Automation of Construction Progress Payments Using BIM and Blockchain Based Framework

By

Muhammad Asfund Khalid

(Registration No: 00000327339)

Department of Construction Engineering And Management (CE&M)

NUST Institute of Civil Engineering

School of Civil and Environmental Engineering (SCEE)

National University of Sciences and Technology (NUST)

Islamabad, Pakistan

(2023)

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A thesis submitted to the National University of Sciences and Technology, Islamabad, in partial fulfillment of the requirements for the degree of

Master of Science in

Construction Engineering and Management

Thesis Supervisor: Dr. Muhammad Usman Hassan

NUST Institute of Civil Engineering

School of Civil and Environmental Engineering National University of Sciences & Technology (NUST)

Islamabad, Pakistan

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Signature:

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Date: 3/11/2023

Signature (HOD): HoD Construction Engineering and Management
NUST Institute of Civil Engineering
School of Civil & Environmental Engineering
National University of Sciences and Technology

Date: 3/11/2023

Signature (Dean & Principal):
PROF DR MUHAMMAD IRFAN
Principal & Dean
SCEE, NUST

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Examination Committee Members

1. Name: Dr.-Ing Abdur Rehman Nasir Signature: ______________

2. Name: Dr. Khurram Iqbal Ahmed Khan Signature: ______________

3. Name: Dr. Muhammad Omer Zubair Signature: ______________

Supervisor's name: Dr. Muhammad Usman Hassan Signature: ______________

Date: 3/11/2023

____
Head of Department

HoD Construction Engineering and Management
NUST Institute of Civil Engineering
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Date

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____
Principal & Dean

PROF DR MUHAMMAD IRFAN
Principal & Dean
SCEE, NUST

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Student Name: Muhammad Asfund Khalid Signature: ____________

Examination Committee:

a) Dr-Ing Abdur Rehman Nasir Signature: ____________
Assistant Professor

b) Dr Khurram Iqbal Ahmed Khan Signature: ____________
Assistant Professor

c) Dr Muhammad Omer Zubair Signature: ____________
Assistant Professor

Supervisor Name: Dr. Muhammad Usman Hassan Signature: ____________

Name of HOD: Dr. Muhammad Usman Hassan Signature: ____________

HoD Construction Engineering and Management
NUST Institute of Civil Engineering
School of Civil & Environmental Engineering
National University of Sciences and Technology

Name of Associate Dean: Dr. S. Muhammad Jamil Signature: ____________

Dr. S. Muhammad Jamil
Associate Dean
NICE, SCEE, NUST

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Dedicated

To

my Parents, Teachers and, Friends.

ACKNOWLEDGEMENTS

I am thankful to Almighty Allah, who gave me strength to complete my research. I would like to pay debt of gratitude to my advisor Dr. Muhammad Usman Hassan, for his fathomless guidance, valuable time, and encouragement, to complete my research work. I also owe my special thanks to Dr Abdul Rehman Nasir and other fellows for their support. I pay my earnest gratitude with a sincere sense of respect to my parents, colleagues and to sincere family members for their unending encouragement, prayers, and patience. I would like to thank my dear friends and colleagues for their continuous support and patience that helped me in completing this study.

ABSTRACT

The construction industry worldwide is rampant with poor payment practices where parties fail to conform to the payment provisions resulting in late or nonpayment. Payment defaults cause a startling effect on the project's health and cause a project to fail. The administrative and contractual solutions are ineffective due to the administrative burden associated with human-intensive processes. This paper presents a blockchain-based payment system to circumvent the traditional payment system's vulnerability using Blockchain, BIM, and cryptocurrency technologies through a Decentralized Application (DApp). An end-to-end system, based on payment conditions coded as a smart contract, was devised to initiate the payment process, generate invoices, and transfer payments from the client to the contractor. A Building information model (BIM) integrated with schedule and pricing information provides the cost and time data for calculating payment amount based on the amount of work done till a particular time subject to a sufficiency check of the contract. Invoices were extracted from BIM and pushed to DApp for payment of the amount, in cryptocurrency, to the contractor digitally on the Ethereum blockchain. The developed system was validated via a case study on an actual construction project. It is observed that the proposed application, which is based on blockchain, can integrate the benefit of smart contracts, BIM, and crypto technologies. It provides the ability to address the overwhelming issues regarding payment security, auditing, and financial discrepancies in a construction project. The developed system also expedites payment, minimizes the need for liaisons, and makes the process digitized, efficient, and seamless.

Keywords: Blockchain, Smart contract, Decentralize application, Cryptocurrency.

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LIST OF ABBREVIATIONS

DApp	Decentralize Application
DAO	Decentralized Autonomous Organization
DeFi	Decentralized Finance
BIM	Building Information Modeling
API	Application Programming Interface
Eth	Ethereum
IPC	Interim Payment Certificate

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CHAPTER 1: INTRODUCTION

1.1 Background

Guaranteed, Continuous, efficient, and secure release of payments is indispensable for the success of the construction project. But the construction industry across the world is rampant with the menace of delayed or nonpayments (Abdul-Rahman et al., 2014). Unfortunately, in the construction industry, parties fail to conform to the payment provisions (Luo et al., 2019) thus, becoming the culprit of the payments default. The global construction sector is among the least productive sectors (Laryea, 2010) and the slowness of the payment system is one of the major hurdles in the path of productivity (McKinsey & Company, 2017). The traditional payment system is centralized (Hamledari & Fischer, 2021b) so by this nature, there is a lot of human intervention (Laryea, 2010) and bureaucratic procedures (Peters et al., 2019) in the payment process making it vulnerable to abuse of the dominant position (Das et al., 2020). The traditional payment system follows a cascade nature of fund disbursement (Latham, 1994; Samuel K. Ansah, 2011). So, a single point of failure to payment provision can cause a domino effect of nonpayments down the tube (Das et al., 2020). So, this makes delayed or non-payments an operational risk (El-Sayegh, 2008) that can cause projects to delay (Kennedy, 2006). Also, construction contracts are prone to information asymmetry (El-Adaway et al., 2016; Abdul-Rahman et al., 2014) which consequently leaves the interpretation of contracts something of personal discretion and becoming ground zero for disputes due to miscommunication or misunderstanding. In some construction projects parties also use misleading payment clauses such as pay-when-paid or pay-if-pay (Enshassi & Abuhamra, 2015) as a means of risk transfer mechanisms resulting in payment delays. Because of all this menace, the construction industry remains credit-heavy worldwide (Hamledari & Fischer, 2021b).

1.2 Research Problem

Late or nonpayment has a daunting effect on the progress of the construction project. Aside from project delays (Abdul-Rahman et al., 2009), irregularities in the progress payments can cause a surge in the overall cost of the project (Sambasivan & Soon, 2007), delays in the disbursement of the salaries (Wu et al., 2008) which causes a reduction in the labor productivity (Ramachandra & Rotimi, 2015). Other than this delayed payments cause severe cash flow discrepancies (Samuel K. Ansah, 2011) and in extreme cases insolvency of the contractor (Griffiths et al., 2017; Peters et al., 2019). Literature suggests that payments-related issues are one of the top reasons for disputes between the parties (Ramachandra & Rotimi, 2015; Ramachandra, T; Rotimi, 2010) resulting in litigation and ADRs (Alternative Dispute Resolution) (Samuel K. Ansah, 2011; Heiskanen, 2017) which are costly as well as lengthy processes (Cheung et al., 2010; Liu et al., 2019). Litigation cases damage the reputation of the party (Peters et al., 2019) and cause difficulty in acquiring new projects (Raman et al., 2016). So, ensuring the guaranteed and timely release of funds is critical for the successful completion of the project and the overall profitability of the contractor (Ng & Tiong, 2002; H. L. Chen & Chen, 2005).

