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# INVESTIGATING HOSTING PROJECT BANK ACCOUNTS (PBAS) ON THE BLOCKCHAIN AND ITS POTENTIAL VALUE CONTRIBUTION TO THE UK CONSTRUCTION INDUSTRY

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***SUMMARY***: *The UK Government mandated using project bank accounts (PBAs) in public-sector construction projects to reduce the risk of damages caused by contractor insolvencies and cash farming. Cash farming is a strategy contractors exploit to maintain high levels of capital for maximising investments into future work at the detriment of the supply chain enduring withheld payments. This article explores the cash flow problem from the technology perspective, particularly whether the programmability of smart contracts and the general-purpose protocol layer of the blockchain can be leveraged to reduce systems fragmentation and increase cash flow automation. This research proposes a PBA blockchain application and tests its hypothesis through proof of concept. Data is collected from construction consultants with working experience of PBAs to validate the proposal from the enterprise perspective. The findings suggest four key practical implications: (1) The proposed application reduces the PBA management workload of contractors due to process flow automation, (2) blockchain and smart contracts include the potential to democratise PBAs across a broader percentage of the supply chain, (3) a blockchain-based PBA can be set-up within a day (vs weeks with banks) and stores transactions permanently (vs a one year cap with banks), and finally, (4) blockchain can improve the granularity and traceability of cash flow data in payment performance reports.*

***KEYWORDS***: *Project bank account, blockchain, payments, smart contract, cash flow, process integration.*

***REFERENCE***: *Denis Scott & Tim Broyd (2024). Investigating hosting project bank accounts (PBAs) on the blockchain and its potential value contribution to the UK construction industry. Journal of Information Technology in Construction (ITcon), Vol. 29, pg. 935-975, DOI: 10.36680/j.itcon.2024.041*

# 1. INTRODUCTION

The construction industry suffers from high data flow fragmentation caused by outdated systems (Jaskula and Papadonikolaki, 2021). Solving the data flow fragmentation problem is suggested as one of the key steps for improving supply chain management in construction (Selvanesan and Satanarachchi, 2023). Another publication supported this claim, stating that construction companies "are still using inefficient, ineffective, and time-consuming techniques to coordinate and communicate with project stakeholders" (Khanna et al., 2021). This research investigates system fragmentation from the technology perspective and whether blockchain can integrate management flows with cash flows to improve systems integration and workflow automation. This research conducts a proof of concept (PoC) of a blockchain payment application using project bank accounts (PBAs) as its test case. The UK Government published the PBA guidance document in 2012, instructing the partitioning of project funds into a trust account to mitigate cash farming (i.e., withheld payments) and contractor insolvency risk (CabinetOffice, 2012b). When a PBA is used in a project, the client would make all project payments to the PBA instead of to the contractor, and the PBA would be used for all liabilities payments to the supply chain (UK_Government, 2012). The proposed application is inspired by and builds upon ideas from existing academic publications to fill research gaps in the topical area of blockchain for cash flow management in construction. Main contractors are disadvantaged when using standard PBAs because they are solely responsible for their set-up, operations, and management; however, it does not provide them with any direct benefits (which will be discussed in greater detail in later sections). Nevertheless, main contractors are mandated by the UK Government to use PBAs in public sector projects (Biddell, 2015). Therefore, this research has practical implications. The primary beneficiaries of PBAs are (1) tier-two subcontractors due to their payments being processed within several days of approval and (2) clients due to them having greater cash flow auditability and contractor insolvency protection. In contrast, supplier payments in standard, non-PBA projects are typically processed over 30 days late (Cowton and San-Jose, 2021)). Despite the PBA guidance document stipulating that tier-three suppliers must be paid from the PBA, the findings suggested that this is not the reality and that payments down to tier-three suppliers and below are excluded from the PBA system due to data processing challenges. This is due to the increased workload PBAs impose on projects (Macaulay, 2019). The proposed application addresses this problem through systems integration and payment automation, with its potential long-term value contribution being PBA democratisation across the entire supply chain and various project types (i.e., using PBAs on private-sector and small projects rather than just large public-sector projects). The immediate benefits of the proposed application to the supply chain are time and cost savings for managing PBAs and faster payment processing.

Research suggests that "fear of reprisal" is the number one factor preventing subcontractors from requesting PBAs in projects, followed by "legal expenses" and "culture" of the industry to resist change (Griffiths et al., 2017). Subcontractors are disadvantaged in projects that do not use PBAs due to them not having late payment protection. Research suggests that subcontractors in the UK spend billions annually chasing overdue payments (Swai et al., 2020). This is because PBAs are only used on large public-sector projects rather than all project types. PBAs are the best defence subcontractors have against cash farming (i.e., unfair withholding of liabilities); thus, making PBAs accessible for a more significant percentage of the supply chain would improve payment performance and reduce supply chain insolvencies. Data from the Office for National Statistics, based on figures from 2016 to 2020, suggest that an average of seven construction companies file for bankruptcy daily in the UK (Office For National Statistics, 2016, Office For National Statistics, 2017, Office For National Statistics, 2018, Office For National Statistics, 2019, Office For National Statistics, 2020). Furthermore, since the 1970s, the UK construction industry has continually maintained a pole position for the industry that contributes to the highest levels of insolvencies vs all other industries, averaging 20% of the total insolvent population, caused by (1) lack of project profitability and (2) poor cash flow management (Lowe and Moroke, 2010). PBAs in their current form reduce the main contractor's project profitability and increase their cash flow management workload, leading to PBAs being implemented ineffectively, which this research addresses by programming blockchain smart contracts to semi-automate the management of PBAs. The term "semi-automation" is used because project participants are still required to transact with the proposed application to insert data and approve works; afterwards, payments autonomously execute based on approval signatures. This research provides a framework, tested through a PoC, demonstrating how PBA workflows can be semi-automated using blockchain and smart contracts.

## 1.1 Research Gap

Only three academic publications are returned when querying the Scopus and Web of Science databases for "blockchain" "and" "project bank accounts". From these, (Li et al., 2019) published a systematic review assessing the potential of using blockchain for PBAs. (Ahmadisheykhsarmast and Sonmez, 2020) provided an alternative to PBAs, whereby the client's project payments get frozen in a smart contract one month before liabilities are due. Lastly, (Tezel et al., 2021) presented a blockchain application; however, it lacked sophistication in terms of adapting to project variations or change orders, and the system did not consider how various project participants, such as the client, project manager, and main contractor, would transact with the application to perform user-specific tasks (Tezel et al., 2021). The research builds upon these earlier works by developing the proposed PBA blockchain application that uses smart contracts to integrate various construction management and PBA systems, such as interoperating cash flow scheduling, approvals, and executions. The research is significant because the UK Government mandates the use of PBAs in public-sector work (UK Parliment, 2019). Data was collected from tier-one contractors because they are solely responsible for setting up and managing PBAs; thus, extracting insight from them was crucial for evaluating the viability of using blockchain and smart contracts to automate PBA processes.

## 1.2 Research Aim and Questions

The research aim is to thoroughly investigate, through a proof of concept (PoC), whether the cited benefits of blockchain and smart contracts, such as disintermediation, programmability, and automation, can contribute to reducing the systems fragmentation and lack of process automation issues concerning the management and operations of PBAs in the current climate. This article is structured around answering the following research questions (RQs):

1. How can blockchain and smart contracts increase systems integration and process flow automation in PBA projects?
2. How would project participants transact with the proposed application to perform PBA activities such as managing and approving payments?
3. From the perspective of construction practitioners experienced in PBAs, what are the strengths, weaknesses, opportunities, and threats of using blockchain and smart contracts for managing PBAs?

## 1.3 Structure

This research is organised into six sections. Section one, ***Introduction***, has already been covered above. Section two, ***Background***, is structured into two subsections such as subsection (2.1), *blockchain and smart contracts*, providing a summary of decentralised technologies in the current environment, and subsection (2.2), *related works*, examines several blockchain test applications from existing literature that overlap with the proposed application's framework, regarding using blockchain and smart contracts for managing cash flow. Section three, ***Methodology***, presents the method used for the primary data collection, the sampling approach for the candidates, and the strategy for analysing the data. Section four, ***Conceptual Framework***, is structured into three subsections such as subsection (4.1), *proposed application process flows*, illustrating how the proposed application automates workflows and how project participants transact with the system; subsection (4.2) *technology setup*, highlights the platforms, tools, and web services that combine to create the application; and subsection (4.3), *user interface*, displays screenshots of the application's user interface and diagrams for how users would use it in a practical context. Section five, ***Findings and Discussion***, thoroughly evaluates the findings and presents the researcher's appraisal of the data. Finally, section six, ***Conclusion***, summarises the Findings and Discussion's key findings and includes a subsection on limitations.

# 2. BACKGROUND

Distributed ledger technology (DLT) is the umbrella term for technologies that include blockchains (Chung et al., 2022). Blockchain is governed bottom-up and is managed by a decentralised network of users that co-contribute to maintaining its network (Lu et al., 2021). Two primary types of blockchains exist: private, which requires an invitation to join the network, and public, which allows anyone to join it (Nawari and Ravindran, 2019). For simplicity, this section will summarise the functionalities of public blockchains. Since no party or organisation owns the blockchain, it relies on a crypto-economic model called mining to incentivise users to maintain the network (Hunhevicz and Hall, 2020). Miners are financially rewarded for storing a full copy of the blockchain ledger and running the consensus algorithm that validates transactions (Dutta et al., 2020). When transactions are validated, they are packed into a container called a block, which is then uploaded to the blockchain for permanent storage (Dutta et al., 2020). Blockchain is a general-purpose technology that is malleable for various functions; hence, it can be configured to manage construction data (Kifokeris and Koch, 2020).

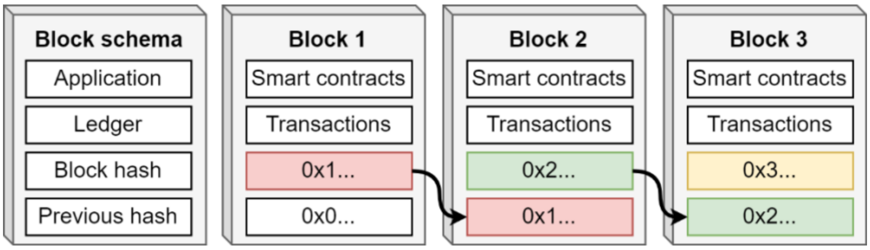



*Figure 1: Displays how blocks are cryptographically chained together. Colours represent each unique hash of a block and how the hash is copied to the subsequent block.*

Despite advances in digitisation in the modern economy, managing financial data (e.g., reconciliation and auditing) is unnecessarily time-consuming and manual-driven due to outdated systems (Hamledari and Fischer, 2021c). Assets, such as bonds, securities, properties, and mortgages, are typically represented by electronic paper documents; however, no system enables these asset classes to be exchanged under one platform (Gaur et al., 2019). Blockchain is investigating whether it can provide a general-purpose medium that allows users to exchange assets frictionlessly with a trusted and auditable data trail (Gaur et al., 2019). Since only one version of a blockchain ledger exists for each blockchain platform, querying and auditing data is straightforward (Smith, 2019). Some of the benefits of blockchain include near-instant cross-border payment settling, automated accounting, and data trail permanence (Li et al., 2019). Blockchain offers conveniences that financial institutions cannot rival, such as low entry barriers for users (e.g., anyone can join), self-sovereign wallets, and immutable bookkeeping (Ward and Rochemont, 2019). Blockchain could also reduce the onboarding cost for small businesses to obtain financial services (e.g., via decentralised finance (DeFi)) (Tezel et al., 2019). However, blockchain suffers from a lack of standardisation in dealing with blockchain-related disputes (e.g., cryptocurrency theft); furthermore, blockchain is difficult to insure because no single entity owns the technology, which creates challenges for the existing legal system because of a lack of central accountability (Goodell and Aste, 2019).

## 2.1 Smart Contracts

Ethereum, the blockchain used for the proposed application, is written in its native programming language, Solidity (Hunhevicz et al., 2022). Ethereum smart contracts are also written in solidity and deployed on the application layer of the blockchain (Perera et al., 2020). An escrow is an intermediary account between two transacting parties (Saygili et al., 2022). It is used when transacting parties do not trust each other or if both parties want greater financial assurances (Saygili et al., 2022). PBAs are a form of escrow (Scott et al., 2022). Escrows are typically set up and managed by centralised companies and are used to safeguard contract funds until both transacting parties are satisfied with contract delivery (Witkowski et al., 2011). The primary difference between a traditional and smart contract-based escrow is the latter does not rely on an intermediary to manage the agreement.

An example of a smart contract escrow used in construction was demonstrated in a study by (Saygili et al., 2022), who used the Kleros escrow to automate the release of progress payments; furthermore, the Kleros escrow was configured to manage the withholding of liabilities during dispute resolutions.

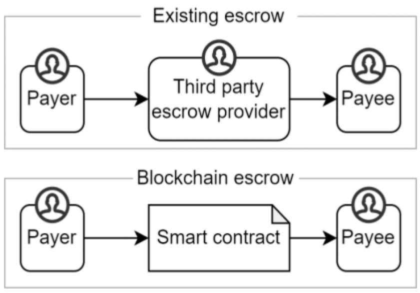



*Figure 2: Centralised vs decentralised escrows.*

## 2.2 Related Works

This subsection reviews 15 academic publications that overlap with the topic and aim of this research: using blockchain and smart contracts to improve cash flow management. Furthermore, these publications are tested through proof of concepts (PoCs), pilots, prototypes, or case studies, which correspond to the method adopted in this article.

Elghaish et al. published a PoC of a blockchain cash flow management application titled "Financial management of construction projects: Hyperledger Fabric and chaincode solutions" (Elghaish et al., 2022). The application proposed a payment system using existing cost management practices such as lump-sum, target-cost, and cost-plus (Elghaish et al., 2022). A user interface (UI) was launched that enables project participants to enter cost and schedule data. Afterwards, the UI integrates with smart contracts that control the execution of payments to the supply chain (Elghaish et al., 2022). The PoC also addressed the problem that contractors face when clients abuse the defects liability period (DLP) by designing smart contracts to automate the release of retentions (Elghaish et al., 2022). DLP is a standard procedure in construction contracts that permits the client to withhold a small percentage of due liabilities to insure against any defects at a project's closeout stage (Davey et al., 2006). In that PoC, Hyperledger Fabric was used for the blockchain and IBM's Blockchain Beta 2.0 Cloud Platform was used for the UI and smart contract templates (Elghaish et al., 2022).

Hamledari and Fischer authored a publication that conducted a simulated study of 14 participants (two groups of seven) to compare the data accuracy and efficiency of proprietary software versus a blockchain application. The publication is titled "Measuring the impact of blockchain and smart contracts on construction supply chain visibility" and focuses on integrating product flows with cash flows (Hamledari and Fischer, 2021b). Product flows are the transporting and installing of materials and components, whereas cash flows are payments for delivered works (Hamledari and Fischer, 2021b). The results showed that blockchain provided higher quality information whenever project data was queried; furthermore, the data was more accurate and traceable (Hamledari and Fischer, 2021b). For example, tracing payments to invoices, cost codes, valuations, and scheduled works was more efficient (Hamledari and Fischer, 2021b). The application was deployed on Ethereum (Hamledari and Fischer, 2021b); it used JSON (JavaScript Object Notation) for the RPC (remote procedure calls) and IPFS (Interplanetary File System) for decentralised storage (Hamledari and Fischer, 2021b).

Hamledari and Fischer published a second article in 2021, prototyping a test application that uses a UAV (drone) and UGV (unmanned ground vehicle) fitted with reality capture technologies (i.e., sensors) to scan the completeness of on-site construction (Hamledari and Fischer, 2021a). Afterwards, the data was uploaded into a 3-D BIM model that integrates with scheduling and pricing data (Hamledari and Fischer, 2021a). The project data is stored in an IPFS repository (a decentralised cloud), and an API (application programming interface) autonomously pushes the payment data into smart contracts for processing (Hamledari and Fischer, 2021a). However, no screenshots of the UI or code were presented (Hamledari and Fischer, 2021a). Thus, the work could not be externally verified or replicated from an application development perspective.

