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A Blockchain-Based System Concept for Managing Payments in the Construction Supply Chain

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Abstract

The construction industry is one of the largest in the world, employing 7% of the global workforce, and accounting for 13% of global GDP. Many stakeholders are involved in the construction supply chain, which includes owners, contractors, subcontractors, and suppliers. The handling of payments in construction supply chains faces a lot of challenges such as delays, rework and errors, late payments, and improper supervision and financial controls. The main objective of this paper is to explore payment issues in the construction supply chain from the literature as well as available solutions and introduce a system concept that addresses these issues and extends existing solutions. Thus, in this paper, we propose a blockchain-based system concept for handling payments in the construction supply chain. We provide a description of the system components and design and discuss how the proposed design addresses the challenges faced by the participants in the construction supply chain.

Keywords

Blockchain, Construction industry, Payments, Supply chain

1. Introduction

The construction supply chain involves all processes and activities involved in a construction project, which starts with demand identification, the design of the construction project, the actual construction work, the maintenance of buildings, until the eventual demolition of buildings and structures. Each year, 13% of the global GDP is spent on construction goods and services, which is around 10 trillion USD, employing 7% of the global workforce. A typical construction supply chain has many stakeholders, which includes owners, designers, contractors, suppliers, and sub-contractors (Studer & De Brito Mello, 2021). According to (Nanayakkara et al., 2021), there are several issues encountered in the construction supply chain with regards to handling payments between the different stakeholders, which includes: delays in completing work due to supply chain issues, going over budget, rework and errors, late payment are acceptable in the industry, work first then get paid later culture, improper supervision and financial controls, coordination issues with many parties, improper withholding of payments and lack of trust between members.

A blockchain can be defined as a decentralized ledger of sequentially ordered transactions that are cryptographically validated and secured to be tamper-proof. A blockchain lives on a network of nodes, each node having a copy of the entire ledger, and the accuracy of the data stored on the blockchain is validated by the collective effort of all the nodes on the network (Levis et al., 2021). With the release of the Ethereum blockchain in 2015, the concept of smart contracts was introduced that allows writing and executing software applications on the blockchain (Zhou et al., 2022). Blockchain can, thus, be characterized as an "immutable" public record of data, with the ability to run decentralized and immutable applications. Due to the transparency, and immutability that blockchain offers, it can be a solution to the challenges faced by stakeholders in the construction industry when handling payments. In this paper, we build on existing research on this topic in literature to propose a concept for a blockchain-based system that addresses the challenges.

The rest of the paper is organized as follows: The Literature Review section provides a brief overview of research relevant to the topic. The Proposed System Concept section provides a description of the system components and design. Lastly, the Results and Discussion section discusses how the proposed concept addresses the payment handling challenges and describes the roadmap and next steps that we plan to perform based on the findings in this paper.

2. Literature Review

The use of blockchain technology in supply chains is a widely investigated topic in the literature due to its characteristics and features of traceability, transparency, decentralization, immutability and automation. In supply chain finance, blockchain can be used to address the challenges of the lack of supply chain visibility, inefficient processing of manual paperwork, and risk fraud (Ioannou & Demirel, 2022). (Archa et al., 2018) introduced a blockchain-based system to address the issue of drug counterfeiting in the pharmaceuticals supply chain. The system tracks the quantities of drugs that each party holds and tracks the movement of drugs across all parties in the supply chain. (Rogerson & Parry, 2020) also lists several cases that demonstrate how blockchain is used to address counterfeiting and improve trust and visibility in the food supply chain.

Blockchain technology is used by researchers to automate payments and address their challenges in supply chains. A study introduced a blockchain-based system to address the issues of trust and visibility between stakeholders and implemented a simple mechanism for handling payment installments between the parties of a supply chain (Kaid & Eljazzar, 2018). Their system works by letting buyers and sellers agree on a rule, say, no payment is made until 50% of the sold services are completed, and then share information about the service on the blockchain. (Tsai, 2023) proposed a blockchain-based scheme for supply chain finance. Their model has three actors: a large enterprise acting as a buyer, an SME acting as a seller, and a financial institution. The financing process starts with the buyer creating a purchase order, then the seller shipping the products, followed by a series of steps to complete the purchase operation such as invoicing and receipt confirmation. The financial institutions then issue a loan to the seller, and the buyer pays off the seller's loan.