1.3 Previous Studies

In literature, several contractual, legislative, and administrative reforms have been suggested to curb the payment problem, which is explained in the below section:

1.3.1 Administrative measures

Ramachandra & Rotimi (2010) suggested several contractual, legislative, and administrative solutions to address the payment issues in the construction industry. Insolvency insurance, prequalification of the upper-tier, and maintaining an escrow account were some of the measures suggested to adequately address payment-related issues, especially payment issues due to the insolvency of the upper tier in construction. Uff & Thornhill (2010) suggested the use of milestone-based payments over interim payments as these won’t require taking any measurements and are easier to administer. Modality of milestone-based payments would also have less administrative cost and are more efficient. Investigating the client's ability to pay, empowering and implementing the timely payment legislative acts in their true spirit, and negotiating the payment term with the client can assist mitigating the problem of late nonpayments (Abdul-Rahman et al., 2014). Providing cash flow training, effective utilization of funds, improved legislation, and a little change in the payment attitude can also help in curbing the payment problem (Azman et al., 2014). Placing charging orders, caveat registration overbuilt properties and issuance of the litigation notice were some of the measures suggested by (Ramachandra & Rotimi, 2015) after analyzing the litigation cases over the payment disputes filed in the New Zealand High court (Ramachandra & Rotimi, 2015). Bolstering professionalism in the upper tier and strictly adhering to the payment's provisions is the real starting point toward achieving a rational solution to payment issues (Peters et al., 2019). Some models to minimize the financing cost of the project was also have been proposed to save the contractor from insolvency (Alavipour & Arditi, 2018). Despite several investigations and suggestions, poor payments are still a prevailing problem (Chong & Diamantopoulos, 2020).

1.3.2 Legislative acts

In the developed world, payment-specific legislations have been enacted to facilitate smooth and timely payments between the construction parties. Some of the famous legal constitutions are the Muller act of 1935 (USA). It required the contractor who undertakes a project exceeding USD $100,000 to furnish a payment bond and a performance bond so that the subcontractor and the material supplies get paid according to the contract. The Housing Grants, Construction and Regeneration Act (HGRA) 1996 (United Kingdom) ensures that payments are to be made promptly throughout the supply chain and that disputes are resolved swiftly. The Building and Construction Industry Security of Payment Act 1999 (New South Wales, Australia) guarantees payment and a reduction in payment delays to the vendors. The Construction Contracts Act 2002 (New Zealand) facilitated regular and timely payment and speedy dispute resolution and provided remedies for nonpayment. The Building and Construction Industry Payment Act 2004 (Queensland, Australia) ensures continuous and timely payments. Security of Payment (SOP) Act 2004 (Singapore) guarantees the speedy release of funds upon construction tasks/service completion. Construction Industry Payment and Adjudication Act (CIPAA) 2012 (Malaysia) repealed the laws of practicing conditional payments. To facilitate regular and timely payment, to provide a mechanism for speedy dispute resolution through adjudication, to provide remedies for the recovery of payment in the construction industry, and to provide for connected and incidental matters. But often such solutions have proved to be adequately address payment-related issues (Ramachandra & Rotimi, 2010) as they overlook the fundamental causes of payment discrepancies (Abdul-Rahman et al., 2014).

Table 1.1: Legislative acts summary

No.	Acts	Country	Description
a	Mullet act, 1935	USA	This act requires the contractor to furnish payment and performance bonds.
b	The Housing Grants, Construction and Regeneration Act, 1996	UK	Ensure that payments are made promptly throughout the supply chain and that disputes are solved swiftly
c	The Construction Contracts Act, 2002	New Zealand	Facilitate regular and timely payment, speedy dispute resolution, and provide remedies for nonpayments.
d	The Building and Construction Industry Payment Act, 2004	Australia	Ensure continuous and timely payments
e	Security of Payment Act, 2004	Singapore	Promises construction service provider of speedy release of funds upon completion.
f	Construction Industry Payment and Adjudication Act, 2012	Malaysia	Outlawed the practice of conditional payments.

1.3.3 Through Project Bank Accounts (PBA's)

To address the payment problem, the National Audit Office of the UK developed the concept of Project Bank Accounts (PBAs) to improve the trickle-down nature of the funds' disbursement (Michael Latham, 2005). PBA's was a significant development in reforming the payments process. Still, administrative burden (Mark Macaulay, 2019), the complex nature of the PBAs (Griffiths et al., 2017), and deterrence from the contractor (Price, 2011) remain the major impediments toward the acceptance of the project bank accounts.

1.3.4 BIM-based solutions

The advent of BIM technology has been the most crucial advancement in the AEC industry as it is a key driver for digitalizing the construction industry (K. Chen et al., 2015). BIM technology has been used for digitizing the payment process. Nguyen (2022) provided a BIM-based QTO framework. While by incorporating reality-capturing technology, a BIM model as per the build condition on the construction site was formulated (Hamledari et al., 2017, 2018), which can be used for progress payments. Digitizing the payment process isn't enough for achieving reliable automation as the payment process still relies on centralized control (Hamledari & Fischer, 2021b), which renders the system to have the same limitations as the traditional system (Hamledari & Fischer, 2021a).

1.4 Blockchain in Payments

In recent times the potential of blockchain technology in streamlining financial services has been recognized. Blockchain technology can reform practices in the financial sector (J. Li et al., 2019) and improve the construction management process (Çevikbaş & Işık, 2021). Vitalik Buterin integrates smart contracts with blockchain technology (Buterin, 2014). A smart contract can be defined as a self-executing contract (Melanie Swan, 2015; G. W. Peters & Panayi, 2016) that can automate business logic (Hunhevicz & Hall, 2020). A smart contract is a major advancement in curbing the security of payment issues (Chong & Diamantopoulos, 2020) as it can act as an escrow bank account (Hamledari & Fischer, 2021a) where funds can get locked (Cardeira, 2015) and released upon completion of the agreed obligation (G. W. Peters & Panayi, 2016; Nawari & Ravindran, 2019a). Smart contracts also enable payments to be conducted without the need for any intermediaries (Dakhli et al., 2019) or human involvement (Ibrahim et al., 2022). By minimizing human interference, bureaucratic procedures can get reduced (J. Li et al., 2019) resulting in the payment process to gets faster, simpler, and cheaper (Titov et al., 2021). Furthermore, data gets stored inside an open immutable database (Qian & Papadonikolaki, 2021) which not only will aid in the audibility and transparency of funds (Qian & Papadonikolaki, 2021; Gurgun et al., 2022) but also fosters trust among the contracting parties, which is crucial for the project's success (Wong & Cheung, 2005). So there is a configuration between the fundamentals of blockchain and the construction industry requisites (Hunhevicz & Hall, 2020).

1.5 The gap in Previous Studies

Despite the potential advantage of payment automation through blockchain technology, still, blockchain payment gateways are far from reality. One of the major impediments in the path of adoption is the information flow from the site to the on-chain (Hamledari & Fischer, 2021a). Attempts to integrate the BIM with the blockchain are provided but still there remains room for development. Research on blockchain applications that focus on payment administration is still in its infancy. A smart contract is the heart and soul of a dApp. Smart contracts have the potential to be widely used across industries (Xu et al., 2021) given that there is an optimized and standard smart contract for payment processing. Mostly the system presented for payment automation in the past literature is conceptual case studies and frameworks. Only very few researchers have developed payment systems. Mostly the blockchain system presented lately was using Ganache blockchain which is a fake blockchain with some major downsides such as no miner actions and no waiting time for the transaction. There remains a gap in research focusing on the development of a fully functional blockchain system, particularly in the area of decentralized applications (Sonmez et al., 2021).