Ahmadisheykhsarmast and Sonmez published an article titled "A Smart contract system for security of payment of construction contracts" and conducted interviews with industry practitioners to investigate the viability of their proposal (Ahmadisheykhsarmast and Sonmez, 2020). Their application involved developing a software plugin that exports text data (e.g., '.txt' format) from MS Projects, and a UI is used to import the text file into Ethereum smart contracts (Ahmadisheykhsarmast and Sonmez, 2020). One limitation is that the client must send milestone payments to a smart contract and freeze the funds one month before liabilities are due to ensure the availability of funds on the payment execution date; afterwards, subcontractors receive automated payments directly from the smart contract. However, in standard construction projects, the main contractor is the one that covers the subcontractors' liabilities and not the client; afterwards, the main contractor claims the expense from the client at agreed milestones. Additionally, research shows that late payments typically start with the client (Abdul-Rahman et al., 2009). Thus, if the client is usually late when payments are due, they will not have the liabilities ready one month in advance. Nevertheless, the work was presented to construction practitioners, whose primary critique was the lack of privacy between the client's and the main contractor's liability payments because all data was publicly viewable (Ahmadisheykhsarmast and Sonmez, 2020). The feedback from the study participants also included "improves financial planning and management", "has a potential to eliminate the majority of the current payment issues of the construction industry", and "when all the payments are made on time, the project performance could improve substantially" (Ahmadisheykhsarmast and Sonmez, 2020). Wu et al. also published a similar article that proposes a blockchain payment application that includes payment freezing and similar approval stages (Wu et al., 2022).

Yang et al. conducted a case study of a blockchain application for the construction industry titled "Public and Private Blockchain in Construction Business Process and Information Integration"; it focuses on the procurement and transportation stages of building components (Yang et al., 2020). The business process documented is as follows: A contract manager and supplier both sign an agreement to supply a building component on-site; the procurement team pay the supplier a 30% deposit for the goods (via smart contract); and the remaining 70% is settled (via smart contract) when the item arrives on site and passes a quality inspection (Yang et al., 2020). The entire process is conducted through the Ethereum blockchain, and smart contracts were used to automate all payments at delivery checkpoints (Yang et al., 2020).

Chong and Diamantopoulos conducted a case study of a web application that integrates Internet of Things (IoT) sensors, BIM, and blockchain to trace façade panels from the manufacturer's warehouse in China to its final installation on-site in Australia (Chong and Diamantopoulos, 2020). Each panel was live-tracked via GPS (geographic positioning system), and the data was synchronised with a BIM model (Chong and Diamantopoulos, 2020). Smart contracts were used to record the data flows at key delivery checkpoints; however, automated payments via smart contracts were not utilised (Chong and Diamantopoulos, 2020). It is the only research case study that used blockchain in a real-life construction project; however, its technical composition was not presented, such as which blockchain platform, web services, or digital tools were used in the application's development. Thus, the application could not be externally verified. The food industry is one area where IoT and blockchain have harmonised to improve the tracking of goods across complex supply chains (Xu et al., 2023). Construction researchers are engaging with knowledge transfer from the food industry to extract insights regarding the infrastructure requirements to improve the tracking, transportation, and logistics of construction materials and components as they journey from warehouse to on-site (Xu et al., 2023).

Sigalov et al. created a web application that uses APIs (application programming interfaces) to integrate a BIM model with a construction bill of quantities (BoQ); afterwards, data is pushed into a back-end system that calculates liabilities owed; finally, APIs are used to transfer data from the back-end to the smart contracts (Sigalov et al., 2021). However, payments were settled via standard bank transfers because of blockchains' regulatory challenges at the time of the study (Sigalov et al., 2021). All technical components in that application were built and comprehensively presented, such as the UI, back-end, data layer, and APIs; furthermore, it is suitable for industry piloting because it mimics a real-life application (Sigalov et al., 2021).

Sonmez et al. developed a web application integrating a BIM model with smart contracts to execute payments. BIM objects were exported manually from Revit via a plugin that converts model data to a '.txt' file; afterwards, the text file was imported into a UI that calculates liabilities owed (Sonmez et al., 2022). The study revealed that the cost of deploying the smart contract was ETH 0.3 (roughly £400 in early 2023) per 500 BIM objects (Sonmez et al., 2022). A limitation of that proposal is that the UI is substantially underdeveloped and does not adequately mimic a real-life application.

Another study that integrated BIM with blockchain is an IPD (integrated project delivery) payment application by Elghaish et al., who presented how smart contracts can manage cash flow activities such as profit, cost saving, and reimbursed cost (Elghaish et al., 2020). The work included drafting equations for how project cash flow would be managed algorithmically; however, no evidence was displayed on how the equations would be codified into smart contracts. Additionally, the UI was minimally configured and did not display any project-relevant data (i.e., amount paid, payment status, payer and payee details, project references, etc.); therefore, users would have to manually call the smart contract every time any data needed querying or retrieving (Elghaish et al., 2020).

Ibrahim et al. authored an academic publication that proposed a web application for managing project schedules, retentions, and liability payments; however, there was no evidence of how the web application integrates with smart contracts (Ibrahim et al., 2022). The main goal of the study was to record the status data of milestone payments (e.g., “submitted”, “approved”, or “paid”) (Ibrahim et al., 2022). However, that study insufficiently demonstrated whether the UI is integrated with the smart contracts or if manual data entry is required to transfer data between the systems.

Perera et al. published a journal article discussing their recent development: a blockchain-based web application for buying and selling land and real estate, using smart contracts to manage agreements and settle transactions (Perera et al., 2021). The UI reflects a real-life application and displays evidence of transactions in Hyperledger Explorer (Perera et al., 2021). Hyperledger Fabric was used as the blockchain platform, and Hyperledger’s software development kit was used to bridge the UI to smart contracts (Perera et al., 2021).

Tezel et al. presented a PBA (project bank account) blockchain payment application that uses smart contracts to represent the PBA (Tezel et al., 2021). The UI mimics a real-life web application, and users transact via the UI to approve scheduled works that trigger payment executions via smart contracts (Tezel et al., 2021). However, the study lacked sophistication in terms of adapting to project variations and change orders, and the system did not consider how various project participants, such as the client, main contractor, subcontractors, consultants, and PBA manager, would transact with the application to perform management tasks (Tezel et al., 2021).

Das published an article titled “Securing interim payments in construction projects through a blockchain-based framework”, proposing a solution for cash flow management and privacy-preserving transactions on public blockchains (Das et al., 2020). The article showcased how multiple users can combine the addresses of their public keys to generate a new shared project wallet for encrypting and decrypting data stored on the blockchain (Das et al., 2020). The interim payment data would be encrypted in smart contracts; then, authorised parties would decrypt the data with the shared project wallet, enabling privacy on a public blockchain (Das et al., 2020). However, payments are settled via standard bank transfers (Das et al., 2020). Smart contracts were only used to automate the process of authenticating payment information, validating payment certificates, and providing proof of executed liabilities (Das et al., 2020).

Ye et al. proposed a blockchain application integrating BIM and bill of quantities (BoQ) data with construction payment approval stages (Ye et al., 2022). They built a web UI that integrates a BIM model, BoQ, schedule, and billing data in one system; afterwards, the data is exported into an information container that integrates with Ethereum smart contracts that execute payments based on approved delivered works (Ye et al., 2022). Their proposal was developed using Hardhat (a smart contract-building tool) and React (a web UI library) to create the front-end and back-end of the system. Furthermore, screenshots of how the UI and smart contracts interoperate were displayed. Their solution is comprehensively developed and suitable for industry piloting.

Wu et al. authored a journal article that presented a blockchain payment application attempting to reduce power imbalances in construction projects, particularly mitigating tier-one parties from unfairly withholding liabilities (Wu et al., 2023). Their application was tested with six simulated project participants, and smart contracts were customised to suit each payment approver. The primary limitation of that proposal was the lack of UI sophistication. For example, the article did not cover how end-users with no coding experience would utilise its smart contract to insert, update, or approve billing data through the UI.

Six related works displayed no code despite proposing blockchain applications (Hamledari and Fischer, 2021b, Chong and Diamantopoulos, 2020, Hamledari and Fischer, 2021a, Ibrahim et al., 2022, Perera et al., 2021, Tezel et al., 2021). Not providing code limits the ability of external researchers to audit, replicate, or build upon existing solutions. All blockchain platforms are open-source; therefore, building closed-source applications above an open-source technology is counterintuitive because external users cannot transparently verify it. External validation is vital in blockchain because of decentralisation, whereby no central authority can be held accountable if the technology malfunctions; thus, blockchain achieves trust through codebase transparency. However, there are several reasons why researchers may not publicly display their code, such as intellectual property restrictions, fear of others stealing their idea, or non-disclosure agreements imposed by academia-industry partnerships.

None of the related works provided a publicly accessible UI, which is limiting because external testing and feedback are fundamental aspects of application development. In contrast, the UI of this article's proposed application is publicly accessible via a standard weblink, and the smart contracts are presented open-source on GitHub (GitHub is a code hosting site). These links are displayed in the Conceptual Framework section.

## 3. METHODOLOGY

This research used an applied research methodology to identify whether blockchain can increase the automation of cash flow management in PBA-based construction projects. According to Guest et al. (2013), "Most applied research contexts, though, are subject to time constraints and have a relatively narrow and defined topic focus". The researcher delimited the focus of this paper to the software application perspective rather than proposing an amendment to the UK Government's Guide to the Implementation of Project Bank Accounts (UK Cabinet Office, 2012a). However, this comes with a key limitation: blockchain applications typically incorporate a financial reward or penalty system built into their design to stimulate user engagement. The challenge with using a monetary reward and penalty system in PBAs is that it increases the project's budget due to surcharges associated with late payment penalties. The UK's PBA guideline stipulates that it does not permit any amendment to its PBA system that increases the project's budget beyond its contractually agreed price. (UK Cabinet Office, 2012a). Due to this limitation, a financial penalty system was excluded from the proposed application's design because it breaches the UK Government's guidelines. Nevertheless, the Conceptual Framework chapter provides a supplementary scheme (Section 4.5: Reward and Penalty System) for how financial rewards and penalties could be appended to the proposed application. Figure 3 displays the area of focus of this paper: an application that improves the management and automation of PBAs.

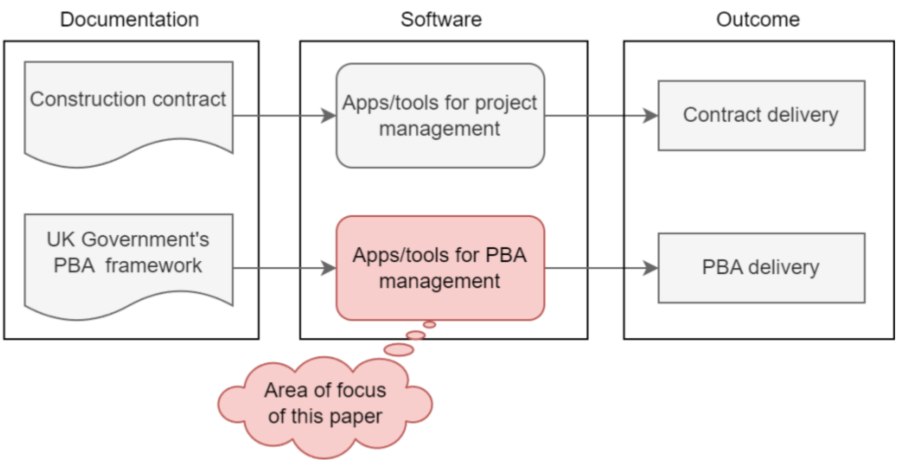



*Figure 3: Area of focus of this research.*

The researcher published a PBA-blockchain conceptual model paper in 2022 (Scott et al., 2022). The ideas from that paper were used as the foundation for developing this article's proposed application and testing it through a proof of concept (PoC).

The primary data collected for testing the proposed application is shown in the *Findings* and *Discussion* section. A focus group interview was used to collect data from construction consultants with working experience of PBAs to test the application's viability from the construction enterprise perspective. A thematic analysis (TA) was used to structure the data collection into four primary themes: (1) strengths, (2) weaknesses, (3) opportunities, and (4) threats (SWOT). These were then organised into 16 subthemes. TA is one of the most common methods for analysing qualitative data and is used to identify patterns in data sets such as transcripts, observations, or documents (Saunders et al., 2019). TA uses axial coding to structure research data into themes and subthemes for better evaluation (Cassell et al., 2018). Lapan suggests that TA "requires the researcher to engage in an iterative process of critical thinking, questioning, and categorising” (Lapan et al., 2012). Other researchers who used a SWOT analysis in their blockchain in construction papers include: (Tezel et al., 2020, Gao et al., 2022). SWOT analysis originated at Harvard Business School in the 1960s and became popular among organisations investigating the value proposition of products or services (Hill and Westbrook, 1997). SWOT analysis was incorporated into this research due to its simplicity, familiarity, and usefulness in reviewing applications.

Candidates for the focus group were collected from several UK main contractors. The only demographic data collected from the participants was regarding employment and PBA experience. The focus group was conducted via video call vs. in-person based on the participants' preferences. The level of data saturation from the participants shown in Table 1 was of satisfactory quality and quantity for thorough data analysis; therefore, a second focus group interview with other participants was unnecessary.

*Table 1: Demographics of the focus group participants.*

| **Employment** | **Years in current employment** | **Country of employment** | **Years working with PBAs** | **Knowledge level of blockchain**[a] |
|---|---|---|---|---|
| Treasurer | 20+ | UK | 10+ | Beginner[a] |
| Contract manager | 16-20 | UK | 6-10 | Beginner[a] |
| Legal consultant | 16-20 | UK | 6-10 | Intermediate[a] |
| Innovation consultant | 11-15 | UK | 3-5 | Advanced[a] |

*Note. a: is based on the researcher’s judgement post-interview.*

The participants agreed to a two-hour focus group interview. However, the interview lasted almost three hours at the participants’ mutually agreed discretion for continuing the interview. The researcher live-presented the proposed application during the interview, and the participants were encouraged to ask questions throughout the demonstration to promote discussions. The focus group format was semi-structured, and Table 2 shows the questions the researcher prepared as a guideline; however, these questions were expanded upon organically while the interview commenced.

*Table 2: These questions were used as a guideline for the semi-structured focus group interview.*

| | |
|---|---|
| 1. | What are the weaknesses or threats of the application? |
| 2. | What are the strengths or opportunities of the application? |
| 3. | If developed more, do you see the application as a feasible solution, or do you have any suggestions for improving it? |
| 4. | Did the application overlook some key cash flow management processes? If so, can you explain which ones? |
| 5. | Do you think the application should integrate with other software? If so, which would you suggest? |
| 6. | Do you think the application would struggle to integrate with current systems within your organisation? If so, why is this? |
| 7. | Do you see any security concerns with the application? |
| 8. | Do you think the application demonstrated how management and cash flow processes could be integrated, and do you have any comments regarding this? |
| 9. | Do you see any legal or regulatory challenges with using blockchain for payments? |
| 10. | What are the challenges with hosting PBAs on the blockchain instead of with a bank? |

The proposed application was presented to the focus group participants in the form of a live demonstration on Microsoft Teams. Figure 4 was shown to the participants before the commencement of the live demonstration. This was followed by a brief explanation of how blockchain smart contracts operate and how they can be programmed to replicate and automate some of the functionalities of traditional PBAs. The proposed application's user interface (UI) was in the form of a web application. This UI is located in Section 4.4: User Interface. The live demonstration included presenting how each member in the PBA system would transact with the proposed application's UI by using their blockchain wallets to sign for financial and non-financial transactions. An example of a non-financial transaction is an approval signature for delivered works. The live demonstration also exemplified how members of the PBA system would sign the PBA trust deed and perform various user-specific activities, such as the main contractor entering the payment schedule, the subcontractor notifying that delivered work is ready for review, and how the management team approves the quality and quantity of delivered work. Payment automation is achieved because a billing and payable team is not required to process the PBA payments manually. Instead, payments are programmatically tied to approval signatures signed by the tier-one management team. A detailed walkthrough of these processes is presented in Chapter 4: Conceptual Framework.

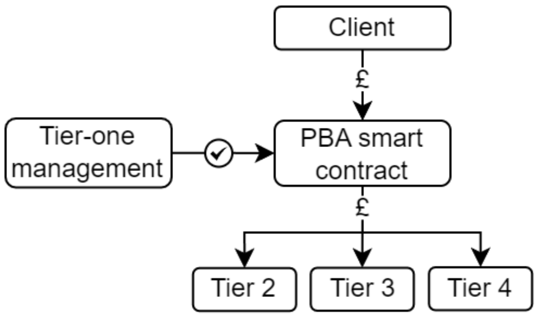



*Figure 4: Overview of the proposed application.*

## 4. CONCEPTUAL FRAMEWORK

This section evaluates in detail the decision points that led to the proposed application's technology selection, architecture, and development; furthermore, it is structured into five sections: (1) proposed application process flow, (2) blockchain selection, (3) technology setup, (4) user interface, and (5) reward and penalty system. This section showcases the integration of construction management and cash flow processes by integrating payment schedules, approvals, certificates, and executions in one application to reduce system fragmentation. Other construction researchers (i.e., (Kifokeris and Koch, 2022, Hamledari and Fischer, 2021b)) also explored integrating product flows with cash flows to increase payment processing automation.

