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Title: Insights into Blockchain Implementation in Construction: Models for Supply Chain Management

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Insights into Blockchain Implementation in Construction: Models for Supply Chain Management

Abstract

The interest in the implementation of distributed ledger technologies (DLTs) is on the rise in the construction sector. One specific type of DLT that has recently attracted much attention is blockchain. Blockchain has been mostly discussed conceptually for construction to date. This study presents some empirical discussions on supply chain management (SCM) applications of blockchain for construction by collecting feedback for three blockchain-based models for Project Bank Accounts (PBAs) for payments, Reverse Auction-based Tendering for bidding and Asset Tokenization for project financing. The feedback was collected from three focus groups and a workshop. The working prototypes for the models were developed on Ethereum. The implementation of blockchain in payment arrangements was found simpler than in tendering and project tokenization workflows. However, the blockchain integration of those workflows may have large-scale impacts on the sector in the future. A broad set of general and model specific benefits/opportunities and requirements/challenges was also identified for blockchain in construction. Some of these include streamlined, transparent transactions and rational trust-building, and the need for challenging the sector culture, upscaling the legacy IT systems and compliance with the regulatory structures.

Keywords: blockchain; construction; supply chain management; models; Ethereum

Introduction

There is a surge in the interest in distributed ledger technologies (DLTs) in the construction sector (Elghaish et al., 2020; Li et al., 2019a; Nawari and Ravindran, 2019; Wang et al., 2020). DLT is a digital system for recording the transaction of assets in which the transactions and their details are recorded in multiple places at the same time on a network of computers (Kuo et al., 2017). One specific type of DLT that has recently gained prominence is blockchain, a peer-to-peer, distributed data storage (ledger) structure that allows transactional data to be recorded chronologically in a chain of data blocks using cryptographic hash codes. It is the underpinning technology of the world's first cryptocurrency, *Bitcoin* (Nakamoto, 2008). When a transaction is executed over blockchain, the transaction is packed with other transactions in a block. The validator nodes (miners) – computers connected by a specific blockchain network - analyze the transaction and validate the block by a predefined consensus protocol. Each identified block is then recorded with a unique crypto-identifying hash code and linked with the preceding chain of blocks on the network. The key aspects of blockchain are (Turk and Klinc, 2017): (i) decentralization, functioning across a peer-to-peer (P2P) network built up of computers as nodes; (ii) immutability, once blocks are chained; (iii) reliability, provided all nodes have the same copy of the blockchain that is checked through an algorithm; and (iv) a proof-of-work procedure that is applied to authenticate the transactions and uses a mathematical and deterministic currency issuance process to reward its miners. Blockchain's core innovation lies in its ability to publicly validate, record and distribute transactions in immutable ledgers (Swan, 2015). Therefore, many regard blockchain as a disruptive technology and believe that it will have profound effects on various sectors by allowing individuals, organizations and machines to transact with each other over the internet without having to trust each other or use a third-party verification (Wang et al., 2019).

Construction is deemed to be a low-productivity/low-innovation sector (Ozorhon et al., 2014) with one the lowest research and development activity (Oesterreich and Teuteberg, 2016). McKinsey Global Institute reports a global productivity gap of $1.6 trillion USD can be tackled by improving the performance of construction (Barbosa et al., 2017). For blockchain to gain a foothold in the sector, it needs to address some of the key challenges in construction such as structural fragmentation, adversarial pricing models and financial fragility (Hall et al., 2018), dysfunctional funding and delivery models, lack of trust and transparency (Li et al., 2019a), inability to secure funding for projects (Woodhead et al., 2018), corruption and unethical behavior (Barbosa et al., 2017), and deficient payment practices leading to disputes and business failures (Wang et al., 2017).

As of January 2020, a blockchain keyword search yields approximately 8700 publications on the *Scopus* database; only a very few of which are within the construction and built environment (BE) domains, despite the recent interest in blockchain research and application (start-ups) (Lam and Fu, 2019; Li et al., 2019a). Moreover, most of the existing blockchain discussions in construction are conceptual (Hunhevicz and Hall, 2020; Li et al., 2019a). Lack of empirical discussions, working prototypes and actual implementation cases are conspicuous (Hunhevicz and Hall, 2020). Collecting empirical evidence and insights for blockchain in construction is therefore necessary (Das et al., 2020; Shemov et al., 2020). Hence, this paper presents some empirical discussions as research outcomes on the implementation of blockchain in SCM in construction. The aim of the study is to explore whether blockchain can help the construction sector overcome some of its key challenges by developing and collecting feedback for three blockchain-based SCM models (working prototypes) for empirical research. The contribution of this research is: (i) identification of three opportunities in SCM workflows for blockchain; (ii) development of blockchain-based working prototypes on Ethereum for the SCM opportunities (models), (iii) collection of feedback for the requirements, utility and applicability of the models for practical implementation in real-life; and (iv) identification of a set of benefits, opportunities and general requirements as well as challenges for blockchain in construction over the models. The rest of the paper is structured as follows. The next section presents the blockchain research background, introducing the SCM workflows the models were developed for. The section that follows describes the research methodology used in conducting the study, followed by the explanation of the models' requirements and details. The empirical findings from the focus groups and workshop are presented in the next section. The final section provides a discussion and summary of the findings with conclusions.

Research background

Blockchain deployment outside finance has been experimental with testing efforts by large organizations like Hyundai, Walmart, Tata Steel, BP and Royal Dutch Shell (Kshetri, 2018; Wang et al., 2019). SCM is a strong fit for blockchain and will be affected by it (Kshetri, 2018; O'Leary, 2017; Treiblmaier, 2018; Wang et al., 2019), where blockchain may facilitate the main SCM targets of regulatory cost reduction (O'Leary, 2017), speed (Perera et al., 2020), dependability, risk reduction, sustainability (Kshetri, 2018), flexibility (Kim and Laskowski, 2018), transparency (Francisco and Swanson, 2018), sense-making, trust-building and reduction of complexities (Wang et al., 2019).

The technology will affect the structure and governance of supply chains as well as relationship configurations and information sharing between supply chain actors (Wang et al., 2019). It is therefore important to experiment with new SCM models for blockchain to better understand its implications (Queiroz and Wamba, 2019; Treiblmaier, 2018). There are also serious challenges before blockchain implementations in SCM (Kshetri, 2018; Sulkowski, 2019): complex, multi-party global supply chain environment operating on diverse laws and regulation, integration challenges relating to bringing all the relevant parties together, and controlling the boundary between the physical and virtual world for fraudulent activities. Wang et al. (2019) group these challenges under five main categories: (i) cost, privacy, legal and security issues; (ii) technological and network interoperability issues; (iii) data input and information sharing issues; (iv) cultural, procedural, governance and collaboration issues; and (v) confidence and related necessity issues.

Blockchain research in the BE is progressing over seven strands (Li et al., 2019a): (i) smart energy; (ii) smart cities and the sharing economy; (iii) smart government; (iv) smart homes; (v) intelligent transport; (vi) Building Information Modeling (BIM) and construction management; and (vii) business models and organizational structures. Despite blockchain’s potential, various general challenges and requirements for blockchain have been identified for the construction sector such as identifying high-value application areas (Wang et al., 2017), developing practical implementation strategies and plans, ensuring resource, process and workforce readiness (Li et al., 2018), compliance with regulations and laws (Li et al., 2019b), upscaling the legacy IT systems, and capturing and documenting benefits and issues in practice (Tezel et al., 2020). The potential blockchain benefits and challenges outlined for construction supply chains are in line with the blockchain discussions in the general SCM literature (Heiskanen, 2017; Perera et al., 2020). Procurement (Barima, 2017; Heiskanen, 2017), payments (Barima, 2017), financing of projects (Elghaish et al., 2020; Wang et al., 2017), and real and digital product/component tracking (Turk and Klinc, 2017; Wang et al., 2020) come to the fore as potential blockchain application areas for construction supply chains.

A key area of interest in this domain is the application of smart contracts with blockchain (Ahmadisheykhsarmast and Sonmez, 2020). A smart contract is a self-executing contract with the terms of the agreement between buyer and seller being directly written into lines of code. The code and the agreements contained therein exist across a DLT (Mason, 2017). Smart-contracts are created by accounts (addresses) and can only be updated by their owners. There exists among practitioners a fear of the unknown and the doubt that a full contract automation and reduction in contractual disputes are possible when value (money) transaction is involved in particular, with an acknowledgement that smart contracts and blockchain could be beneficial for simple supply-type contracts and for reducing the amount of paperwork involved in contract administration (Cardeira, 2015; Mason, 2017; Mason and Escott, 2018). Although their outputs are not directly observable, Badi et al. (2020) suggest that smart-contracts can be applied to construction in a bilateral fashion between supply chain actors.

The fragmentation of construction requires a higher integration and trust in supply chains for better sector performance (Koolwijk et al., 2018). From a wider perspective, trust-building in construction supply chains has been mostly narrated through a relational view focusing on the actors and their interrelations to improve trust and information flows across supply chains (Maciel, 2020). Blockchain shows potential in transforming the trust in construction supply chains from relational to technological (Qian and Papadonikolaki, 2020). In short, blockchain applications can contribute to building system-and cognition-based trust in construction supply chains reducing the need for setting up relation-based trust (Qian and Papadonikolaki, 2020).

The research project of which this paper is one of the outcomes is concerned with developing blockchain-based SCM models for the construction sector. They are very few discussions available in the literature on models or working prototypes in this respect (Wang et al., 2020; Woodhead et al., 2018). Furthermore, it is recommended that researchers and practitioners validate first whether a blockchain-based solution would be suitable for their needs using one of the DLT decision-making frameworks (Li et al., 2019a; Mulligan et al., 2018). Following that validation process, Li et al. (2019a) previously identified the suitability of Project Bank Accounts (PBAs) for blockchain; however, the authors did not present any model or working prototype for PBAs. Building on these scarce discussions in the field, the authors of this paper initially ran a two-day scoping workshop in Northern England in early spring 2019 with two experienced construction project managers with interest in and knowledge of DLTs, and two experienced DLT developers. After reviewing and exploring some available candidates from the literature and practice in terms of technical feasibility, value and validity, three blockchain-based prototypes for Project Bank Accounts (PBAs) for supply chain payments, Reverse Auction-based Tendering for procurement and bidding, and Asset Tokenization for project financing (crowdfunding) were developed for blockchain integration. There is an optional link between the PBA and Reverse-Auction based Tendering model as explained in the subsequent sections (see **Figure 8**). The Asset Tokenization model was envisioned on the premise that funders or donators are part of a project supply chain. Similarly, the models were developed targeting mainly clients/owners/developers as the main users. The models are grouped under the general name of SCM as the main domain, as payment, procurement and project financing practices can be categorized under SCM in construction (Briscoe and Dainty, 2005).

For the blockchain infrastructure of the prototypes, the public and permissionless Ethereum blockchain was adopted for its scalability, relatively fast processing times and transaction affordability (Yang et al., 2020). As of October 2019, the Ethereum blockchain could process about 50 transactions per second with an average time of 20 to 60 seconds for a transaction (Etherscan, 2019). The situation of a transaction can be easily tracked online (e.g. https://etherscan.io/) using crypto addresses or transaction hash codes. As of October 2019, the average and median fees for an Ethereum transaction were $0.119 USD and $0.066 USD respectively (BitInfoCharts.com, 2019). As explained in the research method section, the models were coded with Ethereum integration, deployed online as prototypes and tested/reviewed with practitioners and academics for feedback after this initial scoping workshop.

Project Bank Accounts

Delayed or retained payments represent one of the major problems for the construction sector (Mason and Escott, 2018; Wang et al., 2017; Yap et al., 2019). A PBA is a ring-fenced bank account from which payments are made directly and simultaneously to the members of a hierarchical contracting supply chain with the aim of completing payments in five days or less from the due date (Cabinet Office, 2012). This eases cash flow through the system and supports closer working within the supply chain. According to Griffiths et al. (2017:325):

> *"Under a PBA arrangement, the main contractor submits its progress payment to the client under the main contract showing a breakdown of payments to each of the suppliers. Once approved, the client pays the total amount of the progress payment into the PBA, and payment is then made out of the PBA to each of the suppliers with the dual agreement of the client and main contractor. Direct payment to the suppliers from a PBA enables the traditional lengthy contractual payment credit terms, which typically exist in subcontracts within the construction industry, to be bypassed ensuring a much quicker flow of funds down through the supply chain. "*

According to a study commissioned by the Office of Government Commerce of the UK, public sector projects could expect to save up to 2.5% with PBAs through reduction for cash collection, cash flow risk certainty and Trade Indemnity Insurance (Office of Government Commerce, 2007). However, there have been doubts expressed questioning whether such a saving is realistic (Griffiths et al., 2017). Additionally, the Cabinet Office of the UK underlines some knock-on benefits such as greater productivity and reduction in construction disputes, and supply chain failures (Cabinet Office, 2012). In 2012, it was announced that the Government Construction Board in the UK had committed to deliver £4 billion worth of construction projects using PBAs by 2018 (Cabinet Office, 2012). In 2014, it was announced that £5.2 billion worth public construction projects were being paid through PBAs in the UK (Morby, 2014). In 2016, the Scottish government announced that PBAs would be used on all of its building projects valued more than £4 million. In 2017, the Welsh government announced that PBAs would be used on all public building projects over £2 million.

