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KNOWLEDGE TRANSFER FROM BLOCKCHAIN ENGINEERS TO CONSTRUCTION: EXPLORING THE TECHNICAL CONCERNS OF USING BLOCKCHAIN FOR PAYMENTS IN THE CONSTRUCTION INDUSTRY

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SUMMARY: *Existing construction research is deficient in studies that focus on knowledge transfer from blockchain engineers to the construction industry. Blockchain engineers are the most technically sophisticated in decentralised technologies; thus, they are the most appropriate participants for a knowledge transfer investigation on the technical challenges of using blockchain and smart contracts in construction. Payments are the most progressed aspect of blockchain, and late payments are cited in research as one of the construction industry's most significant problems. Therefore, this research draws insights from experts in the field of blockchain to investigate whether the technology can increase payment processing efficiencies through automation and systems integration. Primary data is collected from blockchain engineers experienced in developing decentralised payment applications. The key findings suggest that blockchain could improve data integration across siloed software, and smart contracts could provide a solution for payment automation. However, the findings also suggest that blockchain lacks infrastructure and services for interoperating effectively with existing centralised systems, such as management software and traditional banking applications. This is one of the primary barriers affecting the adoption of blockchain in construction.*

KEYWORDS: *blockchain, smart contracts, automation, payments, construction industry, cash flow.*

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1. INTRODUCTION

The construction industry's lack of profitability is one of the reasons it spends insufficiently on innovation (Oesterreich and Teuteberg, 2016). A lack of innovation is also suggested as one of the factors that contribute to construction projects being behind schedule and over budget (Agarwal et al., 2016). Other sectors, such as manufacturing, have achieved gradual and measurable improvements year after year for many generations, whereas construction continues to lag due to its lack of digitisation (Nawari and Ravindran, 2019). One article suggests that the construction industry has not yet embraced digital technologies and that research and development (R&D) spending for construction is less than 1% of its revenue, and in contrast, the automotive and aerospace industries spend an average of 4% of their revenue on R&D (Gupta et al., 2020). To exacerbate the challenge of digitisation further, the construction industry faces the ongoing dilemma of trying to increase innovation while simultaneously reducing costs (Nawari and Ravindran, 2019).

This research investigates digitisation from the perspective of increasing cash flow automation. In particular, how to address one of the construction industry's most significant challenges: late payments (Haron and Arazmi, 2020). The late payment problem can be approached from multiple avenues, such as the organisational, technological, and policy perspectives (Li et al., 2019). This research investigates the technical feasibility of utilising blockchain smart contracts to safeguard project funds, integrate management and cash flow systems, and semi-automate payment in the construction industry. The term semi-automation is used because payment approvers are still required to manually authorise transactions; however, payment processing tasks such as data reconciliation, updating payment schedules, and validating payment approval signatures are automated with smart contracts. From a data and analysis perspective, this research gathers technical insights from blockchain engineers and evaluates their concerns and considerations regarding the use of blockchain for enterprise payments in the construction industry.

Existing literature on blockchain in construction lacks knowledge transfer from blockchain engineers. Conceptual frameworks for blockchain applications are conceptualised abundantly and with great variety in construction research. For example, Scott et al. (2021) reviewed 121 scholarly literature on blockchain in construction and uncovered that 46% of the literature proposed new conceptual frameworks. However, none of the 121 papers included a knowledge transfer study. Insights from blockchain engineers are crucial for transitioning the topical area from conceptualisations to practical implementation and enterprise adoption.

This paper's research question is as follows: By engaging with blockchain engineers through a knowledge transfer study, what is the technical feasibility of using blockchain to improve payment processing efficiencies in the construction industry? Answering this question requires achieving the following two research objectives:

1. Present a decentralised payment application to blockchain engineers and collect data on its technical feasibility as an enterprise payment solution for construction.
2. Organise the findings into key themes and evaluate whether blockchain has matured to include adequate services for practical implementation in construction.

This paper's sections are structured as follows: the Background section reviews the construction industry's challenges with payments and systems integration, and how construction research is addressing this issue from the perspective of blockchain. The Methodology section outlines the sampling strategy for recruiting candidates to participate in the research, discusses the method for the data collection, and the approach for the data analysis. The Data section organises the results into key themes and subthemes for a structured presentation of the data and findings. The Analysis and Discussion section comprehensively evaluates the findings, outlines its opportunities and challenges, and includes subsections on validating the presented blockchain application and research limitations. Lastly, the Conclusion section summarises the outcome of the analysis and discussion, its key contributions, and includes a subsection on further work.

2. BACKGROUND

Across ten years spanning 2011 to 2021, the UK Government published six (four new and two revised) legislations on fair payment practices for the construction industry (Scott et al., 2022). These include the 2011 Part 2 of the Construction Act (GovUK, 2011); the 2012 Supply Chain Finance Scheme (GovUK, 2012); the 2012 guide to the implementation of project bank accounts (PBAs) (UK_Government, 2012); the 2013 revised late payments of commercial debts regulations (GovUK, 2013); the 2014 Construction Supply Chain Payment charter (ConstLeaderCouncil, 2018); and 2021 revised Prompt Payment Code (Gov_UK, 2021). Despite these, late payments in the construction industry, from 2008 to 2018, increased by 22% (Constructing Excellence, 2019).

Blockchain is investigated in construction research on whether it can provide the infrastructure that enables better data interoperability between various software systems (Elghaish et al., 2021). Processing payments is administratively time-consuming because it requires data entry tasks from multiple parties using siloed software (Swai and Arewa, 2018). Furthermore, communication between these parties typically occurs over fragmented communication channels such as phone and e-mail (Wu et al., 2022). Better integration between users and technology systems is required to improve cash flow management performance in construction (Kochovski and Stankovski, 2021). Current software systems struggle with data integration because of how centralised technology companies are built, whereby each provider privatises their codebase to maintain a competitive advantage (Hargaden et al., 2019). This makes systems interoperability between competing technology companies complex and resourcefully costly due to the extensive middleware and APIs (application programming interfaces) required to bridge these systems together (Hargaden et al., 2019). A more specific example from the construction industry includes how users of BIM software need IFC to convert 3-D models from one software to another (e.g., from Revit to ArchiCAD); however, substantial model intelligence is lost even when using IFC (Xue and Lu, 2020). A general-purpose data layer is one method to improve data interoperability between fragmented systems (Berglund et al., 2020). The open-source, permissionless, and decentralised properties of blockchain make it a potential technology to explore as a general-purpose data layer (Berglund et al., 2020). A public blockchain platform, such as Ethereum, operates with a more economical model than centralised platforms owned by technology companies because it is not a legal entity that generates profit from services and thus pays no tax; furthermore, it does not have employees, no physical premises, no rent or infrastructure bills, and no shareholder dividends to pay out; instead, it uses a crypto-economic system (i.e., algorithmic mining, staking, and token minting) to incentivise a decentralised network of contributors to maintain the system and provide services (Gurgun et al., 2022). Due to its open-source and decentralised nature, it cannot impose proprietary fees or restrict user access (Veuger, 2018). The only fees associated with the blockchain are those charged by the blockchain miners or stakers that run the consensus algorithm that validates transactions on the blockchain network (Coyne and Onabolu, 2017). However, these miners and stakers are self-governed entities whose fees are algorithmically calculated by the blockchain protocol's codebase; furthermore, these miners and stakers are not owned by the blockchain and do not pay commissions on their earnings (Coyne and Onabolu, 2017). Blockchain is a public asset that anyone can utilise to build and deploy applications without intellectual property restrictions or incurring technology license fees; thus, it is a popular choice for software developers who want to exploit its free protocol infrastructure (Tezel et al., 2020).

In September 2022, the Ethereum blockchain updated its consensus mechanism from proof of work (PoW) to proof of stake (PoS), reducing its annual MtCO2e (million tonnes of carbon dioxide equivalent) emissions from 11 to 0.0009, a reduction of 99.992% (CCRI, 2022). To put that into perspective, the CO_2 emission of Ethereum PoS is equivalent to roughly 200 typical petrol cars (Environmental Protection Agency, 2023). The old Ethereum PoW has been deprecated and is no longer in operation. Therefore, concerns regarding the greenhouse gas emissions of the Ethereum public blockchain have been resolved.

Blockchain is also used for non-financial transactions, such as timestamping data flows and storing file hashes (Penzes, 2018). From a commercial perspective, blockchain can significantly reduce transaction fees while providing automated accounting (Tezel et al., 2019). Many blockchain implementations occur where systems are less digitally sophisticated. For example, in 2018, the Marshall Islands passed a bill to adopt the SOV stablecoin cryptocurrency as its national currency (Republic of the Marshall Islands, 2018). The Marshall Islands attempted this because they are less entrenched with existing financial technology infrastructure; therefore, incorporating new technologies, such as blockchain, was perceived as having fewer barriers (Republic of the Marshall Islands, 2018). However, in 2023, the International Monetary Fund (IMF) expressed disapproval for how the Marshall Islands Government was handling its approach for issuing blockchain stablecoins, stating that the country was potentially jeopardizing its financial integrity, and that a more sophisticated framework for how it would address regulations such as AML (anti-money laundering) and CFT (countering the financing of terrorism) was required (International Monetary Fund, 2023). In 2025, an economic review report published by the Marshall Islands announced that they would be pausing their SOV stablecoin pilot while they focus on maturing the regulatory aspects of their blockchain adoption strategy (Republic of the Marshall Islands, 2025).

Blockchain is reminiscent of the ambitions of the early Internet (i.e., the 1990s), whereby data was democratised, and information exchange was less restricted; however, because blockchain is a decentralised technology, there is less risk that it will fall victim to the centralised control of large technology companies (Gaur et al., 2019). Blockchain is unique in that it achieves trust amongst untrusting parties without requiring the services of trusted third parties (Li et al., 2018a). In an interview with 20 construction practitioners (comprising quantity surveyors, architects, engineers, project managers, and contractors), low awareness, resistance to change, high implementation cost, unclear benefits, and the absence of technology policies were highlighted as the key reasons for their aversion to blockchain (Ebekozien et al., 2023). In contrast, Wulandary et al. (2022) conducted a review of contractual problems in construction and uncovered that blockchain and smart contracts could provide utility in alleviating withheld payments, data processing delays, pre-payment issues, and unstable cash flow. An example of where a blockchain-based system was used to integrate with current technology systems was in a paper by Kamel et al. (2023), who developed a decentralised application (dApp) that integrated with an Excel workbook, smart contract, and the WhatsApp messaging application. In that example, smart contracts were used to sign payment approvals, which sent the signature to the blockchain, then to an Excel workbook that was integrated with WhatsApp to provide users with automated WhatsApp messages on the status of particular payments; therefore, three systems (i.e., blockchain, Excel, and WhatsApp interoperated in one system). The benefit of that solution is that users interact with technologies they already know how to use, such as Excel and WhatsApp, making the user experience more straightforward than building entirely new user interfaces (UIs). Correspondingly, Yang et al. (2022) proposed a framework that integrates purchase orders, planned works, site drawings, billing data, and site photographs into a single system. The benefit of that system is a single source of truth for payment approvals, orders, delivered works, and contracts. A similar framework was proposed by Xu et al. (2023), who integrated construction data from several systems, such as a quality management system, safety management system, smart payment system, logistics system, and supply chain management system, using the blockchain as a data trust layer for managing data flows, approvals, and payments, while also allowing transaction data to export to Excel. Likewise, Sarkar et al. (2023) tested the viability of payment automation in construction projects by appending Internet of Things (IoT) sensors onto building materials, such as steel beams, and enabling the sensor data to synchronise with a building information model (BIM); afterwards, progress payments were executed to subcontractors via smart contracts whenever each component was installed and registered on the BIM model. Similarly, Adel et al. (2023) developed a prototype that allowed on-site managers to upload pictures of completed works via a UI connected to IPFS (a decentralised cloud storage provider); furthermore, each picture verification signature was timestamped on the blockchain and linked to smart contracts to execute automated payments. According to them, the system can be utilised to automate progress payments in conjunction with the agreed contractual parameters as soon as the on-site data is captured and validated by the key stakeholders (Adel et al., 2023). The concept of synchronising payment data was also discussed by Yoon and Pishdad-Bozorgi (2022), who proposed a framework that integrates BIM and Excel data with a web-based UI connected to a smart contract that links work approval signatures to autonomous payments. According to them, blockchain and smart contracts streamline payment processes by mitigating misunderstanding and miscommunication issues in confirming payments for delivered work. Similarly, integration between management software and the blockchain was investigated Ahmadisheykhsarmast and Sonmez (2020), who built a plugin that exports data from Microsoft Projects in a standard text file format; afterwards, the text file was manually imported into smart contracts through a UI. However, the problem with the approach of manually importing text files into smart contracts is the risk of file manipulation, such as a malicious actor altering the data. To mitigate this, the file could be encrypted with the recipient's public key, enabling only the recipient to decrypt the data with their private key; however, this process requires too many intermediary stages and detracts from the purpose of using blockchain to automate processes. Payment for delivered work is the typical approach for automating cash flow in construction projects, as documented in the examples above. However, the payment landscape in construction also includes other aspects, such as carbon taxing. For instance, Blumberg and Sibilla (2023) presented a framework on the viability of using a decentralised marketplace hosted on the blockchain and managed by smart contracts. This marketplace would automate the carbon taxation of construction projects in real-time, eliminating the need for government intervention by taxing each contractor individually. Each carbon credit would be equivalent to one tonne of carbon dioxide emissions, and companies could sell any unused carbon credits at an online marketplace or store the credits for future use (Woo et al., 2021). Using a carbon credit system, construction companies would be financially incentivised to act sustainably (Blumberg and Sibilla, 2023).

3. METHODOLOGY

This research presents a blockchain test application to blockchain engineers. It then requests the blockchain engineers to respond to questions concerning the test application via a questionnaire. The purpose of presenting a test application to blockchain engineers was to investigate its feasibility from a technical perspective. Blockchain engineers were considered the most knowledgeable candidates to answer questions concerning the technical aspects of blockchain application development. Therefore, they were targeted for the data collection for this paper due to their technical understanding of blockchain. Figure 1 illustrates the research methodology's approach to the sampling, data collection, and analysis.