Blockchain was selected as the foundation technology layer because it enables the deployment of applications on its protocol without needing to set up any infrastructure, databases, or cybersecurity systems (Tezel et al., 2020). Blockchain was explored because it allows users to deploy smart contracts that enable programmable money without building complex and costly APIs (application programming interfaces) that pull and push data between management and payment software. Escrows were one of the first use cases for smart contracts and are one of the least technical applications to test on the blockchain (Hassija et al., 2020). This makes it a good starting point for testing a blockchain project bank account (PBA) proof of concept (PoC) for the construction industry, as PBAs are simply a more sophisticated form of escrow. PBA's core functionality is to create a shared, collaborative account while having high transaction auditability (UK_Government, 2012). These are inherent properties of the blockchain due to its transaction transparency and ability to manage multi-party agreements with smart contracts (Scott et al., 2022).

The UK Government commissioned the PBA payment strategy in 2012 and provided a schema for implementing it in construction projects (UK_Government, 2012). This schema is utilised in the proposed application. Due to the payment problems of construction, public-sector clients, such as Highways England, mandate the use of PBAs in public-sector work to ensure government funding is correctly managed (UK Parliment, 2019).

The idea behind the proposed PBA blockchain application was to make it general-purpose enough to allow any construction client to replicate the system and make amendments. The proposed application is an open-source tool that allows anyone to copy the entirety of its codebase at no cost or restriction. In the case of a construction project, the version of the proposed application used would be approved by the client and stated in the construction contract. To ensure that no one has tampered with the version of the PBA blockchain application used in the construction project, it would be cryptographically hashed, and that hash number would be the version reference of the application. Cryptographic hashing is when a file is passed through a cryptographic algorithm to generate a unique identifier (UID), and any slight change to the data would generate an entirely new UID (Penzes, 2018). This makes it easy to identify if the application's codebase was tampered with. To give an example of the easiness of using a hashing algorithm, this website allows users to copy and paste any text into it to generate the UAID of that data: https://www.tools4noobs.com/online_tools/hash/. The construction contract would record the specific hash reference of the proposed application's smart contracts. Therefore, before its smart contracts are deployed, it would pass through the hashing algorithm to verify that its UAID matches the one recorded in the construction contract.

The proposed application was not designed to accommodate the construction supply chain voting on updates to its functionality. The idea is that the governmental client would have the PBA blockchain application template pre-prepared for use in a PBA project, following the UK Government's PBA guidance (UK Cabinet Office, 2012a). Of course, over time, the PBA blockchain application would undergo updates to improve its functionality, as with any piece of technology. However, parties such as the main contractor would not be able to configure the functionality of the proposed application for their own personal gain. For example, they cannot unfairly design the proposed application to favour themselves while asserting unfair terms (such as cash farming) to subcontractors.

The proposed application was not designed to alter how main contractors manage the PBA payment schedule. Instead, it was designed to make current processes more efficient through systems integration and payment automation. Furthermore, the proposed application was designed to allow the main contractor to adapt to realistic construction environments, such as cost and schedule variations that frequently occur in construction projects.

The purpose of using PBAs is that main contractors are not incentivised to withhold supply chain payments because the project budget is partitioned into a ring-fenced account. Thus, in theory, cash farming (i.e., strategic withholding of payments) is not exercised in PBA projects; however, from reviewing existing PBA literature, the researcher could not verify whether cash farming is mitigated in PBA projects entirely. Nevertheless, a solution for integrating a reward and penalty system into the proposed application to reduce late payments is proposed in Section 4.5: Reward and Penalty System.

The author's initial plan was two-fold: (1) to create the proposed PBA blockchain application and (2) a decentralised autonomous organisation (DAO) to manage the system. The proof of concept of the former was achieved in this research, but the latter, which involves a decentralised decision-making system that aggregates input from various members of the construction supply chain to design and develop the PBA system bottom-up, was omitted from this research. As a side note, traditional PBAs are managed top-down by the client and main contractor. Because of this, it opens the possibility for opportunistic behaviour from them. For example, the main contractor can insert clauses into traditional PBA contracts that favour them when disputes arise with subcontractors. Unfortunately, due to blockchain-based PBAs being a nascent topical area, attention was focused on developing a working model of a PBA blockchain application while omitting the DAO aspect of it. The UK Government already has their "Guide to the Implementation of Project Bank Accounts (PBAs) in Construction for Government Clients" (UK Cabinet Office, 2012a). Thus, this research explored the viability of leveraging that system and appending blockchain to improve how PBAs are managed. The challenge with proposing an amendment to the UK Government's PBA strategy and documentation is that it requires approval from the UK Government, and a legislative bill would need to be submitted to the UK Parliament for it to be considered a viable solution. Alternatively, the researcher opted for a more pragmatic approach by utilising the UK's existing PBA system and using the proposed application as a tool that integrates its management and cash flow processes. Nevertheless, the researcher does see the value of incorporating a DAO to manage PBAs bottom-up to capture valuable insights from the supply chain to stimulate collaborative effort for how systems such as PBAs can be managed long-term; however, this was considered beyond the scope of this research to investigate. Furthermore, collecting data to validate both the proposed application and the DAO system would have been excessively voluminous in content to present in this paper alone.

## 4.1 Proposed Application Process Flow

The proposed application's process flow and components are shown in Figure 5. The *process flow* section illustrates the key activities performed, whereas the *components* section displays the relationships between the users and smart contracts (SC). Each SC shown in Figure 5 has a corresponding user interface (UI) that provides a medium for users to transact with the SCs. These UIs are showcased in Chapter 4.4: User Interface.

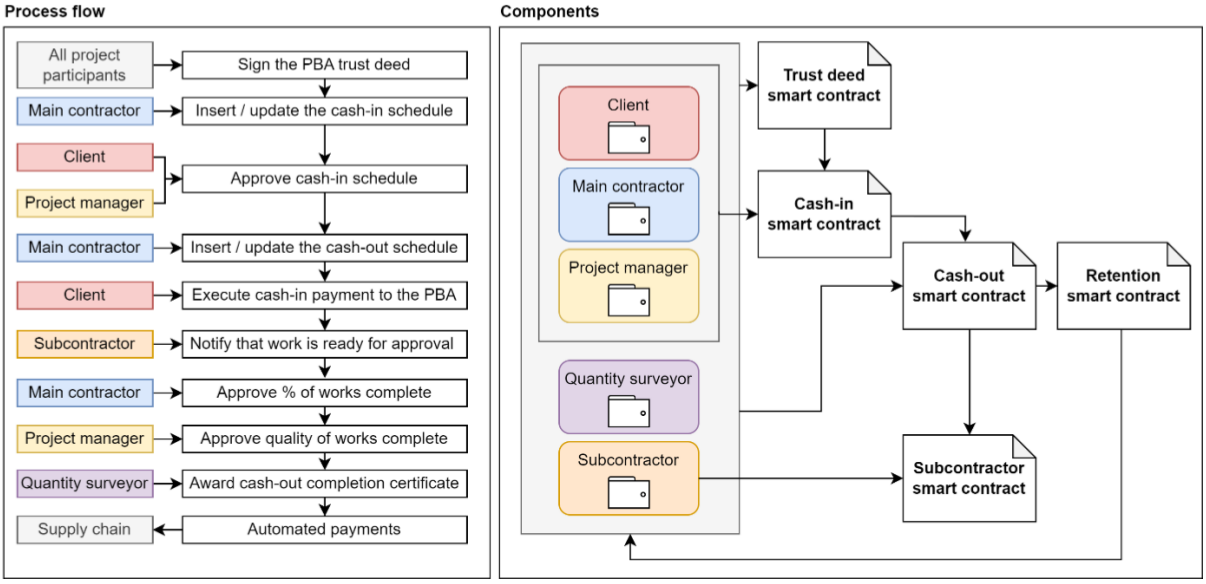



*Figure 5: The proposed application's process flows and components.*

Regarding the SCs deployed in Figure 5, the *trust deed SC* grants the project participants access rights to transact with the *cash-in SC*. The *cash-in SC* stores the milestone payment schedule and enables the client to send payments to the PBA. The *cash-out SC* is the PBA because it stores the project funds and is the account used to make cash-out payments to the supply chain. The *cash-in SC* only permits users to transact with it if their wallet addresses are listed in the *trust deed SC*. The subcontractor transacts with the *cash-out SC* to notify the payment validators (i.e., the main contractor, project manager, and quantity surveyor) when their delivered work is ready for approval. When the payment validators approve the delivered work, the *cash-out SC* processes the payment to the subcontractor and transfers a small percentage (typically 5%) of it to the *retention SC*. The subcontractor would later receive this retention when the defects liability period expires. The defects liability period of a construction project is typically twelve months, but it can vary depending on the contractual agreement (Davey et al., 2006). The *subcontractor SC* filters the payment schedule data from the *cash-out SC* upon request from a subcontractor, allowing each subcontractor to filter the project schedule for deliverables relevant to them. The Figure 6 swimlane diagram expands upon these processes with greater detail.

The proposed application's user interface (UI) and open-source smart contract codebase are available in the below links:

- UI: https://console.atra.io/app/bf26f846-7f16-4f80-90a0-c5488ab6edd3
- Smart contract codebase: https://github.com/D-UCL/PBA-dApp

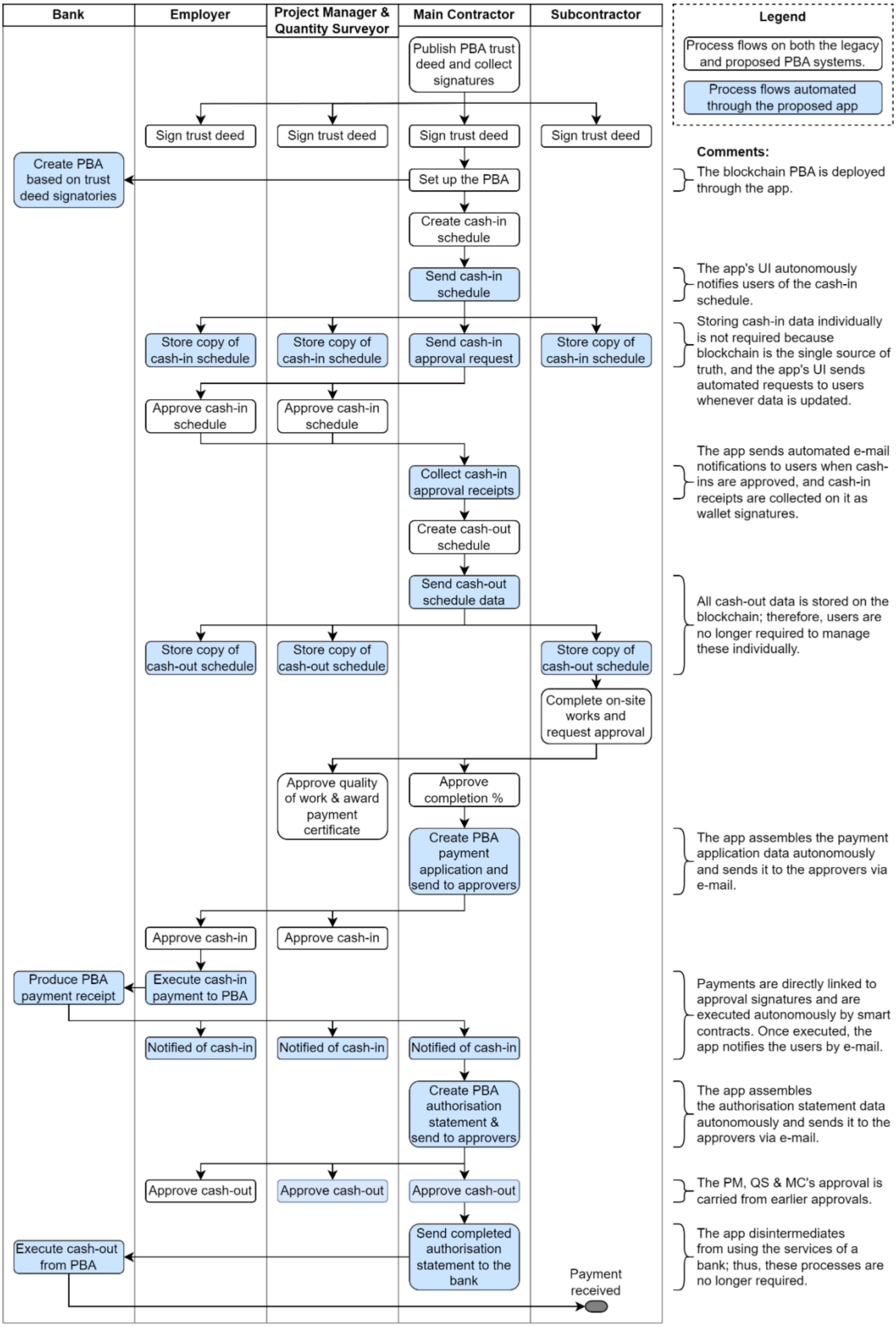



*Figure 6: Illustrating which current PBA processes are automated through the proposed application.*

## 4.2 Blockchain Selection

Assessing which blockchain platform was most suitable for the proposed application was a two-stage process. Stage one included amassing a list of public and private blockchain platforms and reviewing which are satisfactory for managing construction cash flow. The Coin Market Cap (2022) website provided a list of the most successful public blockchains, of which five were selected for consideration in this paper's proof of concept (PoC). Afterwards, a journal article by Chai et al. (2020) provided a review of prominent private blockchains, of which two were selected as potential candidates for the PoC. These blockchain platforms are presented in Table 3.

The next stage for assessing which blockchain was most suitable for the proposed application included evaluating the six key parameters shown in Table 3: (1) extensive ecosystem of decentralised applications; (2) supports stablecoins; (3) provides high security and data trust; (4) supports smart contracts; (5) supports privacy; and (6) consensus is low in CO2 emissions. Having high security and privacy under the same criteria is a dilemma because both cannot be satisfied simultaneously. For example, public blockchains (e.g., Ethereum) are more secure but have less privacy, whereas private blockchains (e.g., Hyperledger) are less secure but offer greater privacy (Chain Stack, 2020). Nevertheless, both parameters (i.e., privacy and security) were crucial to include in the assessment.

*Table 3: Blockchain selection scoring matrix.*

| **Blockchain** | **Parameters for selecting the blockchain platform** | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1. Extensive ecosystem of decentralised applications | 2. Supports stablecoins | 3. Provides high security and data trust | 4. Supports smart contracts | 5. Supports privacy | 6. Consensus is low in CO2 emissions | Yes count |
| **Ethereum** | Yes (Atra, 2019) | Yes (Buterin, 2022) | Yes (Buterin, 2022) | Yes (Buterin, 2022) | No (Banerjee et al., 2020) | Yes (CCRI, 2022) | 5 |
| **Hyperledger Fabric** | Yes (Handy, 2020) | No (Hyperledger, 2017) | No (Hyperledger, 2017) | Yes (Hyperledger, 2017) | Yes (Hyperledger, 2017) | Yes (Hyperledger, 2017) | 4 |
| **Cardano** | No (Joget, 2022a) | Yes (CardanoCube, 2021) | Yes (Kiayias et al., 2017) | Yes (Kiayias et al., 2017) | No (Cardano, 2022) | Yes (Kiayias et al., 2017) | 4 |
| **Polkadot** | No (Nova Bloq, 2022) | Yes (Chen, 2020) | Yes (Wood, 2020) | Yes (Polkadot, 2022) | No (Zk Mega, 2020) | Yes (Wood, 2020) | 4 |
| **Hedera Hashgraph** | No (Joget, 2022b) | Yes (Hedera, 2022) | Yes (Baird et al., 2020) | Yes (Baird et al., 2020) | No (Baird et al., 2020) | Yes (Baird et al., 2020) | 4 |
| **Internet Computer** | No (Blocks, 2022) | Yes (Blocks, 2022) | Yes (Hanke et al., 2018) | Yes (Hanke et al., 2018) | No (Hanke et al., 2018) | Yes (Carbon Crowd, 2022) | 4 |
| **Quorum** | No (Quorum, 2022a) | Yes (Quorum, 2022a) | No (Quorum, 2022b) | Yes (Quorum, 2022b) | Yes (Quorum, 2022b) | Yes (Quorum, 2022b) | 4 |

“Extensive ecosystem of decentralised applications” was a parameter in Table 3 because blockchain applications can be built from open-source templates and third-party services available at relatively no cost. For example, the proposed application was only £40 per month in service fees. This low financial entry point enables users to deploy lightweight solutions, such as the proposed application, that leverage the blockchain’s ecosystem of decentralised services. This is a practical approach for industries, such as construction, that suffer from a lack of capital for investing in technology.