Reverse Auctions

In the procurement of goods and services, different types of auctions (e.g., English auctions (ascending), Dutch auctions (descending), sealed first price auctions, sealed second price auctions, and candle auctions) are being used. In recent years, electronic auctions have been popular due to their convenience and efficiency (Chen et al., 2018). Strategic valuation, communication, winner and payment determination are critical issues while executing open-bid auctions (Chandrashekar et al., 2007). Electronic reverse auctions as a form of auction for supply chain procurement have been adopted widely in many sectors with price benefits of the order of 20% through price competition (Wamuziri, 2009). Reverse auctions are essentially Dutch auctions where the auctioneer starts by setting a relatively high price that is then successively lowered until a bidder is prepared to accept the offer (Shalev and Asbjornsen, 2010). A reverse auction involves an auctioneer setting the starting bid and inviting bidders, who are generally pre-qualified suppliers, to compete in successive rounds of downward bidding. The auction will close when no new bids are received and the closing time has expired (Wamuziri, 2009).

The process is relatively simple, reasonably quick, iterative as competitors are able to submit more than one bid, and provides price competition (Hatipkarasulu and Gill Jr, 2004; Wamuziri and Abu-Shaaban, 2005). However, service providers, suppliers and contractors in particular are concerned with the structure of electronic auction systems that is prone to unethical behavior such as bid shopping (i.e., disclosure of the lowest bid received to pressure other bidders to submit even lower bid) and shill bidding (i.e., when someone bids on a product or service to artificially increase or decrease its price) (Majadi et al., 2017; Wamuziri, 2009). Therefore, reverse auctions are deemed better suited to perishable items such as hand tools and consumables, in other words, for items and services for which many suppliers of similar utility or quality features are available in the market (Pham et al., 2015). To help resolve the trust problem and to eliminate the third-party intermediary costs for the auction validation, it is suggested that blockchain can be adopted for public and sealed bids (Chen et al., 2018; Galal and Youssef, 2018).

Asset Tokenization (Crowdfunding)

Crowdfunding is a financing method which allows entrepreneurs, small businesses or projects, through a crowdfunding platform, to collect funds from a large number of contributors in the form of investment or donation. In comparison to the conventional funding collected from a small group of high-level investors, each individual funder normally needs to invest only a small amount. Therefore, a crowdfunding platform obviates the need for conventional intermediaries such as banks, which are often an obstacle to access financing, especially for small and innovative enterprises (Belleflamme et al., 2014; Dorfleitner et al., 2017). Furthermore, the costs of crowdfunding platforms are lower than finance institutions' (Lam and Law, 2016). There are four distinct crowdfunding forms. These are donation-based crowdfunding, reward-based crowdfunding, crowdlending, and equity crowdfunding (Dorfleitner et al., 2017). Asset tokenization involves turning a tangible or intangible asset into a digital token for crowdfunding where the associated ownership and transactions are recorded on blockchain for immutability and security. Tokenizing assets can help simplify fundraising, especially for start-ups, small businesses, or non-traditional, innovative enterprises. In theory, companies and individuals can sell tokens as if they are stock interests, by-passing the onerous rules and regulations of the finance sector.

Research Methodology

This study follows the Design Science Research (DSR) methodology. The methodology differs to other explanatory approaches, and tends to focus on describing, explaining and predicting the current natural or social world, by not only understanding problems, but also designing solutions to improve human performance (Van Aken, 2005). It involves a rigorous process to design artefacts to solve observed problems, to make research contributions, to evaluate designs, and to communicate results to appropriate audiences (Hevner and Chatterjee, 2010). The DSR process commonly involves the problem identification and motivation, design and development, demonstration, evaluation and communication elements (Peffers et al., 2007). Due to its applied character, DSR is adopted for problem solving in real world through innovation and creation of solutions. Such solutions could be artefacts, theoretical models, algorithms, process models that can contribute to creating new theories (Peffers et al., 2007). Three blockchain-based working prototypes (i.e., Project Bank Accounts, Reverse Auction-based Tendering and Asset Tokenization) were developed for this study as the DSR artefacts.

To ensure relevance to the real world, this study has adopted an iterative research process with feedback loops from application to development (Holmström et al., 2009). To this end, the research process was divided into the following stages and steps, considering the DSR elements:

- ***Stage 1: problem setting/understanding - for problem identification and motivation, and initial artefact design and development***
    - *Step 1: Literature review*
    - *Step 2: Scoping workshop*
    - *Step 3: Initial model development*
- ***Stage 2: artefact development -for detailed artefact design and development***
    - *Step 4: Detailed model development and coding for Ethereum*
- ***Stage 3: analysis and testing – for demonstration, evaluation and communication***
    - *Step 5: Three focus groups for model validation and feedback collection*
    - *Step6: One workshop for model validation and feedback collection*

Stage 1 starts with problem identification and motivation. At this stage, there is a need to carry out primary research to investigate and determine the nature and prevalence of the problem. The research could involve self-interpretation through reflection or an initial literature review (Hevner and Chatterjee, 2010). Diagnosing the problem was achieved through the existing knowledge base by reviewing the literature (Step 1) (scientific articles, industry reports, and code snippets). Consequently, no substantial exemplary use cases or working prototypes for blockchain-based SCM models for construction were identified. March and Smith (1995) suggest that DSR artefacts need to be evaluated against the criteria of value or utility, which are adopted in this study. To guarantee the utility of the artefacts, the theoretical input was combined with input from practice, first through the initial scoping workshop (Step 2) later in Stage 1, and then through the analysis and testing of the artefacts in Stage 3. The initial scoping workshop helped define the scope, focus and objective of the solution(s), which is to enhance the identified SCM practices in the construction sector through blockchain.

In Stage 2, considering the aforementioned objective, the artefacts were developed in terms of their frontend/backend coding, online deployment and testing (Step 4). Creating a technological solution in DSR requires that the process can be automated and the solution facilitates a change/improvement in current work practices (Hevner et al., 2004).

In Stage 3, the artefacts were analyzed through three focus groups and a workshop with 28 participants for feedback collection, following a protocol as suggested in construction management and automation research (Hamid et al., 2018; Osman, 2012; Tetik et al., 2019; Wang et al., 2014). The utility of DSR artefacts must be demonstrated via evaluation methods (Hevner et al., 2004). The focus group and workshop participants were asked of the potential of the artefacts (working prototype models) in enhancing and improving the current SCM applications in question as well as the applicability of the artefacts in practice. See **Table 1** and **Table 2** for details of the focus group and workshop participants respectively.

Interaction and collaboration are key aspects of this type of evaluation, where the participants and the evaluator can both ask questions while testing the artefacts, and the evaluator can guide the participant in the right direction while using the prototypes. The focus group participants were given the opportunity to directly interact with the prototypes after a demonstration. The prototypes were demonstrated to the workshop participants on a large screen, and although they could not control the prototypes directly, each element of the prototypes was gone through with the participants answering their questions for each step. The research process can be seen in **Figure 1** with each step involved in the three main stages and their objectives in brackets. The first feedback for the prototypes was collected from the scoping workshop participants after finalizing the model development process (Step 4). They recommended some model usability and interface related changes, which were incorporated in the prototypes. Feedback was also collected from the analysis and testing stage (Stage

3), which is summarized in the model feedback and evaluation section. However, most of the requirements/feedback from this stage are strategic, long-term focused and comprehensive in nature, requiring a full participation of supply chain stakeholders for future efforts.

(Please insert Figure 1 around here)

(Please insert Table 1 around here)

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Models Requirement and Development

Model development details, including the demand and justification for each model, the architectures for the working prototypes, and their integration with Ethereum are explained in this section. The development process took place over Stage 1 and Stage 2 in the research process (see **Figure 1**).

Project Bank Accounts (PBA) Model

Demand for a PBA model and problem setting

Smart contracts can embed funds into a contract, which will protect contractors, subcontractors and other supply chain members from insolvency (Wang et al., 2017). They could automate the -currently manually administered- principles of payment under a PBA, increasing efficiency, decreasing pay-out time, and minimizing the risk of fraud, back-office costs and other operational risks (Nowiński and Kozma, 2017). The appropriateness of the PBA arrangement for blockchain was identified in the literature (Li et al., 2019a). However, no real model or working prototype has been identified to validate such an arrangement. Therefore, the purpose of the proposed PBA model on blockchain is to automate and streamline the payment process through a construction supply chain, and to render it more secure, traceable and transparent.

Development of the PBA model

The modelling requirements are that this payment model will be adopted mainly by public and large client organizations as envisioned previously (Li et al., 2019a), where upon the creation and approval of a payment for a work package by the client, the payment is executed instantly over cryptocurrency through the supply chain members. Therefore, a blockchain-based payment model mimicking PBAs was developed as shown in **Figure 4**. The model was coded (https://github.com/huddersfield-uni-smart-contracts/contract.eth) to integrate with Ethereum and deployed online (https://contract-eth.herokuapp.com/) for demonstration and feedback collection purposes. The escrow arrangement was adopted in the model, which is a financial arrangement where a party holds and regulates the payment of funds required for two parties involved in a given transaction. It helps render transactions more secure by keeping the payment in an escrow account, which is only released when all of the terms of an agreement are met as overseen by the escrow company (O'Neil, 1986).

(Please insert Figure 4 around here)

In **Figure 4**, the client (owner of the contract and the transaction executor) creates the initial escrow smart-contract, which details the requirements needed to fulfil the contract. After being approved by a validator, the client will build the second smart-contract for payments. The payments smart-contract details the rules for payments to be executed for the supply chain members. The accounts on the system are created and validated using each party's unique crypto-wallet code, a unique code that allows cryptocurrency users to store and retrieve their digital assets, which is also used for the value transaction. A validator is an account which approves/rejects transactions from the client into the escrow. The validator could be a senior contract manager at the client organization or a Tier 1 contractor responsible for supervising the task executions in the supply chain. The payment smart-contract is responsible for holding the information about the payment variables. Payments can be withheld for different reasons such as the work package not being completed to the required standards or problems arising. The task of the validator is to step in when there are disagreements, but otherwise, the monetary flow should be left untouched. See **Figure 5** and **Figure 6** for the smart contact creation and approval respectively.

(Please insert Figure 5 around here)

(Please insert Figure 6 around here)

Smart-contracts authenticate and validate the transactions blockchain real-time with full traceability of who does what and when. In addition to reducing contract execution related disputes, which is very common in construction (Cheung and Pang, 2013), this system may reduce the costs associated with procurement administration. They instantly generate electronic documents in contrast to the traditional process, which necessitates the use of hard copies of documentation and authentication by a third party (Wang et al., 2019). The transactions of creating, approving or rejecting the contracts, creating the second contract and executing the payment to the supply chain take approximately 80 -240 seconds by the prototype on Ethereum. For reference, bank payments need between three to five workdays for the payments to be fully processed and settled. Comparisons between cryptocurrencies and credit/debit cards should be excluded, given the later are payment processors, not payment settlers, a function executed only by banks.

Reverse Auction Model

Demand for an Auction Model and Problem Setting

Unlike PBAs, no comprehensive discussion on the suitability of electronic reverse auctions for blockchain was identified in the literature. To check that suitability, the decision-making framework developed by the World Economic Forum (WEF) (Mulligan et al., 2018) to support businesses in assessing whether a blockchain or DLT-based solution would be suitable for their needs was used at the initial scoping workshop. The decision-making framework was gone through with the scoping workshop participants to validate the implementation of blockchain by answering the *yes-no* questions shown in **Figure 7**. The green arrows on **Figure 7** represent the answers for each decision-making point. Depending on the required level of transaction control and transparency, a strong case for both public and semi-public/private blockchain was found for transaction recording.

(Please insert Figure 7 around here)

Development of the Auction Model

After this initial validation, a blockchain-based reverse auction model was developed (https://github.com/huddersfield-uni-smart-contracts/auction.eth) as shown in **Figure 8** to integrate with Ethereum and deployed online (https://auction-eth.herokuapp.com/). As shown by Galal and Youssef (2018), to apply smart contracts to the auction process, bidders submit homomorphic commitments to their sealed bids on the contract. Subsequently, they reveal their commitments secretly to the auctioneer via a public key encryption scheme. Then, according to the auction rules, the auctioneer determines and announces the winner of the auction. After the winner is confirmed by the validating party, and the workflow comes to an end, the escrow smart-contract as explained in the PBA model could optionally manage the payment workflows to mimic PBAs. Both smart contracts could be linked so that after the bidding process is completed, the winner can enjoy the continuous advantages of having payments going through a linked smart contract.

In **Figure 8,** the purpose is to allow clients to deploy Auction smart-contracts so that approved companies in the ListBid smart-contract can bid for work packages (quantities, milestones, payments conditions) represented by the WorkPackage smart-contract. When a bid is accepted by the client, that information is automatically recorded in a Procurement smart-contract that is only accessible by the client and validators. The client creates a ClientCompany smart-contract with all information regarding the transaction, which contains the work package information and auction results, and can be verified by anyone. The nodes represent the agents interacting in the smart-contracts. The agents can be: (i) owners, as in the addresses (clients) responsible for creating the smart-contracts; or (ii) companies, as in the agents that participate in the auction bidding. The company nodes represent companies that are bidding for the work package. The client is able to short-list a few bidders and invite them for further negotiations, if need be. The transactions of creating the contracts, contract bidding, accepting the winning and rejecting the losing bids, and contract finalization take approximately 120 – 360 seconds on Ethereum, considering only the party with the most steps (contract creator and finalizer) in the prototype.