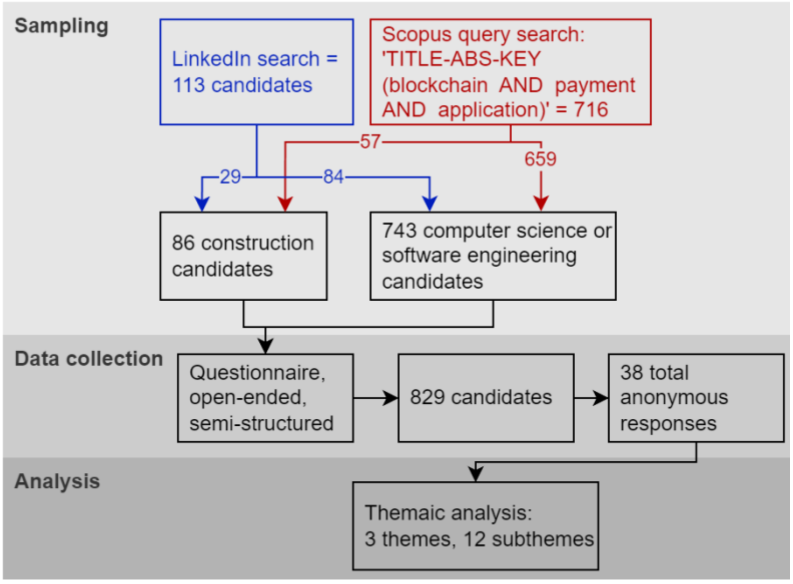

Figure 1: Approach to sampling, data collection, and analysis.

A questionnaire was selected for the research method because a variety of responses from a large sample is more valuable for the research than in-depth interviews. This is because decentralised applications (dApps) are built from numerous components, and blockchain programmers, developers, or engineers tend to favour specific tools. Therefore, having several perspectives on dApp development for construction is crucial for a thorough analysis. Eight hundred and twenty-nine candidates, from researchers to industry practitioners, were invited to participate in the questionnaire. Of this, approximately 88% were from the discipline of computer science and software engineering, and 12% from the construction industry. However, both groups were knowledgeable in dApp development.

Amassing a list of questionnaire candidates followed a two-step approach. Firstly, a search query: "TITLE-ABS-KEY (blockchain AND payment AND application)," was entered into the Scopus database search available on the Scopus webpage. Scopus is the most comprehensive scientific publication database, encompassing 85% of the Web of Science (WoS) literature, whereas WoS is the second most comprehensive scientific publication database (Scott et al., 2021). Therefore, Scopus was selected as the database provider for querying blockchain papers. Each paper retrieved from Scopus was assessed for suitability by checking whether it proposed, developed, or piloted a blockchain payment application. The authors of the suitable papers were then sent an email invitation to participate in the questionnaire. The second approach for recruiting candidates involved searching LinkedIn for dApp developers, assessing their technical experience in developing blockchain applications, and then sending them an invitation to participate in this research via a private LinkedIn message. Of the 829 prospective candidates, whose contact details were obtained from Scopus and LinkedIn, 38 candidates responded to the questionnaire, a response rate of 5%. Participation in the questionnaire was anonymous because the researcher did not want identifiable data to influence the response rate. Furthermore, comparing subgroups of demographic data was not the primary focus of the research, as a purely qualitative approach, such as a thematic analysis, was selected for the method of data analysis. The researcher also estimated that the target sample size for the questionnaire responses would not be large enough to warrant quantitative generalisations; thus, anonymous responses were the preferred choice for the data. The invitation email to the questionnaire candidates specified that this research was collecting data from participants with knowledge and experience in developing blockchain applications. However, the demographic data, such as years of experience or qualifications, was not collected from them. In hindsight, the author believes that this demographic data would have added value to the data analysis. Of the candidates from LinkedIn who were invited to participate in the research, the author verified their suitability by checking their work experience on LinkedIn, specifically whether they have been involved in blockchain projects or work for a blockchain-based organisation. Regarding the candidates obtained from Scopus, the author relied on the search query shown in Figure 1 to filter them for suitability. The questionnaire included a video demonstration of a blockchain payment application (a YouTube link to this video is shown in Section 4: Application). This enabled the candidates to focus their answers on a specific blockchain use case. The participants were then instructed to answer the questionnaire in conjunction with the video demonstration.

The researcher designed the questionnaire to be 15 minutes in duration. In a study conducted on questionnaire durations, the results displayed that the drop-off rate (the rate at which invitees reject taking part in a questionnaire) was 52% at 25 minutes, but only 21% at 10 minutes (Yan et al., 2010). A decision was made to design the questionnaire duration to 15 minutes, as 10 minutes was overly limiting, while a more protracted duration was at risk of a higher drop-off rate. Initially, the author considered sending the questionnaire candidates a prequalification survey to assess their potential competence level for answering the questionnaire. However, the author decided not to include this because of the potential risk of a high rejection rate (i.e., the author assumed that candidates would be less likely to respond to a survey and questionnaires instead of just the latter). A disadvantage of not having a prequalification survey is that some of the questions may be irrelevant to specific participants. The profession of a blockchain engineer can encompass many roles, such as back-end developer, front-end developer, decentralised application (dApp) developer, security engineer, systems architect, and algorithm developer. Therefore, the risk that some questions would remain unanswered among some participants was expected. Part of the reason the author designed all the questions to be open-ended was to allow participants to expand upon their answers as much as possible in questions related to their areas of expertise.

The author believes he took the correct approach in taking steps to maximise the questionnaire response rate. As mentioned previously, of the 800 candidates invited to participate in the questionnaire, only 38 responded. Therefore, reducing entry barriers as much as possible while targeting candidates with knowledge and experience in blockchain application development was crucial to balance. In the invitation email to the questionnaire candidates, they were informed that they had a 2-month timescale to complete it, and all 38 participants responded within that period.

Table 1: Questionnaire questions.

1.	From the perspective of business, legal, or contractual processes, are there any challenges or limitations you see with using the presented application in the enterprise environment?
2.	Do you have any suggestions for altering or reconfiguring the application or its components to improve its architecture or performance?
3.	The application's back-end comprises Ethereum for the blockchain, Node.js for the virtual server, Infura for the blockchain node, MetaMask for the wallet, and IPFS as the decentralised storage provider. Do you have any comments or recommendations for how this setup can be improved?
4.	Would the application be better suited on another blockchain platform or an Ethereum layer-two scaling solution? If so, which one, and why?
5.	The application requires transferring data manually from centralised spreadsheets to smart contracts. What is the best solution for automating data transfer between these media, and what technology systems does it require?
6.	The application's front-end is built from React and JavaScript. Is there a better UI setup you would suggest for payment dApps?
7.	Do you think the application would benefit more if it were hosted entirely on Web 3? Moreover, what are some of the challenges and benefits of this?
8.	How can the application's wallet security be improved, and what general cybersecurity precautions would you advise on?
9.	Are there any blockchain dApps that you would suggest integrating with?

Table 1 presents the nine open-ended questions from the questionnaire. Questions **one** and **two** concern the application's limitations and areas for improvement. Questions **three** to **five** concern back-end systems; question

six relates to the front-end; question **seven** investigates Web 3; Question **eight** concerns security; and question **nine** inquiries about integrating with other dApps.

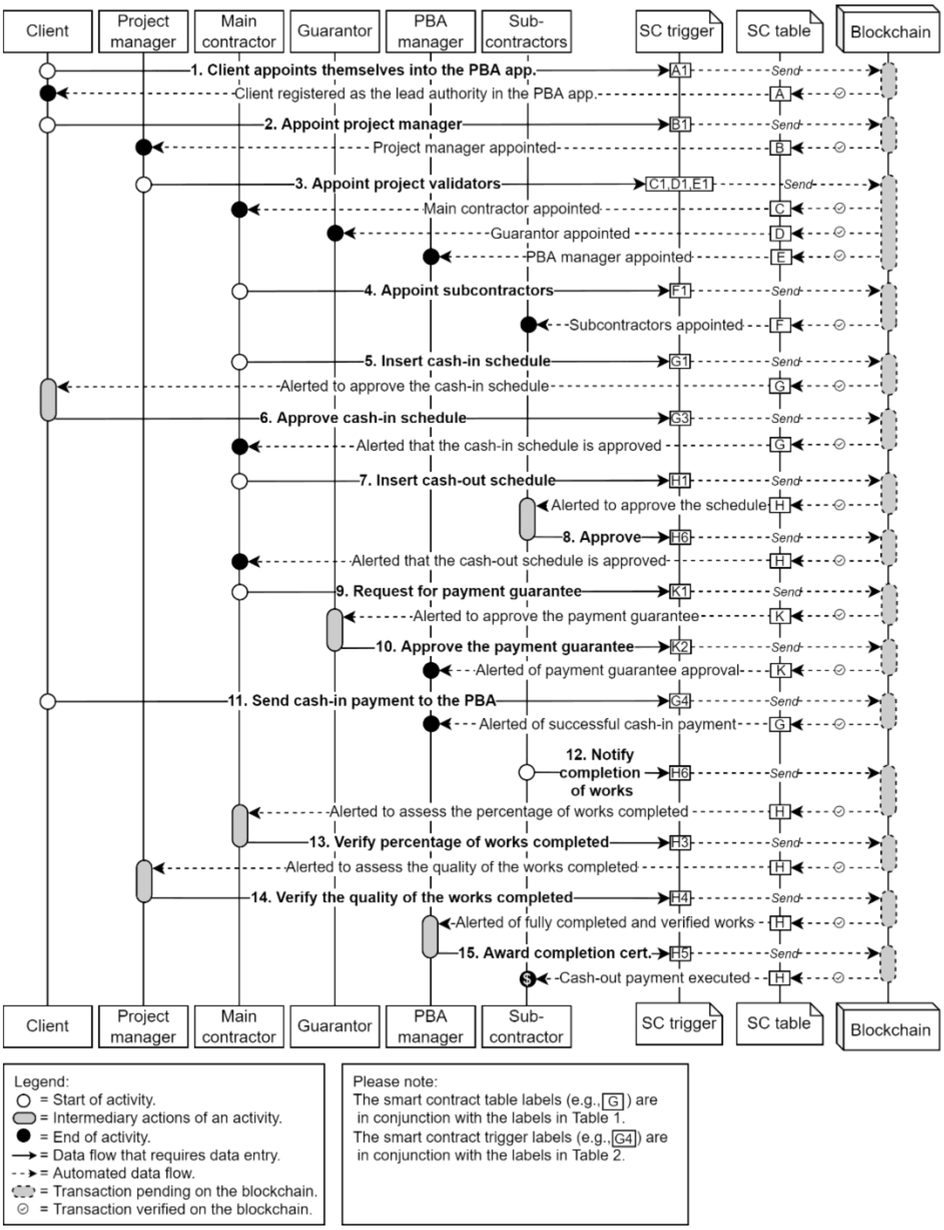

Figure 2: Process flow of the presented blockchain application. Note. This figure was copied from the work by Scott et al. (2024) from a journal article titled Project Bank Account (PBA) Decentralised Application for the Construction Industry, published in the Construction Innovation journal.

4. APPLICATION

A new decentralised application (dApp) was not created solely for this paper; instead, the author used a dApp he created in earlier work in an article published in the Construction Innovation journal, titled Project Bank Account (PBA) Decentralised Application for the Construction Industry (Scott et al., 2024). The author revisited earlier work to expand the research by collecting novel data that covers the technical aspects of the application.

The application's video demonstration, user interface, and smart contract codebase are found in the following links:

- Video demonstration: https://www.youtube.com/watch?v=mwAAAhnowxQ
- UI: https://console.atra.io/app/bf26f846-7f16-4f80-90a0-c5488ab6edd3
- Codebase: https://github.com/D-UCL/PBA-dApp.

The process flow of the application, illustrated in Figure 2, which is the same application shown in the video demonstration to the questionnaire participants, displays a project bank account (PBA) blockchain payment application. The questionnaire participants were informed that they should think of a PBA in the same way as they would think of an escrow account. Escrows were one of the first use cases for blockchain smart contracts (Hassija et al., 2020). Therefore, the author assumed that all the questionnaire participants would be familiar with the functionality of using escrows for managing payments on the blockchain. Furthermore, explaining the specific differences between a PBA and escrow would consume too much time during the questionnaire, and the author wanted to minimise potential ambiguity by introducing as few new concepts as possible to the participants. An escrow is a more ubiquitous term, whereas a PBA is an escrow that is configured specifically for the construction industry (Scott and Broyd, 2024). Since most of the questionnaire candidates were from the computer science and software engineering subject areas, the author opted for a more generalised use of terminology in the questionnaire. Even though the solution proposed by Scott et al. (2024), which is the same application showcased to the questionnaire participants, is a PBA blockchain application; the findings of this research are more generalisable to any construction application that uses smart contracts for managing and executing payments.

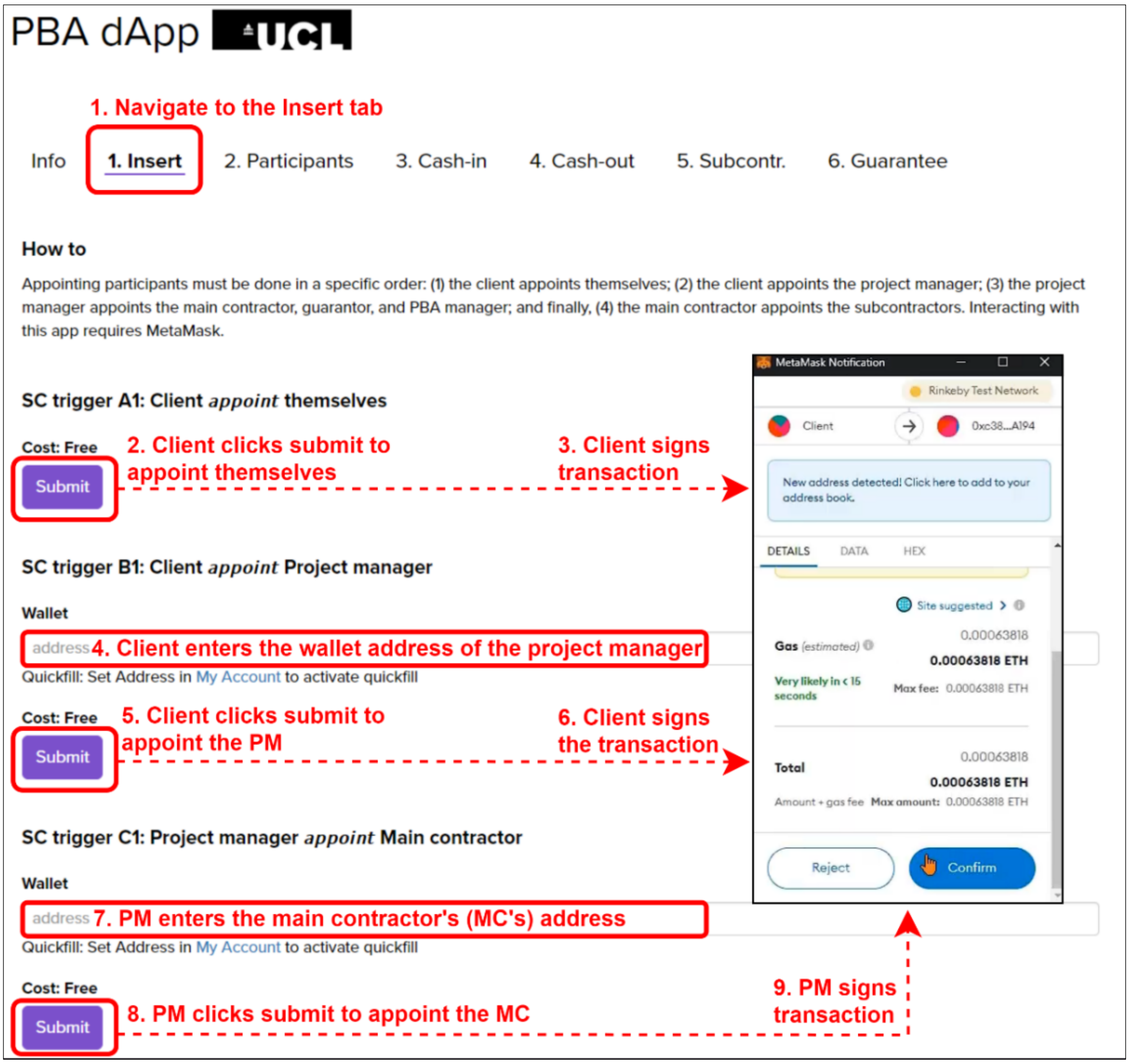

Figure 3: The insert tab of the user interface, which illustrates how project participants are appointed.

