial understanding and informed by our literature review insights, the tackling of such issues and changes should initially place the blockchain solution in parallel or on top of an information infrastructure consisting of different accounting, project planning, site planning, quality control, and access control systems; then, the adoption of common standards for the structuring of ledgers should ensue. As shown in the test iterations for BLogCHAIN at a later stage of the project, we adopted the parallel placement of our solution in relation to the existing information infrastructure and established work practices of the school building site.

Development of the digital business models

Regarding the digital business models, the canvas in Fig. 5.2 (chapter 5) represents the more generic version, where the central value proposition consists of the integration and optimization of several aspects of construction logistics with digital technology. However, in the canvas showing the customized digital business model for Prolog (Fig. 6.1, chapter 6), the central value proposition consists of the facilitation of logistics planning and the integration of the economic, information and material flows. The difference between the value propositions mirrors the actual positioning shown in Prolog's digital business model as depicted in Fig. 6.1, which emphasizes consultancy over digitalization. Another interesting differentiation between the two canvases is found in the customer segments section. While the way of facilitating construction logistics with blockchain can address several customer segments, Prolog focuses more on the construction clients, and more specifically the public clients that operate large scale projects (such as in district development). When it comes to key resources, the "digital asset" in Fig. 5.2, is addressed as an "innovative asset" in the case of Prolog. This can reflect not only Prolog's opportunity to position itself as a possible innovation leader in the field of construction logistics, but also as a statement of evolving their business practices (from currently outsourcing digital solutions to offering an integral, in-house system). Finally, in the revenue streams, Prolog has rejected the use of cryptocurrencies, opting for a crypto-free system. This might be prudent, as Prolog deems current sociomaterial constellations in Swedish construction logistics to be too inert (and inept) to adopt cryptotransactions.

Despite the potential of blockchain, its value can be speculated when data availability and quality cannot be guaranteed (Lamb 2018). However, while a number of actors in some national industries appear to suffer from a relative lack of awareness and required skills (Büyüközkan and Göçer 2018), it can be observed that actors in sociomaterial constellations of construction supply chains in other national industries, such as in Sweden, are becoming increasingly more competent in data capturing and storage – thus potentially mitigating the aforementioned speculation and quickly overcoming "early symptoms" such as the ones described in the previous chapter. This can present an opportunity for Prolog, since it can complement its potential role as an early blockchain adopter and/or solution provider and allow it to get ahead of the competition.

Another consideration regards the challenge of transitioning from physical documents (e.g. shipping fulfilment orders, invoices) to digital ones (e.g. smart contracts), which could jeopardize the value proposition (Loklindt et al. 2018). This challenge could be tackled by being prudent when implementing blockchain, in order to leverage its potential benefits, rather than push for a publicity-pressured adoption (due to the current use of blockchain as a hyped buzzword) which could result in ill-fitting, costly, and even detrimental applications (Verhoeven et al. 2018; Perera et al. 2020).

Coupling the aforementioned critical points, our own field experiences indicate that to realize the value of blockchain (which is claimed to be disruptive) through a digital business model, certain goals need to be attained. These goals include the expansion of the understanding of what blockchain can offer to our sector, the improvement of the realization of its claimed potential in the limited existing visions and prototypes, and the mitigation of the aversion towards changing the autonomy-control status quo of the existing power relations within the sociomaterial construction supply chain and logistics constellations – for example, through proprietorial solutions with permissioned systems, rather than entirely permissionless systems as the blockchain hype would suggest. However, there is optimism that attaining such goals is a realistic aim, as studies on blockchain for construction gain more traction (Hunhevicz and Hall 2020).

Prototype development, tests, and evaluation

Our choice for a sociomaterial understanding did not only inform our background studies and choice of conceptual basis for the development of BLogCHAIN (as also stated earlier in the discussion) but was also realized during our field tests. The prospective testers' experiences at the preparatory stage informed the development of BLogCHAIN itself, the evolution of the pilot's utility was informed by the way it was tested, and the recommendations we got afterwards – all informed by the social relations between the actors and the practical work conduct in the supply chain and logistics constellation – were realizations of a sociomaterial co-shaping between the implementation of the digital technology and the related practices.