1.6 Objectives

The research objectives are as follows:

1. Develop a standard smart contract for the construction progress payment.
2. Develop a fully functional Dapp for construction progress payments.
3. Integrate BIM and Blockchain technologies.
4. Validate the framework of a case study.

1.7 Conclusion

The focus of this research was to materialize a framework for using blockchain-based payments for the construction industry. Developing a fully functional Dapp (decentralized application) which was ready to be deployed on the main net was intended. From this illustrating the potential benefits and exploring the potential of Dapp (decentralized applications) for the construction payments administration was intended.

CHAPTER 2: LITERATURE REVIEW

2.1 Inefficiencies of Traditional Payment

A review of research papers under the genre of payment problems and solutions showed traditional payment systems are prone to irregularities and inefficiencies, as seen in figure 2.1, which are defying the construction industry to culminate its potential. Security of the payment came to be the most discussed shortcoming of the traditional payment system, leading to late or nonpayments (J. Li et al., 2019; E. Peters et al., 2019; Raman et al., 2016). The construction payment system is centralized (Hamledari & Fischer, 2021b), so by this nature, there is a lot of human intervention (Ibrahim et al., 2022; Laryea, 2010) and bureaucratic procedures (E. Peters et al., 2019) in the path of payment, making it vulnerable to abuse of the dominant position (Das et al., 2020). The traditional payment system follows a cascade nature of fund disbursement (Latham, 1994; Samuel K. Ansah, 2011). So, a single point of failure to payment provision can cause a domino effect of nonpayments down the tube (Das et al., 2020), making delayed or nonpayments an operational risk (El-Sayegh, 2008) for the construction industry. Also, the traditional system requires a trusted middle party to work (Dakhli et al., 2019; Zheng et al., 2020). The payment process through the traditional system is time-consuming (Fredriksson, 2014; Laryea, 2010), with information-intensive paperwork (Hamledari & Fischer, 2021b). Data loss and errors are often noted in construction documentation (Ciotta et al., 2021). Construction contracts are prone to information asymmetry (Abdul-Rahman et al., 2014; El-adaway et al., 2016), consequently leaving the interpretation of contracts something of personal discretion and becoming ground zero for disputes due to miscommunication or misunderstanding. In some construction projects, parties use misleading payment clauses such as pay-when-paid or pay-if-pay (Enshassi & Abuhamra, 2015) as risk transfer mechanisms resulting in payment delays. Because of all this menace, the construction industry remains credit-heavy worldwide (Hamledari & Fischer, 2021b).

Content analysis was performed to quantify the problems of the traditional payment system. A total of 34 research papers under the genre of payment problems and solutions were scrutinized. The following 12 facets mentioned in Figure 2.1 came to be the most frequently mentioned limitations. Security of the payment came to be the most discussed shortcoming of the traditional payment followed by the vulnerability to abuse of the dominant position because of human involvement. The third major limitation came to be the slowness of the payment process.

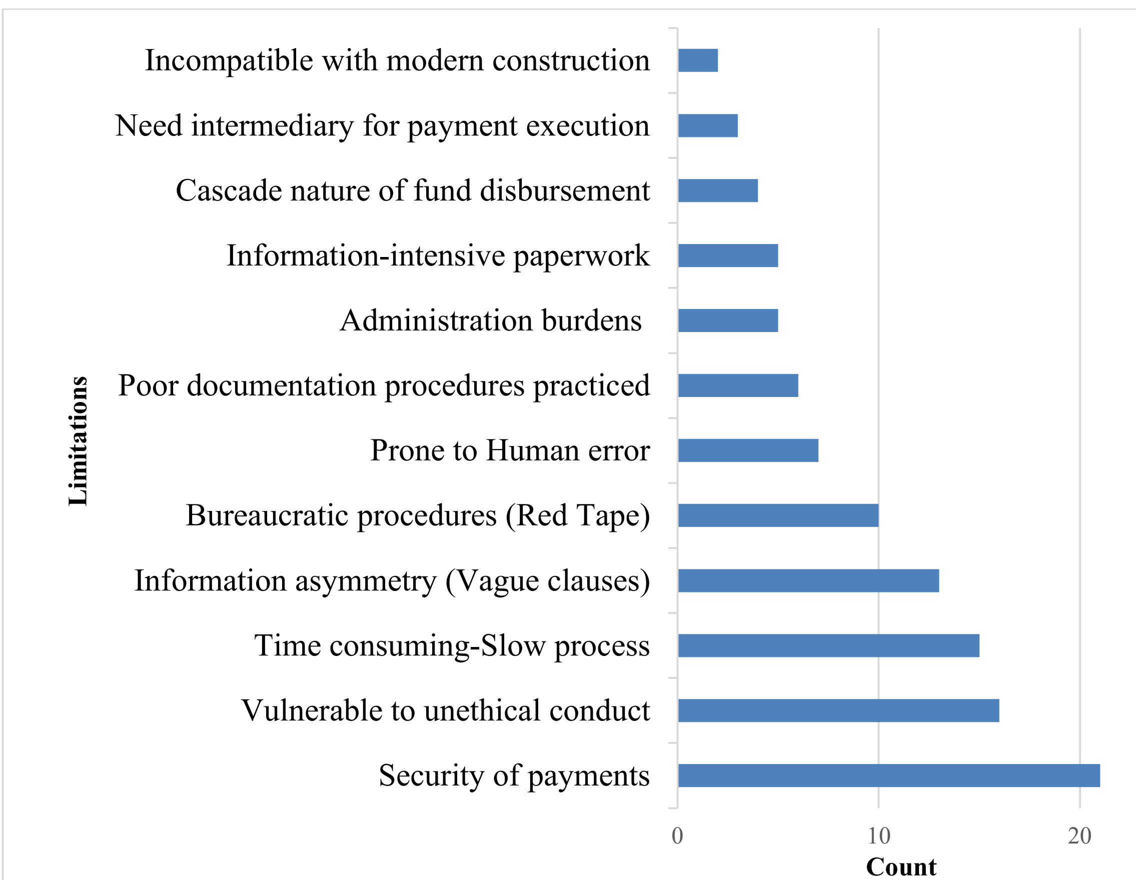

Figure 2.1: Limitation of the traditional payment system

2.2 Blockchain

Blockchain is a newer technology with huge untapped potential. The inception of blockchain commences the next generation of the internet which is known as the internet of value (Truong et al., 2018). It is a transition from web 2.0 to web 3.0 (Rudman & Bruwer, 2016). As its name suggests it is a chain of blocks containing data. Every block in the blockchain has a unique hash which is a randomly generated number obtained by solving a complex computational math problem through a process called the proofing mechanism. A hash identifies the block and all the contents inside that block (Christidis & Devetsikiotis, 2016). And lastly, each block contains the hash of the previous block. Tampering with the data inside any block will result in generating a newer hash thus making the chain invalid as the following blocks do not contain a valid hash of the previous block. The blockchain is community-driven as the community powers the system by granting its computing power for generating newer blocks. Such computers that power the system are called the nodes and people that do so are called miners. The data on the blockchain is open source as it is distributed across various computers/nodes and each node must have the same copy of the blockchain ledger. So, this hashing phenomenon coupled with the proofing mechanism along the decentralized nature of blockchains makes the data secure, immutable, and impossible to tamper with.

The Bitcoin blockchain is the oldest and best known. Also, it's the largest by the number of users (Titov et al., 2021). Bitcoin blockchain and its forks can be referred to as the first generation of the blockchain (Melanie Swan, 2015). The integration of smart contracts with blockchain technology commenced the era of the second generation of the blockchain (Mohanty et al., 2022). The concept of a smart contract was first introduced by scientist Nick Szabo in 1994. He defined the term smart contract as a computerized transaction protocol that seeks to replicate legally binding contracts through a code (Szabo, 1997). The smart contract allows users to customize the payment by associating certain conditions for the release of funds. Currently work is in progress on the third generation of blockchain and on layer 2 solutions which address the limitation of the second generation of blockchains such as scalability (Mohanty et al., 2022), high gas fee, and interoperability (Bodkhe et al., 2020).