Ensuring the flow of funds in a construction supply chain is key to avoiding problems and delays (Studer & De Brito Mello, 2021). But because a smooth flow of funds is a rare occurrence, many studies focused on identifying the challenges and problems that the stakeholders in a construction supply chain face when dealing with payments. Some of these studies attempted to identify a collection of problems such as (Ramachandra & Rotimi, 2015) and (Swai et al., 2020). (Ramachandra & Rotimi, 2015) studied the causes of the payment problems in the New Zealand construction industry and found that among the causes contributing to payment problems are cash flow difficulties due to delays and non-payments on other projects, disputes over payment claims, payment culture in the industry, dishonesty of the payers, improper supervision and financial control, and cost overruns. (Swai et al., 2020) studied the factors causing unfair payment practices in the construction industry in the UK. The study found that among these factors are late payment to contractors, pay when paid, implosion of rates on contractors, unpaid retention to contractors. Other studies focused on proposing a solution to a specific problem such as (Xie et al., 2019). (Xie et al., 2019) investigated the impact of two links in construction supply chain payments (i.e., owner to general contractor and general contractor to subcontract). The authors found that the shortening of the payment period at these two links will accelerate the flow of funds and make it easier to provide advance funds, which ensures smooth progress on construction projects.

Blockchain technology was considered by researchers in the construction supply chain to address various challenges. (Shemov et al., 2020) examined the use of blockchain technology as a digital platform to address the challenges that usually exist in the construction supply chain. The authors concluded that, despite the security threats that come with the use of blockchain, technology is still a viable solution to many challenges of the construction supply chain, most notably trust, and execution delays. (Lu et al., 2021) developed a blockchain-based model for the government supervision of construction work (GSCW) that integrates an incentive mechanism. The model was found to enable information sharing, privacy preservation and is adoptable by existing GSCW teams without disruption of their routines and workflows.

Researchers also considered blockchain technology for addressing challenges with payments in the construction supply chain. (Motawa & Kaka, 2009) introduced an IT system that models different payment systems and let the construction supply chain stakeholders decide on an appropriate payment mechanism to ensure smooth cashflow and shield the supply chain against factors that could potentially disrupt the cashflow., satisfying all members. (Hamledari

& Fischer, 2021) investigated the use of blockchain-based smart contract solutions to automate progress payment tracking in the construction supply chain. (Das et al., 2020) presented a decentralized blockchain-based model for managing interim payments in construction projects. The model does not require trust between the different stakeholders and can enforce terms and conditions of interim payments in an automated manner. It also enables the sharing of sensitive financial information privately between stakeholders.

3. Proposed System Concept

Our proposed concept is inspired by the work in (Raj et al., 2022), which is a blockchain-based system for handling payments in supply chains. The study identified three types of payments in supply chains, namely: *credit payment, advance payment,* and *cash on delivery.* ***Credit payment*** is when the seller sells goods and services to the buyer and then gives them a grace period to pay the price of the sold goods and services. ***Advance payment*** is when the supplier asks the buyer to pay a portion of the total price of the goods and services before they're shipped or delivered, and then pay the rest of the price within a grace period. ***Cash on delivery*** is when the buyer pays the price of the goods once they arrive (i.e., delivered to the buyer by the shipping company). Their system has three actors: the buyer, the seller, and the 3PL (3rd part logistics provider). Their system consists of the following steps (which are implemented in the smart contract of their proposed system):

- The use of the system starts with an offer shared by the seller with the buyer which consists of the products and services that the buyer is requesting, and the payment conditions. The payment conditions describe the amount to be paid as an advance payment, the amount to be paid on delivery and the amount to be paid on credit. The offer also defines the grace period for the credit payment.
- To confirm an order, the buyer pays the advance payment to the seller.
- The supplier pays an advance payment to the 3PL and sends the ordered items to the buyer.
- The 3PL confirms the delivery of the items to the buyer as well as the time of the delivery.
- The buyer pays the agreed amount of cash on delivery payment to the seller.
- The supplier pays the balance of the 3PL fee.
- The buyer pays the balance on the order within the grace period.