4.1 User Interface

The blockchain application's user interface (UI) comprises six navigation tabs (i.e., six web pages). The UI is connected to blockchain smart contracts (SCs); therefore, any information entered through the UI is stored in SCs. Each of the UI tabs (except the Insert tab) has a table, and the data in that table is also stored in an SC. Therefore, the UI is an abstraction layer that enables users to visualise and interact with the data in the SCs. The screenshots of the UI, shown in the following pages, are also labelled with 'SC trigger' and 'SC table' labels (e.g., 'SC Trigger A1' and 'SC Table A'). These labels are also referenced in Figure 2 to allow them to be read in conjunction with the UI. For example, Figure 2 includes a column for SC triggers and a column for the SC tables. These columns include labels for the SC tables (e.g., A, B, C, etc.) and labels for the SC triggers (e.g., A1, B1, C1, etc.).

4.1.1 Insert Tab

Figure 3 to Figure 12, shown below and on the following pages, are annotated in red to illustrate, step by step, how users would interact with the UI to perform cash flow management activities in the presented blockchain application.

4.1.2 Participants Tab

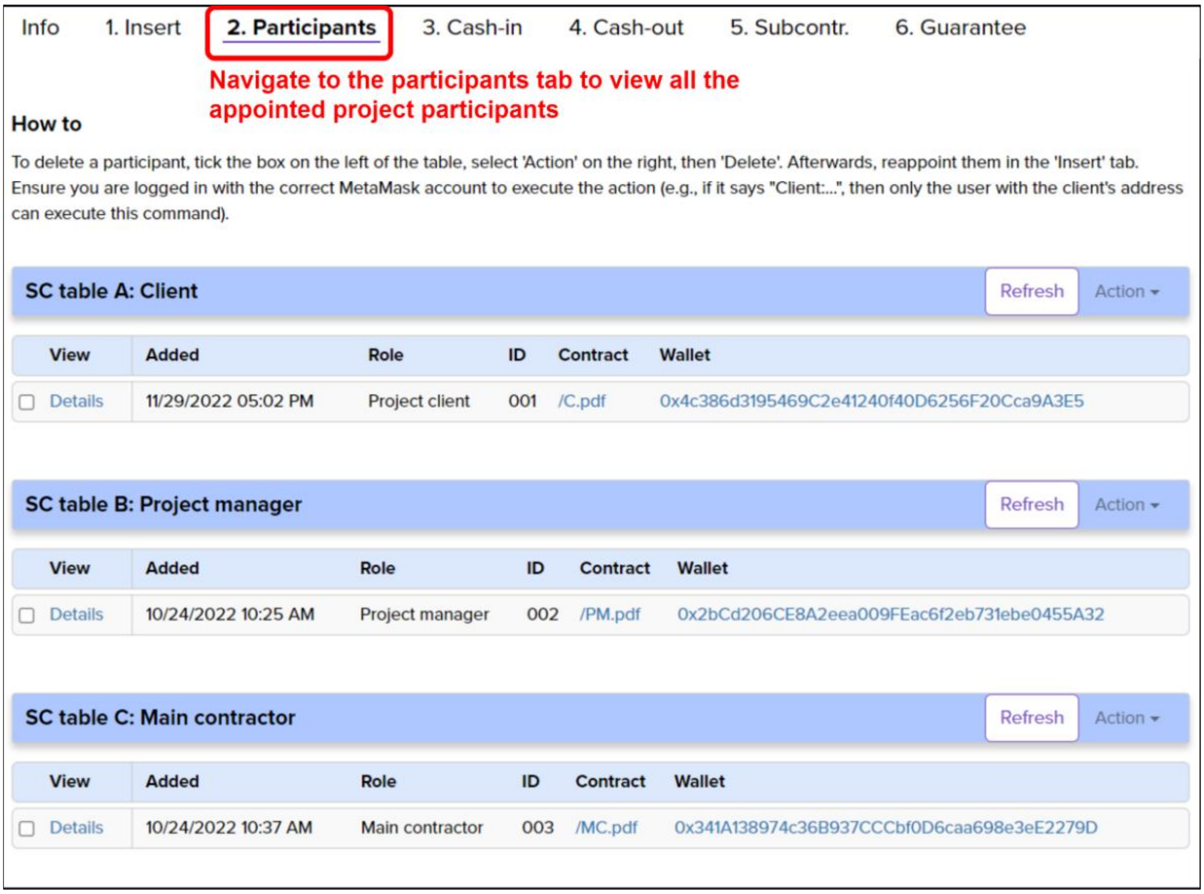

Figure 4: The participants tab of the user interface, which shows the appointed participants.

4.1.3 Cash-In Tab

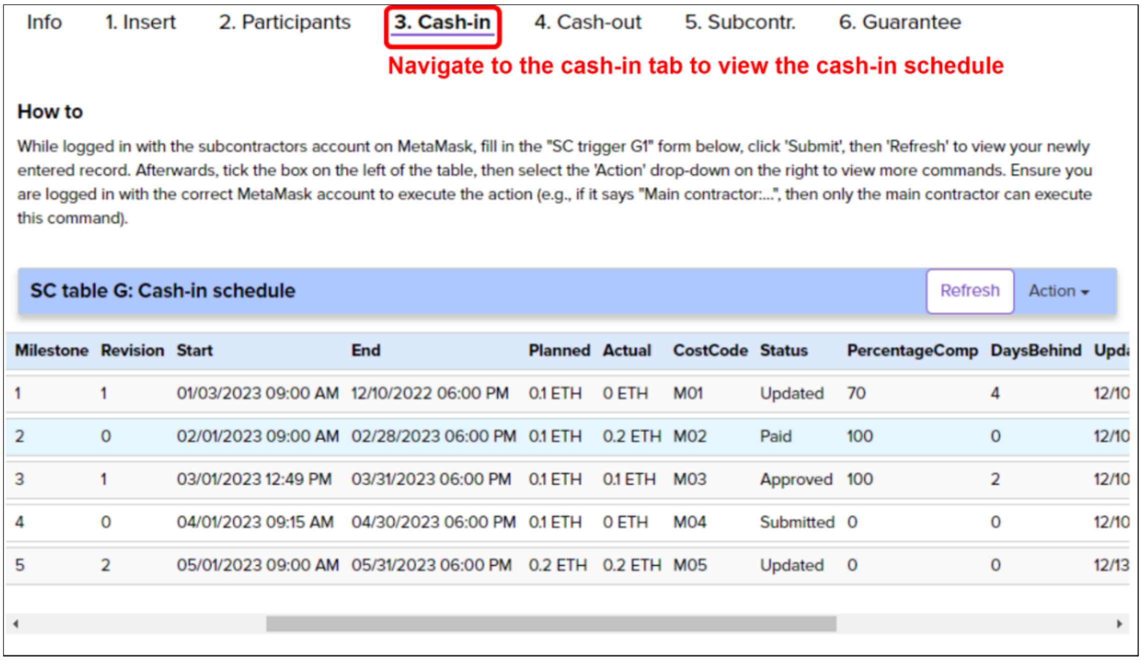

Figure 5: The cash-in tab of the user interface, which displays the cash-in table.

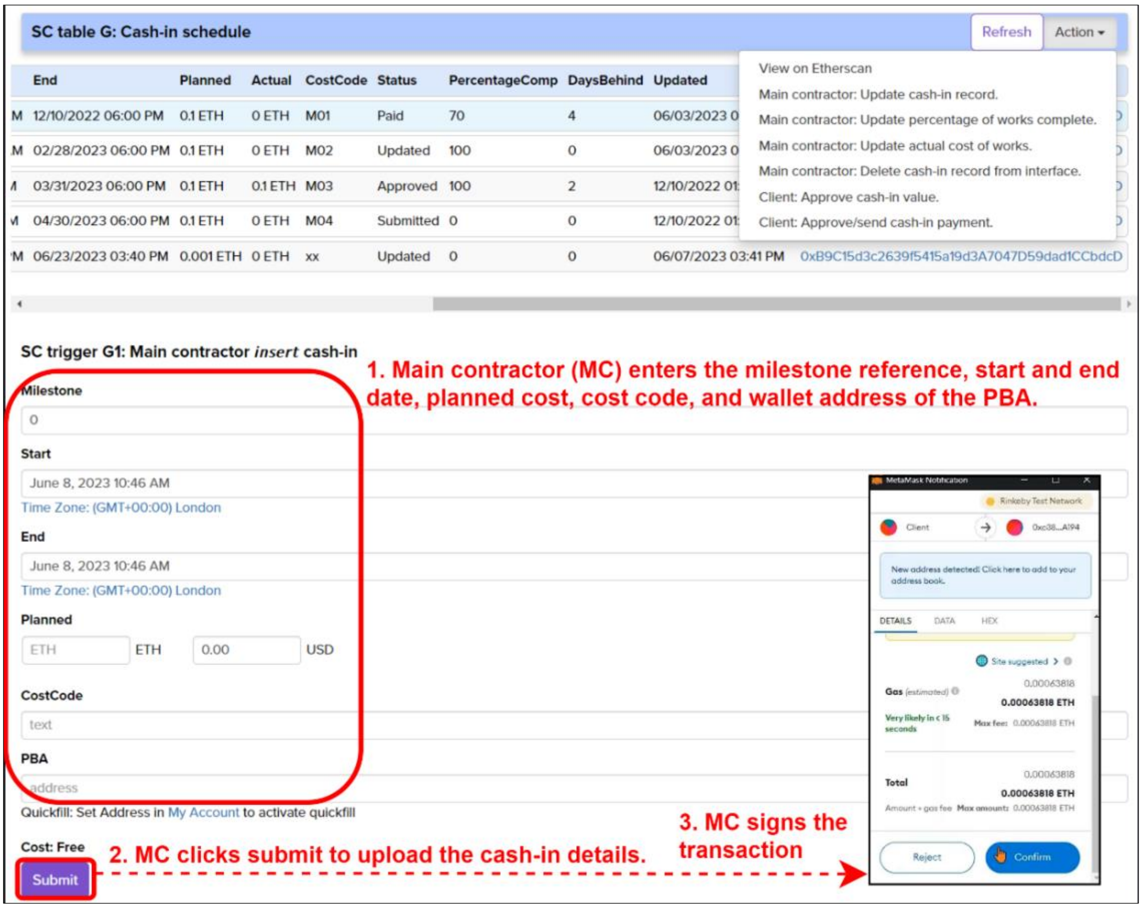

Figure 6: The cash-in tab of the user interface, which illustrates how the contractor uploads data to the table.

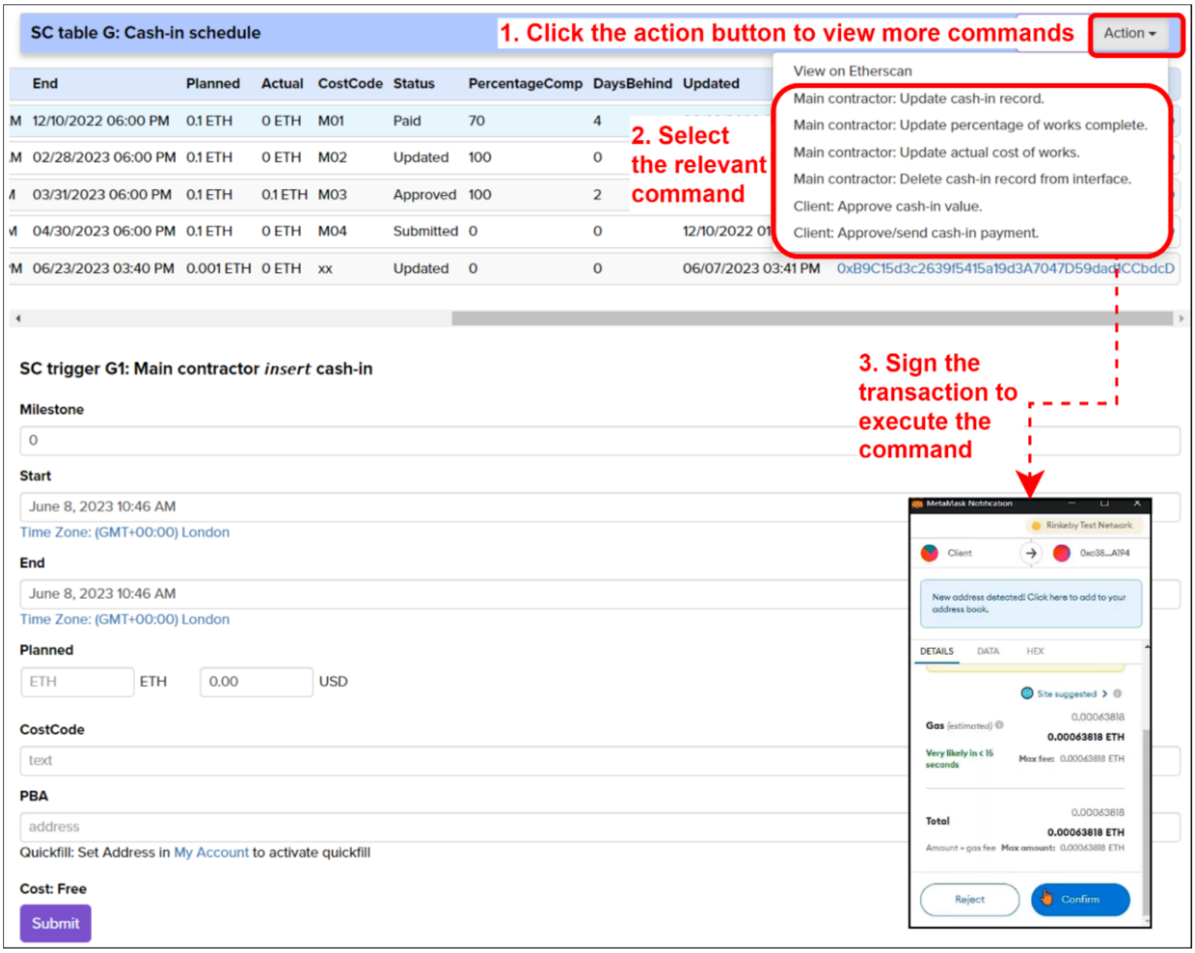

Figure 7: The cash-in tab of the user interface, which shows how users execute additional commands.