2.3 Blockchain in Construction

2.3.1 BC in information management

A plethora of research has been conducted on developing use cases and frameworks of blockchain technology in the domain of information management for construction, as the construction sector experiences challenges in managing and storing data (Perera et al., 2020). Due to the intrinsic characteristics of blockchain, it can help in the management of information and data throughout the lifespan of a construction project. It can act as a universally consistent database and ensures the integrity of the data inside it (J. Li & Kassem, 2021). Turk & Klinc (2017) discusses the potential of blockchain in curbing the problem of information management for construction. Wang (2017) proposed to develop a notarization application using blockchain technology for building trust. Hamida (2017) suggested using the immutable distributed ledger of blockchain for maintaining the land record. Ganter & Lützkendorf (2019) suggests that by using blockchain for data management, data loss can be reduced. Nawari and Ravindran (2019b) highlight the potential advantages blockchain will bring to the BIM workflow and present a framework for automated design examination. Zheng (2019) uses blockchain technology to develop a system to audit and trace the emendation made on the BIM data. Sheng (2020) develops a system for recording and managing quality information documents on the blockchain. A proof of concept for documentation management in the BIM environment using blockchain technology was presented by Ciotta (2021). Sarfaraz (2021) uses blockchain technology in the bidding process for achieving integrity and security.

2.3.2 BC in SCM

The use of blockchain technology for logistics and supply chain management (SCM) has been suggested in the literature as it can bring agility, efficiency, and trust to the process which consequently reduces risk (Qian & Papadonikolaki, 2021). Blockchain would help in tracking materials and actions on the supply chain (Hultgren & Pajala, 2018; San et al., 2019). Fitriawijaya (2019) presented a model by integrating BIM and BC technology for SCM. Blockchain can also help in auditing the compliance of the product with specifications (Nanayakkara, 2019). So, in this way, it enables asserting greater quality control protocols in the supply chain (Wang et al., 2017).

2.3.3 BC in sustainability

Blockchain technology can also help in construction waste management, estimating carbon emissions, and tracing sources for raw materials (Shojaei, 2019; Perera et al., 2020). So, subsequently would help in accomplishing sustainable practices in the construction project.

2.4 Smart Contract

A smart contract can be defined as a self-executing contract. The concept of the smart contract is not new. Firstly, it was introduced by the scientist Nick Szabo in 1994. He defined the term smart contract as a computerized transaction protocol that seeks to replicate legally binding contracts through a code (Szabo, 1997). Vitalik Buterin integrate the concept of the smart contract with the blockchain and founded the Ethereum chain (Buterin, 2015). Before the integration of the smart contract, blockchain just simply acts as a payment transfer system but the smart contracts allow users to associate the release of funds with certain conditions hence allowing the customization of the payments. Unlike traditional contracts which are written on a piece of paper and the state law or courts take responsibility for its execution, a smart contract is simply a piece of code that is deployed on the blockchain and no intermediary is required for its execution the moment the certain conditions fulfilled the payment gets released. To code, smart contracts certain high-level programming languages are being used such as solidity, Plutus, rust, etc.

2.5 Structure of Blockchain

As its name suggests it's a series of blocks linked with each other forming a series of chains of blocks starting from the genesis block which is the first block of the blockchain. As discussed blockchain is an open ledger so in the case of cryptocurrencies, it stores information like which wallet sends how many coins to which wallet. Also, the data in the blockchain is time sealed. Each block has a unique hash, and also the hash of the previous block. So through these hashes, these blocks are being linked with each other. Also, the metadata like time, date, block number, etc are stored in the ledger.

2.6 Web Architecture of Web3.0

In traditional applications, there is a centralized server. The user will reach out to the server. The server will respond with some HTML documents and will display them on the browser. If data modification is deemed, the user sends some type of request to the server, and data after being processed by the server gets modified inside the DB. In short in traditional architecture everything revolves around the centralized server.

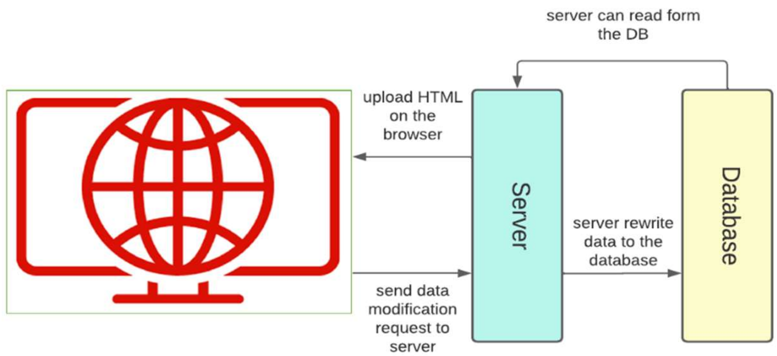

Figure 2.2: Web 2.0 Applications

In web 3.0 applications, there still have a server but its role is dramatically diminished. The server does far less work than it did in the past. In this sort of architect, a server can still send the JavaScript assets or HTML documents down to the browser. The user might interact with the application in some fashion and then at some point in time the data is being indented, it did not reach back out to the server. The server is not at all involved in that process. Instead, the application will make use of web3 which communicates with metamask. Metamask creates a transaction and signs it with the user's private key and sends that transaction to the blockchain network. The only way for the user to change data is through public and private keys. These public and private keys only exist on the user's machine and in any circumstances can’t be asked by the server. So, in short, the server is no longer responsible for writing any data to a database.

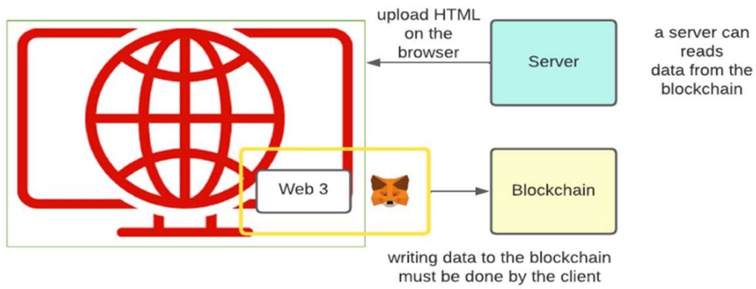

Figure 2.3: Web 3.0 Applications

2.7 Typer of Blockchains

Blockchains can broadly be categorized into two types:

2.7.1 Public Blockchain

Such a blockchain whose ledger is accessible to everyone and no special permissions are required to become the node in the blockchain and to power the network. Bitcoin blockchain, ERC-20, TRC-20, BEP-20, and Cardano are all examples of a public blockchains.

2.7.2 Private blockchains

In the case of a private blockchain, special permissions are required to access the data or to become the node. So in short, the ledger is private to the organization that runs it. Hyperledger fabric is the most famous example of a private blockchain.

2.8 Hash

The literal meaning of the hash is to make a mess. In the world of cryptography, a hash is a one-way cryptographic function meaning it can't be decrypted and takes an input of any size and gives a constant size output. A hash is always a unique number, its collision resistance, and it's used to make sure the integrity of the data. SHA-2 is an example of the hashing algorithm and it's also being used in the bitcoin blockchain for the calculation of hashes.