(Please insert Figure 8 around here)

Asset Tokenization (crowdsale/crowdfunding) Model

Demand for an Asset Tokenization Model and Problem Setting

Transparent crowd-sale, commonly known in the crypto-sphere as a Decentralized Autonomous Initial Coin Offering (DAICO), is a decentralized way of raising funds within a specific blockchain protocol – usually Ethereum – in order to develop a project, idea or company (Adhami et al., 2018). The DAICO contract starts in a "contribution mode", specifying a mechanism by which anyone can contribute to the contract and receive tokens in exchange. This could be a capped sale, an uncapped sale, a Dutch auction, an interactive coin offering with dynamic per-person caps, or some other mechanism the team chooses. Once the contribution period ends, the ability to contribute stops and the initial token balances are set. From there on, the tokens can become tradeable (Butterin, 2018). By creating a public sale, communities could raise auditable funds for construction projects and allocate them transparently to companies, developers and client organizations looking to undertake such projects (crowdfunding) (Wang et al., 2017). This is also the purpose of the developed model. Blockchain is well-suited for the financial and management needs of that kind of a token-based asset transaction (Chen et al., 2018; Mason, 2017; Wang et al., 2017).

Development of the Asset Tokenization Model

A blockchain-based project crowd-sale/crowdfunding model was developed as shown in **Figure 9**. The model is considered to be used for either donation or investment purposes, where upon the creation of the tokens for a project or its parts, the funds are collected and tracked over crypto-tokens. The model was coded (https://github.com/huddersfield-uni-smart-contracts/tokenit.eth) to integrate with Ethereum and deployed online (https://token-eth.herokuapp.com/).

(Please insert Figure 9 around here)

In the proposed model (**Figure 9**), the party seeking investment (owner address) creates a Token smart-contract which functions as "shares" or "representations of the money given to complete a milestone". After the approvals are put in place, a Whitelist smart-contract is created to allow for the previously approved addresses to participate in the crowd sale. This means that the funders or donators are able to participate in different stages of the funding, depending on the investment seeking party's needs. When the tokens are issued, they can be destroyed or given utility depending on the purpose of the crowd sale. For example, the tokens may enable companies to vote on how the funds to be used or can be traded for money in the future, much like regular shares. Depending on the purpose and goals of each investment seeking party and milestone, the token-utility can be adjusted. In **Figure 9** for instance, after the Token, Whitelist and Crowdsale contracts (Milestone 1 and Milestone 2) are created, Company A participates in the initial milestone funding while Company B participates in the second milestone funding. In **Figure 9**, the nodes represent the agents interacting with the smart-contracts. Agents can be: (i) investment seeking parties, as in the addresses (clients) responsible for creating the smart-contracts; or (ii) companies, as in the agents that participate in the crowd sale. In this example, the client uses two different owner accounts to manage the smart-contracts. This could be a security measure to avoid one account owning all the decision-making power. The company nodes represent the entities willing to fund the project.

(Please insert Figure10 around here)

The tokenization smart-contract will enable individuals and organizations to fund projects by milestones, and track the funds transparently. If aligned with automated payments (escrows), it is possible to enable a new way of distributing value among all the network participants. Crowdfunding on blockchain may help projects by streamlining and democratizing their funding needs with full traceability.

Model Implementation and Integration with Ethereum

The implementation of the proposed models requires building and storing an Ethereum architecture, as in a private Ethereum node, to verify the transactions and to store the blockchain data. The Ethereum node holds the private-public key-pair that signs the transactions by sending Ether (Ethereum's digital asset bearer – similar to a bond or other security) (Atzei et al., 2017) to another agent or to a smart-contract. Any application will be able to connect to the private node by submitting transactions or by querying the node for information. The communication between an application and the node is through a JSON remote procedure call (RPC) interface as represented in **Figure 11.**

(Please insert Figure11 around here)

The private Ethereum node is responsible for broadcasting the transactions to the entire Ethereum blockchain. To an outside source, this will seem like a regular transaction, even though there will be instructions encoded in the transaction bytecode that can only be accessed by the smart-contract operators, achieving a certain degree of privacy even in a public distributed ledger. Older applications, such as traditional Web 2.0 applications, can easily communicate with the newer Web 3.0 applications through the application programing interfaces (APIs) connecting to distributed Ethereum servers (e.g., Infura).

Although one can use cloud-based services to store the apps information (server-side) in a private manner and can still adopt a public-blockchain ledger to store the transaction data, it is assumed that private-blockchains may be preferred in practice by subscribers of the cloud services offered by some of the largest technology conglomerates (e.g., IBM, Microsoft, Google, Amazon). In essence, if an organization chooses to opt for blockchain-as-a-service (BaaS), they will not be running their Ethereum private node, meaning they are not verifying transactions and trusting a third-party machine to do so, which defies some of the purposes of blockchain implementation-cases. A representation of the architecture for such an arrangement, which was also envisioned for the prototypes, can be seen in **Figure 12**. The architecture mimics a public chain executed on a cloud-server computer. By using cloud-services, private-chains that use tokens to exchange value can be deployed quickly instead of needing to use the Ethereum-public chain.

(Please insert Figure12 around here)

Model Feedback and Evaluation

The feedback collected for the blockchain-based SCM models/working prototypes, and blockchain implementation in the construction sector in general from the focus group studies and workshop is summarized in this section by each model, which was realized in Stage 3 in the research process (see **Figure 1**).

Focus Groups for Model Evaluation and Feedback

PBA Model

The focus group participants found the PBA model applicable in a shorter-term particularly in open-book or partnering/alliancing type procurement arrangements, where through the model, as stated by one of the participants, one can achieve "a true open-book arrangement". The system was noted as a potential first step or gateway to the DLT and blockchain world for construction organizations. According to the participants, the model could be of immediate interest to clients dealing with a large group of suppliers such as public client organizations, housing associations and councils in the UK. The participants found the model's application relatively simpler provided regulatory and contractual bases for the model are in place. Another potential benefit of the model was found in achieving traceable and correct taxation through payments for governments. The transparent payments discussion was presented as a "double-edge sword", where although automation and streamlining of the payment approval process would be beneficial to the sector, the participants questioned whether clients were ready to transparently automate payments to such degree. They underlined clients' need to control value transfer and the culture of using payment control as a source of power in the sector. Also, it was noted that most of the delays and issues associated with payments to supply chains are due to clients' and Tier 1 contractors' slow internal processes, which should also be streamlined alongside the model. There is also politics involved, where gatekeepers use the payment process as a bargaining tool for projecting power to their supply chains. Another concern highlighted by the participants is data resilience for the correct data to be used for automated payments on the immutable blockchain, which will be demanded by clients. A link between the PBA model and the existing accounting systems was requested by the participants. The payment mechanisms in the standard form of contracts (e.g. NEC and JCT) should be incorporated in future blockchain-based payment systems. Beyond payments and the procurement process, the focus group participants also underlined the relevance of recording near critical data from site operations, such as wind speed and ambient temperature, for blockchain.

Reverse Auction Model

A high value potential was attributed to the reverse auction model by the participants, particularly for inducing transparency, record-keeping, audit trailer and data security in obtaining best price in e-reverse auctions or in public/government procurement. The participants also found the system potentially inclusive for smaller service providers, which large clients want to support in the sector as there is not much investment required from those smaller organizations other than having a crypto-wallet address to participate in the proposed decentralized system. However, the participants noted the implementation of the reverse auction model would be more complex. The issue with the legacy IT systems in the construction sector that need to be aligned with a blockchain-based environment was highlighted as a general barrier. Moreover, to render the system fully transparent and trustworthy, it was found necessary to link the system with the emerging digital organizational identification document (ID) and passport initiatives on blockchain as a future improvement suggestion. This will also support awarding the best value service or product provider beyond just the price parameter, where a client will be able to see the past performance of different bidders in a trustworthy fashion. The participants highlighted that insurers for the sector would be highly interested in the digital passport idea for tendering arrangements. Due to the required scale of implementation and the need for incorporating the existing auction-based procurement and tendering regulations, the reverse auction model was found more difficult to implement than the PBA model with a higher potential value to the sector nevertheless. To render the prototype more scalable, it was suggested that some auction limitation options such as time or price limit could have been added. This was incorporated in the prototype. Who should bear the cost of recording the transactions was also a subject of discussion among the focus group participants. Some participants believe if the cost of transactions on blockchain is transferred to the bidders, that may encourage them to consider their bid more carefully before submitting it. This led to discussions on the cost uncertainty and volatility of cryptocurrencies, which in some form are necessary to record the transactions on a public blockchain, consequently rendering cost forecasts for the procurement and tendering processes more difficult for both clients and service providers.

Asset Tokenization (crowdfunding) Model

The crowdfunding application of the asset tokenization model for donation purposes was found easy to implement with a high potential in rapidly and transparently raising donations for construction projects, which may be of immediate interest to communities, councils and aid organizations. However, for investment purposes, the participants noted that implementing the model would be complicated as the value of tokens is subject to serious fluctuations at the moment. This will potentially put investors off without any return guarantee on the tokens. Additionally, in the cryptocurrency space, most of the utility tokens cannot distribute dividends. A potential remedy for this, until a significant portion of commerce/business in the future is executed on smart contracts and crypto tokens, can be having specific investment tokens issued by governments, big conglomerates (e.g. Facebook's crypto coin Libra) or super-national organizations such as the EU. This may lead to a stock-exchange market like establishment in the sector for asset tokens. The participants agreed that one other way of overcoming the investment barrier through tokens on blockchain for project development is having an *oracle*, an intermediary identity between the conventional and crypto asset worlds. The *oracle* regulates the amount of dividend or benefit the investors of a project will receive based on their token quantities in hand as project shares. However, the *oracle* could still be manipulated through different methods such as corruption, bribery, misinformation etc. According to the participants, another complication or question relating to the investment through tokens is whether or not the token holders will have or demand voting rights for project management and governance. This will introduce further complications to the asset tokenization issue. There was a general agreement on that the potential integration of the models with digital passports on blockchain for identity trust will enhance the models' value and adoption in the future. The participants underlined the relevancy of blockchain for legal project documents beyond contracts such as planning and development permissions. The participants think the asset tokenization model for investment will be of interest to investors and asset developers in particular. A summary of the findings from each focus group can be seen in **Table 3.**

(Please insert Table 3 around here)

Blockchain Workshop

The attendees mostly attributed a very high or high value to the PBA model (see **Figure 13**). The applicability of the PBA model was also found relatively easier than the other models. The need for streamlining internal payment processes with the PBA prototype was highlighted by the workshop attendees as well. Also, some attendees mentioned the need for convincing client organizations and main contractors for faster/direct payments, which may make them feel insecure in terms of controlling their projects and supply chains. Some discussions about changing the culture in the sector for more openness and collaboration were conducted.

The attendees mostly attributed a high or moderate value to the reverse auction model. The applicability of the model was found easy or moderate. The attendees argued that although the system has potential in increasing trust and transparency in auction-based tendering arrangements, suppliers and service providers in the sector are generally hesitant in participating in reverse auction tenders. The integration of the model with digital passports may further increase trust in those tender arrangements. This may possibly change the attitudes of the service providers and suppliers.

The attendees generally saw a high potential in the asset tokenization model for both investment and donation purposes. However, the applicability of the model, particularly for commercial investment purposes, was found moderate or difficult. Similar to the focus groups, the attendees indicated a mechanism to stabilize the value of the investment tokens is necessary to render the model attractive for investors. The results of the questions regarding the applicability and value of the models that were obtained from the workshops participants through an online audience interaction system can be seen in **Figure 13.**

(Please insert Figure 13 around here)

Discussion and Conclusion

Blockchain is an emerging technology with potential to disrupt the SCM practices in many sectors, including construction. However, the technology is still immature and its requirements, consequences, and value have not been well-understood yet. The lack of empirical research beyond conceptual discussions is more evident in construction. To some, blockchain is a hyped buzzword that will fade in time or fall short in living up to its hype, and to some it offers a revolution in value transactions (Hunhevicz and Hall, 2020). In this context, three SCM workflows suitable for blockchain were identified. Three blockchain-based models for the SCM workflows as working prototypes for the construction sector were presented with their feedback from academics and practitioners as part of the DSR approach. In this section, the potential benefits, opportunities as well as the challenges and requirements, specifically for the models/prototypes and generally for blockchain in construction, are summarized and discussed as the final contribution of this research. The findings in general confirm blockchain's potential in solving the sector's problems associated with streamlined and transparent payments and tendering processes (Kinnaird and Geipel, 2017; Li et al., 2019a; Wang et al., 2017) as well as easier access to project finances (Elghaish et al., 2020). However, they also highlight the sector's expectations for the technology's maturity for its day-to-day use (Li et al., 2018), calling for a wider view to blockchain with its potential implications beyond its benefits. The rest of this section elaborates on these points. A summary of the highlights of the models alongside their benefits against the traditional workflows can be seen in **Table 4**

(Please insert Table 4 around here)

Blockchain Benefits and Opportunities

The identified benefits of blockchain for construction SCM from this study is a combination of the proposed models' features, Ethereum characteristics and blockchain capabilities in general. In this section, the model/prototype specific benefits as well as the common benefits shared by the three models/prototypes are summarized;

PBA Prototype

- Of the three prototypes, the PBA prototype could be implemented first with its simpler requirements acting as a gateway for further DLT applications (see **Figure 13).** On the other hand**,** despite their more complicated requirements and needs, the auction and tokenization prototypes may lead to large-scale impacts in longer terms (see **Figure 13** and **Table 4**).
- Payment transaction times can be streamlined when compared to the conventional methods through the PBA prototype (approximately 80 -240 seconds on Ethereum versus bank payments needing between three to five workdays).
- It is deemed of value especially for clients managing large supply chains with many suppliers and service providers with expedited payments.
- Correct taxation monitoring can potentially be facilitated.
- Further payment automation is possible through the prototype's integration with other technologies such as sensor networks for site data input.