Despite Hyperledger Fabric’s popularity as a private blockchain, it scored low in Table 3 because it lacks security and stablecoin services; furthermore, it relies on users to manually set up its architecture and network nodes (Hyperledger, 2017). For example, a private blockchain may occupy 20 nodes set up with trusted parties, whereas a public blockchain would have several thousand nodes because it accommodates anonymous users transacting on its network; therefore, the security requirements for public blockchains are substantially greater (Bitnodes, 2022). Another reason a private blockchain was not selected for the proposed application is that setting up the network and incentivising participants to run nodes on a private blockchain is a technical and costly responsibility that can be bypassed by using a public blockchain (Quasim et al., 2020). Although privacy is not built into Ethereum’s platform, it can achieve private transactions through layer two privacy solutions (Banerjee et al., 2020). Chapter Five, Findings and Discussion, examines layer two privacy solutions in greater detail.

To mitigate the price volatility of cryptocurrencies such as Ether (the native currency of Ethereum), a type of cryptocurrency called stablecoin was invented by the blockchain ecosystem (Bullmann et al., 2019). A stablecoin is the blockchain’s solution for putting fiat currencies, such as USD and GBP, on the blockchain. An example of a GBP stablecoin is Pound Token, a UK-based stablecoin provider issuing GBP tokens fully regulated in the UK (Pound Token, 2023). Unfortunately, stablecoins cannot be used on private blockchains, such as Hyperledger, because cryptocurrencies minted on them do not have value outside their network (Hyperledger, 2017). In contrast, stablecoins minted on Ethereum can be exchanged for fiat at cryptocurrency exchanges. Choosing a blockchain with stablecoin functionalities was crucial for the proposed application; otherwise, payments cannot be processed through it.

The main selling point for using Ethereum as the blockchain for the proposed application is its extensive ecosystem of decentralised services that enable non-technical users to deploy test applications with minimal programming and coding experience. For example, the proposed application was built from the Atra Cloud Platform, a no-code platform that allows users to customise and deploy decentralised applications with all technology components preconfigured, such as the user interface, wallets, node services, and smart contract (Atra, 2019).

Analysing the number of active developers on a blockchain is also a good indicator of its progression. In a study of monthly active developers on blockchain platforms, Ethereum scored the highest with 3900, followed by 1400 for Polkadot, 435 for Hyperledger Fabric, 350 for Cardano, 190 for Internet Computer, 132 for Quorum, and 40 for Hedera (Chain Stack, 2020, Shen et al., 2021). This indicates that Ethereum has the largest ecosystem of active developers who maintain and improve its platform and services. The other blockchains in Table 3 are strong contenders; however, they offer fewer services than Ethereum and are more challenging to develop and test blockchain applications.

Lastly, concerning metric six in Table 3: “consensus is low in CO2 emissions”, Ethereum recently updated its consensus algorithm from proof-of-work to proof-of-stake, reducing its annual tonnes of CO2 equivalent emissions from 11 million to 870, a reduction of 99.992% (CCRI, 2022). This led to it becoming the winning contender vs. the other six blockchain platforms listed in Table 3.

## 4.3 Technology Setup

The proposed application’s technology stack is displayed in Figure 7. The application’s user interface (UI) is a website coded in JavaScript, the most popular programming language for front-end applications and web pages (Vailshery, 2022a). Furthermore, React.JS is the most popular code library used alongside it (Vailshery, 2022b). The application runs an instance of Web 3 to allow third-party blockchain services, such as MetaMask, to connect to the blockchain. The Ethereum blockchain and its smart contracts are the back-end system of the application. Rather than setting up a blockchain node, which is unnecessarily complicated, Infura was used as the third-party node provider that enables the application to send transactions to the blockchain. Since a standard Web 2 webpage is used for the application’s UI, a runtime environment such as Node.JS is needed to process the UI’s JavaScript code. Therefore, the proposed application is a Web2-Web3-blockchain hybrid system. The data layer consists of Ethereum's ledger for logging transactions and IPFS for decentralised cloud storage. Technically, any cloud storage provider can be used instead of IPFS, as all that is needed is a link that directs users to the data repository. The document link would be stored in a smart contract's data field; thus, only the link is stored on the blockchain, not the entire document.

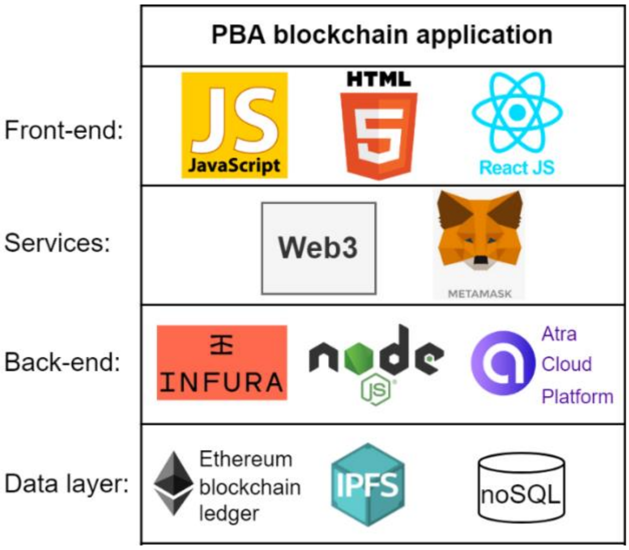



*Figure 7: The proposed application's technology stack.*

## 4.4 User Interface

The user interface (UI) of the proposed application is built with five primary tabs: (1) Trust Deed, (2) Cash-in, (3) Cash-out, (4) Subcontractors, and (5) Retentions, as per Figure 8. Screenshots and flowchart diagrams of each tab are displayed in this section. The proposed application is lightweight and runs on a standard webpage, and users are not required to download any software to use it.

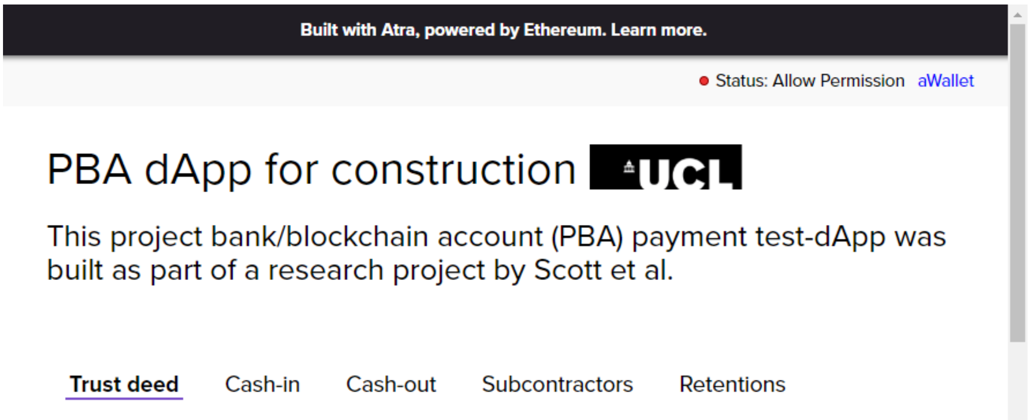



*Figure 8: Cropped view of the proposed application's navigation tab.*

The proposed application also sends e-mail notifications to users whenever they have been appointed or when actions from them are required (as per Figure 9). For example, when the subcontractor verifies (through the application) that on-site works are ready for approval, the application sends an automated e-mail to the payment authorisers notifying them of their responsibility to approve the works within a timescale.

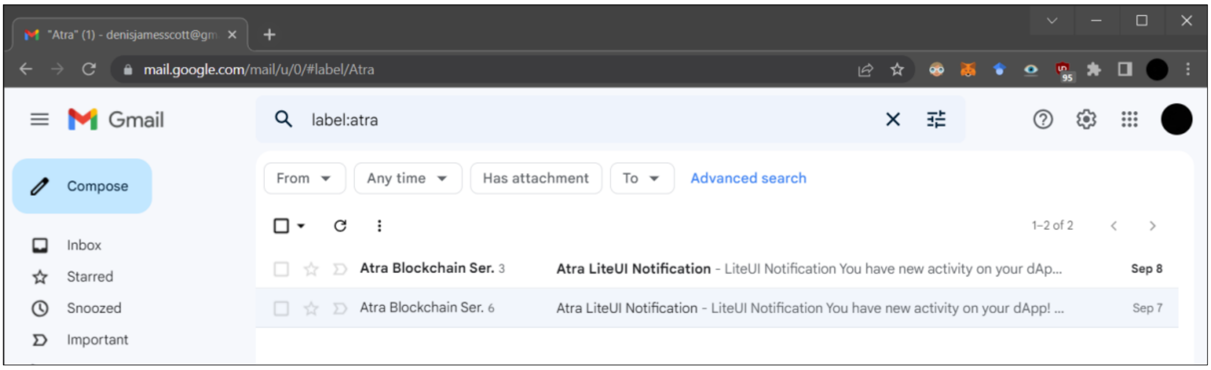



*Figure 9: E-mail notification payment authorisers receive from the proposed application.*

### 4.4.1 Trust Deed Tab

A PBA trust deed is a legal document that states who the PBA payment authorisers and beneficiaries are. The PBA trust deed in the proposed application is a smart contract, and project participants would sign it by clicking "submit" in the Figure 10 screenshot; afterwards, their signature would be uploaded to the smart contract. The trust deed smart contract also acts as a permission control system, granting participants access to perform actions on the other five abovementioned tabs. For example, only the user wallet that signed the trust deed smart contract as the main contractor would have permission to insert payment schedule data into the Cash-in and Cash-out tabs.

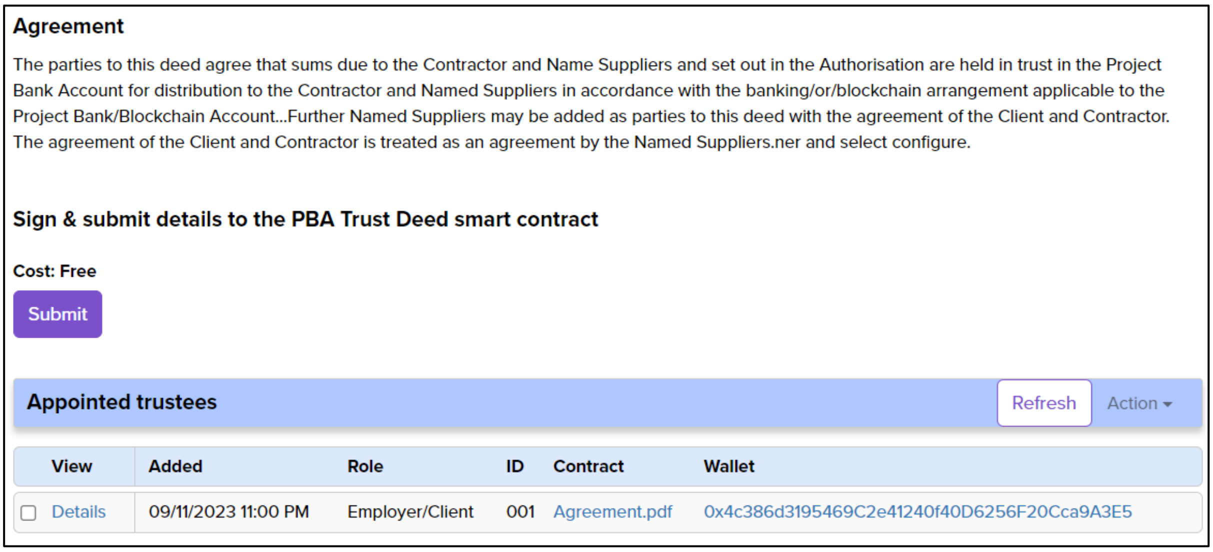
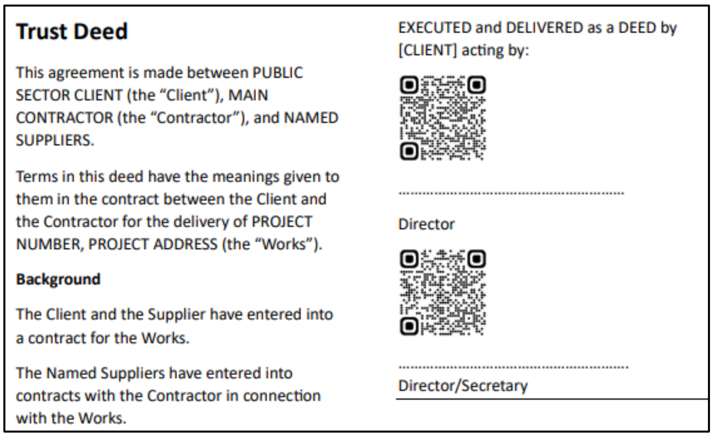



*Figure 10: Cropped view of the application's UI, displaying the 'Trust Deed' tab.*

Figure 11 is a screenshot of the paper-based version of the smart contract trust deed shown above. When participants sign the trust deed, their digital signature will be recorded onto the below document, with the signature verifiable on the blockchain; thus, integrating blockchain was standardised documents.


**Trust Deed**

This agreement is made between PUBLIC SECTOR CLIENT (the "Client"), MAIN CONTRACTOR (the "Contractor"), and NAMED SUPPLIERS.

Terms in this deed have the meanings given to them in the contract between the Client and the Contractor for the delivery of PROJECT NUMBER, PROJECT ADDRESS (the "Works").

**Background**

The Client and the Supplier have entered into a contract for the Works.

The Named Suppliers have entered into contracts with the Contractor in connection with the Works.

EXECUTED and DELIVERED as a DEED by [CLIENT] acting by:

.......................................................

Director

.......................................................

Director/Secretary

*Figure 11: Paper-based view of the trust deed.*

### 4.4.2 Cash-In Tab

Cash inflows (cash-ins) are the flow of cash from the client's account to the PBA. Figure 12 illustrates its process flow, whereas Figure 13 is the application's UI where the actions are performed.

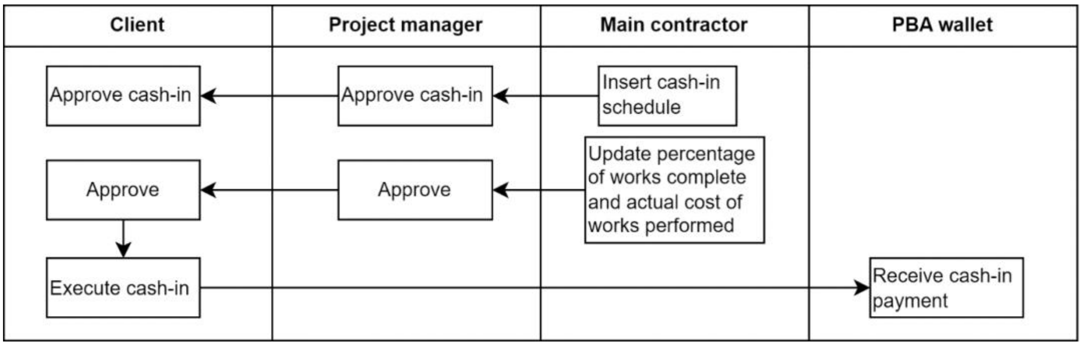



*Figure 12: Process flow for inserting, managing, and executing cash-ins.*

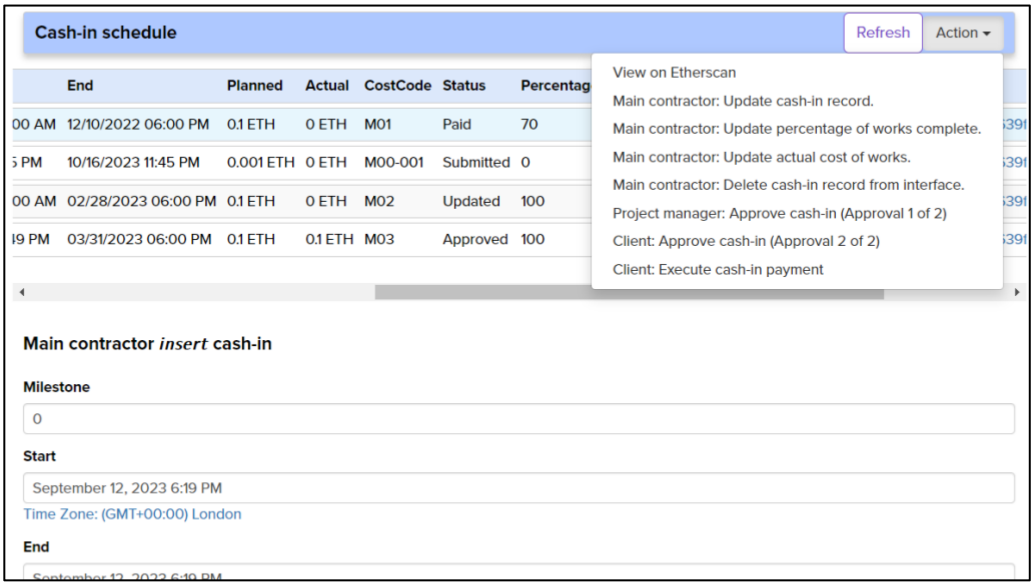



*Figure 13: Cropped view of the application's UI, displaying the 'Cash-in' tab.*

### 4.4.3 Cash-Out Tab

Cash outflows (cash-outs) are the flow of cash from the PBA to the suppliers. Figure 14 illustrates the proposed application's cash-out process, while Figure 15 is the UI where the actions are performed.