2.9 Merkle Tree (root hash)

Each block in the blockchain contains several transactions and each transaction has a hash. So the concept of the Merkle tree also called a hash tree is used in the blockchain and is used for efficient verification of content in a larger chunk of data. Suppose a block contains 8 transactions ranging from Tx1 to Tx8 and each transaction has a hash. So H(Tx1) and H(Tx2) make H12. Similarly, H34 is being calculated. H12 and H34 makeup H1234 and similarly H12345678 is being calculated and through one hash ie H12345678 all eight transactions get verified.

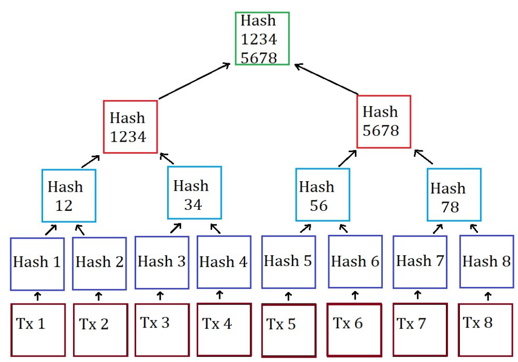

Figure 2.4: Markle tree structure

2.10 Cryptocurrencies

Blockchain is the underlying technology of cryptocurrencies (Chan et al., 2020). Cryptocurrencies are digital coins. They're different from traditional money, what is called fiat currencies because they're not created or controlled by central banks but rather are decentralized in nature. Cryptocurrencies are pear-to-pear cash meaning no intermediaries are needed for conducting transactions. The concept of digital coins was first given by Nick Szabo but faced issues such as the double-spend problem, the byzantine general's problem, etc. All these problems associated with digital coins were solved with the invention of bitcoin and blockchain.

Currently, the market capitalization of cryptocurrencies nearly sits around USD 2.42 Trillion. Bitcoin or in short BTC is the most famous and oldest of all the cryptocurrencies and is also reckoned as the digital gold and is made up of about half of the total crypto market cap. The adoption and demand of cryptocurrencies are growing day by day as it offers several advantages over fiat currencies. In many countries, it's used as a hedge against inflation and as a means of storage of value. Slowly and gradually countries are moving toward these and are using them as legal tender. Currently, Japan and El-Salvador are two countries where bitcoin is being declared as legal tender. But besides all these good things these cryptocurrencies are highly volatile and are speculative assets. So users are advised to act with care.

2.11 Blockchain Explorer

A decentralized, distributed ledger is the backbone of the blockchain. In the case of cryptocurrency transactions, the data regarding the transactions can be accessed on the blockchain explorer. On the blockchain explorer live transactions are being broadcasted and also the data can be traced and filtered based on the wallet address. The flow of assets can be scrutinized so enabling the traceability and auditability of the funds. Every blockchain has its explorer such as https://www.etherscan.io/ is the blockchain explorer of the Ethereum chain. https://bscscan.com/ is the explorer of the Binance blockchain.

2.12 Coin vs Token

Cryptocurrencies can further be classified as coins or tokens. Each blockchain has one coin and can have several tokens conditioning if its supports smart contract property. Having said that a cryptocurrency coin is a digital coin that has its blockchain and it’s the fore face of that particular blockchain’s ecosystem. On the other hand, a cryptocurrency token is something that doesn’t have its blockchain but rather is being created and deployed on the other blockchain. Taking the example of the Ethereum blockchain, ether abbreviated as ETH is the native coin of this blockchain, and cryptocurrencies like 1inch, 0x, sushi, uniswap, etc are some of the common examples of tokens.

2.13 DAPP

A Dapp or decentralized application is a web application that reports back to the blockchain. Like any regular web application, a Dapp constitutes a backend and a front end. The backend of the Dapp consists of a smart contract that gets deployed on the blockchain. A smart contract consists of a bytecode and application binary interface (ABI). The compilation is the process of extracting the ABI and the bytecode from the smart contract. Bytecode is a low-level language that is deployed on the blockchain network. ABI is the JavaScript interpretation of the smart contract.

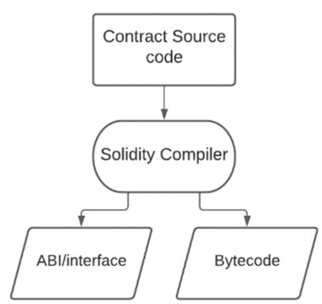

Figure 2.5: Compilation of contract

Metamask is a web extension software wallet. It plays a main part in the blockchain ecosystem as it allows users to interact with the Dapp. For deploying the smart contract on the blockchain, a connection with a node that exists inside the blockchain is required. Infura is a handy service for circumventing the hassle of hosting a local node, which takes a lot of time and effort. Infura provides a public API through which a developer can get access to the node hosted on the blockchain.

Figure 2.6: Web 3 configuration

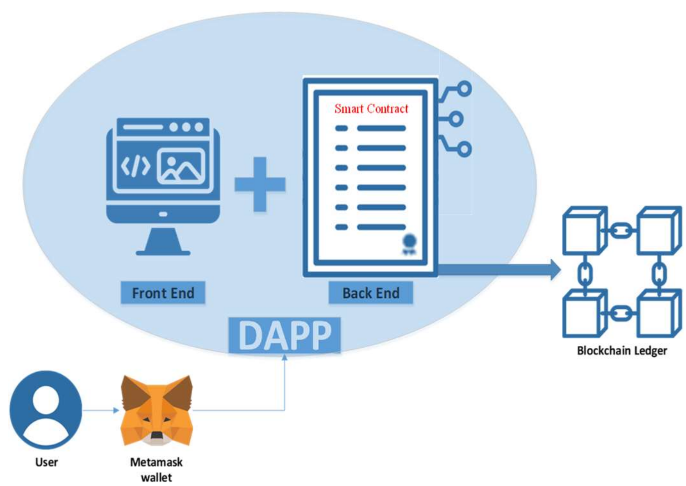

Figure 2.7: Dapp architecture

2.14 Crypto Wallets

As its name suggests a wallet that is used to store cryptocurrencies are a crypto wallet. It can further be classified as a hardware wallet or software wallet. Software wallets are just software that can be installed into the device and they serve as a cash chest for the user. Atomic wallet, Jaxx Liberty are some of the famous software wallets. On the other hand hardware, wallets are wallets that can be touched, unlike software wallets. So the hardware wallet is a USB-like device that is connected to the blockchain network and is used for the storage of cryptocurrencies. Trezor and Ledger are the two famous companies that manufactured hardware wallets.

Figure 2.8: Crypto wallet

2.15 Metamask

Metamask is a web extension software wallet. By far it's the most famous web extension wallet of all. It plays a main part in the Ethereum ecosystem by allowing the user to access and interact with the Ethereum blockchain. It can also be customized and can be converted to any other chain by specifying the chain ID and RPC URL of that particular chain. https://metamask.io/ is the official site of the metamask.

2.16 Public and Private Keys

A crypto wallet consists of two keys, one public and the other private. A private key can be referred to as the password which is used to access the wallet, in other words, a private key is a key that is used to open the wallet and to get access to the funds in it. On the other hand, a public key is like an account number of the wallet. If person A needs to send some crypto to person B, then A needs to have a public key of B and will transfer the funds to the public key of the B. The public key has to be kept secret while the private key can be shared with everyone.

2.17 DeFi

DeFi is decentralized finance. Unlike centralized finance or the traditional monetary system where governments, banks, or any other centralized authority control the flow of money a deFi is decentralized and not controlled by any central authority. DeFi is built on three main things: Cryptography, blockchain technology, and smart contracts. So a smart contract working on the backend allows users to exchange value or assets without the need for any human intervention. So, in this case, the code act as a bank. Talking about the advantages of the DeFi over the traditional monetary system is that it's censorship-resistant and much cheaper as there is no administration needed, once code is developed it can self-execute itself and hence act as an epitome of sustainability.