Reverse Auction-based Tendering Prototype

- Integration of the tendering and payment processes into a single collection of information that will create the basis for an integrated approval and value transaction system ,which has been deemed of value for the sector (Das et al., 2020; Dujak and Sajter, 2019).
- Increased inclusivity for smaller tenderers can be achieved with its simpler working mechanisms and access features, which is a priority for larger clients.
- Reduced transaction times when compared to the conventional project financing and tendering arrangements with lengthy regulatory durations (Ashuri and Mostaan, 2015), which take on average 120-360 seconds on the reverse auction prototype.

- Unethical practices such as shill-bidding in procurement (Ahsan and Paul, 2018) can potentially be overcome.

Asset Tokenization (Crowdfunding) Prototype

- Easy access for smaller service providers and suppliers to project financing instruments, helping large clients with supporting smaller organizations for inclusivity and social sustainability (Kuitert et al., 2019; Montalbán-Domingo et al., 2019).
- Increased accessibility to commission-free project financing for investment or donation over DLT tokens without having to include third-party organizations as in the traditional project financing.
- Further democratization in project governance through issued project tokens, if voting rights are given to the token owners.
- With support from super-national organizations such as the EU, mass use of blockchain systems by the public, potentially leading to a crypto token-exchange market for construction investments and web services for construction tendering.

Common Benefits and Opportunities

Increased transparency is a common benefit of the prototypes as the transactions can be easily tracked online (e.g. https://etherscan.io/) in terms of where in the process any transaction is sitting, which is a key concern in conventional SCM practices (Meng et al., 2011) and in establishing cooperative partnerships (Gunduz and Abdi, 2020). Similarly, all stakeholders can participate and input information in the models at any time, and data is available to all relevant parties for augmented interoperability. The prototypes present an advantage over the conventional relational databases, where the traditional workflows sit, in terms of providing a robust, fault-tolerant way to store critical data on Ethereum (Galal and Youssef, 2018), which most of the SCM data (commercial) can be categorized as. Moreover, Ethereum transaction fees are affordable at the moment ($0.066 USD median cost per transaction) against the expensive database investment and maintenance costs. The prototypes' being open-source and flexible, as consortia on Ethereum are not locked into the IT environment of a single vendor, should be also underlined. As identified from the focus groups, the prototypes can facilitate relational contracting practices, and new business and cooperation models by helping achieve a true open-book arrangement and transparent transactions for payments (Koolwijk et al., 2018). The frequently pronounced transparency and openness induced by the prototypes support the claim that blockchain may help change the trust-building in construction supply chains from relational (soft) to rational (technological) (Qian and Papadonikolaki, 2020) so that entities can trust the information but not necessarily each other (Lumineau et al., 2020).

Blockchain Requirements and Challenges

The empirical findings from the model development process confirm the general requirements for blockchain in the construction sector, some of which have been conceptually outlined in the literature;

PBA Prototype

- The prevalent business culture (power dynamics) in construction supply chains, using payments as a power projection mechanism (Wang et al., 2017), should be challenged for the adoption of automation in payments as in the PBA prototype.
- Blockchain-based systems' current compliances with the existing accounting systems, regulations/frameworks, standard contracts and laws should be increased (Li et al., 2019b), which was also identified from this study.
- As identified from the focus groups and workshop, mechanisms allowing to modify the immutable data (e.g. payment amounts in case of any payment changes, change orders or penalties) (Das et al., 2020) are required in blockchain-based applications.

Reverse Auction-based Tendering Prototype

- The need for blockchain-based systems' compliance with the existing accounting systems, regulations/frameworks, standard contracts and laws (Li et al., 2019b) was also identified over this prototype.
- Fluctuating and volatile token values and transaction costs may pose various challenges for the execution of this prototype. In line with this, there is a need for clarifying what party will bear the transaction costs in blockchain-based tenders.

- Suppliers' and service providers' negative perceptions against some blockchain-suitable tendering arrangements (e.g. reverse auction) (Assaad et al., 2021) in the sector may pose a challenge for the prototype.

Asset Tokenization (Crowdfunding) Prototype

- Fluctuating and volatile token values and transaction costs on blockchain may pose various challenges for the execution of this prototype as well.
- Complications regarding the governance of projects with many token-holders.
- The current technical challenges associated with distributing and controlling dividends over blockchain will affect the adoption of the prototype for investment purposes.

Common Requirements and Challenges

The need for upscaling the legacy IT systems in the sector for blockchain, which is highlighted in the literature (Tezel et al., 2020), was also identified from this study. The sector practitioners emphasized that validating the real-life data to be recorded on blockchain is necessary. This increases the importance of data resilience questions from real-life to digital in the sector in terms of controlling the boundary between the physical and virtual world for fraudulent activities (Kshetri, 2018; Sulkowski, 2019). In that regard, legislative reforms to confirm the immutability of data stored on blockchain along with the elucidated rights and primacies related to funds arranged in smart contracts will be required. Streamlining internal/organizational processes in line with blockchain, potentially through some enabling technologies such as digital passports, remote sensing or the IoT (Li et al., 2018), will be necessary for fully exploiting the blockchain features. Further maturity in the technology to execute multi-party SCM arrangements (e.g. reverse tendering and project tokenization) with shared value (Blockchain 2.0) and digital identity (Blockchain 3.0) capacities respectively (Swan, 2015) is essential. An expectation for more blockchain use cases executed by informed individuals (human-resources) for further blockchain validation was observed. This may be understood as a cautious requirement for blockchain business case. The amount of potential employment loss in the sector due to the automation and P2P transactions facilitated by blockchain is a general concern.

Beyond those generic requirements and challenges, future blockchain based models should be analyzed for their specific requirements and challenges as identified from the asset tokenization (crowdfunding) model for investment, for instance, where the issues of dividend payments, project governance rights and the requirement for a prevailing crypto-token by national or super-national legislative bodies came to the fore. Furthermore, questions relating to the practical application of the models such as who (client, service providers or both) will bear the transaction costs on a DLT and perhaps more importantly, who owns/operates (i.e., joint or single ownership of an actor(s)) blockchain-based solutions for SCM arrangements in the sector may lead to interesting discussions and findings. Blockchain protocol-wise, it is suggested that organizations fully understand the trade-offs and compromises across the different protocols and not consider the private and permissioned protocols only due to some reservations relating to "losing the control" (Wang et al., 2019). Large and public clients in particular are in the "wait-and-see state" and looking for guidance from policy -makers (e.g. frameworks) to position the technology in their day-to-day workflows at the moment. Summary of the general and model specific findings can be seen in **Figure 14,** where the opportunities and benefits are grouped on the left, and the challenges and needs are grouped on the right.

(Please insert Figure 14 around here)

Conclusion and Future Directions

The real-life implementation of the prototypes could not be realized within this study, which is a research limitation. The authors intend to test the models empirically in real-life construction projects as a follow-up study. As for future steps for the models, linking the models with digital passports (ID) on blockchain is deemed to be an important milestone. Alongside the development and investigation of actual implementation cases, identification of key project or asset information/document types to be recorded on blockchain over the project life-cycle presents another prospective research opportunity. In this regard, systematically analyzing SCM workflows in the sector for blockchain-suitability by following a decision-making framework as demonstrated in the reverse auction model's development constitutes a research opportunity. Some of the SCM workflows that could be considered for this analysis are product and service provider authentication (e.g. responsible sourcing, licensing), logistics management and tracking (e.g. off-site/prefabricated components), property/project/shareholder portfolio data management on a DLT, life-cycle data management on a DLT for plant, materials and components, legal documentation and approvals (e.g. planning/building permissions, land registry records), due diligence workflows, contractually binding documentation (e.g. change orders), tendering decisions over different stages (e.g. two-stage tendering or negotiation), project sponsors' or core-groups' meeting records in relational contracts and data transactions for handover/facilities management .

Additionally, developing a blockchain benefit realization model with quantifiable benefit parameters, understanding the change requirements for blockchain in the current procurement systems/structures, how DLTs can positively or negatively affect digitalization, and their implications on data management and flow in construction supply chains will be useful. Investigations into the interaction between blockchain and other popular technologies such as remote sensing, the IoT, data analytics and BIM will increasingly continue. The definition and role of data resilience in the DLT era, reviewing the standard payment mechanism, contracts, procurement and commercial laws and regulations for DLT, analyzing the implications of important decisions on SCM practices such as what blockchain protocols to be adopted or who should own and govern the DLT arrangements, and investigations into steps toward establishing blockchain process standards for the construction sector remain as important topics of future research in this domain.

Data Availability Statement

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

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Table 1. Focus group studies

Focus Group	Supply Chain Role	Participants	Years in Industry
1	Contractor	Operations Director	20-25
		Finance Manager	20-25
		IT Systems Manager	15-20
		IT Systems Developer	15-20
		Non-Executive Director	25-30
2	Academia/ DLT Application Development	Professor of Construction Project Management	25-30
		Professor of Supply Chain Management	20-25
		DLT Developer	10-15
		DLT Developer	10-15
3	Client	Procurement Manager	15-20
		Senior Quantity Surveyor	15-20
		Contract Manager	20-25
		Commercial Manager	20-25
		IT Systems Manager	15-20
		Project Director	25-30

Table 2. Workshop participants

Workshop Attendees' Background	**Number of Attendees**
Academia	10
Contractor	4
Client	4
Consultant	3
Designer	3
IT Professional	2
Maintenance/Facilities Management	1
Public Servant/Government	1
Total	**28**

Table 3. Summary of the focus group studies

		Focus Groups					
Model Name		***Contractors (Focus Group 1)***		***Blockchain Developers and Academics (Focus Group 2)***		***Clients (Focus Group3)***	
		Application	**Value**	**Application**	**Value**	**Application**	**Value**
Project Bank Accounts (Escrow Payments)		Easy	High	Easy	High	Easy	Moderate
Reverse Auction based Tendering		Doable	Very High	Doable	Very High	Doable	High
Asset Tokenisation	***Crowdfunding (Donation)***	Easy	High	Easy	High	Easy	High
	Investment	Not so Easy	Very High	Not so Easy	Very High	Not so Easy	Very High

Table 4. Highlights from the developed models

Developed Models	Requirement	Process	Advantages over Traditional Workflows	Overall/Long-term Benefits	Issues
Project Bank Accounts (PBA) model	Automating payments to the supply chain members to be a substitute for the conventional PBA	Overcoming gatekeepers for interrupted value flow through (almost) immediate and transparent payments	Quicker payments (approximately 80 -240 seconds) for minimal transactional costs ($0.066 USD median cost/transaction)	Ensuring a much quicker flow of funds down through the supply chain	Sector culture related issues that may not favor automated payments,
	Protecting contractors, subcontractors and other supply chain members from insolvency	Creating, validating, authenticating and auditing contracts and agreements in real-time, across borders	Transparent tracking and execution of payment transactions and secondary liabilities such as taxes at all times.	Reducing contract execution related disputes, reducing costs associated with administration of procurement	Need for integrating the model with clients' accounting systems
Transparent reverse auction model	Allowing transparency and facilitating the identification of best-value bids in reverse auctions	Relatively simple, reasonably quick, and iterative	Allowing competitors to submit more than one bid, and providing price competition with less regulatory processing-automation of regulatory tendering tasks.	Paving the way for the creation of a web-based project tendering system on blockchain for the public.	Need for integrating the model with digital IDs, accounting systems and the existing contracts and frameworks
	Allowing clients to deploy Auction smart-contracts so that approved companies can bid in work packages. The payment mechanism	Transactions of creating the contracts, contract bidding, accepting the winning and rejecting the losing bids, and contract finalization	Helping overcome the transparency and bid ethics related concerns surrounding reverse auctions at reasonable transaction costs ($0.066		

	is linked with the PBA model.		USD median cost/transaction) and transaction speeds (120-360 seconds) with increased inclusivity for smaller organizations.		
Asset tokenization (crowdfunding) model	Creating tokens for a project or its parts, collecting funds and tracking over crypto-tokens	Holding the information about the token being created, the approved companies' information, and each crowd sale milestone	Quick access to project financing sources for both small and large organizations (crowdfunding) without third party costs, lengthy regulatory procedures and financial liabilities Enabling individuals and companies to easily fund projects by milestones (project progress) for investment or donation purposes, and track/audit their funds transparently	Paving the way for the creation of a token-exchange market similar to the stock-exchange market for project financing, investment and governance	Issues with fluctuating token values, dividend payments over tokens and governance-rights of projects over tokens