4.1.4 Cash-Out Tab

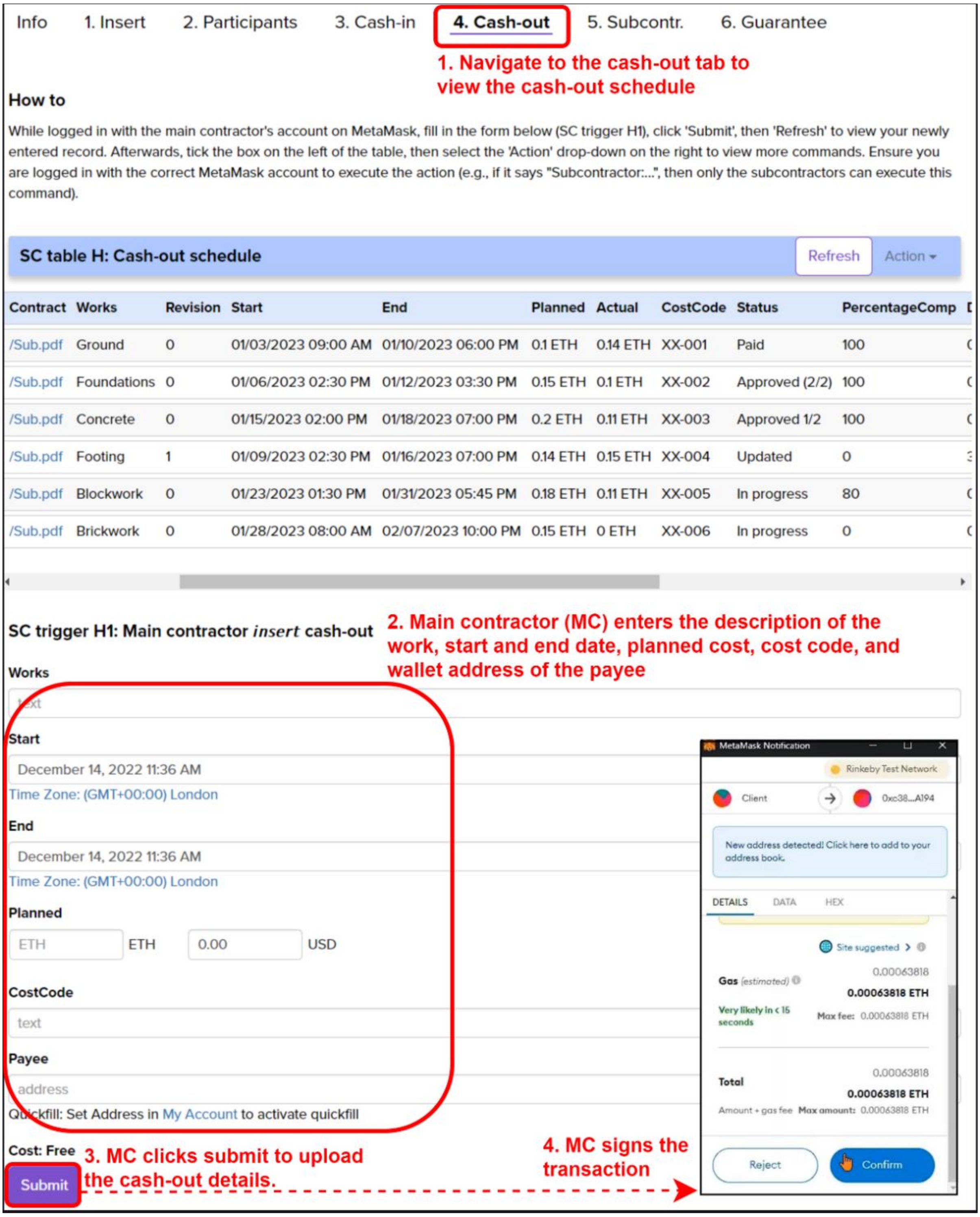

Figure 8: The cash-out tab of the user interface, which shows how the contractor uploads table data.

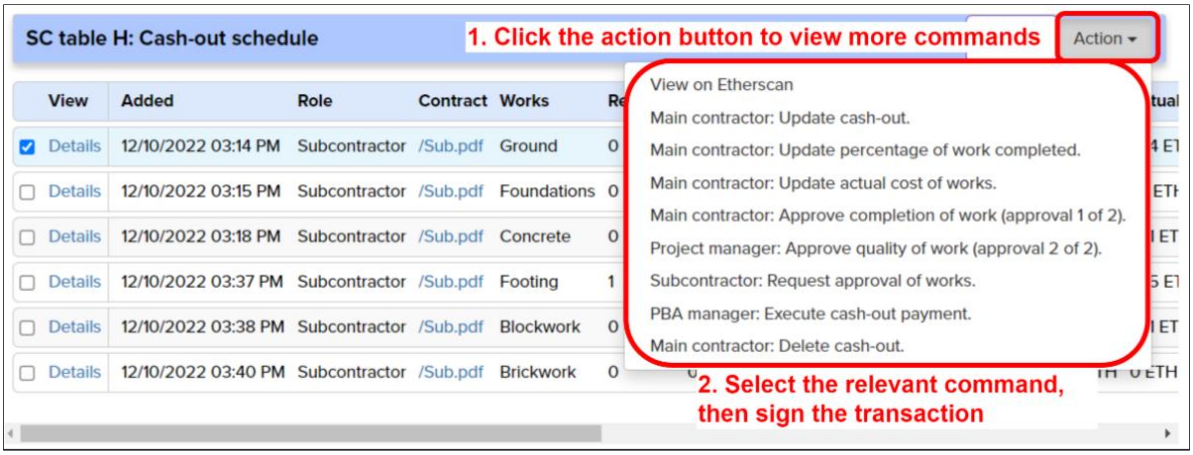

Figure 9: The cash-out tab of the user interface, which displays how users can execute more commands.

4.1.5 Subcontractor Tab

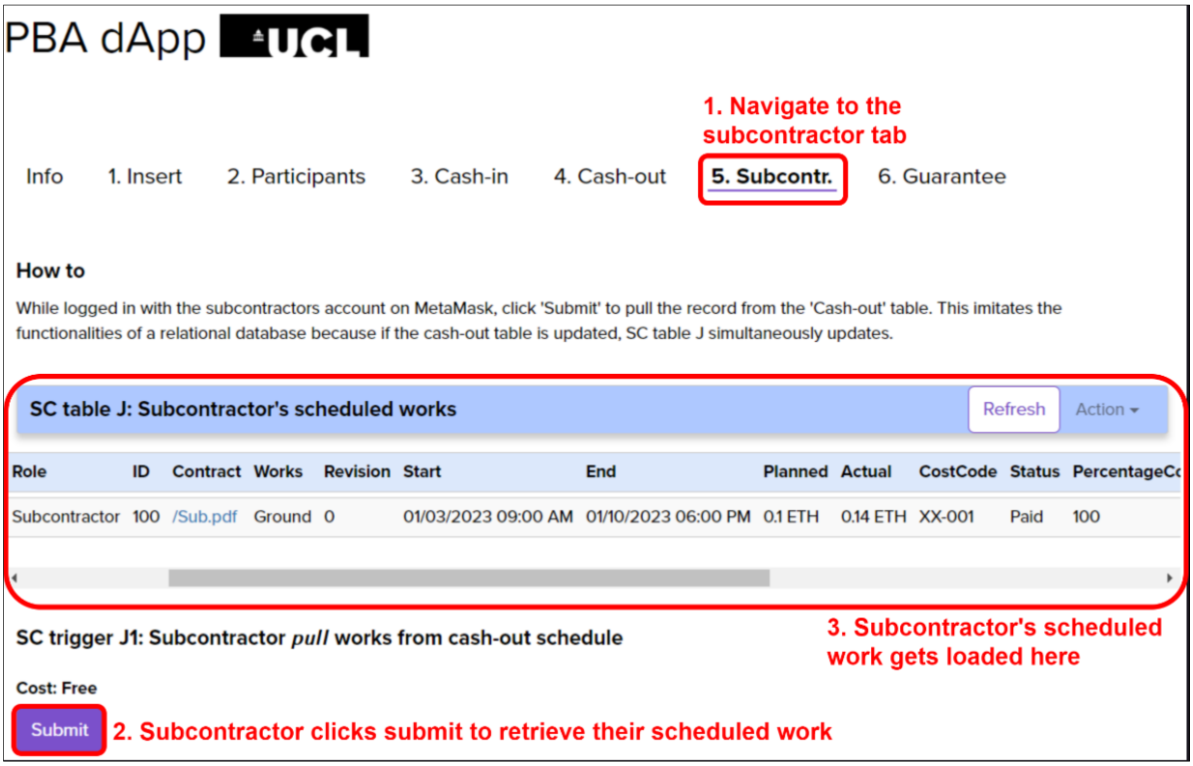

Figure 10: The subcontractor tab, which illustrates how a subcontractor can view their schedule work.

4.1.6 Guarantee Tab

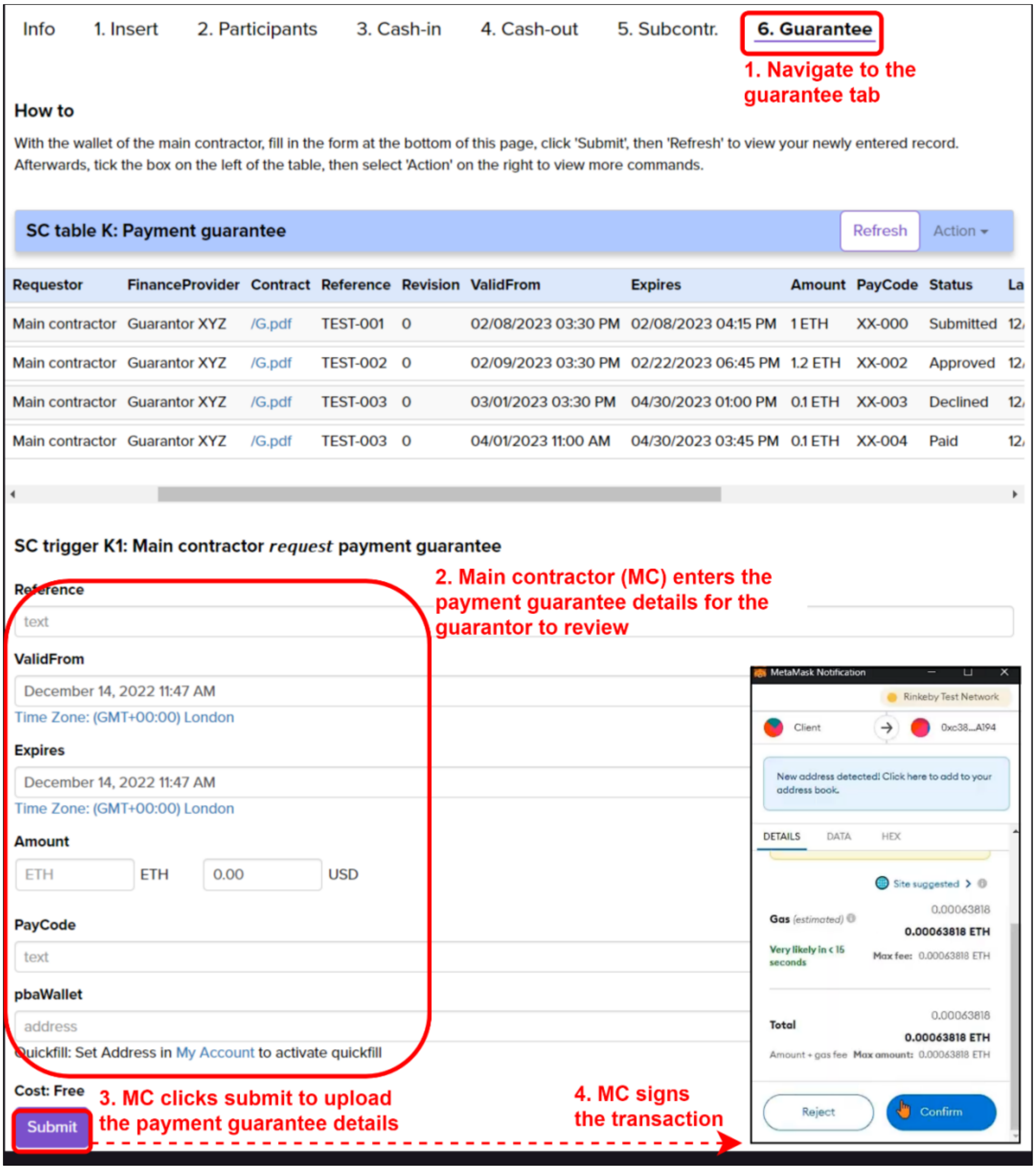

Figure 11: The guarantee tab, which displays how the contractor can request payment guarantees.

Figure 12: The guarantee tab, which shows how the guarantor can approve or decline the guarantee request.