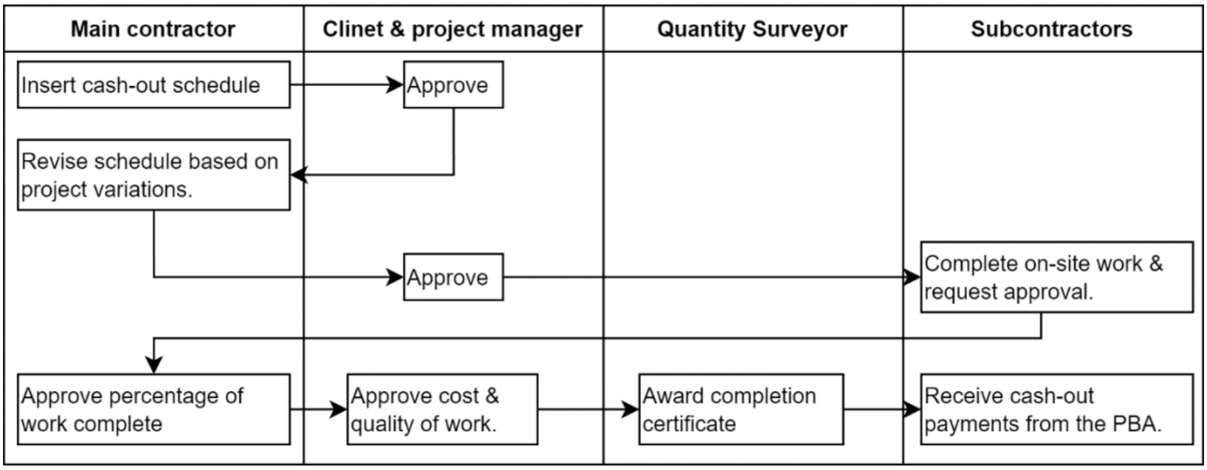



*Figure 14: Process flow for inserting, managing, and executing cash-outs.*

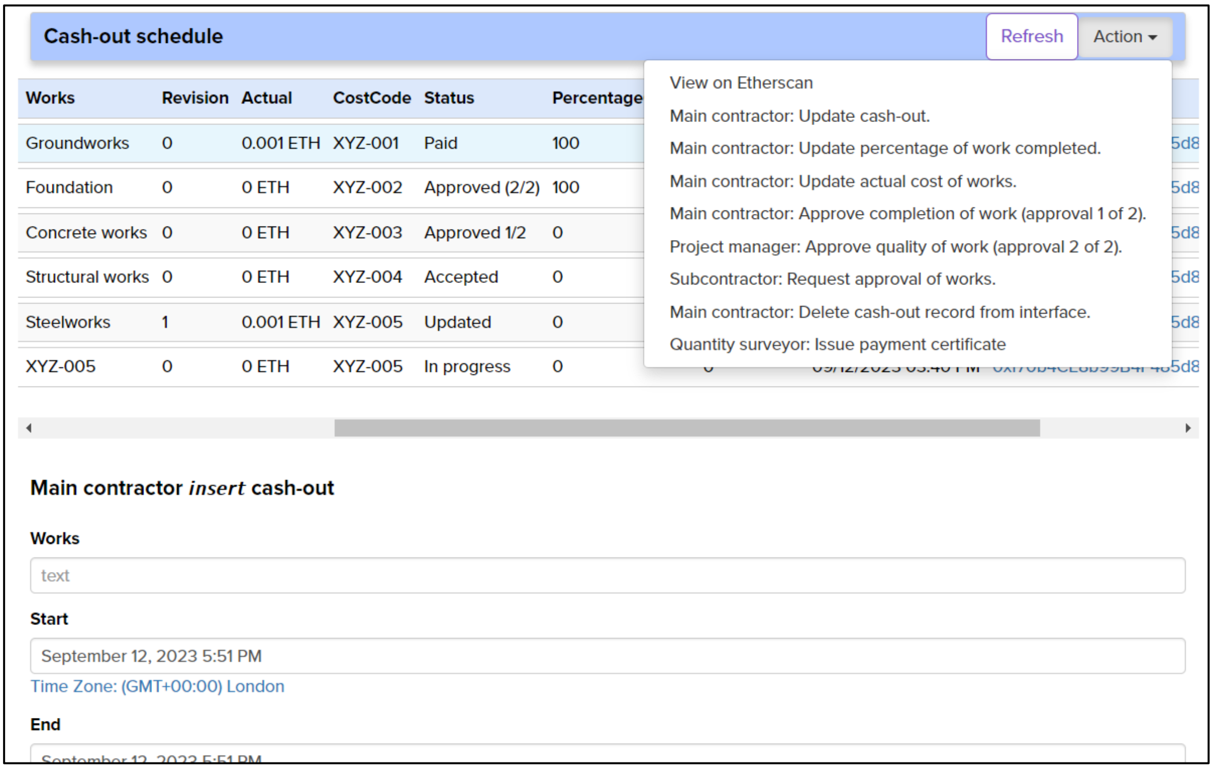



*Figure 15: Cropped view of the application's UI, displaying its 'Cash-out' tab.*

### 4.4.4 Subcontractor Tab

Figure 16 illustrates how a subcontractor can pull their scheduled work from the cash-out smart contract. To do this, the subcontractor would access the UI and click the *Submit* button in Figure 16. Afterwards, their schedule data would be automatically pulled from the cash-out schedule. This is useful because each supplier would only get the schedule information relevant to them and not the full cash-out schedule. Furthermore, the subcontractor's schedule operates like a relational database; therefore, if the cash-out schedule is updated, the subcontractor's schedule will update accordingly, and the subcontractor will be notified of any changes.

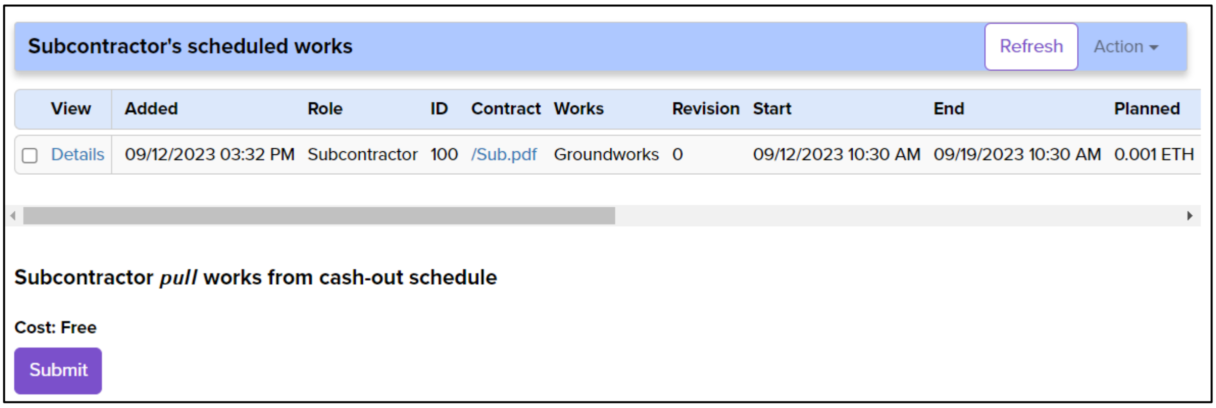



*Figure 16: Cropped view of the application's UI, displaying the Subcontractor tab.*

### 4.4.5 Retentions Tab

The retention tab operates like a relational database and autonomously pulls data from the cash-in and cash-out smart contract tables to reduce manual data entry for the main contractor and suppliers. All the main contractor would need to do is click the *Submit* button on the Figure 18 UI. Afterwards, the retention tables would synchronise with the cash-in and cash-out tables to display the retention amounts due to suppliers.

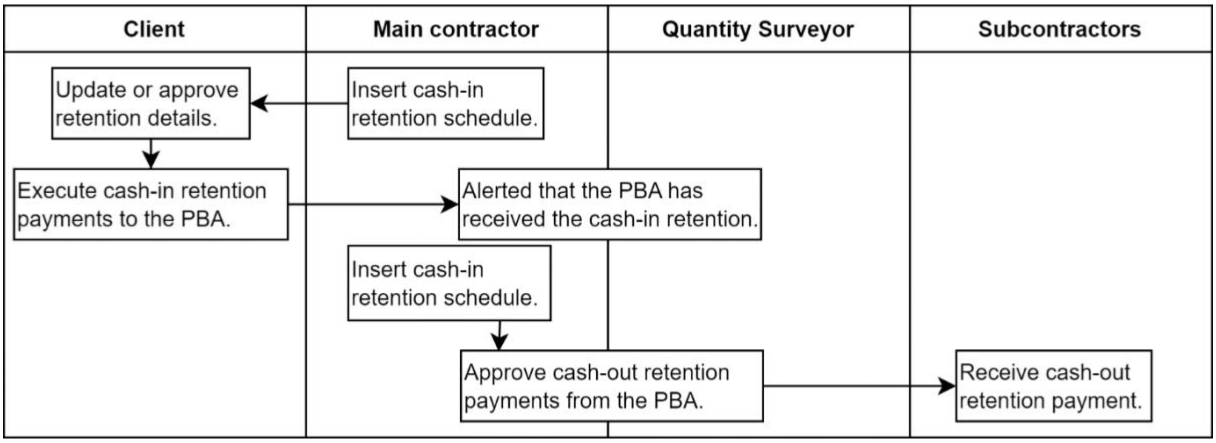



*Figure 17: Process flow of the retention process.*

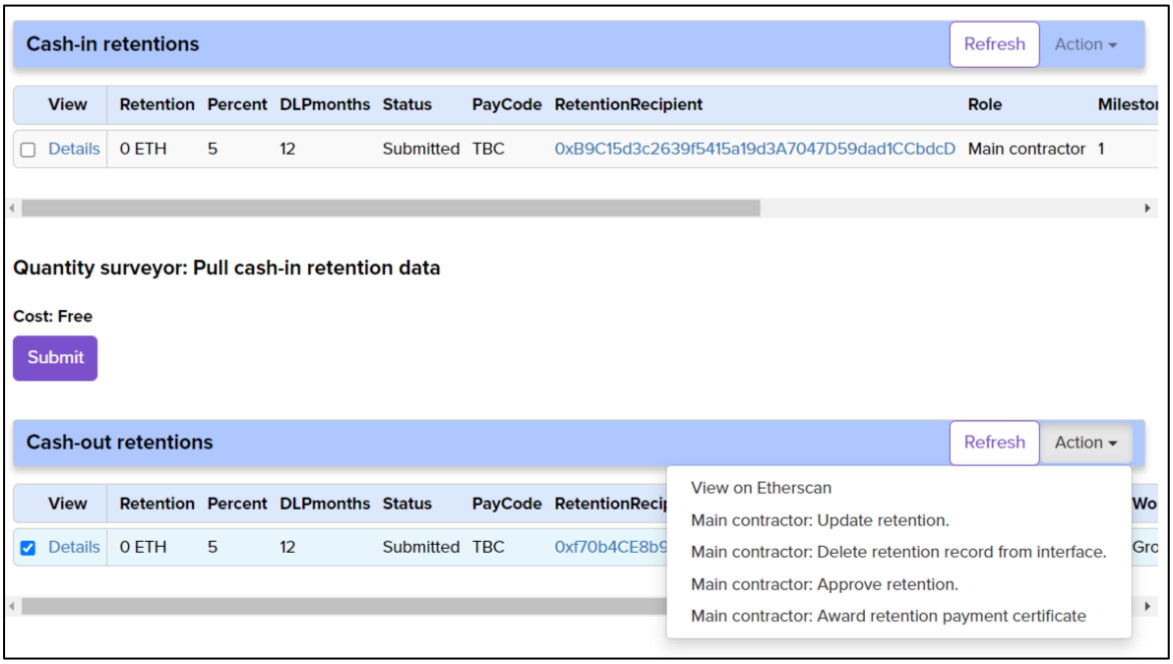



*Figure 18: Cropped view of the application's UI, displaying the Retentions tab.*

## 4.5 Reward and Penalty System

A reward and penalty system is an optional extension of the proposed application. This section discusses why this was not integrated into the application's original design but theorises how it can be included to improve its functionality. Crypto-economics is the term given when algorithmic rewards and penalties are built into a blockchain system to stimulate user activity (Hunhevicz and Hall, 2020). For example, financial compensation for good behaviour and fines for bad behaviour. Before progressing with this reward and penalty system, a brief explanation of its barriers is crucial to highlight.

The challenge with proposing modifications to the UK Government's PBA strategy by incorporating a crypto-economic system is that long-term engagements with stakeholders and governmental bodies are required to append the amendment. For example, the UK Government's (UK Cabinet Office, 2012a) PBA guidance document would need to be updated to accommodate the reward and penalty system, and a legislative bill would need to be sent to the UK Parliament to approve the request.

Until this section in the paper, the researcher carefully deliberated not to alter how traditional PBAs operate at the process level to avoid necessitating an amendment to the PBA guidance document. For example, the proposed application maintains these five key functions of PBAs: (1) cash-ins (payment from the client to the PBA) flow at key project milestones, (2) cash-outs (payments from the PBA to the supply chain) flow at payment approval stages, (3) a trust deed is used to verify payers and payees, (4) an escrow-based trust account is used to store project funds, and (5) all PBA cash flows are auditable by the client. This increases the adoptability potential of the proposed application in the real-world environment because existing business processes for managing PBAs remain intact. Similarly, DocuSign is an example of a digital solution to an existing process. It is an application that enables users to sign contracts digitally; however, it does not change how the underlying agreements within the contracts operate. Similarly, the proposed application is a tool for digitising PBAs without altering their core functionalities.

The UK Government's (UK Cabinet Office, 2012a) PBA guidance document stipulates a PBA "does not include the client prefunding" or "add any cost to the project". Including a reward and penalty system in PBAs would increase the project budget because additional funds would be required to cover the rewards or penalties, breaking the terms instructed in the PBA guidance document. Nevertheless, since crypto-economics is a core feature of blockchain applications, proposing a blockchain application that omits it contradicts one of the key features of the blockchain (i.e., crypto-economics). Therefore, this paper explores how a crypto-economic system can be incorporated into the proposed application. Figure 19 displays how this system could operate by adding a reimbursement smart contract (SC) to the proposed application. In the pre-construction stage of a project, the client would deposit 1% of the total project cost into the reimbursement SC. This 1% is reimbursed to the client when prompt payments are made to the supply chain. In contrast, if the client is late with the payments, the 1% is transferred to the supply chain as an inconvenience allowance. The 1% is an arbitrary value, and the exact percentage can be contractually agreed upon by the client and key project stakeholders. A reimbursement system is more effective than billing clients after every late payment because they are incentivised to approve supply chain payments on time to receive their deposit back. In contrast, if the client is billed after each late payment, it creates process redundancies, such as chasing late payment fees and the client having to settle each bill manually. The proposed application was designed modularly to allow additional components, such as the reimbursement SC, to be appended with no complications. Therefore, the proposed application can operate with or without the reimbursement SC.