1055

Figure 1

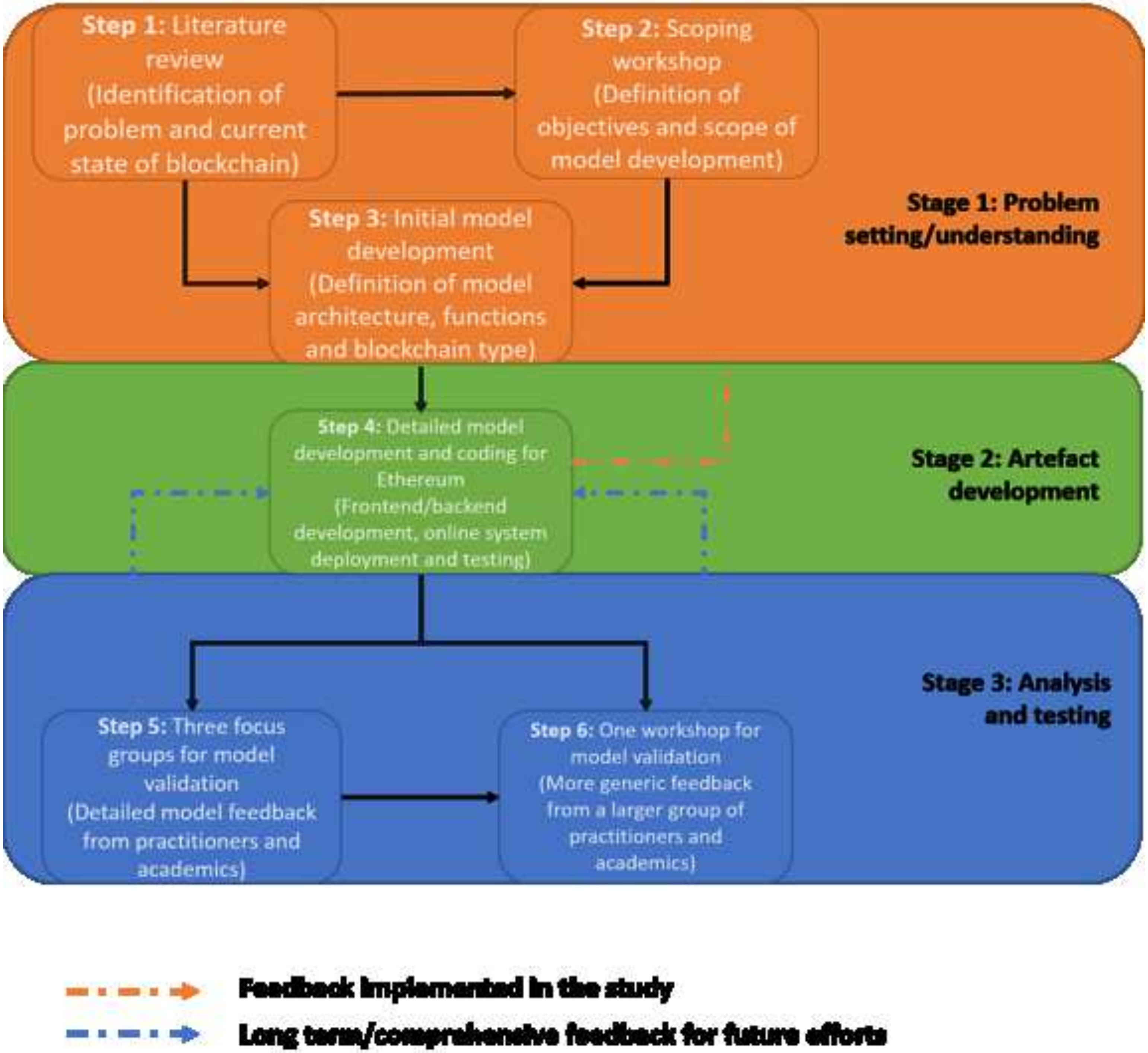
Step 1: Literature review (Identification of problem and current state of blockchain)
Step 2: Scoping workshop (Definition of objectives and scope of model development)
Step 3: Initial model development (Definition of model architecture, functions and blockchain type)
Stage 1: Problem setting/understanding
Step 4: Detailed model development and coding for Ethereum (Frontend/backend development, online system deployment and testing)
Stage 2: Artefact development
Step 5: Three focus groups for model validation (Detailed model feedback from practitioners and academics)
Step 6: One workshop for model validation (More generic feedback from a larger group of practitioners and academics)
Stage 3: Analysis and testing
Feedback implemented in the study
Long term/comprehensive feedback for future efforts

Figure 2

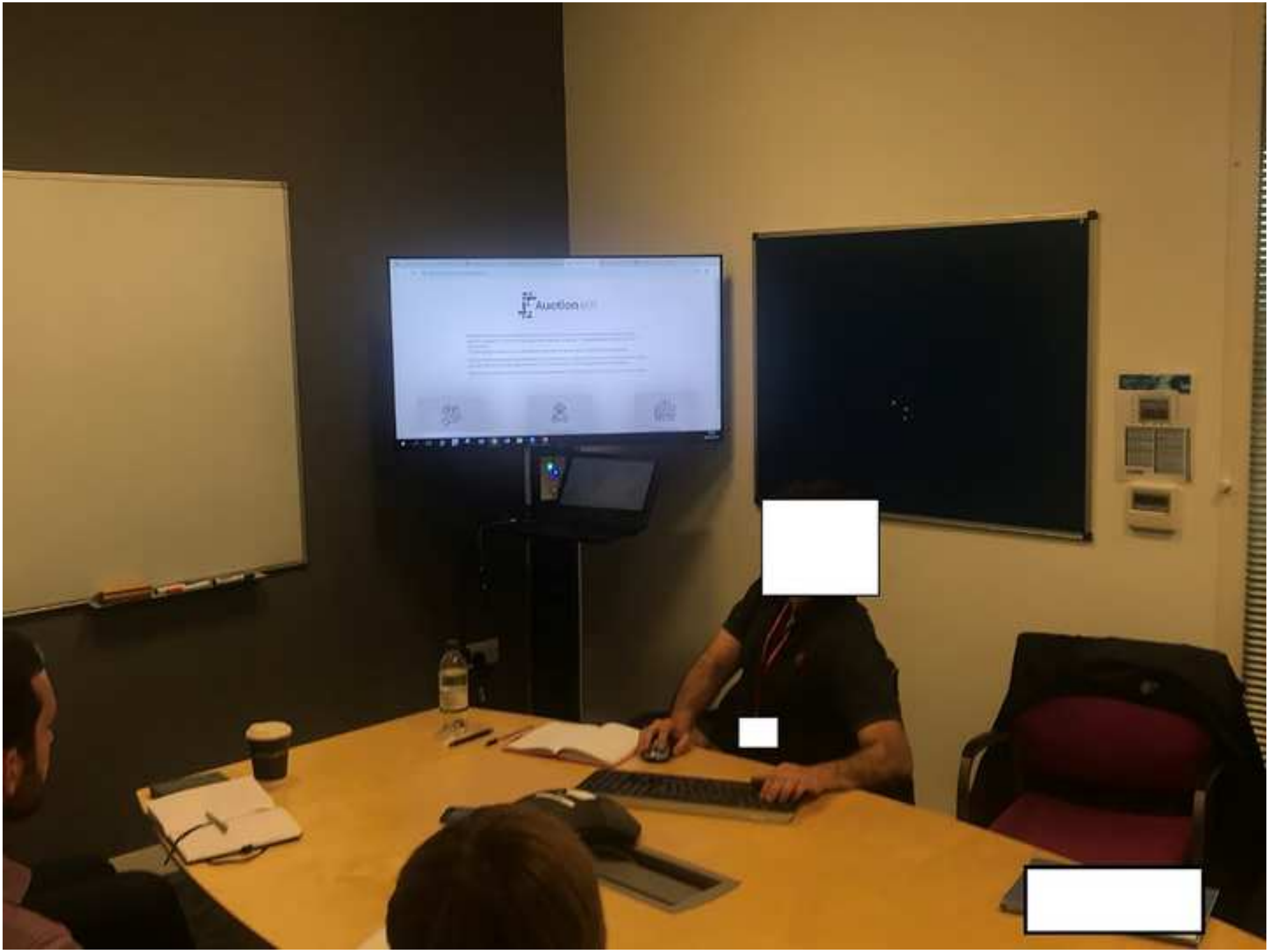

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Figure 3

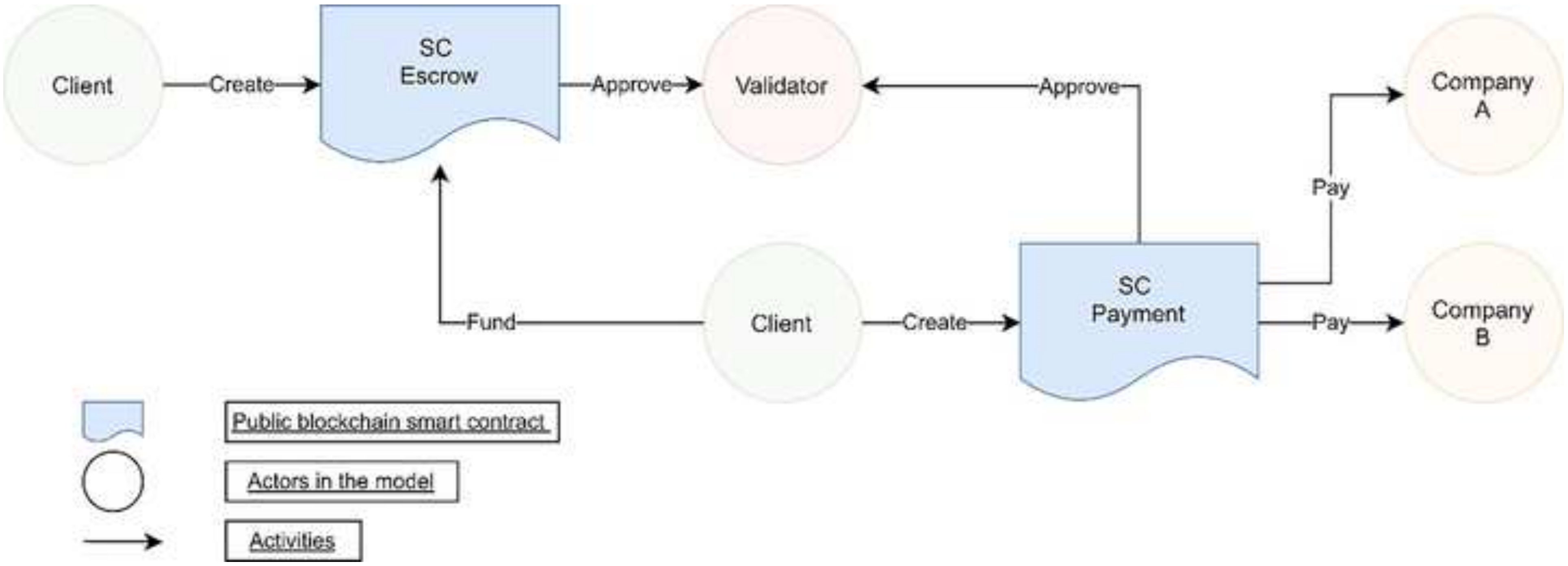

Client
Create
SC
Escrow
Approve
Validator
Approve
Company
A
Pay
Fund
Client
Create
SC
Payment
Pay
Company
B
Public blockchain smart contract
Actors in the model
Activities