2.18 Crypto Mining

Mining is the process of adding a new block in the blockchain network and validating the newly created block. So giving power to the system is mining. People who do mining are known as miners in the blockchain world. The beauty of this technology is decentralization. The control in the blockchain is not in the hands of a few but rather is run by communities. Regardless of race color or sect anyone can be a part of the network and can power the system. Broadly mining consensus is of two types, either a coin work on proof of work mechanism or it can be a proof of stake.

2.19 Block Reward

Because of powering the network by mining, protocols are designed in such a way as to incentivize those miners so that they keep empowering the system and compensate them for their cost and time. Blockchain rewards the miners in two ways, either some amount of the transaction fee is being tipped to the miners like in the case of Ethereum or there is a fixed amount of coins associated with the development of each block like in the case of the bitcoin.

Talking about the bitcoin blockchain a rule in the bitcoin software says that after every 210,000 blocks mined, the block reward is halved by 50%. This phenomenon is known as bitcoin halving. It's considered a significant event in the blockchain as its slows down the generation of new coins as it's being engraved in the code of bitcoin that there can only be 21 million bitcoins in this world. After every 3.5 to 4 years this phenomenon of halving takes place. So this halving phenomenon manages the law of supply and demand.

2.20 PoW

In proof of work (PoW) consensus mining machines are required. More the processing power of the machine more chances for that machine to find the exact nonce associated with the transaction. The processing power of any machine can be measured in the hash rate. Bitcoin, Ethereum classic, dogecoin, etc all work on the PoW algorithm.

2.21 PoS

In proof of stake consensus, no mining machine is required but rather a user can become a validator by just allocating the funds to the protocol. And through this transactions are being conducted.

PoS consensus is given weightage over the PoW consensus as PoW requires excessive electricity for computing and conditioning of the mining machines. The poS method is a much greener method that requires minimal electricity to proceed as compared to the PoW. That’s the reason developers are moving toward PoS consensus. Ethereum which was originally based on the proof of work mechanism but after the EIP-1559 also known as the London hard fork has shifted their consensus to PoS.

2.22 PBA's

Project bank accounts are being suggested as a means of making the payment system in the construction project more efficient has smooth. The main concept of the PBA's is that each project has a specified bank account. And all the construction parties involved in the project will be connected to that bank account. When the client clears the invoice of the project, the cash will be disbursed to the respective parties according to the breakdown of the contract. Hence undermining the cascade nature of the traditional payment system in which firstly the client pays off to the main contractor and the contractor pays to the sub-contractor or the material suppliers. Besides the advantages of the PBA's this concept was unable to take off other than its place of origin. The reasons are high set-up costs and administrative burden. Also, it didn't prove to be a cost-effective solution for the client.

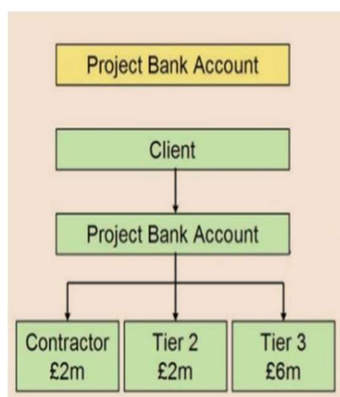

Figure 2.9: Project Bank Account Structure

2.23 BIM

BIM is the process of creating information models or data sets formed of graphical and non-graphical information in a shared digital space. The main feature of BIM is coordination. It enhances collaboration among the team members and helps in visualization and clash detection. BIM is of paramount importance when it comes to the automation and digitization of the AEC industry.

2.24 BIM Dimensions

BIM has several dimensions ranging from 3D to up to nD. 4D is the time aspect in which the 3D model is linked to the time aspect. Hence helps in better scheduling of the project. 5D is the cost aspect in which we associate the cost aspect with the model which helps engineers better estimate the cost of the project. As per UK standards, 6D is the operation and maintenance O&M aspect of the project but according to the USA 6D is the energy or sustainability analysis and 7D is the O&M aspect.

2.25 CDE

CDE stretched out as a common data environment is the central data repository of the project. It can be cloud storage or a server. CDE is the subset of there and each CDE contains the data of a single project. So in this way a CDE act as a single source of data for a project. There are several standards for managing the CDE of the project.

2.26 Phycology of Cash Flow

In projects, cashflow is of huge importance and it is often a major point of contention between the contractual parties. Cash is a tool that helps drive projects forward. Cash flow is used as a point of leverage to make the project run smoothly and efficiently. The general equation of cash flow is:$Revenue = Expenses - Capital\ in\ hand$ Revenue is the money coming into a company while expenses are the money leaving the company, the money that a company pays for the work that they do. And capital is what's remaining at the very end. There are generally two types of accounting methods which are cash and accrual accounting. Cash accounting is based on the actual receipts and the actual payments. Whereas accrual is based on the receipts that have been earned and the payments that are due. Accrual is a generally accepted accounting method and companies use it all the time but the problem with this method is accounts show the firm to have the cash to spend but they don't have the money to spend. So, for construction, a generally accepted accounting principle is conservatism which is followed by most of the world around. The idea of conservatism is that the expense is recognized as soon as it may exist. But for revenue, its recognize once a company has received it. As contractor can't be 100% certain, that he will be reimbursed for all the work that's being billed. There can be uncertainties. And also when the general contractor submits a bill to the client, the client reviews it which takes time. The time in which the client and the general contractor are reviewing the work of the claimed bill is called a certification period. so because of all this revenue is only recognized when it is there and the firm is being conservative. But the expenses are being tracked using the accrual method and the expenses creep up and keep growing daily.

For a contractor, cash flow comes from billings and payments. The billing cycle is of important consideration which tells how frequently the contractor bills the client. For most projects, a billing cycle of 30 days is used. The amount of the bill is the earned value minus the retainage amount. Earned value is the amount of the contract while retainage is a portion of the payment that the client generally withholds. Retainage can range from as low as 2 or 5% or as high as 15 to 20%. This retention amount is then paid at the very end of the project. This retention money is essentially the profit of the contractor, but the client doesn't want to pay or incentivized the contractor so much that he got the profit on this job early on and might want to walk away. So, the client makes the contractor finance the project from his pocket and keeps the GC in debt almost for the whole project. So the contractor works for the last project payment.

2.27 Improving Cash Flows

The nature of the construction business is such that it is at the very last where the contractor makes the profit and steers itself into the positive cash flow while for the rest of the project the contractor has to finance the projects by himself. By financing the contractor leverages itself and put himself at risk. A contractor with cash in hand is a happy contractor. As cash provides the buying power and the ability to drive the project forward. There are several ways by which the contractor can improve its cashflows and consequently get in less debt.

2.27.1 Bill frequency

The contractor can accelerate revenues by increasing the billing frequency. Instead of just submitting a bill every month, the contractor can submit interim bills. So, in this way instead of getting one big, stepped payment after a month, inflow to the company keeps flowing. A two-week pay cycle can be used but this requires a client and a general contractor, to dedicate themselves to processing payment instead of managing the work. So this causes an additional cost in the form of administrative costs that most clients don't want to entertain.

2.27.2 Mobilization Advance

A potential issue concerning payment in the construction industry is a client is always looking to pay for work completed instead of potential work completed. But most clients do agree that there is a cost associated with preparing the construction site and mustering the machinery, staff, and raw material at the job site. So, as a sign of good faith, the client pay for mobilization to the contractor and this payment help the contractor offset some of those initial costs that aren't necessarily captured as items of work and keep the contractor financially sound.