Our proposed system is based on the principle of associating work with payments, i.e., a payment for certain goods and services is to be made only when these goods and services are delivered. Figure 1 shows the relationship between different actors and the proposed system. The proposed system extends the work in (Raj et al., 2022) by introducing the following:

- The *3PL* actor is replaced with a broader *auditor* role. The actors *credit risk assessment agency* and *authority* are introduced.
- Payment for the auditor's fees is handled off-chain (i.e., the delivery costs paid to the 3PL in the work of (Raj et al., 2022)).
- Instead of one *payment on delivery*, and one *credit payment*, our system introduces the ability to define one or more *installments*, and each of those installments can be paid either as payment on delivery and/or payment on credit.
- We extended the seller offer with additional information that needs to be specified by the seller and renamed it as *payment plan*.
- We introduced a new *workflow* to accommodate the new features.
- We introduce the concepts of *escrow money* and *credit risk*.

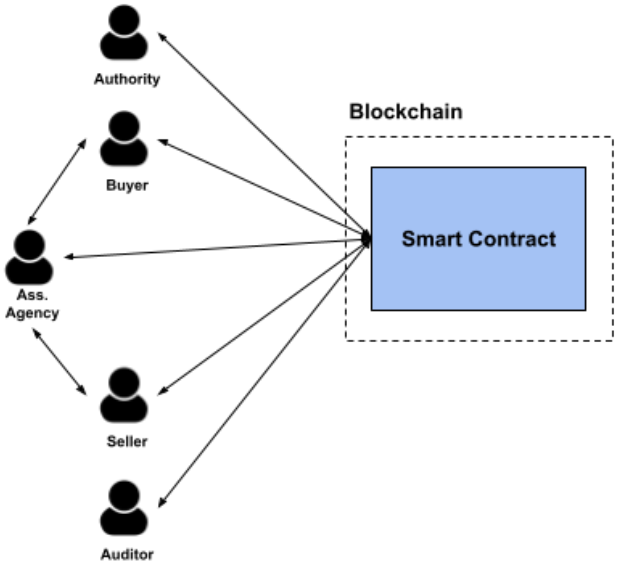

Figure 1. System actors and their relationship with it.

3.1 Actors

The construction supply chain consists of all the stakeholders involved in the supply of raw materials, services and operations required to carry out a construction operation that concludes with a completed building. It is always a priority for all relevant stakeholders to ensure that the construction supply chain has a smooth flow of information, materials, and money. Any delays, issues, or obstacles at any part of the construction supply chain will propagate to all parts of the supply chain, causing disruptions and delays (Studer & De Brito Mello, 2021). Figure 2 is an illustration of a typical construction supply chain.

The proposed system concept has five actors: *buyer, seller, auditor, credit risk assessment agency* and *authority*. The ***buyer*** is any supply chain participant that wants to purchase goods and services from another participant (such as the owner buying services from the designer or the main contractor buying services from the subcontractors). The ***seller*** is the participant that sells the goods and services to a given buyer. The ***auditor*** is an entity responsible for resolving disputes or confirming work so that payments are scheduled and released. The ***credit risk assessment agency*** provides a risk assessment of the buyer and the seller based on information about their financial situation. Lastly, the ***authority*** is an entity that manages the system and oversees deploying the service and maintaining it.

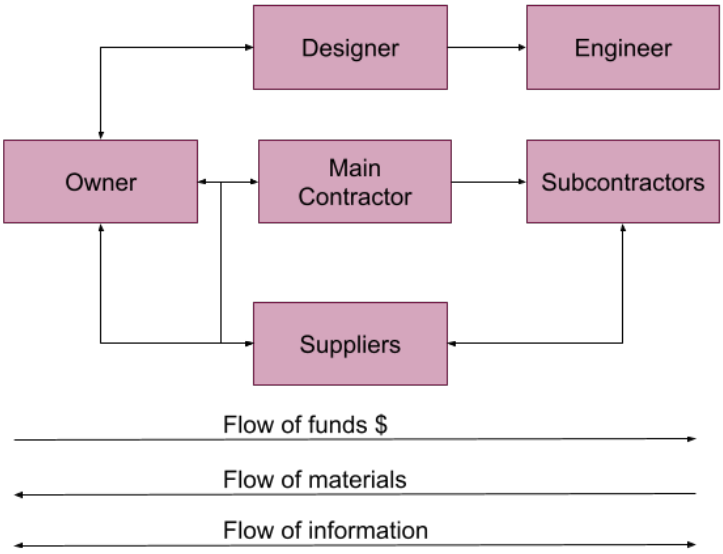

Figure 2. A typical construction supply chain. Adapted from (Studer & De Brito Mello, 2021) and (Shemov et al., 2020).