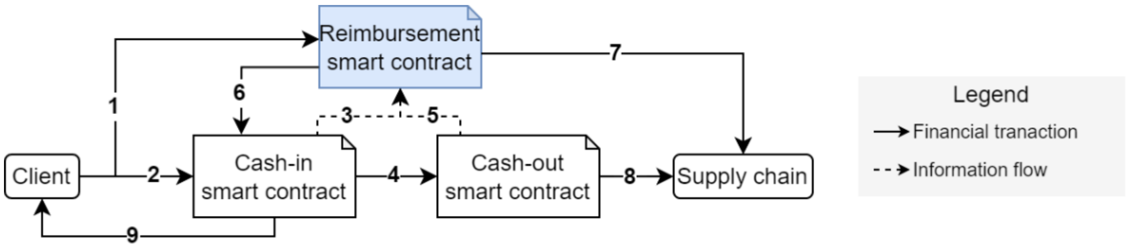



*Figure 19: The reward and penalty system.*

Figure 19 is labelled from one to nine to illustrate the process flows of how the reimbursement SC can integrate with the proposed application. These steps are as follows:

1. After project participants sign the PBA trust deed (shown in Figure 10 in Section 4.4.1: Trust Deed Tab), the client deposits funds equal to 1% of the total project budget to the reimbursement smart contract (SC).
2. When the construction project commences and liabilities for delivered works are due, the client sends the payment to the cash-in SC in response to the payment validators (i.e. the client, project manager, and main contractor) signing that all works for a particular project milestone have been delivered correctly. This signing occurs on the cash-in SC.
3. Every time the client makes a milestone payment via the cash-in SC, the cash-in SC autonomously checks the payment schedule to verify if it is late, then notifies the reimbursement SC if its withheld funds should be transferred to the client or supply chain.
4. The cash-in SC is a medium the client uses to send milestone payments to the PBA. It stores the payment approval signatures of the payment validators, and when all signatures are received, it authorises a milestone payment to execute to the cash-out SC. The cash-out SC is the component in the proposed application that replicates the PBA. It is used to store and distribute the project's funds. All funds are stored in the cash-out SC (i.e., the PBA) until they are authorised to debit to the supply chain.
5. The cash-out SC logs whether payments for each supplier under the project milestone were paid on time and within a 19-day window, then it sends this log to the reimbursement SC for processing. The UK Government's PBA strategy stipulates that all cash-out payments are to be processed within 19 days while all cash-in are to be processed within 14 days (UK Cabinet Office, 2012a).
6. If the client sends a milestone payment to the cash-in SC within 14 days of its due date and each supply chain party under that milestone is paid within 19 days of payment approval, then funds transfer from the reimbursement SC to the cash-in SC. This allows the client's consecutive milestone payment to be discounted at the sum of the reimbursement value. If the client refuses to approve a subcontractor's payment and the project manager and main contractor deem the reason valid, then an amendment to the project's payment schedule in the cash-out SC would occur. However, if the client's request is rejected, the cash-in payment will be considered late, and the supply chain will receive the reimbursement.
7. Each supply chain member with owed liabilities would receive a compensation of 1% of the owed value (i.e., if £100,000 is owed, £1000 is reimbursed). Figures from Construction Index 2023 suggest that the

average margin of the top 100 contractors in the UK is 1.6% (Construction Index, 2023). Therefore, the researcher deems 1% to be suitable compensation for late payments. However, this value is arbitrary and open to negotiation by key project stakeholders at the contract drafting stage.

8. The cash-out SC autonomously debits its funds to the supply chain when payment approval signatures are received from the project validators. The cash-out SC stores the entirety of the cash-out schedule and includes the approval status of each supply chain payment, as shown in Figure 15 in Section 4.4.3: Cash Out Tab.
9. When the client makes their final milestone payment to the PBA, and if it is paid on time, then the reimbursement SC would immediately reimburse its funds in the client's wallet.

## 5. FINDINGS AND DISCUSSION

Blockchain has three dimensions that affect its implementation in the construction industry: (1) Socio-technical, (2) process, and (3) policy (Li et al., 2019). The research overlaps with all three dimensions because it investigates how construction managers can engage with blockchain to improve project performance (i.e., the socio-technical dimension); furthermore, the research also integrates management flows with cash flows to reduce process redundancies and improve automation (i.e., the process dimension), and it incorporates the UK Government's PBA strategy in its framework design (i.e., the policy dimension). PBA was targeted for the research because it is a system enforced by the UK Government, and contractors are mandated to implement it in public-sector work; thus, it has a solid practical foundation.

From the literature review, only one academic publication by (Chong and Diamantopoulos, 2020) provides evidence of a blockchain application used in a real-life construction project; however, that application was closed-source, its technology components were not itemised, and there was no evidence that the solution was commercialised; thus, it cannot be externally verified and lacks credibility. The findings indicate that PBAs suffer from improper adoption due to the additional workload it imposes on main contractors; furthermore, PBAs are hampered by the same challenges that plague the construction industry: (1) System fragmentation that causes unnecessary data duplication and (2) lack of process and data flow automation.

The research questions (RQs) were the foundation for accomplishing the research aim mentioned in the introduction. How these RQs were addressed is covered in this section. A reiteration of these RQs is as follows:

1. How can blockchain and smart contracts increase systems integration and process flow automation in PBA projects?
2. How would project participants transact with the proposed application to perform PBA activities such as managing and approving payments?
3. From the perspective of construction practitioners experienced in PBAs, what are the strengths, weaknesses, opportunities, and threats of using blockchain and smart contracts for managing PBAs?

RQ one was answered by conceptualising and developing a PBA blockchain payment application that accommodates the UK Government's PBA strategy, and exemplifying its functionalities from a blockchain application perspective. Figure 5 and Figure 7 from Chapter Four: Conceptual Framework, illustrated the PBA process flows and technology component of the application and presented its codebase open-source to enable external users to replicate the solution. RQ two was answered by developing the user interface shown in section 4.4: User Interface, showcasing how each project participant in the PBA system would transact with the application to insert, update, manage, and approve project data and execute PBA payments via smart contracts. Figure 6 in the Conceptual Framework (CF) chapter illustrated how the proposed application can automate up to 50% of PBA's process flows No evidence exists of commercial adoption of blockchain in construction; thus, this research area (i.e., blockchain for PBAs) is still in its exploratory stage. Therefore, the researcher brought it upon himself to develop the proposed application as a test model. The application exemplifies how blockchain, smart contracts, and web applications can integrate project scheduling, supply chain management, and payment executions in one system to improve process automation. PBA was selected as the test case because it aims to achieve greater cash flow transparency and auditability, which are inherent properties of the blockchain; thus, PBA and blockchain are harmonious to integrate. Furthermore, PBA uses a ring-fenced bank account to safeguard project funds, which smart contracts can achieve without needing the services of financial intermediaries such as banks.

RQ three was answered by collecting primary data and using thematic analysis to organise the responses into categories and subcategories. The key findings of each sub-category are shown in Table 4. These findings amalgamate to answer RQ three. A summary of the key findings reveals that most of the benefits of using a blockchain-based PBA are based on future projections, with the only immediate benefits being data traceability and process automation. In contrast, from the perspective of limitations, a blockchain-based PBA has numerous immediate challenges, such as a lack of integration with centralised software and traditional finance (i.e., banks). Furthermore, smart contracts are not legally binding and thus cannot be used to replace traditional, paper-based agreements. A summary of the findings is itemised in Table 4.

*Table 4: A summary of the data collection in response to research question two.*

| Theme | Subtheme | Findings |
|---|---|---|
| A. Strengths | A1. Data traceability and permanence | According to one interviewee, banks only store PBA transaction records for one year. In contrast, blockchain transactions are stored permanently with no time limitations. |
| | | Two interviewees highlighted that the blockchain's timestamping, traceability, and single source of truth would reduce the data reconciliation problems with cash book data and increase transparency in project reports. |
| | A2. Event-driven architecture | The proposed application (i.e., the app) demonstrated how to reduce communication redundancies using an event-driven architecture. One interviewee commented: "It immediately mitigates having to chase people to do things." This is in response to how the app sends users automated e-mail notifications users, reminding them to complete tasks. |
| | | One interviewee highlighted how the high data trust of the blockchain would provide a suitable substrate for integrating with analytics dashboards. |
| Weaknesses | B1. Overlooked PBA procedures | One interviewee commented on how the app overlooked the PBA contract wording approval process in its design. This approval process comprises several project authorities signing that they approve the PBA contract's wording and terms and conditions. Extending the app's functionality to include this process would make a suitable addition. |
| | | Although a PBA trust deed (TD) smart contract was developed for the app, it is not legally binding; therefore, a traditional, paper-based PBA document is still required, according to one interviewee. |
| | | The app demonstrated how the data entry of standardised PBA forms, such as the *payment application* and *authorisation statement*, can be automated. However, according to one interviewee, it did not explain how users can download and access these forms from an end-user perspective. |
| | B2. Overlooked management processes | One interviewee stipulated that PBA payment approvals and interim valuation stages are separate but overlapping processes; however, the app only focused on the PBA aspect of payment approvals. The interviewee recommended that the app consider including interim valuation stages in its design. |
| | | Two interviewees highlighted that payment approval stages can differ for each contract and that the app should be designed to be malleable to adapt to the bespoke nature of contracts. |
| | | One interviewee commented that the app's retention process is overly simplified and lacks payment approval stages. However, one interviewee advised that including retentions in the PBA process is non-standard and can be omitted from the app. |
| | B3. Lack of integration with existing systems | The app requires the main contractor to manually transfer data from their centralised spreadsheet to the app's smart contracts. One interviewee stipulated that data transfer between these mediums should be automated to mitigate duplicate data entry. |
| | | Blockchain needs more integration tools to interoperate effectively with existing centralised software. One interviewee advised that large construction companies rely entirely on software packages, such as ERPs (enterprise resource planning), for daily operations; therefore, integrating with them is mandatory for the app's success. |

| | | |
|---|---|---|
| | B4. Lack of integration with banks | One interviewee commented that PBA payments typically flow through a payment terminal management system (TMS) heavily integrated with banks and that replacing this infrastructure with a blockchain-based solution will face challenges. |
| | | Another interviewee highlighted that the UK Government does not allow PBAs to acquire finance because it increases their national debt, hindering decentralised finance (DeFi) from entering the PBA space. |
| | | The app initially investigated whether it could extend its functionalities to integrate with the system banks use for supplying construction projects with payment guarantees. However, two interviewees advised against this and clarified that banks will not change their systems to integrate with the app. |
| | B5. Technology duplication | One interviewee highlighted that blockchain was designed as a settlement layer; thus, it should be used for transactions more than data management. |
| | | The app stored contracts in IPFS (a general-purpose decentralised cloud). One interviewee advised that this is inadequate because construction, NEC-specific cloud-based software already exists for the commercial management of contract documents. |
| Opportunities | C1. Cryptocurrency price stability | Regarding the price volatility of the Ethereum cryptocurrency that two interviewees brought up, the researcher informed them that stablecoins already exist that mitigate this problem and that the only reason stablecoins were not implemented in the app is because it was deployed on the Ethereum test-network. |
| | | Concerning whether the app interferes with standard tax duties, an issue brought up by one interviewee, the researcher responded that the payments would be converted from stablecoins to fiat; thus, the app would not affect how standard tax duties are processed. |
| | C2. Systems integration | The app verified that blockchain and smart contracts can integrate management flows and cash flows. One interviewee highlighted how this is a step towards reducing system fragmentation in construction. |
| | | The ability to configure smart contracts to operate like relational databases (RDBs), as shown in the app, is impactful because RDBs' are the standard format for storing structured data and are used ubiquitously worldwide. |
| | | Blockchain-based PBAs could reduce the set-up complexities of PBAs in joint venture projects, according to one interviewee. |
| | C3. User accessibility | One interviewee highlighted how dApps provide developers with more freedom for accessing free information due to the open-source nature of blockchains, transpiring into better services for users. |
| | | Having to sign for each transaction manually is a user experience problem when using dApps. One interviewee highlighted that this can be mitigated by a tool called 'signing agent', which allows multiple transactions to be batched and signed simultaneously under one transaction. |
| | | One interviewee advised that some blockchain dApps provide white-label solutions that allow their work to be rebranded and commercialised without intellectual property restrictions, allowing for better technology dissemination. |
| | C4. Blockchain-based finance | Insurance against code faults or hacks is a severe problem for decentralised technologies because no entity can be held centrally accountable for damages. One interviewee stipulated that one wallet dApp in particular, Qredo, addresses this problem and provides up to £460 million in insurance for any funds lost or stolen via their dApp. |
| | | DeFi protocols exist, such as Maple Finance, that provide the loan underwriting services of traditional finance (TradFi) while using blockchain to settle transactions, merging TradFi with DeFi, according to one interviewee. |
| | | One interviewee commented that invoice finance is unregulated in the UK and most other countries. They added that this makes it a good entry point for the DeFi space to offer short-term financing with fewer regulatory restrictions. |

| | | |
|---|---|---|
| | C5. Improvement proposals | According to one interviewee, smart contracts could automate charging clients' statutory interest on unpaid liabilities, mitigating suppliers from having to process claims manually. |
| | | One interviewee advised that smart contracts could automate the process of NEC claims, such as compensation events for delays caused by rainfall. |
| | | Banks take several weeks to set up the PBA, based on the feedback of one interviewee. In contrast, a blockchain PBA can be set up within a day. |
| | | One interviewee suggested that the app include the estimator's costs at the bidding stage to see how project costs evolve from estimation to budget, planned, and actual. |
| | C7. Privacy and Security | Regarding privacy concerns highlighted by two interviewees, the researcher responded that zero-knowledge proofs (ZKPs) could be used to achieve privacy on public blockchains. More ZKPs and privacy is discussed later in this chapter. |
| | | Concerning wallet security, one interviewee highlighted that multi-party computation (MPC) wallets are currently the most sophisticated blockchain wallets and should be used in the app. |
| Threats | D1. Legal Tender | Stablecoins are not yet considered legal tender; therefore, they cannot be used for payments. However, one interviewee advised that the UK Parliament is reviewing a stablecoin bill and added that, if approved, it would grant stablecoins legal tender status. |
| | | According to one interviewee, until the UK stablecoin bill is passed, stablecoins are considered capital gains and are subject to capital gains tax. |
| | D2. Bank retaliation | According to one interviewee, blockchains rely on banks to off-ramp their cryptocurrencies to fiat and added that this is problematic because banks can directly affect the success of dApps in the blockchain space. |
| | | One interviewee stated that banks have significant power and influence over construction companies and can thwart blockchain-based PBAs if their services feel threatened. Nevertheless, PBAs are negligible to the overall services offered by banks. |
| | D3. Know-Your-Customer Verification | One interviewee advised that know-your-customer (KYC) was not built into the system and that this should be a significant factor of the app. |
| | | According to one interviewee, "the app should imitate or integrate with a Docu-sign-style system" to allow users to sign the PBA trust deed with their blockchain wallets. The researcher acted on this suggestion and updated the app to enable users to sign the trust deed with their blockchain wallets. |

Advances in cryptography have enabled public blockchains to achieve private transactions (Robinson, 2020). Layer two (L2) is when additional infrastructure is built atop the blockchain to improve its performance (i.e., L2 privacy or L2 scaling solutions) (Yin et al., 2021). One example of these privacy solutions is zero-knowledge proof (ZKP). The researcher was aware of ZKP before data was collected for this paper, however, it was not incorporated into the proposed application because of a lack of cryptographic expertise in how to program its functionality into blockchain transactions. Nevertheless, in a real-life project, configuring the proposed application to include ZKPs would be outsourced to a blockchain engineer. ZKP allows data within a transaction to be stored encrypted on the blockchain (Li and Xue, 2021). This data can only be decrypted in the form of a mathematical proof attesting to the correctness of the data within the transaction (Banerjee et al., 2020). The proof of the ZK can only be generated by the transacting parties because revealing the proof requires a private-key signature from the wallet address of one of the transacting parties (Li and Xue, 2021). ZKPs are relatively impossible to decipher based on current encryption methods (Jivanyan and Mamikonyan, 2020). An added benefit of using ZKPs is that they incur less blockchain computation to process than standard transactions and are thus lower in transaction fees (Ma et al., 2020). ZKPs existed before the invention of the blockchain, are mathematically proven reliable, and have been used in applications such as privacy-preserving online public auctions, whereby a person's identity can be anonymously verified online without them publicly revealing any personal data (Li and Xue, 2021). In a real-life project, all transactions executed through the proposed application would be encrypted via a ZKP, enabling project participants to transact with privacy on a public blockchain.

However, the researcher found no literature discussing the potential auditing problems of ZKPs. For example, if mass data is stored on the blockchain encrypted, it may cause traceability problems for auditing authorities. For example, the auditing authority would need to request mathematical proofs from the transacting parties every time they want a transaction decrypted, which is data processing intensive. Nevertheless, analysing scalable solutions for the auditing problems of ZKPs is beyond the scope of this paper to investigate.