2.27.3 Front loading

Another tool that contractors used to accelerate revenues is called front-loading or front-end loading. Some parties object to this while some say it's immoral or unethical. Front-end loading is shifting the value of the project toward the front as a contractor. So rather than distributing overhead profits throughout the entire project, a contractor will try to shift all your overhead and profits into the first few activities

2.27.4 Delay expenses

A credit agreement is a form of payment agreement to deliver an item or complete work with payment provided in the future. So, it’s like vendors and suppliers will submit their billings to the contractor but will get paid a month later. This is based on having a good relationship among parties. If a contractor has never worked with a vendor or supplier before, it's very unlikely that they'll afford a credit. But if a contractor has this sort of leverage then it is a great tool. The credit agreement doesn't impact the revenue side, it impacts the cost side. So, in essence, the contractor can buy himself some time by shifting the expenses a little bit. It can astronomically reduce the financing need and a contractor can see positive cash flow earlier in this project.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Research Methodology Framework

The methodology of this research project can be broken down into three parts. In the first part, an initial study was conducted in which by reviewing the past literature, a testbed for the use of blockchain and smart contract technologies to circumvent the limitations of the traditional payment system was devised. After orchestrating the research questions and objectives, work on the development of the system framework commenced in the second stage. The grail of this part is the development of a Dapp (decentralized application) for payment administration. The developed application is referred to as payment Dapp in this paper. Besides this, the selection of blockchain and the clauses of the smart contract to be coded were also studied. Alongside Dapp, a mechanism for the development of monthly invoices and uploading the invoice on the Dapp was also architected. Lastly, through a case study, the newly developed payment Dapp was validated, and a questionnaire survey was conducted to reveal the opinion of the construction professionals on the payment Dapp. The research methodology is summarized in

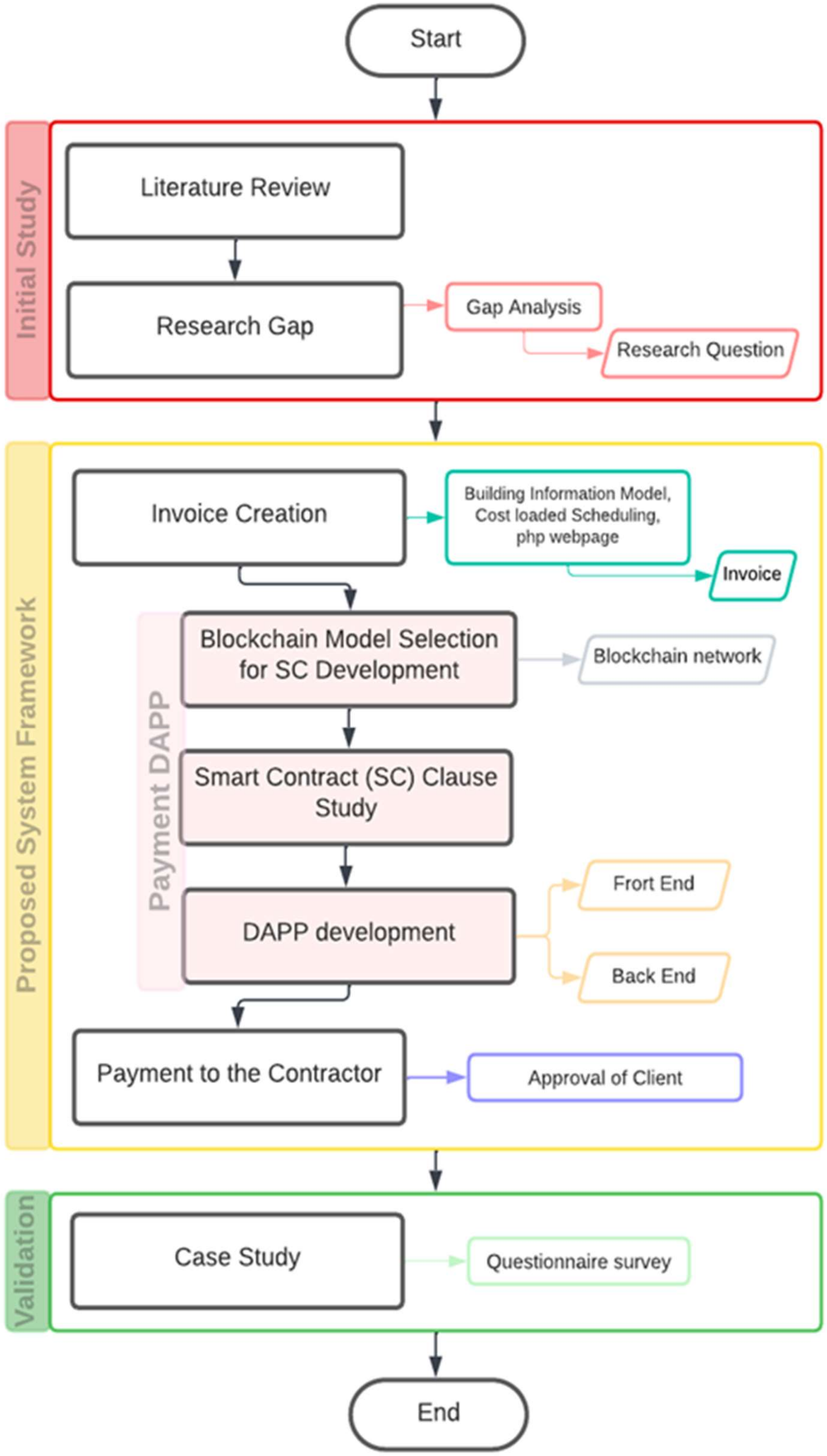

Figure 3.1: Research Methodology

3.2 Proposed System Framework

Figure 3.2 depicts a high-level overview of the system. The working of system can supposedly be divided into two phases. First, for the creation of an invoice, a BIM environment was created, which comprised a BIM model. Next, pertaining data from the BIM model was extracted by using a script and the information was imported into a scheduling software to create a cost-loaded schedule. The generated cost-loaded schedule was imported into a database. A web page was developed which was connected to a database containing the cost-loaded schedule and this created an invoice out of the cost-loaded schedule. Lastly, the genetared invoice gets uploaded on the Dapp, which acts as an intermediary between the client and the contractor and this assists in the payment administration of the project.