Figure 5

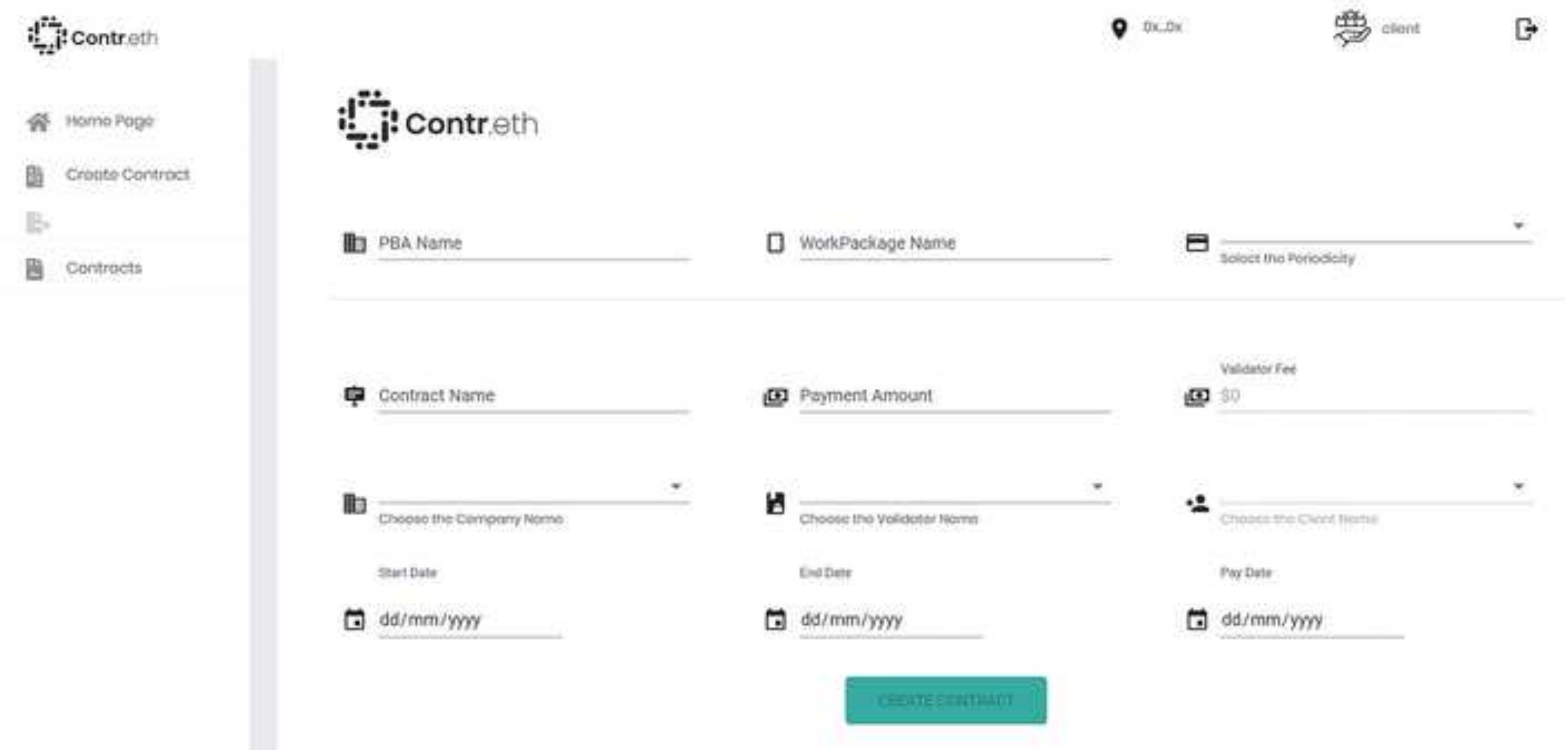
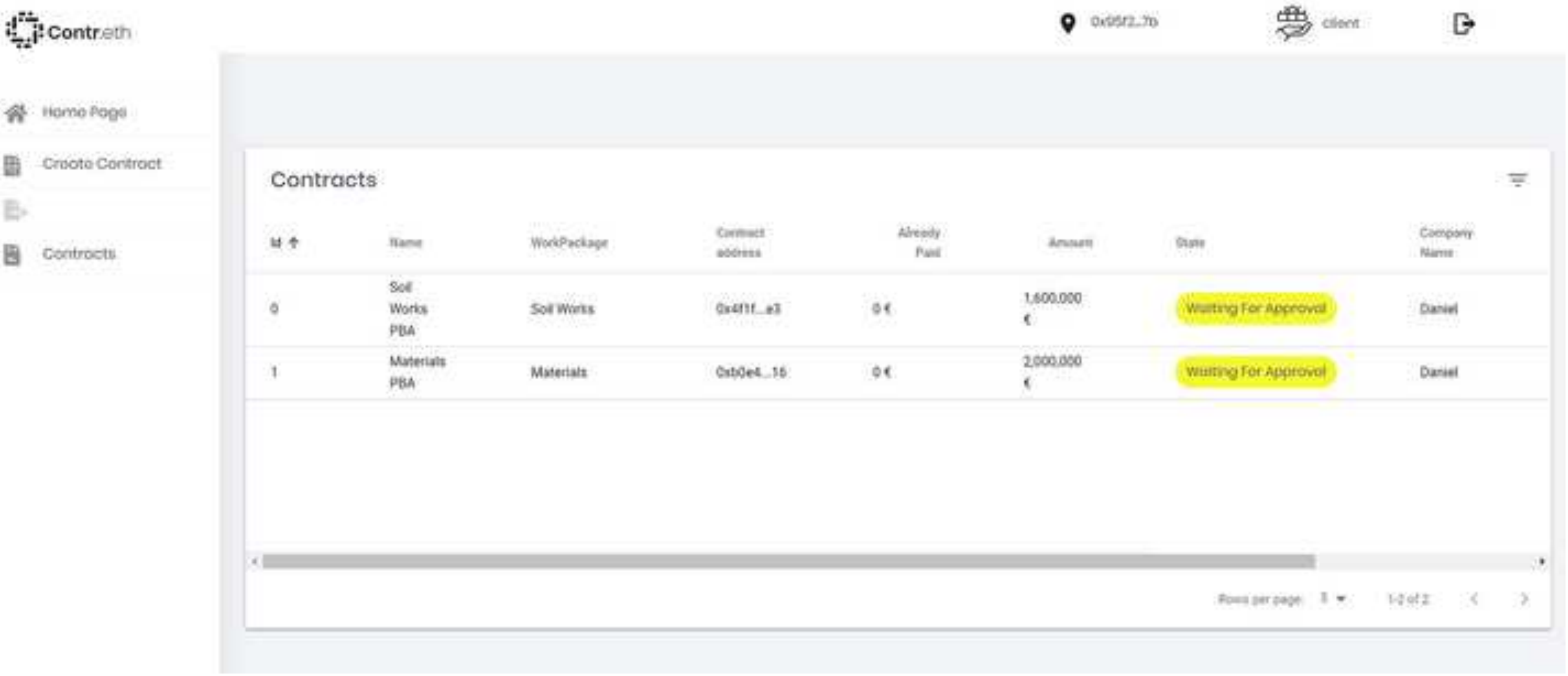

Contr.eth
0x..0x
client
Home Page
Create Contract
Contracts
Contr.eth
PBA Name
WorkPackage Name
Select the Periodicity
Contract Name
Payment Amount
Validator Fee
$0
Choose the Company Name
Choose the Validator Name
Choose the Client Name
Start Date
dd/mm/yyyy
End Date
dd/mm/yyyy
Pay Date
dd/mm/yyyy
CREATE CONTRACT

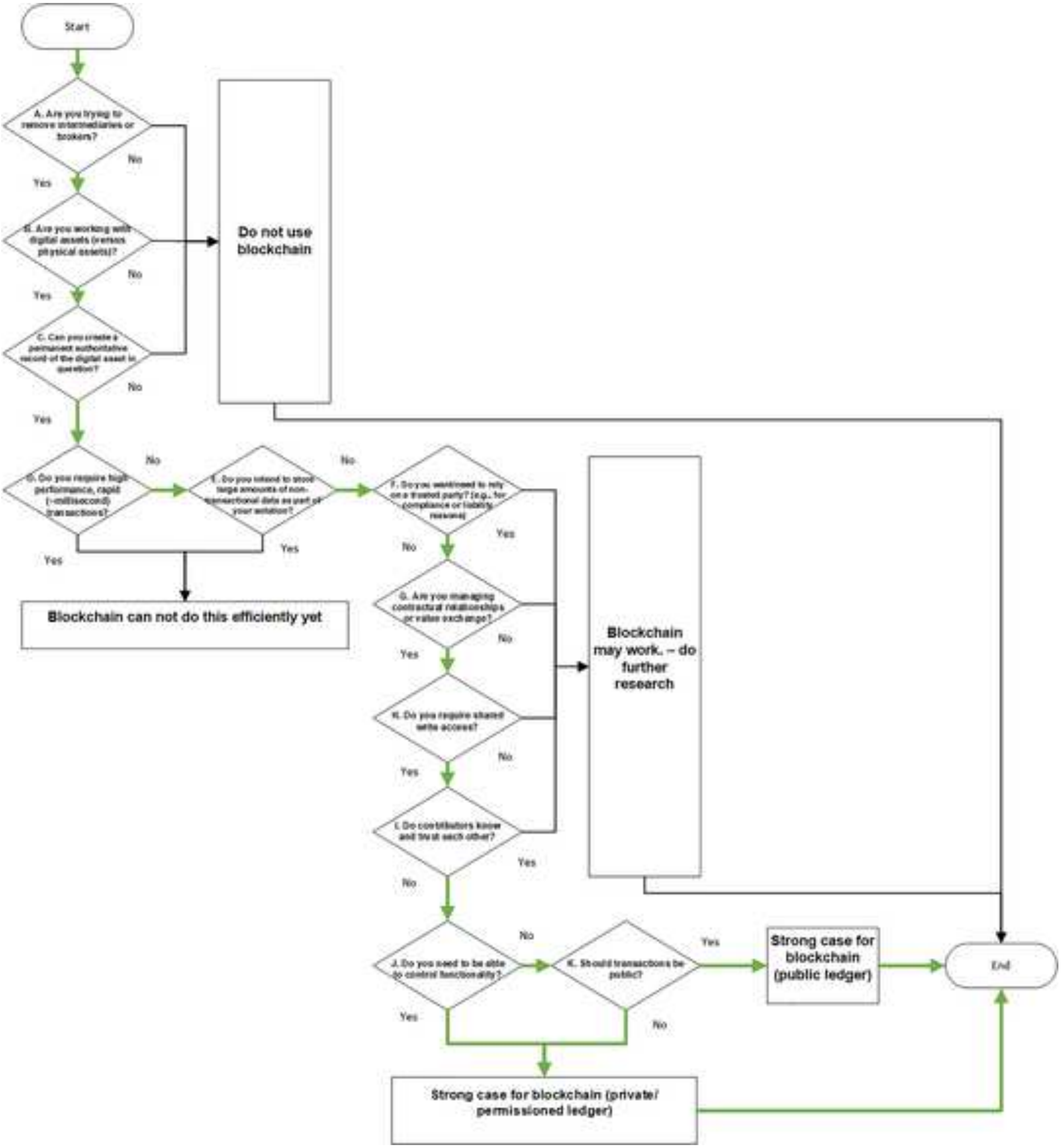
Figure 6



Contracts

Id ↑	Name	WorkPackage	Contract address	Already Paid	Amount	State	Company Name
0	Soil Works PBA	Soil Works	0x4f1f...e3	0 €	1,600,000 €	Waiting For Approval	Daniel
1	Materials PBA	Materials	0xb0e4...16	0 €	2,000,000 €	Waiting For Approval	Daniel

Figure 7


Start
A. Are you trying to remove intermediaries or brokers?
No
Yes
B. Are you working with digital assets (versus physical assets)?
No
Yes
C. Can you create a permanent authoritative record of the digital asset in question?
No
Yes
Do not use blockchain
D. Do you require high performance, rapid (~millisecond) transactions?
No
Yes
E. Do you intend to store large amounts of non-transactional data as part of your solution?
No
Yes
Blockchain can not do this efficiently yet
F. Do you want/need to rely on a trusted party? (e.g., for compliance or liability reasons)
Yes
No
G. Are you managing contractual relationships or value exchange?
No
Yes
H. Do you require shared write access?
No
Yes
I. Do contributors know and trust each other?
Yes
No
Blockchain may work. – do further research
J. Do you need to be able to control functionality?
No
Yes
K. Should transactions be public?
Yes
No
Strong case for blockchain (public ledger)
End
Strong case for blockchain (private/ permissioned ledger)