Private blockchains are an alternative method for achieving privacy; however, they require deploying a private network and incentivising users to run validator nodes, which are laborious, technical, and costly tasks (Quasim et al., 2020). Public blockchains, such as Ethereum, already come preconfigured with thousands of transaction validators and are maintained by hundreds of decentralised core developers that contribute to managing and maintaining its network; therefore, users can transact, build applications, or deploy smart contracts on Ethereum without having to set up any infrastructure (Chain Stack, 2020, Shen et al., 2021).

Returning to the challenges of PBA, according to one interviewee, "The bank can set up the PBA within several weeks upon receipt of the signed PBA trust deed" (a PBA trust deed is a legal document that lists all the PBA's trustees and is the most crucial document in the PBA system). In contrast, the proposed application showcased how project participants with no programming knowledge can set up a blockchain-based PBA within a day. Another interviewee added, "Waiting for the bank to initialise the PBA is one factor that causes delays in PBA projects, but it is not one of the main ones". Therefore, although PBAs do not cause significant project delay risks, a blockchain-based PBA could mitigate this entirely. Another mentioned that one of the primary differences between PBA and standard payments is that the "Head contractor must get approval from the client before they can spend anything, unlike in traditional projects where the contractor has full control." This states that according to standard PBA procedures, the client oversees all cash-outs from the PBA, which places greater surveillance over the contractor. In a non-PBA project, the contractor is responsible for all cash-outs to subcontractors, which the client has no traceability over. In contrast, in PBAs, the client and PM are mandated to approve all cash-outs to the supply chain, giving the client's team full traceability over project payments to subcontractors. Another critical point highlighted by one interviewee is that "PBAs are only used for payments down to tier-two subcontractors because they are too complicated to set up and manage and the contracts between tier two and tier three are completely different" and that "not all banks offer PBA services." Furthermore, they added that they "have managed over 40 PBAs, and none of them was used to make payments to tier three". Since most of the supply chain exists below tier-two suppliers, a solution is needed that provides greater accessibility of PBAs to the lower-tier supply chain (i.e., tier three, four, and so on). This is crucial because lower-tier suppliers are at greater risk of financial adversity due to their lower working capital.

As mentioned above, one of the challenges of PBAs in the current environment is that they cannot be used for payments down to tier-three suppliers. This conflicts with the UK Government's stipulation in the PBA guidance document that states that PBAs must accommodate payments down to tier three (i.e., (UK_Government, 2012)). According to one interviewee, the main contractor cannot approve the works of tier-three suppliers because they are not responsible for managing tier-three contracts; consequently, they cannot process payment to tier-three. The interviewee added that only the tier-two suppliers can approve the works of the tier-three. An amendment to the UK Government's PBA guidance document would be required to allow the main contractor to authorise payments to tier-three suppliers based on payment approval certificates received from tier two. However, this has several challenges: The PBA trust deed currently only stores the signatures of tier-one and tier-two suppliers. Amending it to include tier-three suppliers would substantially increase the trust deed's management workload. For example, suppose the main contractor employs 20 tier-two subcontractors, and each tier-two subcontractor hires ten tier-three suppliers. In that case, the contractor must collect and manage hundreds of trust deed signatures, causing delays in data processing. This problem becomes exponentially more complicated when considering the inclusion of tier-four and tier-five suppliers. The UK PBA strategy mandates that all cash-outs from PBAs require authorisation from the client, project manager, and main contractor (UK_Government, 2012). Therefore, the bank must verify these signatures every time a payment is executed from the PBA. Including tier-three suppliers in PBAs also increases the bank's payment processing workload. This is because PBA *authorisation statements* are paper-based documents submitted by the contractor to the bank whenever supplier payments are due. Contractors already have an aversion to using a PBA in projects because it increases their management workload; therefore, adding additional complexities, such as incorporating tier-three to tier-five suppliers into the PBA payment system, is not a proposal they support. Therefore, a more automated system is required to improve the management of PBAs. Research shows that the primary reason subcontractors do not request PBAs is because of fear of potential exclusion from future work (Griffiths et al., 2017). Nevertheless, more research is needed on the payment problems of the lower-tier supply chain to verify whether they would benefit from PBAs. This is because solving the late payment problem using PBAs between tier-one and tier-suppliers might positively cascade down the supply chain, potentially rendering PBA unnecessary for the lower tiers.

This paragraph discusses two of the most crucial forms in PBAs: (1) the *payment application* and (2) the *authorisation statement*. The payment application is a request for cash-ins to the PBA, whereas an *authorisation statement* is a request for cash-outs from the PBA. The payment application is a form the contractor submits to the tier-one payment approvers (i.e., the client and PM) stipulating the amounts due to the PBA. These payment approvers then check whether the amount requested matches the project's order value, and once approved, the client executes the cash-in to the PBA. Similarly, the authorisation statement is a form the MC signs and submits to the tier-one payment approvers (client, MC, PM, etc.) requesting approval to debit cash from the PBA. Once all tier-one parties sign the form, the MC sends it to the bank for processing. Technically, the MC's signature also comprises signatures from the quantity surveyor, commercial manager, and contract manager; however, these signatures are managed by the MC and are thus grouped under the MC's signature for simplification in this discussion. One interviewee mentioned that standard PBA forms, such as the payment application and the authorisation statement, were not shown in the proposed application. The researcher explained that the proposed application automates the payment application process when it sends a cash-in request notification (via e-mail) to the payment approvers whenever cash-ins are due; thus, the contractor is no longer required to manually submit this form because it is automated in the background. The interviewee advised that "even though it is automated, publishing a formal document would still be required for management and archiving purposes". Regarding the authorisation statement mentioned above, the proposed application also automated this form because when a subcontractor sends a notification via the proposed application that works are ready for approval, the application's payment authorisers receive an automated e-mail with a link directing them to the location on the UI where an approval signature is required; therefore, the contractor no longer needs to manage the authorisation statement form manually. The proposed application executes autonomous cash-outs from the PBA to the suppliers when all payments are authorised.

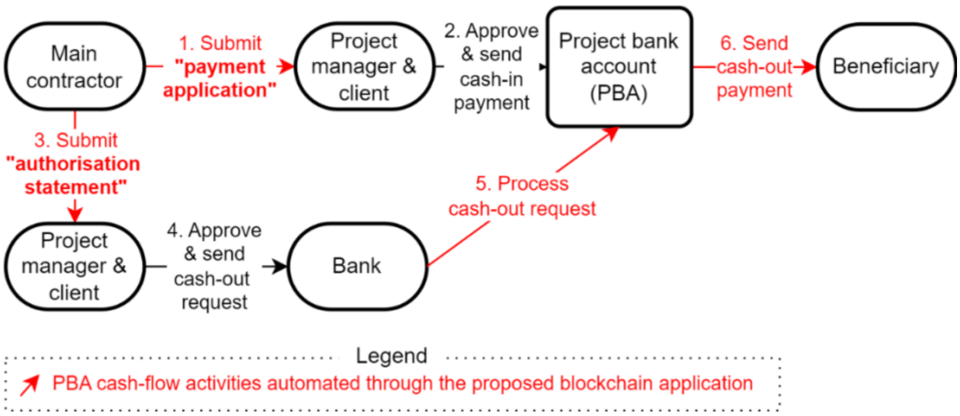



*Figure 20: PBA payment application and authorisation statement process flow.*

One interviewee commented, "The quantity surveyor (QS) must be included in the payment approval process before the authorisation statement is even sent to the PM. Their role includes measuring the works delivered and issuing a payment certificate or payless notice suggesting how much to spend within the PBA." The proposed application was designed to allow configurations, and adding more approval parties, such as the QS, was easily appended to the application after the focus-group interview. In the proposed application, suppliers are no longer required to submit invoices because payments are directly linked to approval signatures; however, for formality purposes, invoice documents could be made available for download in PDF format for storage and archiving purposes. Hypothetically, the invoice data would be automatically generated based on the information in the cash-in and cash-out tables in Figure 13 and Figure 15 from section 4.4.5: User Interface. However, the researcher understands that additional information, such as tax codes, must be appended to the invoice to make it more legally and formally acceptable. Nevertheless, the proposed application has not yet reached the stage where details like this are being architected into the system, as the focal point is the application's general framework design.

In standard PBAs, only the bank has the authority to debit cash from the PBA, hence the need for an authorisation statement instructing them to execute cash-outs. Since the proposed application disintermediates from using a bank, the process of sending them a PBA authorisation statement is irrelevant because cash-outs from the PBA wallet are automatically triggered when payment approvers (client, MC, etc.) sign and approve a supplier's cash-out. In the current version of the proposed application, the approval certificate is a blockchain signature rather than an official document; however, a future iteration of the proposed application could append these signatures directly onto standard payment certificate documents, extending the use of blockchain for certificate authentication.

Two interviewees highlighted that existing construction processes lack traceability. One said, "Current systems lack traceability with payment approvals and signoffs," and another mentioned that they "frequently suffer reconciliation issues when managing cash book data". All actions performed through the proposed application are recorded on the blockchain as transactions, allowing management parties to query and trace data flows from origin to destination with an intact data trail. This was supported by another interviewee, who discussed how they "see the automated accounting of blockchain as a potential solution to logging and timestamping cash flow events". Blockchain automates the logging of transactions through its network of nodes that run a consensus algorithm that validates data. All data on the blockchain is immutable, making it a suitable medium as a single source of truth; furthermore, it mitigates reconciliation errors when project managers synchronise data across interim stages. According to one interviewee, banks only keep PBA transaction records for "six to twelve months". Since all transactions on the blockchain are permanently stored, they can be instantly queried after many years; as one interviewee highlighted, "Blockchain would make a good system for permanently storing PBA transaction records."

The proposed application sends automated e-mails to project participants when tasks require performing instead of relying on them to communicate manually. For example, when a subcontractor registers on the application that their works are ready for approval, the contractor is sent an automated e-mail stating that a review of the works is due. Furthermore, since data flows are immutably recorded on the blockchain, harmful management practices, such as late payments, are easy to identify and penalise. One interviewee commented, "The fact that users are automatically reminded when tasks need to be performed is brilliant; it immediately mitigates having to chase people to do things." The automated e-mail notification feature is not an invention of the blockchain or Web 3; it is a function already implemented in standard web applications. Nevertheless, integrating web applications with the blockchain is more accessible than integrating them with proprietary software. This is because web applications are the default user interface of blockchains. Therefore, the infrastructure requirements of blockchain applications are lightweight, require no infrastructure prerequisites, and can be accessed on standard web pages instead of having to build complex bespoke software packages.

The standard, centralised method for sending payments is via a terminal management system (TMS), as advised by one interviewee who stated, "All PBA payments are made through a TMS set up with the bank." However, TMS is a legacy system that is closed-source, licenced and does not offer programmable payments. One software system used regularly by large construction companies is ERP software. One interviewee mentioned they "use an ERP for managing orders and payment data, but it cannot integrate with other software systems". ERP software is more specialised and technical (unlike spreadsheet software, which is general-purpose and straightforward to integrate). Similarly, another interviewee discussed how they "tried integrating management information on SharePoint but ended up with too many bespoke systems that no one knew how to manage." The technology siloing of legacy, centralised systems makes data integration challenging. Due to the general-purpose properties of the blockchain and the programmability of smart contracts, they could be used as intermediary systems for integrating data from fragmented software, as shown in Figure 21 below.

The ability of various project participants to collaborate and access information effectively is critical to a blockchain application's success (Lawal and Nawari, 2023). One perspective for evaluating accessibility is how easily project participants can use and benefit from the application or how easily developers can replicate it. Due to the open-source nature of blockchains, copying technology is normalised and encouraged within the blockchain ecosystem. For example, Litecoin is a fork of Bitcoin, and Feathercoin is a fork of Litecoin. In that example, a *fork* is when the codebase of one blockchain is copied, edited, and deployed as a new blockchain. One interviewee remarked, "Since blockchain is open-source and legally backed by a copyleft vs. copyright licence, the technology can be copied, modified, used, and redistributed without intellectual property issues." They added: "The same applies to any dApps built on public blockchains." Blockchains differ from centralised software because they place free and permissionless information sharing as the top priority over profit. For example, the Ethereum Foundation

(EF) is a non-profit organisation comprising hundreds of decentralised core developers managing and maintaining the Ethereum blockchain (Ethereum Foundation, 2023). Furthermore, anyone can submit an Ethereum Improvement Proposal for consideration by the EF. The business model of public blockchains is vastly different from any organisation that existed before them because they operate through a transparent and publicly verifiable system, unlike centralised companies, which rely heavily on privacy and profit. One interviewee commented, "Some blockchain dApps, such as Qredo, take the idea of open-source further by providing white-label solutions that enable their work to be copied and rebranded without risk of copyright infringement". Construction companies can leverage the services of a white-label dApp, rebrand it as a new product, and even profit from it without the risk of copyright breach. Furthermore, since dApps are hosted on the blockchain, their codebase is open-source and openly replicable. An example of how the proposed application can benefit from a white-label dApp is copying the codebase of another white-label dApp, such as a wallet provider, and deploying it as a new service within the proposed application, thereby reducing reliance on third-party wallet providers while also benefitting from cost-free technology infrastructure.

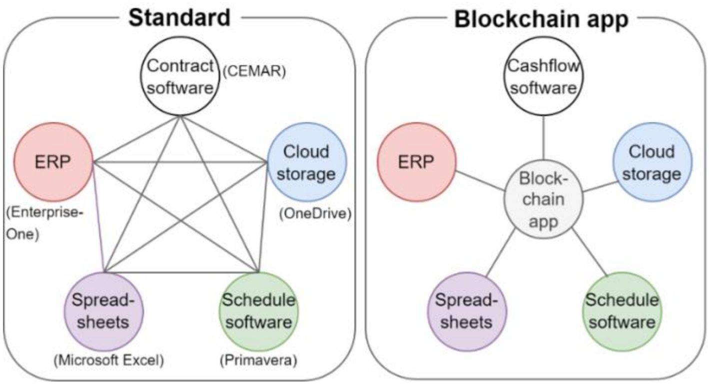



*Figure 21: Illustration of how blockchain can reduce the number of APIs between systems.*

MetaMask (the wallet provider used in the proposed application) cannot be liable for damages since decentralised wallets are self-owned rather than managed by a bank. Despite that, one interviewee advised, "Wallet dApps such as Qredo provide insurance up to the value of USD 600 million for any funds lost through wallet hacks on their platform." This insurance is of high enough value to provide adequate coverage for large construction projects.

Each scheduled work in the proposed application includes a weblink that users can click to access their contract. The contracts are in PDF format, stored in a decentralised cloud (i.e., IPFS), accessed via a weblink, and uploaded by the contractor. However, IPFS is optional, and documents can be managed using whatever cloud storage is preferred by its users, as all that is needed is a weblink to the storage repository. Furthermore, although the proposed application improves systems integration, it is not a document management system; thus, data hygiene (i.e., managing and organising files) is the responsibility of its users. Concerning how the proposed application stores contract documents in IPFS, one interviewee stipulated, "Standard cloud is not designed to handle the commercial complexities of contract management" and that "Cloud-based solutions for this already exist, such as CEMAR." They added, "CEMAR is designed to operate with NEC and provides users with dashboards for tracking and managing contract data." Furthermore, they clarified, "It automates the generation of charts, dashboards, and reports, such as percentage of early warnings managed effectively, communications dealt with on time, and compensation events approved." An easy and indirect way to instantly link CEMAR files with the proposed application is to store a hyperlink of CEMAR's contract repository in the proposed application (as shown in Figure 22 below) while also storing a similar hyperlink in CEMAR, allowing the two systems to be indirectly connected. They are indirectly connected because if the hyperlink in one system is changed, it does not automatically update the hyperlink in the other system; therefore, data entry on two systems is required.

| Role | ID | Contract | Works | Revision | Start | End | Planned | Actual | CostCode | Status | PercentageCo |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Subcontractor | 100 | /Sub.pdf | Ground | 0 | 01/03/2023 09:00 AM | 01/10/2023 06:00 PM | 0.1 ETH | 0.14 ETH | XX-001 | Paid | 100 |

*Figure 22: Screenshot of the cash-out table, highlighting a web link to the supplier's contract document.*

One interviewee advised, “There is a plethora of project management software that does management tasks better than blockchain, so it is best to use blockchain for what it is good at, which is a settlement layer.” The proposed application did not intend to imitate or replicate another software. Instead, it was designed to integrate payment approvals with executions. For example, when on-site works are approved (via the proposed application’s UI), it triggers an autonomous payment to the supplier.