The created value for the users and companies involved was limited in the tests, but nonetheless demonstrated the utility of blockchain in four dimensions: increasing integration, facilitating the opportunity of a reduced number of transactions, increasing transparency, and creating opportunities for future value creation. The integration occurred among members of site management supporting transparent coordination. Deficiencies in coordination are known to create quality defects, and transparency can help in ameliorating those, e.g. more precise information on truck deliveries can reduce waiting times and on-site work interruptions. The opportunity of reduced transactions relates to the order and accounting processes in the participating companies, where a common ledger can lead to less human intermediation – which is currently substantial, if not voluminous.

The prototype also highlighted the possibility of a more active and digitally supported role of the clients, despite not having included a client node in the distributed digital ledger of the first iteration. Enabling the online surveillance of the construction supply chain flows (especially the economic flow and accumulated costs) can provide the client with valuable knowledge, which could otherwise have been mostly accessed by the contractor, or indirectly through independent logistics consultants.

A dilemma of compulsory versus voluntary checks and steps within smart contracts in blockchain surfaced. Some users (e.g. site managers) requested making blockchain transactions obligatory, while others (e.g. suppliers) preferred a more flexible solution maintaining some transactions as voluntary. This is a dilemma for future development; however, it can already be considered that to avoid unnecessary bottlenecks in the process it is maybe advisable to keep most steps voluntary. Nonetheless, it is possible that in the future, blockchain can support standardized processes involving obligatory steps.

System disintegration seems to be a major deficit in the operation of the present prototype. Integration with other systems is crucial for the creation of value for the participating actors. However, the present project did not have enough resources to develop the necessary application programming interfaces (APIs) with other systems in the domain.

Further perspectives

Our present blockchain prototype for building logistics can be interpreted as positioning itself in a small niche, compared to the large number of articulated visions and prototypes of blockchain applications in the international construction context (e.g. see in Gerber and Nguyen (2019), and Nguyen et al. (2019)). It can be argued that the present ongoing differentiation into niches can be instrumental for moving the development and application of blockchain closer to actual use. However, it may also imply that this general-purpose technology is dispersed into a number of dissimilar applications, where construction logistics is only just one – and not widely researched yet.

It is rarely recognized that blockchain is a general-purpose technology in need of contextualization – in other words, an empty shell with wide application possibilities that need to be developed before any value creation really materializes. To take a step like the one taken in this project is thus of tantamount importance, even if practical results remain limited. As such, a continuous development journey is needed to strengthen sociomaterial embedding.

Furthermore, the hindrances and barriers in adopting the solution, can also be contextualized and be attributed to current issues in construction supply chains that need to be overcome – such as data unavailability, relative lack of blockchain awareness, and the existing power balances within sociomaterial constellations. These issues can also present challenges in the specific case of Prolog – especially the upsetting of the existing power balance in a sociomaterial construction logistics setting, in which the contractors have a dominant role. Prolog has so far been a neutral (in terms of interactions and power distribution) strategic consultant for the facilitation of logistics flows, a role signified according to the clients' prerogative. However, if it elects to implement the blockchain solution and incorporate it within its business model, Prolog may shift the power setup, since the contractors will have to relinquish some power and control over e.g. the economic flow.

11 CONCLUSIONS

This project addresses the research question of how a site-specific solution for construction logistics, in which the information, material and economic flows are integrated in an event-driven way through blockchain technology, can be conceptualized and incorporated into a new digital business model for an independent building logistic consultant.

Our literature review on the studies researching blockchain for the construction sector, shows that they mostly have a differentiated scope and focus on specific niches and processes of the industry, indicates that the core properties of blockchain can generate value-adding benefits for construction in a number of areas. The research on, specifically, blockchain for construction supply chains and logistics, also delineates a number of such benefits (e.g. the reduction of administrative and accounting rework); however, the studies reflect a maturity level no higher than that of prototypes, and no implemented blockchain solutions have been found. Moreover, excluding the efforts connected to this research report, no studies have adopted a sociomaterial lens, and there has been no specific focus on either the integration of all three supply chain flows, or the particular operation of independent logistics consultants in Sweden.