3.2 Credit Risk and Escrow

We introduced *credit risk* to our system concept. ***Credit risk*** helps the buyer and the seller evaluate the financial health of each other. This information helps both parties in determining several terms and conditions of the payment plan, such as the insurance amount, the down payment amount, and the number of installments. The credit risk is determined based on financial information shared by both the buyer and the seller with the credit assessment agency. The assessment agency then shares that information with the buyer and the seller as a part of the payment process. Credit assessment is based on several indicators of a business. For example, the information taken into account when evaluating the credit risk of SMEs may include short term debt/equity, cash/assets, EBITDA/assets, retained earnings/assets and EBITDA/interest expenses (Altman & Sabato, 2007).

Escrow and payment retention are well known practices in the construction industry used to protect the interests of owners. In (Antipin & Trufanova, 2021), escrow accounts are used to protect the shareholders of a construction project from developers with unclear financial records about the status of their solvency. The escrow account is used to deposit funds from shareholders then a bank finances the operations of the construction project. Only when an object is commissioned does the developer receive the funds from the escrow account. As in (Swai et al., 2020), payments are retained to ensure that the contractor fulfills their contract dutifully, thus protecting the interests of the owners.

In our system concept, we introduced the ability to define an ***escrow***, which is an amount that both the buyer and the seller deposit in the smart contract as insurance money that can be used to compensate for any damages caused to the buyer or the seller in case one of them fails to comply with their commitments to the payment plan. The insurance amount is determined by consensus between the buyer and the seller. Both parties can rely on credit risk information, the work history of both the buyer and the seller, as well as other payment plans previously managed in the system to determine a suitable escrow amount. The principle is that the riskier it is to work with a buyer or a seller, the higher the escrow amount paid by that buyer (or seller) should be. The escrow money is refunded to the buyer and seller once the payment process is complete.

3.3 Payment Plan

The proposed system allows defining a ***payment plan***, which specifies the terms and conditions of the price and the payment activities between the buyer and the seller. A payment plan is defined by the seller and contains the terms and conditions of the arrangement for paying the price of the goods and services by the buyer. When defining a payment plan, the seller specifies the following:

- The total price of the goods and services.

- The advance payment (or down payment) that the buyer is required to pay before the seller commences the delivery of the goods and services.
- The number of installments that the total price will be paid on. For each installment, the seller defines: the amount of the installment, whether it will be paid as a payment on delivery, or a payment on credit (also defines the grace period if credit payment was selected), and the amount of time it takes the seller to complete the work associated with the installment.
- The escrow amount to be paid by the seller and by the buyer. That amount is determined based on input from the credit assessment agency.
- The auditor that will oversee confirming activities and resolving disputes.
- Whether the total price can be increased during the delivery of goods and services.

3.4 Workflow

The proposed system's workflow consists of a several steps to create and manage a payment operation between the buyer and a seller. Figure 3 is a flow chart that summarizes the steps of a payment operation. the payment workflow steps are as follows:

- **Deployment and Registration**. The authority deploys the smart contract in charge of managing the payment activities. The buyer, seller, auditor, and assessment agency will register, and their accounts will be verified by the authority. An event of account verification is committed to the blockchain. This step happens only once.
- **Payment Plan**. The seller creates a Payment Plan and specifies the total price of the goods and services, the advance payment amount, the escrow amount, the auditor account, the number of installments and amount, payment mode, work duration of each installment. The payment plan is stored on the blockchain.
- **Escrow**. The seller confirms the payment plan by depositing their escrow amount. The buyer also reviews and confirms the payment plan by depositing their share of the escrow amount. The escrow amount is deposited in the smart contract and an event is announced on the blockchain.
- **Down Payment**. The buyer then confirms the service commencement by depositing the down payment. The down payment is deposited in the smart contract.
- **Installments**. At this stage, the seller will start completing the work and delivering the goods and services. The seller will, thus, receive the installment amounts as defined in the payment plan. The steps for receiving an installment are as follows:
    - The seller performs the service (or supplies the goods), and marks the activities as completed on the system. An event is committed to the blockchain announcing that.
    - The auditor reviews the completed work and confirms its completion, which automatically triggers the installment that's associated with the work as "due", and the counting of the grace period starts (if the payment mode was payment on credit). An event of that is committed to the blockchain.
    - If the payment mode was cash on delivery, the buyer confirms the work completion by the full amount of the installment to the seller. If it was a credit payment, the buyer confirms the work by paying withing the grace period. The installment amount is paid to the smart contract, and the smart contract transfers the amount to the seller. An event of that is committed to the blockchain.
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- **Extension**. If the seller requires more time and/or money to complete the work, the seller can send a request to them explaining the reasons why they need more time and/or money to the buyer. The buyer can then choose to approve the additional time and money or terminate the contract. Both the buyer and the seller can also choose to add more to the escrow amount. The request and its approval are managed on the blockchain, and events are committed on the blockchain for the request, approval, or termination.
- **Failure to Comply with Payment Plan**: There are two conditions where the buyer or the seller may fail to comply with the payment plan, namely: failure to complete work, and failure to pay installment in time. If the seller does not finish the defined work in time, the buyer can extend the time for the work, which pushes the schedule ahead and updates the payment schedule. Or the buyer can choose to terminate the contract. If the buyer does not pay the installment amount in time, the seller can extend the grace period, or they can terminate the contract. Payment plan termination works as follows:
    - The auditor reviews the work done, estimates the damages to the buyer and the seller, and inputs an amount that needs to be paid to the buyer and the seller.
    - The system conducts a series of payments and refunds to settle the balances according to the auditor's input. The cancellation and/or return of the goods and services already delivered is handled off-chain.

- Events of the termination request, auditor reviews are committed on the blockchain.

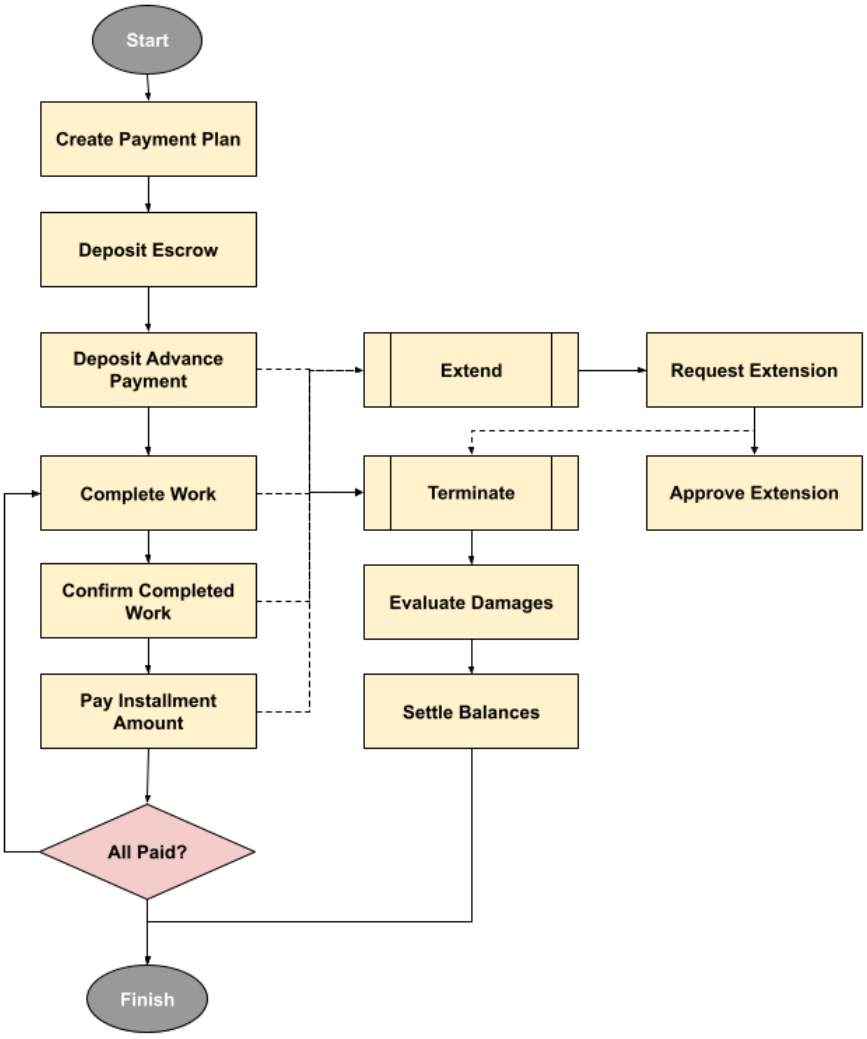

Figure 3. steps for handling a payment operation in the proposed system (excluding the Deployment and Registration step, which happens only once).