4.2 System Architecture

The presented application deployed two smart contract (SC) types: SC triggers and SC tables. The relationship between them is shown in Figure 13. SC triggers have three primary actions: *Insert, update, and delete*. These are how users interact with the SC trigger to send requests to the SC table. *Insert* adds new data, *update* revises it, and *delete* removes it from the SC table. Even though data may appear deleted from the SC table, the blockchain keeps a permanent and traceable record of all events. Thus, any deleted data can be recovered or audited at any time. Users can initiate payments through the SC trigger by calling the *update* action and requesting it to execute payments listed in the SC table. SC triggers store codified *conditions* that cannot be altered once an SC is deployed, whereas SC tables store codified *permissions* that can be changed even after the SC table's deployment; therefore, storing SC conditions in SC triggers and using the SC trigger as a user endpoint is more reliable than storing conditions in SC tables. This allows SC conditions, such as who can interact with the SC table, to change without having to redeploy the SC table. SC tables are spreadsheet-style databases that store project management data. Therefore, ensuring the SC table is not redeployed midway through a project is vital in ensuring that project-critical data, such as timestamps and signatures, are not lost.

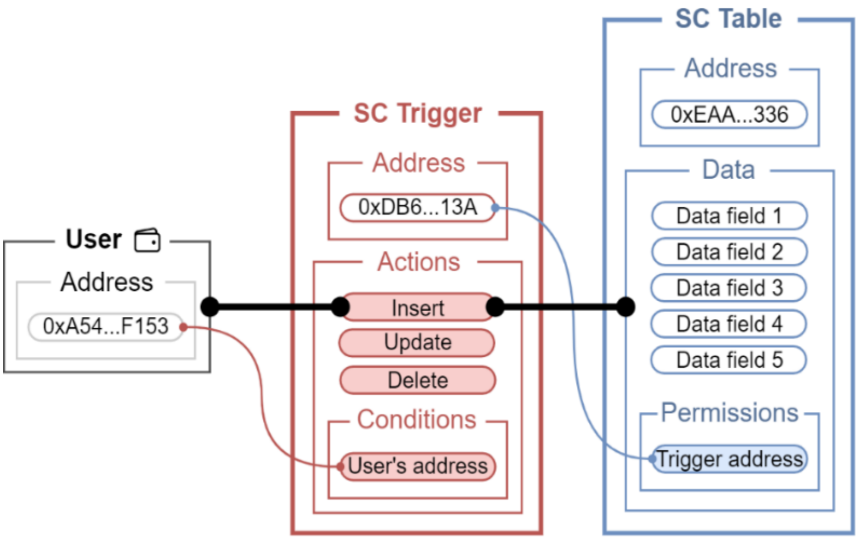

Figure 13: Smart contract (SC) trigger and table schema.

Figure 14 displays the presented application's technology composition. The process flow starts with users interacting with the UI and logging in with their MetaMask wallet. Afterwards, the UI enables them to send transactions via SC triggers to insert, update, or delete data in the SC tables. When an SC table receives a transaction request, the transaction is autonomously sent to the blockchain for validation. Once validated, the SC table updates its state with the new data. The presented application has an API (application programming interface) that autonomously pulls data from the SC tables and displays it on the UI.

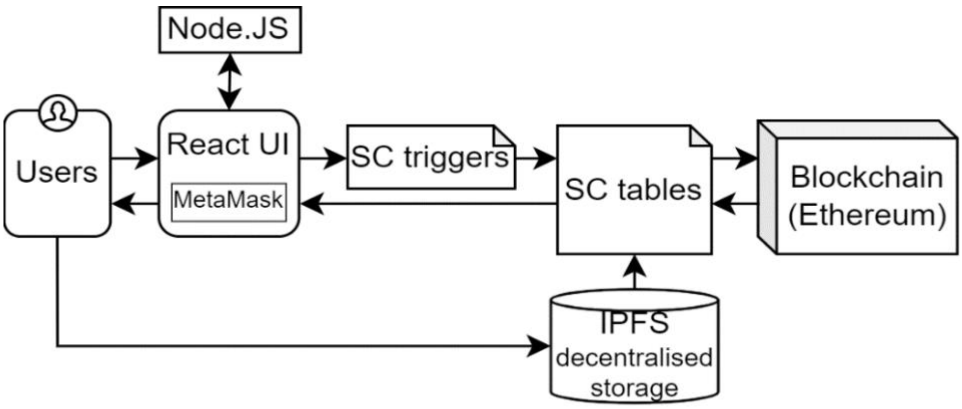

Figure 14: The presented application's technology composition.

Figure 15, shown below, is an abstraction of how the presented application's numerous SC triggers and SC tables interoperate. It displays three SC triggers and three SC tables; however, the entire SC map in the presnted application could not be displayed because it contains 50 SCs (40 SC triggers and 10 SC tables) and is overly extensive to illustrate.

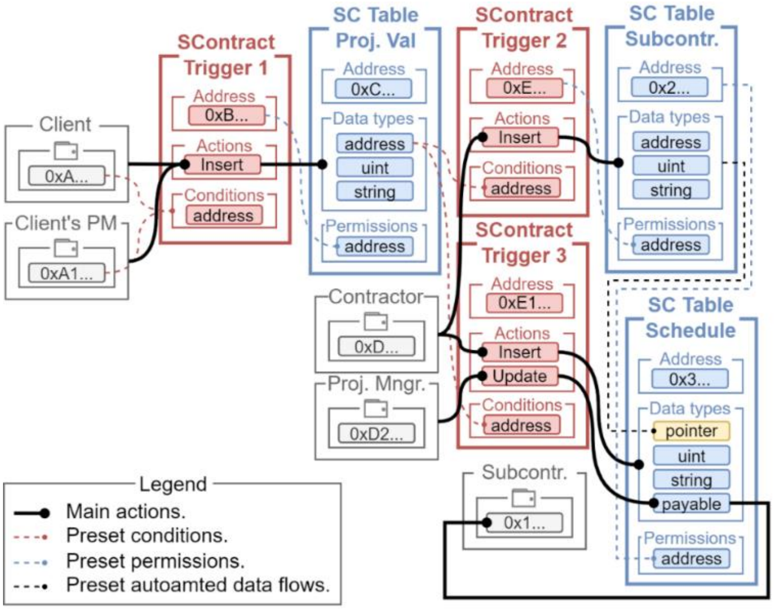

Figure 15: A map displaying the interconnectivity of three SC triggers and three SC tables.

A summary of the functionality of Figure 5 is as follows: *SC Trigger 1* has a codified condition pointing to the wallet addresses of the client and the client's PM (project manager); thus, only these participants can interact with *SC Trigger 1. SC Trigger 2* and *SC Trigger 3* operate differently because their conditions point to the address field of *SC Table Project Validator;* thus, any participants entered into *SC Table Project Validator* are granted access to interact with *SC Trigger 2* and *SC Trigger 3.* The contractor interacts with *SC Trigger 2* to store a list of the subcontractors in *SC Table Subcontractor.* The contractor also interacts with *SC Trigger 3* to insert the scheduled works of the subcontractors in *SC Table Schedule.* The project manager interacts with *SC trigger 3* to verify the completion of works in the *SC Table Schedule*, which triggers a payment to the subcontractors. *SC Table Schedule* has a pointer function that automatically pulls any relevant data from *SC Table Subcontractor* (e.g., start and end date, ID numbers, job role, contract documents, etc.). *SC Table Subcontractor* imitates the functionalities of a relational database because if it is updated, it autonomously updates the state of the *SC Table Schedule* via the pointer function.

The presented application's deployment cost, shown in Table 2, is estimated based on a one-year project duration. However, SCs only need to be deployed once throughout an entire project; therefore, if the project duration is longer, the SC deployment costs will not incur additional fees. In contrast, blockchain transactions are charged per execution, and a quantity of 1200, 100 per month, was included in the estimation; furthermore, the UI's web hosting fees are charged monthly.

*Table 2: The total cost of deploying and operating the blockchain payment application. Note. * = Costs based on an exchange rate of $1500 per Ether, with an Ethereum gas price of 3 Gwei.*

Description	*Unit Cost*	*Quantity*	*Total (USD)*
Smart contract table deployment fee	*$12* (each)*	*10*	*$120*
Smart contract trigger deployment fee	*$6* (each)*	*40*	*$240*
Ethereum transaction fee	*$0.90* (each)*	*1200*	*$1,080*
Atra Cloud Platform's web hosting services	*$50 (per month)*	*12*	*$600*
Total =			*$2,040*

5. DATA

A thematic analysis was used to organise the questionnaire responses into three primary themes: (1) blockchain, (2) web services, and (3) security. These themes were then structured into twelve subthemes, presented throughout this section. A separate subsection, titled "Keywords," displays the most common keywords mentioned by the questionnaire respondents. These keywords were used to structure the themes and subthemes of the thematic analysis.

5.1 Theme One: Blockchain

The blockchain theme is the largest of the three primary themes and covers everything intrinsic to blockchain technology. This theme is structured into six subthemes: (1) restructuring business processes, (2) tokens, (3) blockchain services, (4) scaling solutions, (5) privacy solutions, and (6) Ethereum alternatives.

5.1.1 Restructuring business processes

The restructuring business processes subtheme refers to the high-level considerations regarding how blockchain may affect the internal workflows of enterprises. Concerning this, one questionnaire participant commented, “Before enterprises embark on a blockchain journey, they should assess whether they are willing to restructure their business workflows, retrain staff, and have the resources to maintain it long-term”. Regarding this, another questionnaire participant shared, “companies would need to reconfigure how their internal systems operate entirely”, and another questionnaire participant added, “The fundamental structure of how businesses operate will probably require remodelling”. Regarding the potential legal accountability challenges of the blockchain, one questionnaire participant commented, “if a smart contract malfunctions and project funds are lost or stolen, the courts of law might find it difficult to hold someone centrally accountable for damages”. Similarly, another questionnaire participant added, “at the moment, we’re not entirely sure how problematic blockchain might be in judicial proceedings, central accountability with decentralised technologies is potentially challenging”.

5.1.2 Tokens

A cryptocurrency is the native currency of a blockchain platform, which is minted when the platform is launched. In contrast, a blockchain token is a type of cryptocurrency minted when a blockchain is already in operation, such as NFTs (non-fungible tokens) and stablecoins. Regarding this, one questionnaire participant commented, “The presented application needs to incorporate a crypto-economic incentive system as part of its core function.” Crypto-economics is an automated, algorithmic reward and penalty system built into dApps to incentivise good behaviour and penalise bad behaviour from their users (Bao and Roubaud, 2022). Concerning the price volatility of cryptocurrencies. One questionnaire participant said, “Stablecoins should be implemented in the application to mitigate the price fluctuations of Ether”, and that “incorporating it would ultimately decide the application’s success”. Another questionnaire participant advised to “use stablecoins as the default currency, and pair that with an exchange platform to convert them to fiat”. Regarding NFTs (non-fungible tokens), one questionnaire participant mentioned, “NFTs would be useful to explore because many digital and physical assets are unique and would benefit from easy verification and transferability”. Furthermore, another questionnaire participant added, “If construction companies adopted NFTs, they could use them to represent asset ownership certificates, which can be used as a medium of exchange when providing banks collateral for finance.” Moreover, they added, “This would reduce the banks’ processing time for verifying the authenticity of data, leading to reduced processing times for financial services.”

5.1.3 Third-party services

An ‘Off-ramp solution’ for cryptocurrencies (i.e., moving funds from the blockchain to the traditional banks) was the most prominent keyword of this subtheme, as shown in Table 5. For example, one questionnaire participant stated, “Off-ramping services so people can spend their crypto in shops and pay their bills is probably the most important feature.” The keywords “free code”, “free tools”, “free libraries”, and “free templates” were quoted several times by the questionnaire participants, suggesting that they value information sharing and a key property of dApps. Regarding this, one questionnaire participant was quoted as saying, “The good thing about blockchain is the availability of free resources out there, and there’s no fear that you’ll be sued by anyone for copying their code because everything’s out there and it’s open source”.

Regarding whether the technology components of the presented application were appropriately selected, one questionnaire participant highlighted, “Alchemy can be substituted for Infura for hosting the blockchain node, Infura specialises in decentralised storage, while Alchemy specialises in NFTs, Otherwise, they are relatively similar.” Another questionnaire participant mentioned, “Foundry provides a comprehensive toolkit for testing blockchain applications, it includes Forge (a testing framework like Truffle and Hardhat), Cast (a tool for smart contracts), and Anvil (a local Ethereum node like Ganache)”. Another questionnaire participant commented, “OpenZeppelin provides a library of community-reviewed smart contract templates that align with Ethereum’s most updated standards”. Another questionnaire participant remarked, “The Graph is a blockchain platform that provides indexing and oracle and API services to other blockchains”, and another highlighted, “Amazon and IBM provide blockchain-as-a-service (BaaS) for users seeking an instant blockchain solution with inbuilt services that integrate with their systems.”

5.1.4 Scaling solutions

Concerning the high transaction fees of Ethereum, one questionnaire participant commented, “Transaction fees on Ethereum are slow and expensive, so you need a layer 2.” Layer-two (L2) is a separate blockchain platform built above an existing layer one (L1) blockchain, such as Ethereum. The incentive of deploying an L2 blockchain above an L1 blockchain is that numerous L2 transactions can be grouped together and sent to the L1 as one transaction. Doing this also allows the L2 to leverage the security of L1 (Liang et al., 2022). This L2 blockchain is more commonly called an L2 scaling solution. Regarding this, one questionnaire participant mentioned, “Polygon, part of the L2 sidechain family, can reduce transaction fees by a factor of a thousand”. The range of L2 scaling solutions, as suggested by the questionnaire participants, comprises “sidechains”, “zero-knowledge proofs”, “ZK rollups”, “Optimistic rollups”, “State channels”, “Plasma chains”, and “Validium.” Table 3 (in the Keywords section) displays the popularity of these L2 scaling solutions, as mentioned by the questionnaire participants.

5.1.5 Privacy solutions

Regarding how to achieve privacy on Ethereum, 12 questionnaire participants advised using zero-knowledge proofs (ZKP). ZKP is a cryptographic protocol that enables users to mathematically prove that a piece of encrypted data is correct without having to decrypt it (Li and Xue, 2021). Another questionnaire participant highlighted, “Privacy can be achieved directly on layer one using the stealth address (SA) protocol” and added, “It allows users to generate sub-addresses that are one-time-use and cryptographically linked to their primary wallet”. Umbra is an example of a stealth address protocol for Ethereum (Solomon and DiFrancesco, 2021). Once a user transfers funds from the SA to their primary wallet, the SA is never used again, and a new SA is generated for a new private transaction (Solomon and DiFrancesco, 2021). Sending funds from a user’s SA wallet to their primary wallet can be achieved via a cryptocurrency exchange. Regarding this, one questionnaire participant mentioned, “Cryptocurrency exchanges are mixers that pool the funds of a huge quantity of users and obscure the origin of transactions, so all you need to do is send the funds there, then withdraw it from the exchange to the user’s primary wallet.” Other recommendations for privacy solutions, as advised by the by the questionnaire participants, include “privacy wallets” and “ring signatures.” However, they did not explain how these operate. Lastly, two questionnaire participants suggested using a “private blockchain” to achieve private transactions.