In our empirical work on business models within the Swedish context, we tried to couple the insights and address the shortcomings of the current literature, in order to conceptualize a construction logistics solution featuring blockchain for integrated flows, and then embed this solution in the value proposition of a digital business model canvas for independent logistics consultants. The Swedish construction sector encompasses a well-established set of such actors, and it was thus considered suitable to accommodate such a value proposition. This resulted in a generic version of a digital business model depicted in a canvas, reflecting independent building logistics consultants as a business type where the central value proposition consists of the integration and optimization of several aspects of construction logistics with digital technology.

Following this generic model version, the digital business model development with Prolog focused on a central value proposition entailing the facilitation of logistics planning and the integration of the economic, information and material flows. The difference between the value propositions of the generic and the Prolog-specific case is mirrored in the depiction of Prolog's digital business model, which emphasizes consultancy over digitalization, as well as the customer segments section where the generic model addresses several customer segments, when the Prolog-specific focuses more on (public). Prolog has also rejected the use of cryptocurrencies for the time being, opting for an information system.

The conceptual solution, forming part of the value proposition of the generic and especially the Prolog-specific digital business model, emerged into an event-driven, blockchain-induced flow integration across all phases of the related processes, i.e. from the issuing of purchasing orders until the completion of the on-site deliveries. The envisaged benefits of the solution included (among others) the streamlining, integration and transparency of logistics processes, the improvement of productivity and value creation. However, certain issues (mostly tied to the wider construction context) have to be addressed, so that the realization of such value will not be hindered; such issues include, among others, data unavailability, a relative lack of wide blockchain awareness, and the existing power balances within sociomaterial constellations.

The development, tests and evaluation of the blockchain prototype commenced with the prospective testers' experiences informing the development of BLogCHAIN itself, the evolution of the pilot's utility was informed by the way it was used during the tests, and the recommendations we got afterwards were informed by the work practices in the supply chain and logistics constellation at the testing site. These have thus become realizations of a sociomaterial co-shaping of the digital technology with the related practices during testing, and with further implication for future implementation.

The created value for the users and companies involved was limited in the test, but nonetheless demonstrated the utility of blockchain in four dimensions: increasing integration, facilitating the opportunity of a reduced number of transactions, increasing transparency, and creating opportunities for future value creation. The integration and transparency occurred among members of site management supporting transparent coordination. The opportunity of reduced transactions and value creation remained future options as the system was tested as a standalone prototype in a context more in need of architectural integration between systems for planning, purchasing and accounting and not revising existing purchasing contracts.

The prototype also highlighted the possibility of a more active and digitally supported role of the clients. Enabling the online surveillance of construction progress (especially the economic flows and accumulated costs) can be considered to provide the client with valuable knowledge, which otherwise benefits other stakeholders.

The adoption of a sociomaterial framework of understanding reflects not only our theoretical considerations on the way blockchain, a general-purpose technology, can be properly contextualized within construction logistics setups in Sweden – but also our empirical understanding of the real-life function of such setups. We interpreted those as different sociotechnical solutions involving characteristic distributions of power, rather than viewing the respective actions as technical choices among rationally discernible operational models. Another conceptual pitfall to avoid is to view the interactions as merely knowledge exchange and remember the in-built political games which are co-shaped along the utilized technological frameworks. Moreover, the sociomaterial approach leads to the understanding of mutual trust as a crucial issue in blockchain adoption. A permissioned private system can establish procedures to protect the blockchain network both from external and internal threat and/or abuse; in other words, supporting an outright permissionless system is here seen as an abstracted vision with little bearing. As a future perspective, integrating the new technology would change the work practices, social setups and organizational structure of the participating companies and projects. Thus, our choice for a sociomaterial understanding did not only inform our background studies and choice of conceptual basis for the development of BLogCHAIN but was also realized during our field tests and influences our evaluation and our conceptualization of future perspectives.

The delimitations of this study include the choice of a particular context (i.e. Sweden) and of a particular actor (the independent logistics consultants) in a specific construction logistics setup, for which the presented blockchain solution and digital business model were conceptualized. The main downsides of this choice are, first, that the same conceptualizations cannot be easily replicated for other contexts, unless new context-specific analyses are first conducted; and second, that within Sweden itself, the dominant setup (in which the main contractor internalizes the logistics responsibility and/or services) is not hereby investigated (despite the field tests being largely conducted in such a setup). However, we believe that our choices of context, actor, and solution, complement each other into a concise proposition for the improvement of construction logistics in Sweden.