4 Results and Discussion

The proposed system implements a series of measures that act as a deterrent to the buyer and the seller and creates a risk for both parties that motivates them to comply with their commitments to each other, with respect to payments. Table 1 explains how these measures address various issues with payments in the construction supply chain found in the literature. The measures and their effects are as follows:

- The presence of an escrow condition acts as a deterrent which motivates both the buyer and the seller to comply with their commitments to avoid the risk of losing the escrow amount. The risk of the other party failing to commit to the payment plan is also mitigated thanks to the credit risk information shared by the assessment agency. This helps specify an escrow amount that matches the risk involved in working with the other party. Thus, both the buyer and the seller will have an idea about the risks associated with working with each other.
- Both buyer and the seller always have the right to terminate the contract if the other party fails to comply with their commitments.
- The entire operation is controlled in a transparent and tamper-proof manner because the system is implemented on the blockchain.
- The data trace resulting from a payment plan managed by the system is public and immutable, which adds a layer of transparency about the history of both the buyer and seller in their business relationships with other

participants. So, the buyer and the seller will be motivated to comply with their commitments to avoid risking their reputation.

- A third party that both the buyer and the seller agree on can act as an independent entity for confirming work completion and that an installment is due for payment. That entity is also responsible for resolving disputes and ensuring a fair situation for all parties in the case of contract termination.

Table 1. Payment issues in the construction supply chain and how they're addressed in the proposed system. The payment issues are adapted from several articles in the literature (Nanayakkara et al., 2021), (Ramachandra & Rotimi, 2015), (Xie et al., 2019), (Swai et al., 2020).

Payment Issue	**Solution in Proposed System**
Lack of initial capital	The lack of initial capital may cause cashflow problems down the line. The presence of a credit assessment agency that provides information about both the buyer and seller enables painting the full picture about the financial situation of both parties, thus assessing relevant risks and deciding on escrow amounts accordingly to prevent any delays due to cashflow problems or canceling the contracting altogether if deemed too risky.
Delays in completing work due to supply chain issues.	If work is delayed, the buyer can choose to give more time until it completes or terminates the contract. Delays by the seller are minimized due to risk of losing escrow money.
Going over budget	The amount to be paid is predetermined in the payment plan. The only way to change the budget is if the seller requests that from the buyer and the buyer approves. This, thus, gives the buyer and the seller the chance to negotiate fair terms for that extension and avoid unexpected costs. Otherwise, the contract is terminated.
Rework and errors	The seller will be motivated to minimize their work errors. The seller's work history is present on the blockchain for the buyer to review prior to engaging with the seller. If the seller commits errors and/or needs a lot of reworks, the buyer can terminate the contract.
Late payments are acceptable in the industry	The payment time is controlled by the system and delays are insured by the escrow amount. If the seller doesn't extend the grace period for the payment, the contract can be terminated, and the buyer may lose their escrow.
Delay in the progress payment by the owner to general contractor causing ripple effect of delays across the entire chain of subcontractors.	
Work first then gets paid later culture. Also, the culture of "pay when get paid".	The system contributes to addressing that culture and gradually changing it over time by introducing such concepts as escrow and advance payment. When the buyer knows they can lose their escrow, they will be motivated to continue to comply with their commitments in good will.
Improper supervision and financial controls, improper withholding of payments	The system completely solves these issues by automating the payment handling operation with strict controls over the terms and conditions of how payments are processed and introducing the role of the auditor that can ensure that the arrangements are fair for both the buyer and the seller. The seller has the right to terminate the contract, and the escrow amount serves as an instrument for mitigating the risk of payment withholding or non-payment.
Coordination issues with many parties	The system eliminates this issue and makes it the responsibility of either the buyer or the seller because the system handles failure to comply with payment commitments regardless of the reason, even if coordination was the reason.
Lack of trust between members	By using the system, the buyer and seller can trust the system to ensure it keeps the relationship fair for both. The use of blockchain technology and the transparency and control it offers contributes to that trust.