5.1.6 Ethereum alternatives

The popularity of Ethereum has resulted in high transaction fees due to network congestion. In response, several blockchain platforms were recommended by the questionnaire participants as potential alternatives, as shown in Table 3 in the Keywords section. One questionnaire participant remarked, “Solana” can achieve substantially higher transactions per second and lower transaction fees than Ethereum”, and another claimed that “Polkadot solves a critical problem that most blockchains have with cross-chain interoperability and is faster and cheaper than Ethereum”. Another questionnaire participant highlighted, “Internet Computer blockchain uses the same client-server model of Web 2 but decentralises them using Web 3 and blockchain, making transactions cheaper and providing better infrastructure for dApps.” Another questionnaire participant commented, “Hyperledger is a private blockchain with high throughput and no transaction fees.”

5.2 Theme Two: Web Services

The web services theme covers the additional components blockchain-based web applications require to integrate with the blockchain. This theme includes four subthemes: (1) Web 3, (2) user interface, (3) oracles and APIs, and (4) server-side logic.

5.2.1 Web 3

Regarding Web 3, one questionnaire participant stated, "The goal of Web 3 is to fully decentralise the web, but at the moment it lacks technical maturity." Similarly, another mentioned, "Web 3 is underdeveloped and needs more time to expand its services and tools." One of the questionnaire participants responded, "In a pure blockchain app, the back-end would be the blockchain and smart contracts only". Although this is true, blockchain applications typically require integration with web applications to increase user accessibility. One questionnaire participant commented, "The problem with Web 2 is that technology companies monetise the data of users"; however, they added, "Its services are cheap and scalable because it has had decades of development". Examples of common types of Web 3 services that may be useful for the presented application, as advised by several questionnaire participants, include "decentralised storage" (e.g., IPFS), "decentralised finance", and decentralised identity". Another questionnaire participant highlighted, "A hybrid approach integrating Web 2 and Web 3 is more practical in the current environment because a full Web 3 setup offers less value to developers and customers". Another questionnaire participant mentioned, "Making an entire application censorship-resistant by using Web 3, storing documents in IPFS, and using ENS (Ethereum name service) is excessive, these services are more catered for anonymous transacting parties". Another questionnaire participant remarked, "If the application aims to process payments with smart contracts, then using Web 3 just for the user interface would not add value". Another questionnaire participant stated, "Web 3 compliments blockchain, but blockchain applications can operate fine without it". Furthermore, another added, "there is little evidence that the application can benefit from Web 3". This was supported by another questionnaire participant, who commented, "Whether or not to use Web 3 is a balance between complete decentralisation versus retaining some operational control over the application", and another added, "If the plan is to build a large ecosystem of blockchain services or if planning to set up a DAO, then the rationale to use Web 3 becomes stronger". A DAO (decentralised autonomous organisation) is an entity managed by a decentralised network of contributors that use smart contracts to manage the system (Qian and Papadonikolaki, 2020). Lastly, one questionnaire participant highlighted, "Web 3 is optimal if complete decentralisation is the only goal"; however, they added, "improving the application's business logic should take precedence over decentralisation".

5.2.2 User interface

The presented application's user interface (UI) was built using JavaScript and React, a common front-end setup for web applications. When asked about other potential approaches for the UI, one questionnaire participant replied, "An alternative to React is Vue (a lightweight JavaScript framework) and Angular (a more technical Typescript framework)"; however, they added, "the decision on which web framework to choose is predominantly based on the developer's preference". Another questionnaire participant commented, "Pure.js allows developers to create simple web apps without requiring a front-end framework, but its features are limited". Another questionnaire participant mentioned, "Svelte is a front-end framework that supports both TypeScript and JavaScript"; furthermore, they added, "it compiles code to vanilla JavaScript, making syntax easy to read." Another questionnaire participant remarked, "Fleek provides services for hosting full Web 3 front-ends that connect to Ethereum, Internet Computer blockchain, IPFS, and Filecoin", and another questionnaire participant stated, "Drizzle (part of Ethereum's Truffle suite) is a front-end library that integrates with React, Web 3, and Ethereum". Another questionnaire participant advised that "Hardhat specialises in Web 3 application plugins". Another highlighted, "Python's Web 3 library (Web3.py) provides tools for construction industry software, such as Revit, to connect to blockchains". Lastly, one questionnaire participant commented, "Libsodium is a software library for Web 3 that provides tools for simplifying cryptography in web applications without compromising security".

5.2.3 Oracles and APIs

Blockchain oracles are application programming interfaces (APIs) that send data from the real world to the blockchain (Sonmez et al., 2022). Regarding this, one questionnaire participant mentioned, "ChainLink was first in the oracle scene, so they're probably the best starting point for these services, and they have a lot of free code". Another questionnaire participant remarked, "Dfinity is a non-profit organisation specialising in decentralised services and provides free oracles frameworks and templates for users to customise and deploy." Another questionnaire participant stated, "Web 3 oracles can be built from JavaScript (Web3.js) and Python (Web3.py)", and another questionnaire participant highlighted, "a lot of dApps provide free resources for oracles, or it can be outsourced to blockchain-as-a-service (BaaS) providers for a fee. Another questionnaire participant stated, "an oracle isn't necessarily needed if using a web application for the front end, an RPC and REST would do." RPC (remote procedure calls) or REST (representational state transfer) are standard types of APIs for web applications.

5.2.4 Off-chain integration

One questionnaire participant mentioned, "Off-chain integration is essential because the blockchain cannot be used for computationally intensive tasks or storing data-rich files". In the context of blockchain, off-chain is when data processing that typically occurs on the blockchain is transferred to an off-the-blockchain system, such as a server (Nawari and Ravindran, 2019). Regarding this, one questionnaire participant said, "It's important for Web 2 to integrate with Web 3 and blockchain, I don't know why people talk about these as rivals, they can all benefit much better if they work together." Similarly, another questionnaire participant replied, "There's no reason dApps should not leverage Web 2 systems", and another commented, "Web 3 lacks infrastructure, so creating a hybrid system that amalgamates Web 2 is better for the ecosystem", and another questionnaire participant commented, "interoperability between Web 2 and 3 would ultimately provide better services for users".

Concerning how to improve the presented application's business logic, one questionnaire participant remarked, "One of the ways that the application's business logic could improve is by incorporating a failsafe function that enables it to inform users if their transaction will fail before they send it", and another commented more generally by saying, "off-chain is one sure way to increase the processing speeds and capacity of the blockchain". Another questionnaire participant suggested that the application should include "automated alerts to project leads when project expenses exceed a threshold or if on a trajectory to exceed it, then they could react more quickly to risk" and another questionnaire participant highlighted, "An object-relational mapping (ORM) tool would improve the application's ability to interoperate smart contracts with relational databases". ORMs allow relational data to be collected from databases and presented as classes and objects in object-oriented programming languages (Colley et al., 2019). JavaScript and Solidity are examples of object-oriented programming languages. Lastly, another questionnaire participant commented, "Incorporating batch processing in the application would allow numerous transactions to be grouped and processed together with one signature, resulting in a better user experience because users would not be constantly prompted for MetaMask signatures every time they send a transaction". Furthermore, they added, "it would enable the application to work in offline mode because transactions can be parsed in the background and sent when back online".

5.3 Theme Three: Security

This theme is organised into two subthemes: (1) cybersecurity and (2) wallet security. There are specific differences in how cybersecurity and wallet security are analysed, with the former being more general-purpose and the latter being blockchain-focused.

5.3.1 Cybersecurity

Concerning the presented application's cybersecurity considerations, one questionnaire participant mentioned, "Decentralisation does not automatically equate to increased security, and more emphasis must be placed on ensuring the application is correctly built, managed, and maintained". Another questionnaire participant remarked, "Overreliance on blockchain services jeopardises security", and another added, "Deploying a blockchain node internally within the application is more secure than relying on third-party node services such as Infura". One questionnaire participant stated, "Some dApps link biometric authentication (e.g., fingerprint and face recognition) to blockchain wallets, incorporating it would be a solution". Another questionnaire participant highlighted, "standard email logins and two-factor authentication can be used to secure the app." Lastly, another questionnaire participant commented, "OAuth 2 is a technology standard for managing data trust in web applications, which needs consideration if planning to process or store user-identifiable data".

5.3.2 Wallet Security

Wallet security is a critical aspect of blockchain applications because a blockchain wallet is owned by its user and not a trusted third party. Concerning this, one questionnaire participant stated, "There is insufficient evidence that third-party blockchain wallets, such as MetaMask, can provide adequate proof of their security promises.” They added that “MetaMask operates through a web browser that collects data on user activity, so it is vulnerable to attacks”. Another highlighted, “Multi-signature wallets and multi-signature smart contracts should be used so transactions can only execute when a predefined number of authorised users sign for it”. Another questionnaire participant commented, “Threshold wallets are an updated version of multi-signature wallets”, and that “the difference is that one private key is divided into many parts and given to multiple users.” Another questionnaire participant mentioned, “An instant way to improve the security and performance of blockchain wallets is to ensure that they are generated using the most updated algorithm, such as the Edward Curve 25519”. Edward Curve generates more secure wallets that occupy fewer characters in their address length; thus, network fees are cheaper because less memory is required to store the wallet’s data on the blockchain (Brendel et al., 2021). Another questionnaire participant remarked, “Performing KYC (know your customer) verification on the wallet addresses of the application’s users is good practice to ensure users can be trusted and people are who they say they are.” Lastly, another questionnaire participant stated, “Decentralised identity (DID) has gained popularity in blockchain because it allows users to partition identity information away from third parties.” Similarly, another questionnaire participant commented, “Users can use their wallet purely for DID verification rather than transactions.” When a person uses their primary wallet for DID verification, that same wallet can produce sub-addresses that can be used for private transactions. This was mentioned earlier by several questionnaire participants who called these sub-addresses “stealth addresses” (SAs). When using a DID wallet with SAs, only the DID wallet’s owner can provide mathematical proof, via a wallet signature, that they own the SAs (Solomon and DiFrancesco, 2021). No external party can provide this proof; therefore, identity verification can occur with the user’s DID wallet while private transactions occur using the SA.

5.4 Keywords

Table 3 presents the keywords used to form the themes and subthemes of the thematic analysis. Those keywords were extracted from the questionnaire responses.

Table 3: Keywords of the thematic analysis.

Theme	Subtheme	Keywords	Total	%
Theme 1: Blockchain	Restructuring business processes	(‘Businesses’ or ‘companies’ or ‘enterprises’) and (‘Restructure’ or ‘remodel’ or ‘reorganise’ or ‘reconfigure’ or ‘redesign’) and (‘processes’ or ‘workflows’ or ‘operations’ or ‘procedures’)	6	21%
		(‘Businesses’ or ‘companies’ or ‘enterprises’) and (‘resource’ or ‘investment’ or ‘capital’ or ‘funding’)	5	13%
		(‘accountability’ or ‘central’ or ‘legal’ or ‘liability’) and (‘challenging’ or ‘difficult’ or ‘problematic’)	3	8%
		(‘Businesses’ or ‘companies’) and (‘retrain’ or train or ‘educate’) and (‘staff’ or ‘employees’ or ‘workforce’)	3	8%
	Tokens	‘Stablecoins’	15	39%
		(‘Crypto-economic’ or ‘reward and penalty’ or ‘incentive’) and (‘system’ or ‘mechanism’)	6	16%
		‘NFT’ and (‘digital’ or ‘asset’) and (‘unique’ or ‘certificate’)	4	11%
	Third-party services	(‘Off-ramp’ or ((‘withdraw’ or ‘exchange’ or ‘trade’ or ‘covert’)) and (‘crypto’ or ‘stablecoin’ or ‘solution’ or ‘system’)	11	29%
		‘Free’ and (‘tools’ or ‘resource’ or ‘libraries’ or ‘code’ or templates)	4	11%
		‘NFT’	4	11%
		‘Smart contract’ and (‘templates’ or ‘libraries’)	3	8%
		‘Decentralised non-profit’	1	3%
		‘Oracle and API services’	1	3%
		‘blockchain-as-a-service’	1	3%

Theme	Subtheme	Keywords	Total	%
	Scaling solutions	‘Off-chain’ or ‘layer-two’	14	37%
		(‘Lower’ or ‘cheaper’ or ‘economical’ or ‘cost-efficient’ or ‘competitive’) and (‘fees’ or ‘transactions’)	8	21%
		(‘faster’ or ‘quicker’ or ‘higher’ or ‘scalable’) and (‘TPS’ or ‘transactions’ or ‘throughput’)	7	18%
		‘Thousands of times cheaper’	1	3%
		‘sidechain’	9	24%
		‘zero-knowledge proofs’	7	18%
		‘ZK rollup’	3	8%
		‘Optimistic rollup’	2	5%
		‘State channel’	1	3%
		‘Plasma chain’	1	3%
		‘Validium’	1	3%
	Privacy solutions	(‘Zero-knowledge’) and (‘proofs’ or ‘protocols’ or ‘systems’)	12	32%
		(‘Off-chain’ or ‘layer-two’) and (‘solution’ or ‘integration’ or ‘wallet’ or ‘system’ or ‘application’)	8	21%
		‘Stealth address’	7	18%
		‘Privacy wallets’	3	8%
		‘Ring signatures’	2	5%
		‘Private blockchain’	2	5%
	Ethereum alternatives	*‘Cardano’*	*5*	13%
		‘Internet Computer’	*4*	11%
		‘Polkadot’	*4*	11%
		‘Solana’	*4*	11%
		‘Quorum’	*3*	8%
		‘Hedera Hashgraph’ or Hashgraph	*3*	8%
		‘Hyperledger’	*3*	8%
		‘Algorand’	*2*	5%
		‘Tron’	*2*	5%
		‘Vechain	*2*	5%
		‘Cosmos’	*2*	5%
		‘Consensys’	*2*	5%
		‘IBM Blockchain’	*1*	3%
		‘AWS Blockchain’	*1*	3%
Theme 2: Web services	Web 3	(‘Decentralise’ or ‘distributed’ or ‘peer-to-peer’) and (‘internet’ or ‘web’)	4	11%
		‘Web 3’ and (‘underdeveloped developed’ or ‘lacks maturity’ or ‘offers less value’ or ‘is excessive’).	4	11%
		‘Web 3’ and ‘for anonymous’ and (‘transactions’ or ‘users’ or ‘parties’)	3	8%
		‘Open source’	3	8%
		(‘Open’ or ‘free’) and ‘licence’	2	5%
		‘Web 2’ and (‘companies’ or ‘enterprises’) and (‘monetise’ or ‘exploit’) and ‘users’	2	5%