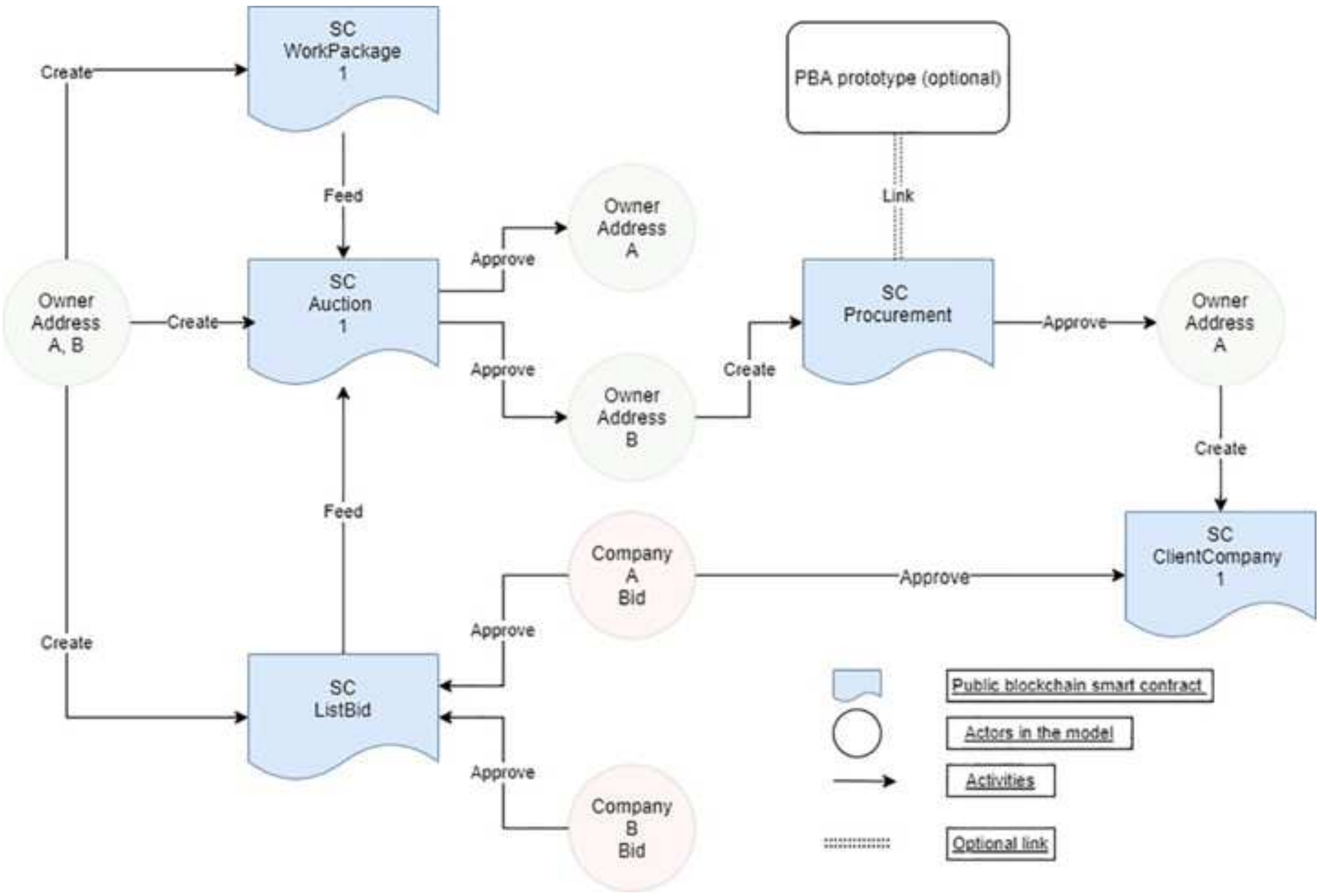

SC WorkPackage 1
PBA prototype (optional)
Create
Feed
Link
Owner Address A
Approve
Owner Address A, B
Create
SC Auction 1
SC Procurement
Approve
Owner Address A
Approve
Create
Owner Address B
Create
Feed
SC ClientCompany 1
Company A Bid
Approve
Approve
Create
SC ListBid
Approve
Company B Bid
Public blockchain smart contract
Actors in the model
Activities
Optional link

Figure 9

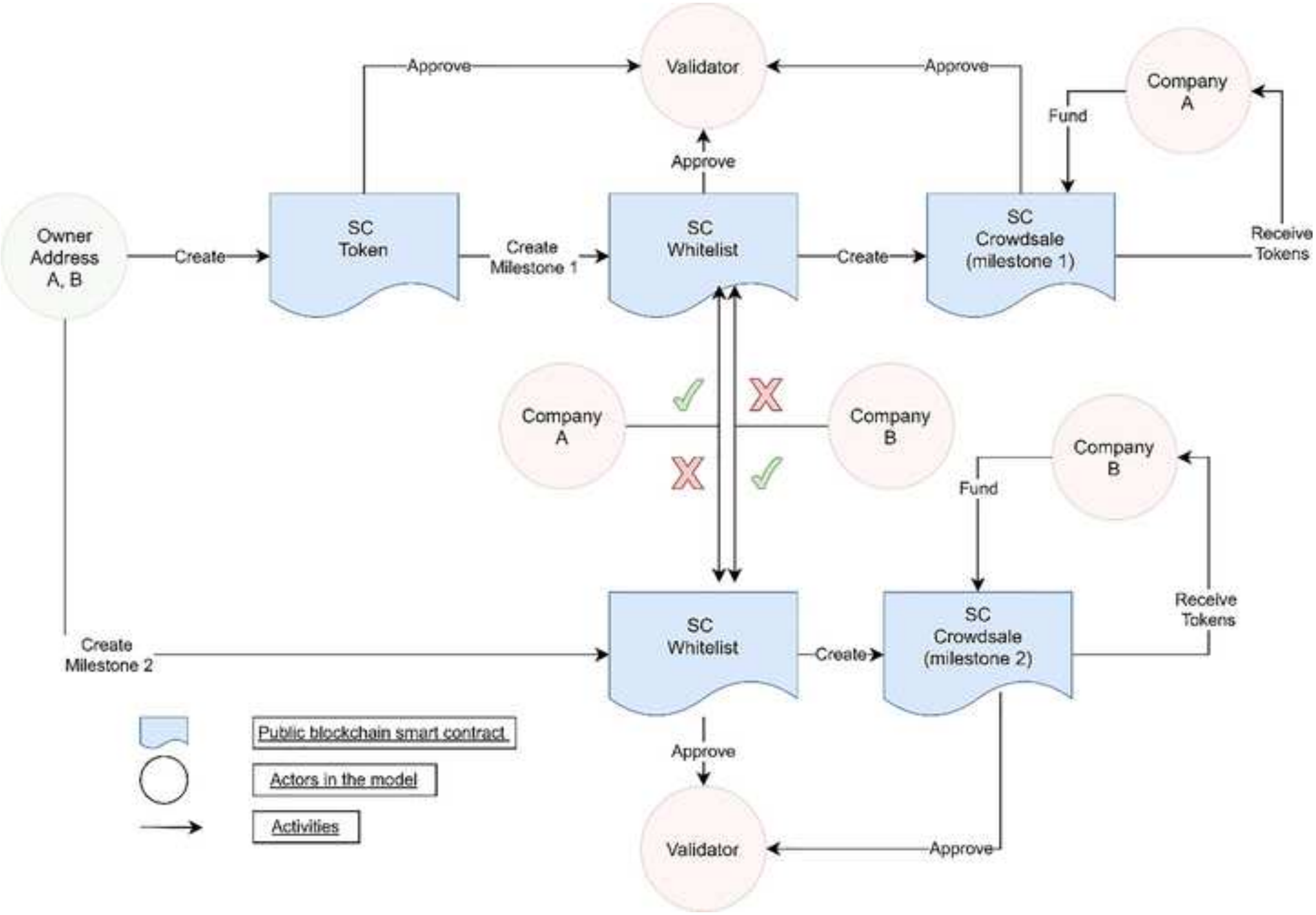
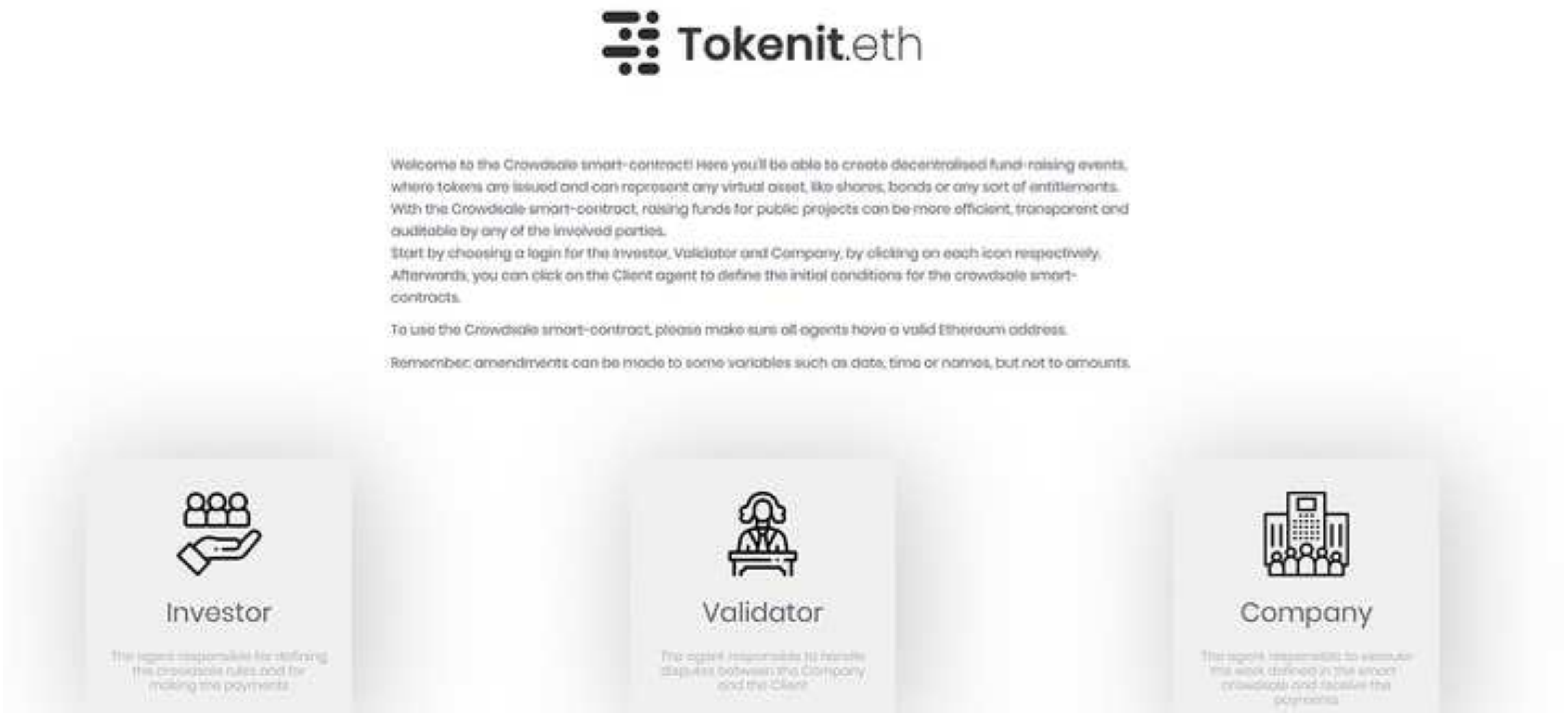

Validator
Approve
Approve
Approve
Company A
Fund
Owner Address A, B
Create
SC Token
Create Milestone 1
SC Whitelist
Create
SC Crowdsale (milestone 1)
Receive Tokens
Company A
✓
X
Company B
X
✓
Company B
Fund
Receive Tokens
Create Milestone 2
SC Whitelist
Create
SC Crowdsale (milestone 2)
Approve
Validator
Approve
Public blockchain smart contract
Actors in the model
Activities

Figure 10



Welcome to the Crowdsale smart-contract! Here you'll be able to create decentralised fund-raising events, where tokens are issued and can represent any virtual asset, like shares, bonds or any sort of entitlements. With the Crowdsale smart-contract, raising funds for public projects can be more efficient, transparent and auditable by any of the involved parties.
Start by choosing a login for the Investor, Validator and Company, by clicking on each icon respectively. Afterwards, you can click on the Client agent to define the initial conditions for the crowdsale smart-contracts.

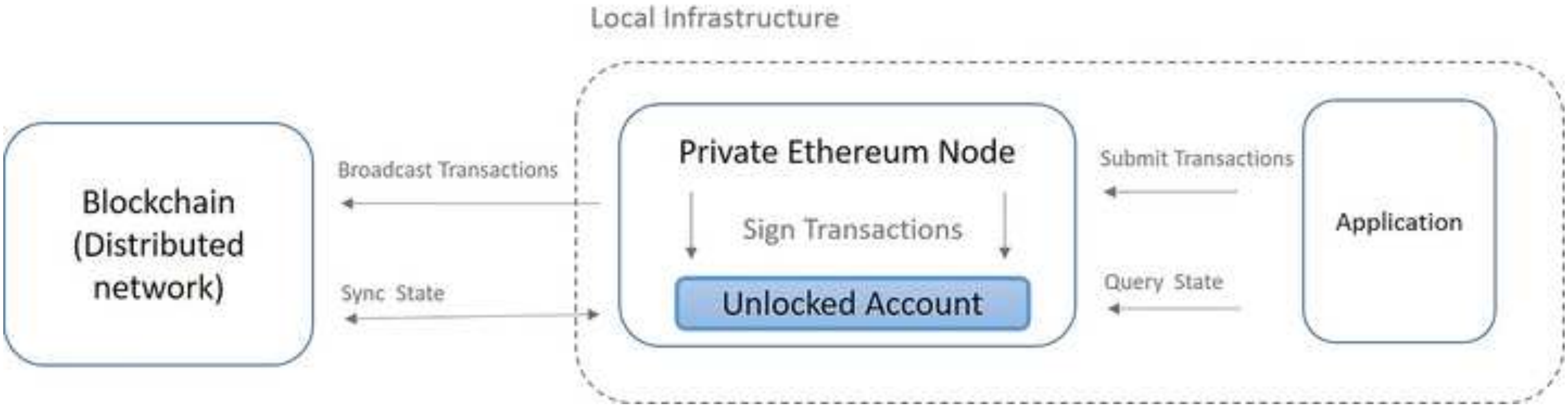
To use the Crowdsale smart-contract, please make sure all agents have a valid Ethereum address.

Remember: amendments can be made to some variables such as date, time or names, but not to amounts.