Disputes over quality of work	By laying out the work that needs to get done in specific terms and having an auditor review the completed work, both the buyer and the seller can have peace of mind that the transaction will be fair for both. Further, the risk of losing the escrow amount will be a motivation for both parties to act in good faith and complete their part of the transaction in a fair manner.

4.1 Comparison with Existing Solutions

In this section, we compare our proposed system concept to two studies from literature, (Wu et al., 2023) and (Tezel et al., 2021). The authors in (Wu et al., 2023) presented a blockchain-based payment system for the construction supply chain. The purpose of their solution is to re-balance power by utilizing a consensus mechanism for payment approvals, thus preventing bad actors from blockchain a payment and delaying an entire construction project. Their solution includes elements similar to ours such as 3rd Party Inspection and Payment Approval. However, it lacks the concept of Escrow Accounts. Further, their solution works with more stakeholders than ours (Client, Quality Inspector, Main Contractor, Sub-Contract, Progress Inspector, 3rd Party Auditor); our system's stakeholders are Buyer, Seller, Authority, Auditor, Credit Assessment Agency. The authors of (Tezel et al., 2021) provided an implementation of a blockchain-based model for project bank accounts (PBAs). The model works by holding the money in an escrow account and releasing it only when the work done by the contractor is completed and approved. Our proposed system supports this concept and extends it by introducing a mutual deposit of escrow into the system where both the buyer and the seller deposit some escrow money to ensure the smooth progress of the project by both parties. Further, our system concept will allow defining an entire payment plan and the ability to make changes to a payment arrangement if both parties agree to the change.

4.2 Roadmap of Future Work

This paper is the first stage of our project that aims to develop a blockchain-based payment system for the construction supply chain. Our main objective in this paper was to explore the various issues with construction supply chain payments and present a system concept that addresses those issues by putting together different solutions from the literature and organizing them into one complete system. The next stage in our payment system project is to provide an implementation of the system presented here using blockchain and other technologies and run a simulation to examine its advantages, limitations as well as any needed improvements. Moreover, we plan on experimenting with the supply chain of a real-world construction project as a use case to test the proposed system's practicality and level of adoption by stakeholders in the construction industry. We will then report our findings from the simulation and the use case in a future paper.

5. Conclusion

In this paper, we introduced a blockchain-based system concept for handling payments in the construction supply chain. The concept builds on a similar system in the literature and extends it to address the issues associated with payments in the construction supply chain. The proposed concept introduces three features, namely: credit risk and escrow, the auditor role, and an improved workflow. The improved workflow allows the buyer and seller greater options for handling different events that may come up during their work together such as the need for extension and how the contract is terminated. The escrow serves as an insurance money that both the buyer and seller deposit in the system, which is used to compensate for the damages caused if one party fails to comply with their commitments to the other party. The auditor ensures that the agreed payment plan is executed fairly for both parties. We then discussed how the proposed system concept addresses the payment issues in the construction supply chain. In the future, we're planning to propose an implementation of the proposed concept, deploy it and test it on the Ethereum blockchain.

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Biographies

Samer Haffar: Samer received his BSc in Information Engineering from Al-Shahbaa University in 2014, majoring in Information Technology. In 2017, he completed his MSc studies at the Industrial Engineering department in Gaziantep University, focusing on location-allocation problems in military applications. Samer is currently a PhD candidate at the same department, and his research mainly focuses on the use of Industry 4.0, particularly blockchain technology, in supply chain digitalization. Samer also has an extensive experience in the private sector, mainly in the areas of digital transformation, business consultancy, tech startups and software product management.

Eren Ozceylan: Prof. Dr. Ozceylan received his Bachelor of Science degree in Industrial Engineering Department in 2007 from Selçuk University. In 2010, he completed his Master's studies in the same department on supply chain modeling at Selçuk University. In 2013 he completed his Ph.D. research in the Computer Engineering Department at Selçuk University. His thesis work mainly focused on the simultaneous modeling of closed-loop supply chains and disassembly line balancing problems under fuzziness. In 2019, he was at Northeastern University to conduct postdoctoral research. He joined the Department of Industrial Engineering, University of Gaziantep in 2014 and is interested in supply chain modeling, fuzzy logic, and disassembly line balancing.