Theme	Subtheme	Keywords	Total	%
		‘Web 3’ and ‘complete decentralisation’	2	5%
		‘Decentralised storage’	2	5%
		‘Decentralised finance’	2	5%
		‘Decentralised identity’	1	3%
	User interface	Vue*	4	11%
		Angular*	3	8%
		Fleek*	3	8%
		Python*	3	8%
		Drizzle*	2	5%
		Hardhat*	2	5%
		Pure.JS*	1	3%
		Svelte*	1	3%
		Libsodium*	1	3%
	Oracles and APIs	‘Free’ and ‘oracles’ and (‘tools’ or ‘resource’ or ‘code’ or templates)	4	11%
		‘Chainlink’	3	8%
		‘Dfinity’	3	8%
		‘JavaScript’ and ‘Python’ and ‘Web 3 oracles’	1	3%
	Off-chain integration	(‘Web 2’ and ‘blockchain’) and (‘integrate’ or ‘combine’ or ‘leverage’ or ‘merge’ or ‘consolidate’)	4	11%
		(‘Web 2’ and ‘Web 3’) and (‘integrate’ or ‘amalgamate’ or ‘interoperability’)	3	8%
		(‘Increase’ or ‘improve’) and ((‘business logic’ or (‘processing’ and ‘capacity’)	3	8%
		‘Batch’ and (‘processing’ or ‘transactions’)	2	5%
		‘Failsafe functionality	1	3%
Theme 3: Security	Cybersecurity	‘Standard’ and (‘email login’ or ‘two-factor authentication’)	3	8%
		‘Biometric’ and (‘authentication’ or ‘verification’ or ‘system’)	3	8%
		‘Over-reliance on blockchain services jeopardises security’	1	3%
	Wallet security	(‘multi-signature’ or ‘multi-party computation’ or ‘threshold’ and ‘wallet’ or ‘smart contract’	12	32%
		(‘cold’ or ‘offline’ or ‘hardware’) and (‘wallet’ or ‘store’)	10	26%
		(‘Wallet’ or ‘seed’ or ‘key’) and ‘management’	9	24%
		‘Know-your-customer’ and (‘validation’ or ‘verification)	3	8%
		‘Decentralised identity’ and ‘Web 3’ or ‘blockchain’	2	5%
		‘Edward 25519 is the latest algorithm for generating wallets’	1	3%

Note. Total = number of keyword occurrences. % = percentage of questionnaire participants who responded with that keyword. Since there were 38 total respondents, if one participant responded with a particular keyword, then the % would display 3% (i.e., 1 out of 38).

6. ANALYSIS AND DISCUSSION

The structure of this section is organised into four parts: (1) it starts with a reiteration of the research objectives and research question, and summarises how these were achieved and addressed in the research findings; (2) a discussion of the thematic analysis and the keywords that shaped the categorisation of its themes and subthemes; (3) the blockchain payment application displayed in Section 4, Application, is evaluated to identify the its key challenges for adoption; and lastly, (4) the research limitations discusses a potential shortfall in this paper's methodological approach, and the primary barriers of the blockchain application presented in this paper.

Research objective one (i.e., 'present a decentralised payment application to blockchain engineers and collect data on its technical feasibility as an enterprise payment solution for construction') was focused on collecting data from blockchain engineers to examine the technological composition of decentralised payment applications for construction and provide expert recommendations on how to reconfigure and improve its setup to make it more technologically sound for construction enterprises. Technologically sound refers to whether a piece of technology is correctly assembled, functional, and reliable for its purpose. The participants targeted for the data collection were blockchain engineers, and the questionnaire questions were designed open-ended to encourage a more natural discourse from the participants. Research objective two (i.e., 'organise the findings into key themes and evaluate whether blockchain has matured to include adequate services for practical implementation in construction') was focused on analysing and structuring the findings to allow for thorough evaluation of the key insights collected from the blockchain engineers. The primary contribution of the thematic analysis was the twelve subthemes and the expansion of topics that emerged from them regarding the use of blockchain for payments. The combination of the two research objectives (i.e., collect technical insight from blockchain engineers, and thematic analysis of the findings) contributed the answering the research question: 'By engaging with blockchain engineers through a knowledge transfer study, what is the technical feasibility of using blockchain to improve payment processing efficiencies in the construction industry?' A separate subsection, titled 'Validating the Application', presents the most crucial factors that determine the feasibility of blockchain for construction payments.

6.1 Discussing the Thematic Analysis

Regarding the restructuring business processes subtheme of the thematic analysis, it encompasses several keywords, such as restructure workflows, training and education, resource investment, and legal accountability. This relates to how companies must restructure their internal business processes to accommodate decentralised technologies such as blockchain, smart contracts, and decentralised applications. This restructuring would require companies to provide training and education to ensure employees understand how to interface with blockchain systems securely. This training involves resource investment (i.e., time and money) to facilitate the integration of decentralised and centralised systems, which is an expense that construction companies must be aware of when considering the implementation of a blockchain solution. Construction is a centralised industry that relies on central accountability for construction failures. The challenge with using decentralised technologies, such as blockchain, is that no one owns the technology, which makes central accountability problematic when blockchain-related faults occur. For example, if project funds are lost due to theft or coding errors in smart contracts, central accountability can be challenging to pinpoint. Furthermore, the courts of law lack documented examples for managing blockchain-related disputes in the construction industry. In contrast, any other dispute that occurs in construction will likely have decades of historic records that can be used as precedent.

Regarding the Ethereum alternatives subtheme, other blockchain platforms exist that offer lower transaction fees and higher transaction throughput than Ethereum, including Algorand, Polkadot, Hashgraph, Internet Computer, Cardano, Hyperledger, and Quorum. A comparison of these blockchain platforms against Ethereum was conducted by Scott and Broyd (2024), and the results showed that Ethereum scored the highest overall based on these six parameters: (1) has an extensive ecosystem of decentralised applications (dApps), (2) supports stablecoins, (3) provides high security and data trust, (4) has smart contracts, (5) has privacy solutions, and (6) is low in CO2 emissions. Nevertheless, considerable value exists in building and testing dApps on other blockchain platforms to comparatively assess their barriers and opportunities against Ethereum-based dApps.

The scaling solutions subtheme encompasses several keywords such as lower transaction fees, higher transaction speeds, and Ethereum layer-two scaling solutions. Although transaction fees on public blockchains are not free, Ethereum layer-two (L2) scaling solutions, such as Polygon, can reduce these fees by a factor of 1000, making transaction fees on Ethereum negligible. Polygon belongs to a type of L2 scaling solution called a sidechain. However, other types of L2 scaling solutions also exist, such as Validium (e.g., Starkware), State channels (e.g., Raiden), and rollups (e.g., zkSync).

The privacy solutions subtheme overlaps with the previous subtheme. This is because Ethereum layer-two (L2) solutions branch into two categories: (1) scaling and (2) privacy. Two of the most popular suggestions from the questionnaire concerning L2 privacy solutions for Ethereum include zero-knowledge proofs (ZKPs) and stealth addresses. ZKP is a method where the data within a blockchain transaction is stored encrypted on the blockchain, and only the transacting parties have the keys to decrypt the data within the transaction. When a ZKP is used to encrypt transaction data, the transaction remains immutably stored on the blockchain; however, the addresses of the transacting parties and the transaction value remain encrypted. Another method for achieving privacy on Ethereum is the use of stealth addresses. A stealth address is when a user creates a sub-address from their primary blockchain wallet. It is impossible (based on current encryption methods) to decipher that the sub-address is cryptographically connected to a user's primary wallet. Funds can be transferred from the sub-address to the primary wallet using two approaches: (1) using a ZKP to hide the transaction's data, or (2) sending the funds from the stealth address to a cryptocurrency exchange, then from the cryptocurrency exchange to the user's primary wallet. Cryptocurrency exchanges do not disclose the origin of funds that pass through their systems, providing a means for private transactions. However, cryptocurrency exchanges are unlikely to be a feasible method for achieving privacy because of a lack of data traceability, which is problematic for auditors and regulatory bodies that rely on greater transaction transparency. In contrast, ZKP allows encrypted blockchain transactions to be decrypted privately by auditing authorities.

The tokens subtheme comprises the keywords stablecoins, off-ramping solutions, incentive systems, data authenticity, and non-fungible tokens (NFTs). Stablecoins are a cryptocurrency version of traditional fiat currencies, such as the British Pound, the Euro, or the US Dollar. The stablecoin always maintains its value at the same level as the fiat currency it is pegged to. This resolves the price volatility problem of cryptocurrencies such as Ether (the native cryptocurrency of Ethereum). One of the most significant determining factors on the practical feasibility of a blockchain payment application for construction is whether stablecoins can be used as legal tender or can be converted seamlessly into fiat currencies. In 2023, the UK Treasury published a proposal for regulating stablecoins as legal tender; however, it halted its progress in November 2024, stating that stablecoins will remain unregulated in the current climate until market demand for them increases (HM Treasury, 2025). Therefore, if stablecoins cannot be used as legal tender in the current commercial climate, a solution for off-ramping them is critical for using blockchain for payments. Off-ramping refers to the ability to convert cryptocurrencies, such as stablecoins, to fiat currencies. If stablecoins remain unregulated, additional off-ramp infrastructure will be required to convert stablecoins into fiat. Another keyword mentioned in the tokens subtheme was incentive systems. The terms incentive system, reward and penalty system, and crypto-economics are used interchangeably to represent the incorporation of an automated reward and penalty system for blockchain-based systems such as dApps. For example, reimbursements for prompt payments and surcharges for late payments. An incentive system was not incorporated into the presented application at the time of its development. However, the author believes an incentive system would be a valuable addition to the application. The incorporation of an incentive system may appear straightforward, but its algorithmic functions are technically complex to code in smart contracts; thus, the author decided to exclude it from the presented application.

The third-party applications subtheme primarily consisted of third-party solutions recommended by questionnaire participants, such as substituting Alchemy for Infura as the blockchain node, utilising Foundry's dApp testing toolkit, OpenZeppelin for community-reviewed smart contract templates, and The Graph for blockchain API and oracle services. NFTs were also mentioned in the third-party applications subtheme in the context of using them to represent digital certificates for construction, such as payment certificates and asset ownership certificates.

The Oracles and APIs subtheme consisted of recommendations of technology providers that provide free API services for blockchain applications. In the context of blockchain, an oracle is an API that retrieves data from non-blockchain-based systems, such as web servers, and transmits the data to the blockchain. For example, pulling weather data from a weather station server and pushing it into the blockchain to enable smart contracts to process the data. Popular programming languages such as Python and JavaScript provide open-source tools and libraries that allow users to write and deploy oracles.

The key finding from the off-chain integration subtheme is that blockchain applications must integrate with off-chain (i.e., non-blockchain) systems, such as standard web servers and cloud servers, to increase the processing and data storage capabilities of blockchain applications. This is because processing and storing data directly on the blockchain (i.e., on-chain) is slow and expensive; therefore, on-chain solutions must be integrated with off-chain to improve the blockchain's performance. When these are integrated, business logic improvements, such as batch processing (i.e., signing numerous transactions with one signature) and fail-safe functionalities (i.e., notifying users that their transaction will fail before they submit it), can be incorporated into blockchain applications.

Concerning the Web 3 subtheme, the data suggests that deploying the presented application entirely on Web 3 for complete decentralisation is unnecessary and more costly than deploying a hybrid solution that incorporates Web 2 and Web 3. Web 2 is the internet as it currently exists, where technology companies host web servers and provide web applications for users (e.g., Facebook). In Contrast, Web 3 is an entirely decentralised internet, where no central entity owns any of the technology, and all developers benefit from an open-source and open-access environment. Web 3 is better suited when complete decentralisation is the primary goal, such as in applications where users transact anonymously, like online cryptocurrency exchanges, or when managing a decentralised autonomous organisation. However, in the case of the presented application, which involves known identities transacting with each other, deploying the application primarily on Web 2 will result in a more economical and better-performing application. This is because Web 2 has existed for decades and is the standard system for developing web applications; thus, it has substantially more services and tools for streamlining web application development. Blockchain applications typically use a web application as their user interface; therefore, leveraging existing web application programming languages, such as JavaScript, for building blockchain services improves the interoperability capacity between Web 2 and Web 3.

Regarding the Cybersecurity subtheme, standard Web 2 solutions for cybersecurity, such as two-factor authentication and biometric authentication (i.e., fingerprint and facial recognition), are suitable for the web aspect of the presented application. However, this does not cover wallet security. The wallet security subtheme advised that the wallet application used in the presented application (i.e., MetaMask) is not safe for enterprises because it operates on a web browser, and web browsers store data on their users. Therefore, a blockchain wallet explicitly designed for enterprises should be used for the presented application. Additionally, when using blockchain wallets or smart contracts to hold project funds, a multi-signature system is a minimum requirement. Multi-signature is a process where multiple users must cooperatively sign a blockchain transaction for it to be executed, and the transaction cannot be executed until a predefined number of users have signed it. Lastly, a system for know-your-customer (KYC) authentication is another minimum requirement for enterprises transacting on the blockchain, because a method for verifying that a particular person or business is the rightful owner of a specific blockchain wallet is mandatory for security.

Seven of the twelve subthemes included overlapping keywords, as shown in Figure 16. Regarding the scaling solutions and privacy solutions subthemes, the keywords that overlap with them include zero-knowledge proofs (ZKPs), layer-two (L2) solutions, and off-chain solutions, which are all approaches for increasing transaction scalability and privacy. The third-party services and the tokens subthemes overlap with the non-fungible token (NFT) keyword. A blockchain token can be used as a medium of exchange (e.g., stablecoins) or as an NFT that represents unique digital assets, such as construction certificates. For example, an asset ownership certificate could be represented as an NFT, and a smart contract could be used to transfer it autonomously from one party to another. The third-party services and the API and oracles subthemes overlap with these keywords: free tools, resources, libraries, code, and templates, and API and oracles services. This is because dApp developers have the option to build their own APIs and oracles or outsource them from third parties; thus, two subthemes for these keywords were required. Furthermore, third-party services encompass a broad range of blockchain services, of which APIs and oracles are one of these services. Therefore, merging the third-party services and the API and oracles subthemes into one subtheme would be categorically inconsistent. Lastly, the wallet security and the Web 3 subthemes overlapped with the keyword decentralised identity (DID). In a DID system, a user's blockchain wallet would be relationally connected to personal information about them, and the ID data would be stored encrypted in a decentralised database that permits only the user's wallet to decrypt it. Connecting blockchain wallets to user-identifiable data is a service provided by dApps deployed in the Web3 environment. A typical route for accessing blockchain services is through Web 3 because it is more decentralised than Web 2 and is therefore preferred by dApp developers. The motivation for using DID services is to reduce reliance on centralised companies that exploit and profit from user data, and to enable the blockchain to have greater autonomy.