The agent responsible for defining the crowdsale rules and for making the payments

The agent responsible to handle disputes between the Company and the Client

The agent responsible to execute the work defined in the smart crowdsale and receive the payments


Local Infrastructure
Blockchain (Distributed network)
Broadcast Transactions
Sync State
Private Ethereum Node
Sign Transactions
Unlocked Account
Submit Transactions
Query State
Application

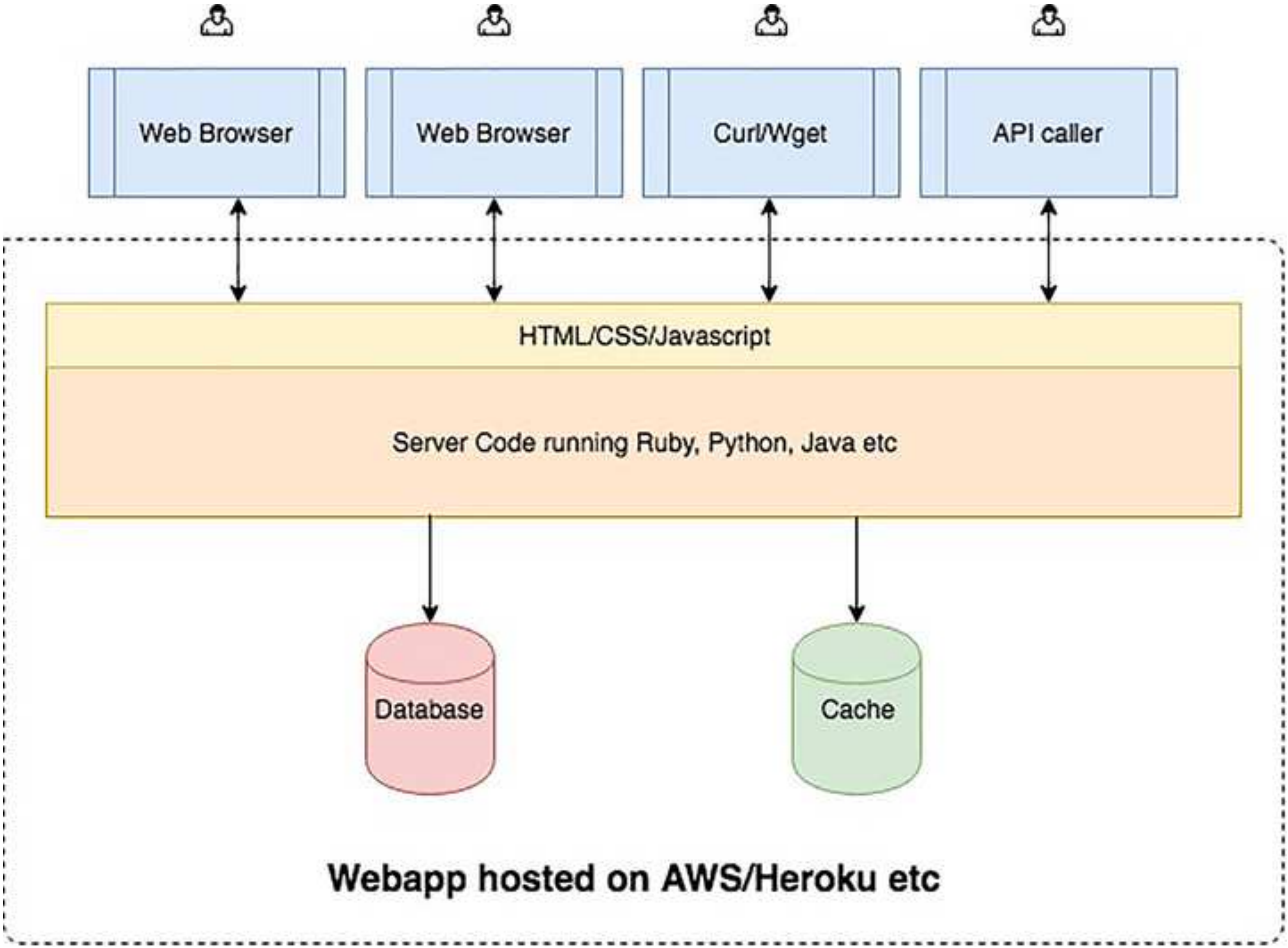

Web Browser
Web Browser
Curl/Wget
API caller
HTML/CSS/Javascript
Server Code running Ruby, Python, Java etc
Database
Cache
Webapp hosted on AWS/Heroku etc

Figure 13

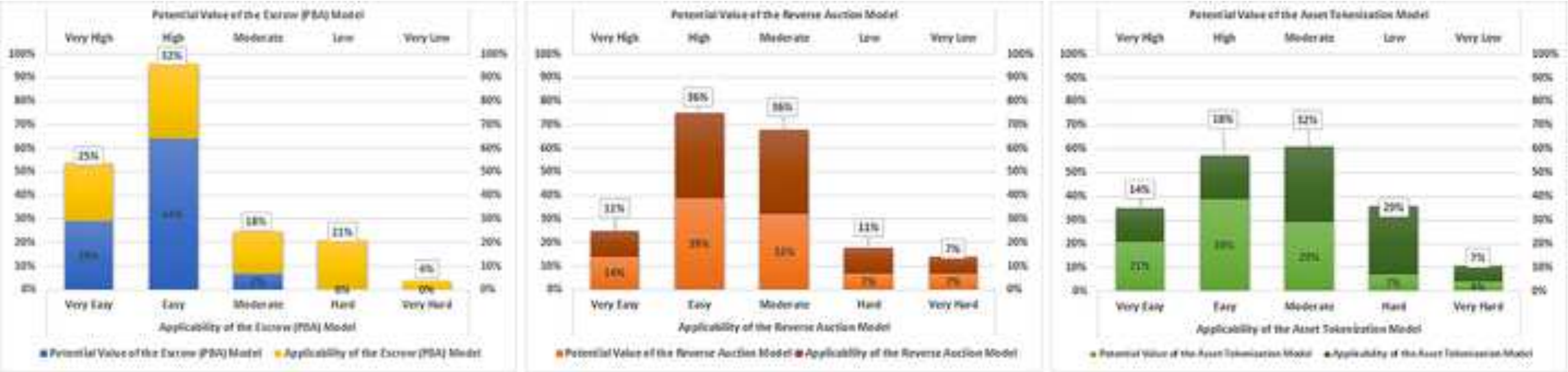

Potential Value of the Escrow (PBA) Model
Very High
High
Moderate
Low
Very Low
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
25%
32%
18%
21%
4%
29%
64%
7%
0%
0%
Very Easy
Easy
Moderate
Hard
Very Hard
Applicability of the Escrow (PBA) Model
Potential Value of the Escrow (PBA) Model
Applicability of the Escrow (PBA) Model
Potential Value of the Reverse Auction Model
Very High
High
Moderate
Low
Very Low
11%
36%
36%
11%
7%
14%
39%
32%
7%
7%
Very Easy
Easy
Moderate
Hard
Very Hard
Applicability of the Reverse Auction Model
Potential Value of the Reverse Auction Model
Applicability of the Reverse Auction Model
Potential Value of the Asset Tokenization Model
Very High
High
Moderate
Low
Very Low
14%
18%
32%
29%
7%
21%
39%
29%
7%
4%
Very Easy
Easy
Moderate
Hard
Very Hard
Applicability of the Asset Tokenization Model
Potential Value of the Asset Tokenization Model
Applicability of the Asset Tokenization Model

Figure 14

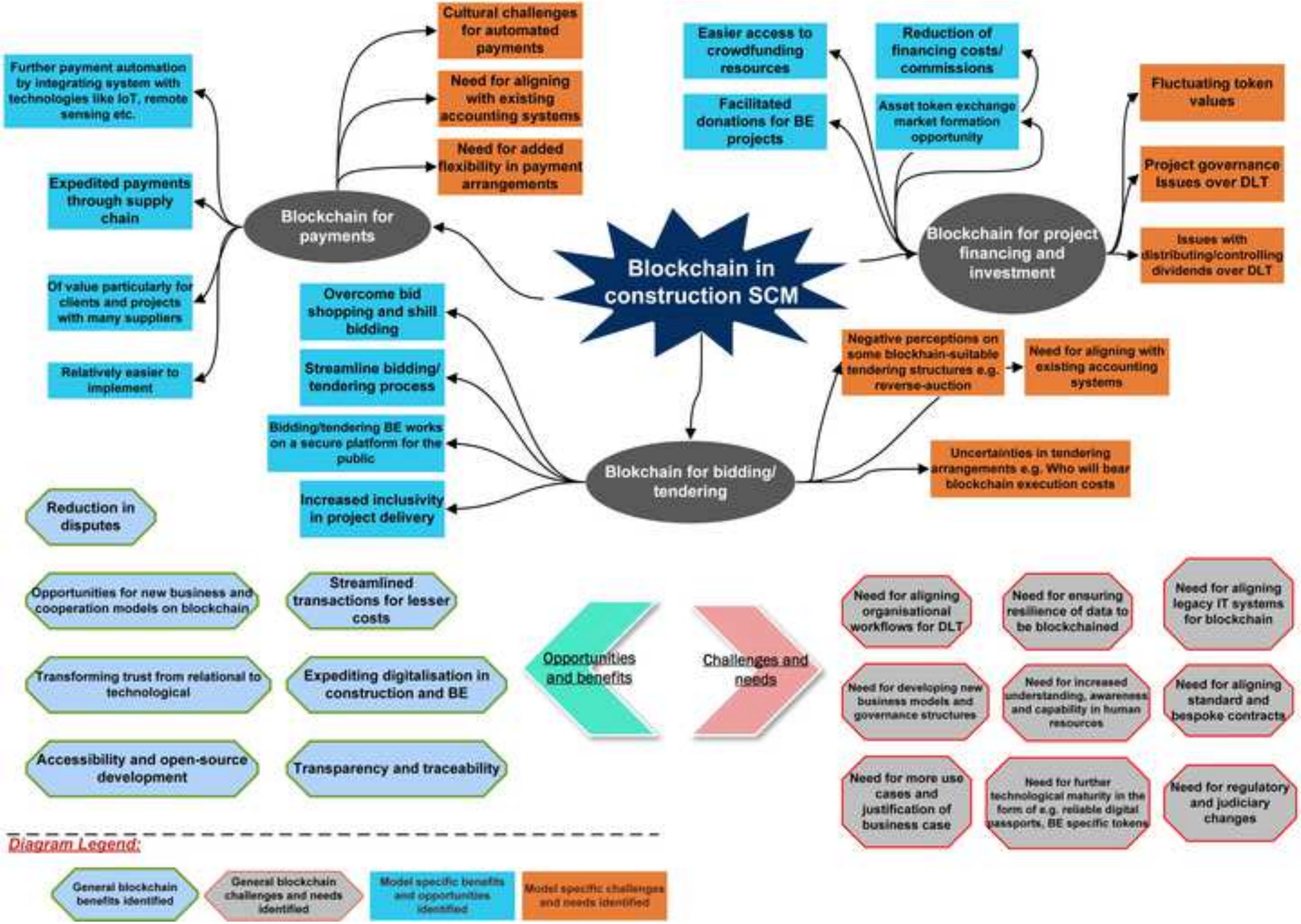

Blockchain in construction SCM
Blockchain for payments
Cultural challenges for automated payments
Need for aligning with existing accounting systems
Need for added flexibility in payment arrangements
Further payment automation by integrating system with technologies like IoT, remote sensing etc.
Expedited payments through supply chain
Of value particularly for clients and projects with many suppliers
Relatively easier to implement
Blockchain for project financing and investment
Easier access to crowdfunding resources
Reduction of financing costs/ commissions
Facilitated donations for BE projects
Asset token exchange market formation opportunity
Fluctuating token values
Project governance issues over DLT
Issues with distributing/controlling dividends over DLT
Blokchain for bidding/ tendering
Overcome bid shopping and shill bidding
Streamline bidding/ tendering process
Bidding/tendering BE works on a secure platform for the public
Increased inclusivity in project delivery
Negative perceptions on some blockchain-suitable tendering structures e.g. reverse-auction
Need for aligning with existing accounting systems
Uncertainties in tendering arrangements e.g. Who will bear blockchain execution costs
Reduction in disputes
Opportunities for new business and cooperation models on blockchain
Streamlined transactions for lesser costs
Transforming trust from relational to technological
Expediting digitalisation in construction and BE
Accessibility and open-source development
Transparency and traceability
Opportunities and benefits
Challenges and needs
Need for aligning organisational workflows for DLT
Need for ensuring resilience of data to be blockchained
Need for aligning legacy IT systems for blockchain
Need for developing new business models and governance structures
Need for increased understanding, awareness and capability in human resources
Need for aligning standard and bespoke contracts
Need for more use cases and justification of business case
Need for further technological maturity in the form of e.g. reliable digital passports, BE specific tokens
Need for regulatory and judiciary changes
Diagram Legend:
General blockchain benefits identified
General blockchain challenges and needs identified
Model specific benefits and opportunities identified
Model specific challenges and needs identified

Figure Caption List

- Figure 1– Research process over the stages with the main feedback loops

- Figure 2– Focus group study with participants from client organizations.

- Figure 3– Workshop study of the models.

- Figure 4 – The PBA model

- Figure 5 – Smart-contract creation screen. Each party uses the system with their unique crypto-wallet code.

- Figure 6 – Contract validation and approval screen

- Figure 7 – Blockchain validation for reverse auction systems on WEF's (Mulligan et al., 2018) decision making framework. The green arrows represent the answers for the suitability of reverse auctions for blockchain

- Figure 8 – The reverse auction model. There is an optional link between the PBA prototype for supply chain payments when the tendering is set

- Figure 9 – The asset tokenization model

- Figure 10 – The asset tokenization (crowdfunding) model's main screen.

- Figure 11 – The models' Ethereum integration

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- Figure 14– Summary of the general and model specific findings associated with blockchain in SCM