Although stablecoins mitigate cryptocurrency price volatility, one interviewee stipulated, “stablecoins are not yet considered legal tender, but this should be ironed out when the stablecoin bill is approved”. Furthermore, they added that “The bill for regulating stablecoins is currently with the House of Lords”. The *Queen’s Speech: Economic Affairs and Business Report* highlighted regulating stablecoins as a matter of high legislative consideration (UK Parliment, 2022). However, until the abovementioned stablecoin bill is approved, a solution for off-ramping stablecoins is required. One interviewee cautioned that “off-ramping ramping stablecoins is where most of the challenges are”. To convert stablecoins to fiat, the beneficiary (i.e., suppliers receiving payments from the PBA) would exchange them via the stablecoin provider’s platform and then deposit the fiat to their commercial bank. However, due to the high-risk profile of blockchain services, banks can freeze deposits from stablecoin providers due to tighter governmental controls with anti-money laundering (AML) regulations. Banks are cautious about accepting money from stablecoin providers due to the numerous frauds that have taken place regarding cryptocurrencies. For example, FTX Trading Limited was considered a reputable and regulation-abiding cryptocurrency services provider until it filed for bankruptcy in 2022 (Palma et al., 2022). Furthermore, FTX lost an estimated USD 32 billion worth of customer and creditor funds and was labelled “one of the biggest US financial frauds in history” (Palma et al., 2022). This is why banks are cautious about accepting deposits from cryptocurrency services companies. When asked about the viability of paying taxes with cryptocurrencies, the researcher explained that using cryptocurrency stablecoins for payments would not affect standard tax duties because beneficiaries would still receive payments in fiat after they convert their stablecoins. Therefore, the existing method of managing and filing taxes remains unchanged. Furthermore, the blockchain transactions would include reference codes that enable auditors to track and verify the origin and destination of payments on the blockchain.

Central bank digital currencies (CBDCs) are an alternative to stablecoins; however, at best, they are still in the piloting stage and have not reached adoption. CBDCs and stablecoins are similar in that they are both blockchain tokens. The primary difference is that CBDCs are issued by the central bank, whereas private organisations issue stablecoins. Nevertheless, the demand for blockchain caused the UK Government to set up the CBDC Taskforce to investigate whether the Bank of England can use blockchain to improve the management, issuance, and tracking of blockchain-based GBP (HM Treasury, 2021, Bank of England, 2020). Although blockchain is challenging to regulate because of its decentralised nature, it is being tested at a multi-sector and governmental level, and bodies such as ISO include 26 registered blockchain standards; however, most of the standards are still under development (ISO, 2022).

In traditional construction projects, the client and the contractor can obtain payment or performance guarantees from banks to reduce financial risk in construction projects (Chovancova et al., 2019). The payment guarantee protects the contractor if the client cannot pay liabilities, and the performance guarantee protects the client if the contractor cannot deliver works (Chovancova et al., 2019). Payment guarantees are only triggered in extreme cases, such as if the client or contractor becomes insolvent because they can take over a year to process (Wu et al., 2019). Thus, although payment guarantees provide construction projects with assurances, they are ineffective at improving general cash liquidity. One interviewee stipulated, “Payment guarantees for PBAs are unnecessary because the client is the government and is cash-rich”, and another added, “The government does not allow PBAs to acquire finance because it increases their national debt due to interest repayments.” Before the focus group interview, the researcher was unaware that PBAs imposed restrictions on finance. Therefore, obtaining payment guarantees or loans (e.g., supply chain finance) is not permissible with PBAs. The only time finance would be permitted for PBAs is if the government extends them to include the private sector. In response to a question asked by the researcher regarding whether PBAs are also used in the private sector, one interviewee replied, “Not currently, but the government is considering rolling it out to include them.”

One interviewee pointed out that “the client has the final say in what financial system to use for PBA, and at the moment, it is with traditional finance, but it could be blockchain if the value proposition is big enough”. Therefore, from the perspective of that interviewee, contractors are open and willing to experiment with alternative solutions for PBA if requested by their clients. One interviewee added, “Public sector clients in the UK have a governmental login portal that they use to monitor and access PBAs". Technically, the UI of the proposed application is just a graphical display and can be configured to suit any back-end system; therefore, this back-end system can be in the form of blockchain and smart contracts.

When the researcher asked the interviewees whether they saw any potential threats with enterprises adopting the proposed application, one replied, "The threat is with the bank and not the enterprises because blockchain will take business away from them." Furthermore, they added, "Banks can indeed make it harder for crypto companies to off-ramp crypto assets if they feel threatened." For example, banks can freeze funds from cryptocurrency companies if they deem them high risk under regulatory controls such as anti-money laundering (AML). Another interviewee highlighted that "stablecoins are not yet considered legal tender"; therefore, in the current environment, any blockchain applications must cooperate with traditional banking systems until the government approves stablecoins as legal tender. According to one interviewee, if the government approves the "bill for regulating stablecoins, there will be a fast expansion of real-life use cases for blockchain". However, until then, cooperation between cryptocurrency stablecoin services and traditional finance (i.e., banks) is fundamental for construction companies considering blockchain for payments.

Know-your-customer (KYC) checks are procedures for verifying the identity of users to ensure people are whom they say they are and can be trusted (Arner et al., 2019). For example, when a customer opens a bank account, the bank is legally obliged to conduct KYC (Arner et al., 2019). Trusted authorities, such as banks, can be used for outsourcing KYC services for blockchain applications (Chai et al., 2020). UnionPay is an example of a Chinese financial technology company that leverages a commercial bank's KYC services to verify the wallet addresses of its cryptocurrency customers (Chai et al., 2020). The type of KYC required in the proposed application comprises proving that the wallet addresses of project participants are owned by real identities. One interviewee highlighted, "The wallet addresses of project participants should be linked to a KYC-approved registry to ensure only verified users can be entered into the application." This would mitigate the risk of data entry errors or malicious actors entering fraudulent wallets into the proposed application. The challenge with the main contractor internally managing the KYC of their suppliers' wallets is that they would be held legally accountable for authenticating users and maintaining privacy against hacks. Furthermore, suppliers may not feel comfortable with a contractor having control over their blockchain identities. Due to the complexities of user authentication, KYC is best outsourced to FinTech (financial technology) companies or CeFi (centralised finance) organisations that specialise in this field (Nath, 2023). FinTech is less regulated and focuses on providing services for moving money faster and cheaper between people and businesses (Nath, 2023). In contrast, CeFi is more regulated and is used to manage assets such as mortgages, stocks, and bonds. FinTech and CeFi can provide KYC services, although CeFi is more reputable because the government monitors them more closely for regulatory purposes (Nath, 2023). One interviewee stipulated, "In the PBA trust deed, it will say which bank account to use for the PBA; there should be no problem in specifying a blockchain wallet as the PBA provided the right KYC and insurance are in place throughout." Another interviewee highlighted how KYC should be accompanied by "white-listing" to "enable users to limit transactions to verified wallets only." White-listing is when the wallet address of a project participant is placed into a repository, such as a database or smart contract, to validate them as safe to use in a project (Tezel et al., 2021). In the case of PBAs, the white-listed wallets would include the signatories of the PBA trust deed, ensuring that only those parties can approve or receive payments from the proposed application's smart contracts. The difference between KYC and white-listing is that the former is used for identity authentication only and managed by a third-party provider, whereas the latter would be managed by the main contractor on a project-by-project basis. White-listing combined with KYC provides a two-stage verification process for ensuring the safety of user wallets.

One interviewee stated that the Trust Deed tab should "link up with the contractor's internal spreadsheet rather than having to enter supplier details twice" (once in the spreadsheet and again in the proposed application). General-purpose management software, such as Microsoft Excel, includes add-in capabilities that enable spreadsheets to integrate with web applications, mitigating developers from needing to set up APIs (Hiron-Grimes, 2017). Alternatively, many third-party party providers can deliver this service (Appizy, 2023). Since web applications are lightweight and accessed via standard web pages, they provide a highly accessible medium for transferring spreadsheet data to the blockchain and vice versa.

Concerning the proposed application's cash-in and cash-out tables, one interviewee advised that it "only showed planned vs actual costs; why not extend it to include budget and estimated costs?". This can be achieved by adding additional data columns to the cash-in and cash-out tables to include estimated and budget costs and providing access rights for other parties, such as the estimator, to access the cash-in and cash-out tables to insert cost data. Alternatively, a separate smart contract for managing estimated and budget costs could directly feed into the cash-in and cash-out tables. Regarding this, one interviewee commented, "If these costs are in one place, linking them to analytics dashboards would be straightforward." Linking the cost data to analytics dashboards would be highly effective because it allows cost performance data to be displayed in real-time rather than waiting for the publication of month-end reports. Since the data would be timestamped, immutable, and with a complete record of when it was revised and by whom, an intact data trail would be available for project analysis. This correlates to one interviewee who stipulated how current systems "lack data trust because users can overwrite it any time, and it relies on people manually entering the information correctly". Another interviewee added, "Live analytics would be highly beneficial to projects" and that "having the visibility of knowing, with pinpoint accuracy, when works were approved on-site, certificates awarded, and liabilities executed, would be useful for project reporting."

Regarding the proposed application's cash-in tab, shown in Figure 13 from section 4.4.2, one interviewee highlighted that it "should include the status of the commercial manager's interim valuation, which the client and the PM would then sign to authorise the payment." In contrast, the PBA guidance document published by the UK Government stipulates that "A PBA does not cut across contractual provisions governing the preparation and submission of interim applications or the valuation, authorisation or certification of interim payments" (UK_Government, 2012). Therefore, the researcher purposely excluded interim valuation processes from the proposed application's design to ensure it did not interfere with the government's guidelines.

Concerning how all project participants can view all payment data on the proposed application's user interface (UI), one interviewee commented, "The subcontractors should not have full visibility of this". The researcher responded that for testing purposes, the cash-in and cash-out schedules were displayed under the same UI; however, in a real-life application, these schedules would be partitioned into separate UIs.

The proposed application's *Subcontractor* tab, shown in Figure 16, was designed to enable subcontractors to pull their project data (such as scheduling, approvals, and payment data) instantly without needing to query it directly from the main contractor, saving unnecessary communications and delays in data retrieval. Concerning this, one interviewee mentioned, "This reduces the number of unnecessary communications between management parties and suppliers because much time is wasted simply relaying information." Another interviewee added, "In a typical large project, ten people, on average, spend two full days per week answering queries related to schedules, orders, and payments." These comments suggest that contractors spend substantial time relaying information and answering supplier questions. Time wastage could be reduced by leveraging the proposed application as a single source of truth for storing project data. One interviewee commented, "Enabling subcontractors to pull the most updated version of their scheduled work is very useful for data consistency, and it reduces the burden on them managing this information themselves." That highlights how time savings can be made from the suppliers' perspective since their schedule data automatically synchronises with the contractor's project schedule. Regarding data consistency, one interviewee commented that one of the problems they face is "maintaining an accurate data trail between the lead contractor and subcontractor." The proposed application would mitigate the data inconsistency problem because each data entry, revision, approval, and payment performed through it is documented on the blockchain and can be audited.

Initially, the proposed application included a payment guarantee tab; however, this was removed upon feedback from the findings. One interviewee mentioned: "Banks already have a formal process for administering finance; they will not change their internal process just for one application." Since PBAs are disallowed from obtaining finance, it hampers decentralised finance protocols from providing blockchain-based lending to PBAs. Another interviewee advised, "Payment guarantees for PBAs are unnecessary because the client is the government and is cash-rich." Based on the above feedback, the payment guarantee tab was omitted from the proposed application.

One contractor commented, "NEC contracts have a clause in them that state that if planned works are affected by heavy rain, such as if the on-site rainfall is 5mm above the ten-year average, then the contractor is permitted to claim an extension of time for the number of days affected by heavy rain." Furthermore, they suggested that "smart contracts could be used to pull weather data from weather stations to process these claims automatically." The infrastructure that would enable this to operate is Web 3 oracles (also synonymously called oracles or blockchain oracles).

The researcher assumed that inserting PBA clauses into a PBA contract (i.e., a construction contract with PBA clauses embedded into it) came from a standardised template; however, one interviewee clarified this as incorrect and stipulated that six primary steps are required, such as: (1) "Bid manager identifies actual or potential PBA requirements from the tender documents and advises treasury lead", (2) "treasury lead confirms PBA wording and identifies whether any changes are required", (3) "Bid manager raises any required changes to type and wording with the client at tender stage", (4) "type and wording resolution processes commences", (5) "bid manager communicates the outcome of the tender process to the commercial manager", (6) "commercial manager sends it to the treasury lead, who approves the PBA and trust deed wording and includes it in the contract's document pack to be executed". The PBA contract approval process requires engagements with many parties revising and exchanging documents over e-mail. The problem with exchanging documents via e-mail is that people can read or approve an outdated version, and someone needs to manage the version control process (i.e., archiving, revising, and recirculating documents). This creates unnecessary process redundancies, which blockchain could alleviate through its single, shared ledger that autonomously timestamps events, such as document signatures and revisions. According to one interviewee, "the application should imitate or integrate with a Docu-sign-style system" to allow users to sign the PBA trust deed with their blockchain wallets. The researcher acted on this suggestion and updated the proposed application to enable project participants to sign the PBA trust deed with their blockchain wallets.

# 6. CONCLUSION

The proposed application demonstrated how blockchain and smart contracts can improve the delivery of project bank accounts (PBAs) through process flow automation. For example, cash flows to and from PBAs are controlled by two forms: (1) payment applications and (2) authorisation statements. The former is used for cash-ins, while the latter is used for cash-outs. Figure 20 in Chapter Five: Findings and Discussion, illustrates and discusses how these forms, alongside the data flows from management systems to payment systems, are automated in the application. Blockchain and smart contracts could also democratise PBAs by making them more accessible to a broader percentage of the construction supply chain. PBAs in the UK are only used for payments down to tier-two suppliers, not tier-three or below, due to the increased payment processing responsibilities PBAs impose on construction projects. For example, executing a payment from the PBA requires approval by the client, main contractor, project manager, quantity surveyor, commercial manager, payable manager, and bank. Leveraging smart contracts to manage data flows would reduce the payment-processing workload of PBAs significantly, as shown in Figure 20. One of the problems with banks hosting PBAs is that they only store PBA transaction records for one year and take several weeks to set up the PBA. In contrast, all transactions on the blockchain are stored permanently with no time restrictions, and the proposed application's smart contracts can be deployed within a working day. The automated logging and timestamping of payment approvals, certificate awarding, and liability executions on the blockchain would increase the traceability of cash flow data in project reports. This would also provide a trusted data layer for integrating with analytics dashboards to automate project monitoring.

Overall, the findings suggest that although the blockchain can improve systems integration, process flow automation, data traceability, and cash flow programmability in PBA projects, it has several concerns that hamper its adoption in construction, such as a lack of interoperability with existing software, services for off-ramping cryptocurrencies to traditional banks, and legal accountability. These limitations are discussed in the following section.

## 6.1 Limitations

The research's proof of concept (PoC) was not verified longitudinally by testing it over a more protracted period. For example, data was only collected on one occasion. The nature of the data collection was also qualitative, and all the interview questions were open-ended; thus, the responses covered a wide range of topics, making generalisations challenging as the sample size was limited to four participants. Nevertheless, there was consensus from the interviewees across four key areas: (1) the proposed application needs to interoperate more with existing construction software; (2) blockchain solutions are costly to develop in the current commercial climate; (3) there is a lack of off-ramping infrastructure for withdrawing cryptocurrency assets, such as stablecoins, to commercial banks; and finally, (4) decentralised technologies suffer from a lack of legal accountability. These points are expanded below:

1. The findings uncovered that the proposed application needs to interoperate more effectively with ERPs (enterprise resource planning), contract management (e.g., CEMAR), and spreadsheet (e.g., Microsoft Excel) software. Furthermore, the application should be cautious not to duplicate the functionalities of existing software to not waste resources unnecessarily building new systems.
2. Despite blockchain providing cost-free technology infrastructure by being open-source and open-licence, it suffers from a lack of formal adoption frameworks and skill shortages in dApp developers, making the technology expensive to utilise in the current climate.
3. Another crucial finding is that banks can block cash deposits from cryptocurrency service providers if they deem them high-risk. This is problematic since the supply chain relies heavily on banks for essential financial services such as checking accounts. The risk of suppliers not having access to funds due to banks denying or freezing transactions from cryptocurrency companies due to regulatory issues is a significant deterrent for construction companies. However, the approval of the stablecoin bill currently under review by the UK Parliament would mitigate this problem.
4. Enterprises are centralised entities that rely on centralised accountability when doing business. Since blockchain applications are decentralised, they cannot be held legally accountable or responsible for potential damages caused by hacks or technology malfunctions. This creates legal accountability problems with judicial systems because the party liable for damages is ambiguous to define, and business agreements operate through clear liability terms.

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