From analysing the findings, one of the primary barriers of using blockchain for construction payments is the internal restructuring construction companies would need to undergo to accommodate it, and the additional training and resource investment required to educate their team on how to safely use the technology (e.g., training staff on how to store and manage blockchain wallet private keys). Additionally, construction contracts would need to be updated to reflect a blockchain-based payment system, and new approaches for managing blockchain-related disputes would require careful deliberation by contract managers and legal teams. For example, if a blockchain smart contract malfunctions due to incorrectly written code and project funds are lost, central accountability must be identifiable, and adequate insurance must be in place to cover the damages. While researching blockchain insurance, the author came across one decentralised application (dApp) provider, Qredo, which provides insurance coverage up to the value of USD 600 million for theft or damages caused by technical malfunctions on their system (Qredo, 2022). Therefore, decentralised service providers are responding to the financial risk associated with blockchain-based systems by providing mitigation solutions, such as insurance, as part of their service offerings to customers and enterprises.

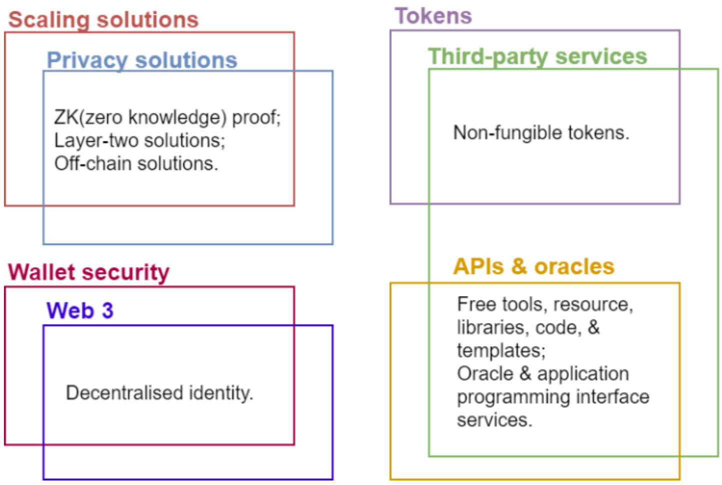

Figure 16: Displaying which keywords overlap with multiple subthemes.

The second-largest barrier to using blockchain for construction payments is the ability to utilise stablecoins as legal tender. Although the UK Government published a proposal in 2023 outlining its plans to regulate stablecoins as legal tender, they have not yet initiated the proposal and has instead decided to pause its regulatory efforts until greater market demand for stablecoins increases (HM Treasury, 2025). Without government approval of stablecoins as legal tender, additional off-ramp infrastructure is required to bridge the cryptocurrency and fiat currency landscapes to allow construction companies to withdraw their funds from the blockchain. The UK Government's delay in regulating stablecoins creates a barrier to using blockchain to settle payments in the UK, as payments for delivered works must be settled in a legal tender currency. El Salvador has been the only country that approved cryptocurrencies as legal tender (which it did in 2021); however, in 2024, the El Salvador Government scaled back its cryptocurrency regulation, whereby users are permitted to transact with cryptocurrency but are not allowed to use it to pay taxes or state bills (Wirtz, 2025). Until stablecoins are approved as legal tender, there will be substantial challenges in using cryptocurrency assets as a medium of exchange. Off-ramp services exist that bridge the cryptocurrency and fiat currency landscapes; however, exploring these solutions was beyond the scope of this paper. At the time the author conducted the research for this paper, the demand for blockchain was high, and the UK Government was ambitious to regulate stablecoins (HM Treasury, 2023). However, since then, the popularity of blockchain has decreased, and the pace of blockchain regulation has slowed.

Despite the two abovementioned barriers of using blockchain for payments (i.e., (1) companies needing to restructure their internal business processes, which includes updating contracts, retraining staff, and new methods for settling legal accountability, and (2) lack of government regulation for stablecoins), the findings suggest that, from the technology perspective, blockchain is in a mature state for commercial testing because of advancements in three key areas: Scaling solutions (e.g., layer-two sidechains), privacy solutions (e.g., zero-knowledge proofs), and blockchain oracle and API services. Scalability (i.e., higher transaction throughput and lower transaction fees) is crucial because businesses will not invest in a new technology if it is slower and more expensive than their current system. Privacy is essential because enterprises rely on it for standard business operations, whether through communications, transactions, contracts, or user data. This makes privacy one of the most critical factors that determine the adoption potential of blockchain for enterprises. The third factor is the availability of blockchain API services, which enable enterprises to integrate web applications and traditional software with blockchain smart contracts. Creating decentralised versions of current software is impractical; therefore, systems integration between the centralised and decentralised landscapes is crucial.

One of the key benefits a blockchain payment application has in comparison to a traditional finance application is the programmability freedom of smart contracts (i.e., any agreement within the technical bounds of the blockchain and legal bounds of the government can be programmed in a smart contract without needing permission from a technology provider, and blockchain platforms are unable to charge commission for any applications commercialised on their platform). Other key benefits of the blockchain include unrestricted access to an open-source and open-licence technology, no proprietary software fees, and its immutable ledger that enables users to offload the responsibility of data persistence to a trusted ledger.

6.2 Evaluating the Application

The presented application was used as a test case to extract technical insight from blockchain engineers. This insight involved investigating the feasibility of a blockchain payment application for the construction industry. The motivation for using the presented application as a mechanism for data collection was due to three reasons: (1) to provide an unambiguous and specific use case for blockchain engineers to respond to; (2) the author was able to use a blockchain application he previously built as the test case for this research; and lastly, (3) to identify areas of consensus amongst blockchain engineers for how they would address specific technical challenges and opportunities in blockchain payment application development. Since this research was primarily designed to target the technical aspects of a blockchain application, it was the focal point for evaluating the application. 29% of questionnaire respondents suggested that an 'off-ramp' service, which enables users to withdraw their money from the presented application, is one of the key components that should be added to the presented application. The most straightforward approach is to outsource this off-ramp service to a third party. Many centralised and decentralised providers can offer this off-ramp service; however, designing a framework for how it would operate in conjunction with the presented application and exploring which third-party provider would be suitable requires further investigation. Using layer-two (L2) scaling solutions to increase Ethereum's throughput (discussed by 37% of respondents) and utilising L2 solutions for privacy (discussed by 21% of respondents) were suggested methods for achieving transaction scalability and privacy in the presented application. Of these two L2 solutions, privacy is the more important because an enterprise blockchain application cannot operate without it. In contrast, high transaction throughput (i.e., scalability) is less concerning because payments in construction are not reliant on instantaneous settlement. The most suitable L2 privacy solution, as advised by 32% of respondents in the questionnaire, was zero-knowledge proofs (ZKPs). However, despite the questionnaire being open-ended, the respondents did not provide further clarification as to why ZKP was superior to the other L2 privacy solutions (a list of all privacy solutions, as suggested by the questionnaire respondents, is shown in Table 3 in Section 5: Data). From the perspective of validating whether the presented application was successful in its deployment as a payment application for construction, the three factors mentioned above (i.e., off-ramp services, L2 scaling solutions, and L2 privacy solutions) need to be incorporated into the presented application before it can be considered a potential payment system for construction. Nevertheless, the aim of this research was not to deploy a blockchain application for enterprise pilot testing at this stage, but rather to gather technical insights from blockchain engineers on how they would approach certain technical aspects of blockchain payment application development, such as off-ramping, privacy, and scalability.

6.3 Research Limitations

A solution for integrating decentralised finance (DeFi) protocols with banks to provide off-ramping services was overlooked in the presented application. Providing the infrastructure that allows enterprises to exchange their cryptocurrencies for fiat and off-ramp them to commercial banks at scale was suggested by one questionnaire participant as the most significant barrier to overcome. Banks have an aversion to accepting deposits from cryptocurrency companies due to regulatory uncertainty and the anti-money laundering (AML) risks associated with blockchains. Blockchain payment applications could exacerbate the construction industry's late payment problem if an off-ramping service is poorly designed. This is because banks can freeze cash withdrawals or deposits associated with blockchain if they deem them high-risk under AML or any other regulatory checks. Construction suppliers already receive late payments from contractors, and exacerbating the problem by banks freezing payments is a risk that the construction industry cannot afford. Therefore, careful implementation and testing of off-ramping infrastructure are crucial to the success of blockchain payment applications for construction.

Excluding demographic data from the questionnaire was one of the limitations of this research. However, delimiting the questionnaire participants to those with knowledge and experience in both the computer science and the construction industry subject areas would have potentially reduced the sample of participants to insubstantial levels. Among the participants invited to complete the questionnaire, 88% were from the computer science field, whereas 12% were from the construction industry. Since the questionnaire was designed to provide anonymous responses, no demographic data was collected from the 38 questionnaire participants. Therefore, although the questionnaire responses are likely to be biased towards computer science solutions, the exact division of which responses came from which subject areas could not be measured. The reason demographic data was not collected was to provide the candidates with a guarantee of anonymity. The author assumed anonymity would yield a higher response rate, and the author did not want to risk insubstantial responses as a factor in why this research could not be conducted.

7. CONCLUSION

This section summarises the key findings and concludes its fundamental points. It covers topics such as payment automation, systems integration, privacy solutions, scaling solutions, wallet security, and business logic for the presented application. Overall, this research suggests that blockchain and smart contracts could provide a potential solution for automating payments and reducing process redundancies in construction projects; however, the presented application lacks integration capabilities with existing centralised systems, such as management software and banking applications.

Systems integration and data trust are significant problems in construction (Sarkar et al., 2023). For example, data from scheduling, contract management, and payment software is currently challenging to integrate due to the technology-siloing nature of existing software. This is compounded further by a lack of assurance and traceability that data was not manipulated as it passes from one software to another. In contrast, data inserted, updated, or removed from a smart contract is timestamped and permanently recorded on the blockchain. To fully automate the data flow to the blockchain without intermediary systems, oracles (which are blockchain APIs) are necessary for providing the connectivity. The lack of data integration capabilities between existing software and payment applications was a motivating factor in investigating blockchain as a solution for integrating management systems and payment systems. The data suggests that the key considerations for companies adopting blockchain are to ask themselves whether they are prepared to restructure their internal workflows, fund the technology's management and operations in the long term, and provide the resources to retrain staff on how to operate decentralised systems safely (e.g., cybersecurity precautions and wallet management). The presented application demonstrated how management and cash flow data can be integrated into a single system to automate payments. However, some concerns with using blockchain include a lack of regulatory maturity regarding governments' acceptance of cryptocurrency as legal tender and the absence of infrastructure for off-ramping cryptocurrencies to traditional banks.

One of the areas in which centralised companies can benefit from blockchain and dApps is leveraging their open-source codebase to copy, modify, and redistribute the technology without copyright issues. Most dApps provide their codebase as open-source, as open-source software proliferates faster than closed-source software, and because closed-source software lacks data trust due to a lack of codebase transparency. Concerning the lack of legal accountability associated with decentralised technologies, some wallet dApps, such as Qredo, provide insurance coverage worth $600 million for any funds lost or stolen through their dApp.

The difference between the economic structures of decentralised and centralised technology providers is that the former provides cost-free and open-source technology but no customer support, whereas the latter provides costly and closed-source infrastructure but offers free customer support. Therefore, if a construction company is looking to explore and test blockchain solutions, hiring or outsourcing blockchain experts is crucial for providing that technical support. An alternative is outsourcing BaaS (blockchain-as-a-service) from technology companies, such as Amazon or IBM; however, these services are centralised, defeating the original purpose of using blockchain for technology democratisation. Another critical feature of blockchain is that dApps built on it keep 100% of the revenue generated from their dApp. In contrast, centralised technology companies charge 15 to 30% commission on revenue generated via their platform (Google, 2023).

Transaction scalability and privacy can be achieved on Ethereum layer-two (L2) solutions. Polygon is a popular L2 scaling solution that can reduce transaction fees by a factor of 1000. For example, a transaction fee of $20 would be reduced to $0.002. Furthermore, redeploying all the presented application's smart contracts on Polygon would reduce its total deployment fee to $0.15, making transaction fees negligible. L2 is also used for achieving private transactions through systems such as zero-knowledge proofs (ZKPs). ZKP was the most popular suggestion from the questionnaire participants for how to achieve private transactions on Ethereum. ZKPs enable transactions to be stored on the blockchain in an encrypted form, with only the transacting parties able to decrypt them.

The presented application's smart contract (SC) tables were designed with relational database functionalities, which reduces process redundancies and improves data synchronicity. For example, if several SC tables are interconnected and one SC table is updated, all the other SC tables in the network would synchronise instantaneously. This replicates how relational databases operate. Relational databases have existed for over 50 years and are the standard method for storing data in tabular format (Batra, 2018). Thus, converting SCs to operate like relational databases is a step towards integrating spreadsheet data with smart contracts to automate payments. The primary business logic recommendations suggested by the questionnaire participants include (1) batch processing and (2) fail-safe functionalities. Batch processing enables multiple transactions to be clustered and signed as a single transaction; it also allows the application to operate offline, as transactions can be grouped, signed, and executed when the application is back online. Fail-safe functionality is when a dApp notifies users if transactions will fail before they send them, thereby saving users from paying fees for transactions that will fail to execute.

7.1 Further Work

A qualitative approach was used to analyse the data of this research. Further work includes a more formalised study that quantitatively measures the efficiency gains of using the presented application versus traditional payment process flows, and calculating the implied time and cost savings of transitioning to a blockchain-based system. This could form part of a cost-benefit analysis to assess whether the presented application warrants resource investment from the perspective of a construction company considering blockchain adoption. Although a questionnaire was suitable for collecting preliminary technical data, a more action-oriented research approach, such as a pilot with a construction company and a dApp developer, would be more beneficial for testing the solution in a practical context. A main contractor would be the preferred construction candidate for the pilot, as they are predominantly responsible for managing payments in construction projects and would provide crucial organisational insight.

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