Recommendations for future work include the conduct of further sociomaterial field studies, the further development of the prototype application connected to the blockchain solution, and the pilot testing of such an updated prototype in at least one real construction site. It is hoped that the investigation within this context will not only contribute to the improvement of construction supply chains and logistics in Sweden, but also impact on other contexts where independent logistics consultants are active.

Blockchain has the potential to play a positive role within the ongoing digitalization within the construction industry (in general) and construction supply chains and logistics (in particular), and can complement well-established technologies such as BIM, and/or other currently investigated cutting-edge technologies, such as IoT. We hope that our study will push research and development in the direction of continued efforts of strong contextualization that will enable the competitiveness of the Swedish construction industry - and even society.

12 RECOMMENDATIONS – FUTURE WORK

In our documentation of the feedback we received after the 2nd testing iteration of BLogCHAIN (chapter 8), as well as in our evaluation of the project results and outcomes (chapter 9), our discussion (chapter 10), and our conclusions (chapter 11), we have already pointed to certain recommendations for future work. However, the aforementioned recommendations were mostly of a smaller scope and particularized in the evolution of the BLogCHAIN prototype itself, or concerned specific current and future theoretical, methodological, developmental and contextual concerns.

However, in this closing section of our report, we will briefly offer future work recommendations of a wider scope, having either to do with large-scale field tests, and/or innovation on a research project-level. In particular, we propose:

1. Carrying tests which are followed directly on site. Due to the current COVID-19 restrictions, the researchers could not be present at the site during the tests carried out in this finished project.
2. Designing and carrying out an innovation project where subcontractors, along with the material suppliers, are integrated into the blockchain solution. The combination of flows related to subcontractors and main contractors is recurrent on building sites, and an integrating blockchain solution has the potential to improve coordination and mitigate clashes between different deliveries. It could also be fruitful to design a test of the system in the installation phase, which usually involves more companies and flows than the early project stage during which the tests of the current project were conducted.
3. Designing and carrying out an innovation project where the Internet of Things is coupled with blockchain to track materials and facilitate provenance tracking.
4. Designing and carrying out an innovation project that directly involves cryptocurrencies, as well as the translation to ordinary (fiat) currencies, to facilitate bank transactions in relation to payments across the construction supply chains and logistics flows.

We believe that following through these proposals can potentially stimulate research into a direction which can take serious account of the application possibilities blockchain can have for construction supply chains and logistics in the Swedish context.

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APPENDIX

List of publications connected to this project

Journal articles

Kifokeris, D., and Koch, C. (2020). A conceptual digital business model for construction logistics consultants, featuring a sociomaterial blockchain solution for integrated economic, material and information flows. *Journal of Information Technology in Construction (ITcon)*, 25, 500-521, DOI: 10.36680/j.itcon.2020.029.

Book chapters

Kifokeris, D., and Koch, C. (fo.a). The proof-of-concept of a blockchain solution for construction logistics inte-grating flows: Lessons from Sweden. In: Dounas, T., and Lombardi, D. (Eds.). *Blockchain in Construction*. Springer.

Papers in peer-reviewed conference proceedings

Kifokeris, D., and Koch, C. (fo.b). BLogCHAIN: proof-of-concept and pilot testing of a blockchain application prototype for construction logistics in Sweden. In: *Volume II – Proceedings of the 2021 European Conference on Computing in Construction*. Rhodes: EC3.

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Moreover, as part of communication and dissemination activities, parts and insights of the project were presented to interested parties in the following conferences and workshops:

- 2019 Smart Built Environment (SBE) Conference "Uppkopplad byggplats – Projekter med SBE", Stockholm, Sweden, 21-22 May 2019.
- 1st Blockchain in Construction workshop, Zürich, Switzerland, 20-21 February 2020.
- AI in AEC 2021 Conference, online, 24-25 March 2021.

- 2nd Blockchain in Construction workshop, online, 15-16 April 2021.