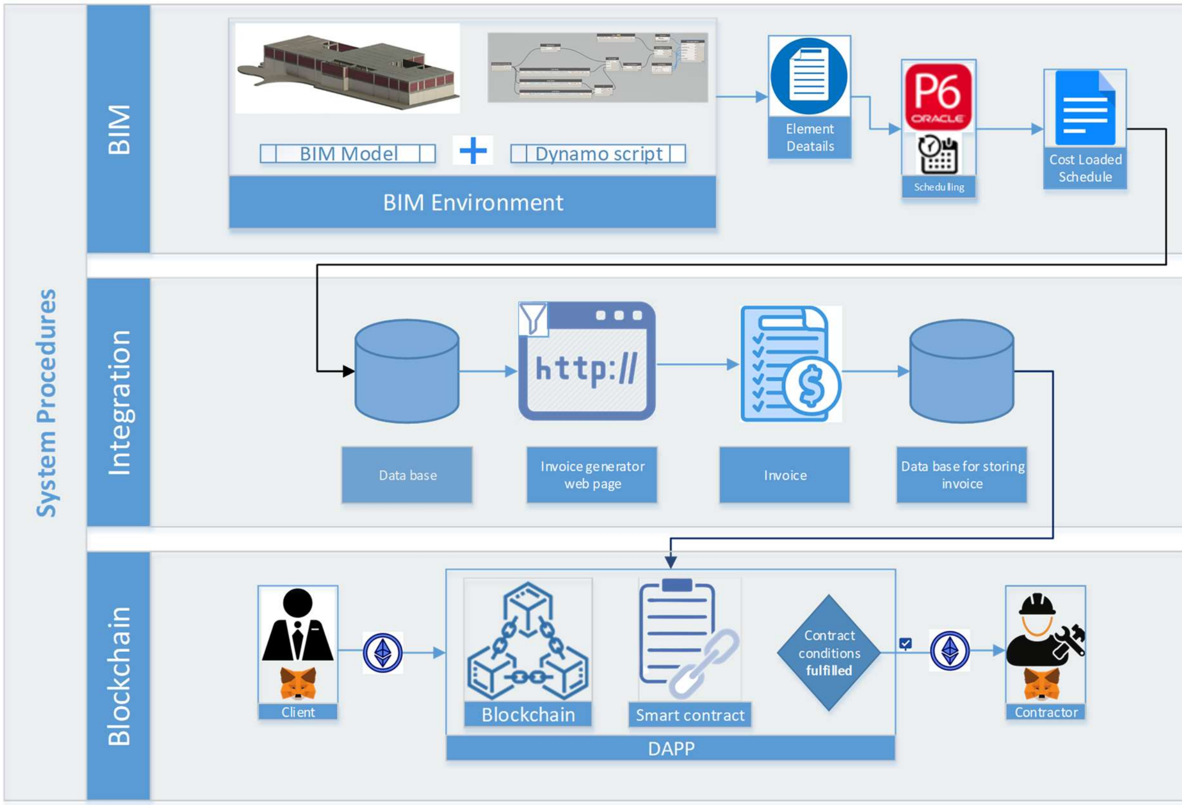

Figure 3.2: Developed system summary

3.3 Invoice Creation

3.3.1 Cost-loaded schedule from BIM

By utilizing the dexterity of BIM technology, a mechanism for generating a monthly invoice was developed. Autodesk Revit 2022 was selected as BIM software for creating building information models. The contractor will be asked to incorporate the unit cost of each BIM member into the model at the time of bidding. So, the BIM model will act as a digital BOQ for the project. Then by using the dynamo programming language, logic was developed to extract the information of model members', their quantities, and costs into an excel file, which will play the role of interim data storage. Then the extracted data will be uploaded into the primavera P6 software for scheduling and a timeline against the members will be obtained. By integrating the cost with the generated schedule, a cost-loaded schedule will get developed and this schedule will be uploaded to the database. A rational database MySQL was selected for this purpose and this database will assist in the generation of invoices.

3.3.2 Php Webpage

To get the monthly invoice, a filter was put in place that filters the activities based on finish dates following the current date. If the current system date is greater than equal to the finish date of the member, then its cost adds up for generating an invoice otherwise it is to be skipped. In this manner, a cumulative sum amount of the total work done will be obtained. As invoices run cumulatively so the invoice amount for a particular month will be obtained by subtracting the cumulative amount of that particular month from the previous month. By subtracting two cumulative amounts, a total payable amount will be obtained. Relevant deductions will be made on the invoice amount such as retention money, taxes, etc. By incorporating the deductions in the total payable amount, a net-payable amount will be obtained which is to be paid to the contractor. The exchange of value is to be conducted in an Ether coin which is a cryptocurrency and the native coin of the Ethereum blockchain. The value of crypto coins isn't consistent as price volatility is somewhat innate in cryptocurrencies. To counter this problem, the whole work on the invoice will be conducted in fiat currency. In the case of this research work USD, and when the invoice is to be created, the live ether rate will be fetched from the market by using the API of coingecko. By multiplying the exchange rate, the net payable USD amount will be converted into equivalent $ETH. The process of generating an invoice is explained in figure 3.3. A simple web page using PHP programming language was developed for the manifestation of the above-discussed logic. A connection between the PHP webpage and database comprising cost-loaded schedule data was made and by calling an ajax query the live ether rate from the coingecko API was extracted. A distinct MySQL database was created to house the data related to generated invoices.

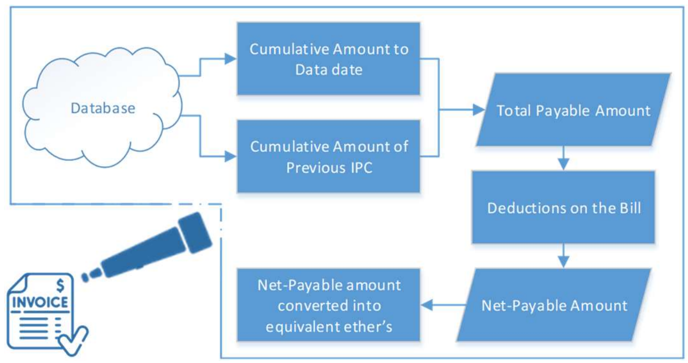

Figure 3.3: Invoice creation mechanism

3.4 Payment Dapp

3.4.1 Blockchain Model Selection for SC Development

There are three main categories of blockchain, public, private, and consortium. Data on a public blockchain is accessible to everyone which makes this blockchain immutable and decentralized. In a private blockchain, data isn't accessible to everyone. The company running this blockchain controls the data and if desired can change the data on the blockchain. A consortium is a hybrid form of blockchain in which the preselected nodes determine the consensus mechanism (Buterin, 2015). The guaranteed execution of the agreed contract conditions does not always hold in the private blockchain (Hamledari & Fischer, 2021a). To reinforce the trust among the parties, permission blockchains must be avoided as these blockchains create antitrust issues (Schrepel, 2019; Schrepel & Buterin, 2020). Public blockchain was selected for the deployment of the smart contract for this research as they depict decentralization and transparency (Sonmez et al., 2021).

The blockchain to be selected must exhibit the smart contract property. So, all the first-generation blockchains simply fizzled out. By using the design decision framework for selecting the blockchain for project management applications provided by Sonmez et al. (2021), public-EOSIO and public-Ethereum blockchains came to be the potential blockchain networks. Among these two, the Ethereum blockchain was chosen for deployment as it's one of the most established blockchains and is the most popular blockchain for the deployment of smart contracts (X. Li et al., 2020).

3.4.2 Smart Contract (SC) Clause Study

A smart contract is a major proponent for automating the payment process via blockchain. Its logic must be designed carefully as any imprudence in the logic of smart contracts would incapacitate the whole system. In constituting the logic of smart contracts, the major considerations are to address the security of payment issue and secondly to come up with a logic that can be standardized or formally acceptable for the construction industry. For defining the logic of the smart contract, various construction contracts were analyzed but FIDIC conditions for payment seem to be a perfect fit as the FIDIC document is widely used globally (Rameezdeen & Rajapakse, 2007; Rameezdeen & Rodrigo, 2014). So, in tailoring the logic for smart contract guidance was taken from the FIDIC 2017 documents. Clause 14.4 discusses the schedule of payments. This clause talks about a non-binding estimate to be submitted to the client by the contractor quarterly. The rationale behind this is that client gets to know about the estimated cash required in a particular quarter and arranges that amount beforehand.

3.4.3 DApp Development

The backend of the Dapp constitutes a smart contract that was coded in the solidity programming language. Solidity is a backend language for the development of Ethereum contracts. Solc npm package has been used for the compilation of the smart contract and the bytecode of the contract was deployed on the Ethereum blockchain using the infura service. The smart contract will initially get the quarterly estimate from the contractor. Then the client will deposit the fund in the smart contract following the given estimate. After depositing funds, the contractor will start the execution at the job site. The contractor will raise the monthly statement using the PHP module and the bill will be forwarded to the smart contract. The smart contract will apply the preliminary check on the bill. It will examine the billing period which has to be greater than 30 days and if the bill amount is greater than the minimum bill amount. This minimum bill limit will be specified at the time of deployment of the smart contract. Upon fulfillment of the contract conditions, the bill gets forwarded to the Dapp for further confirmation.

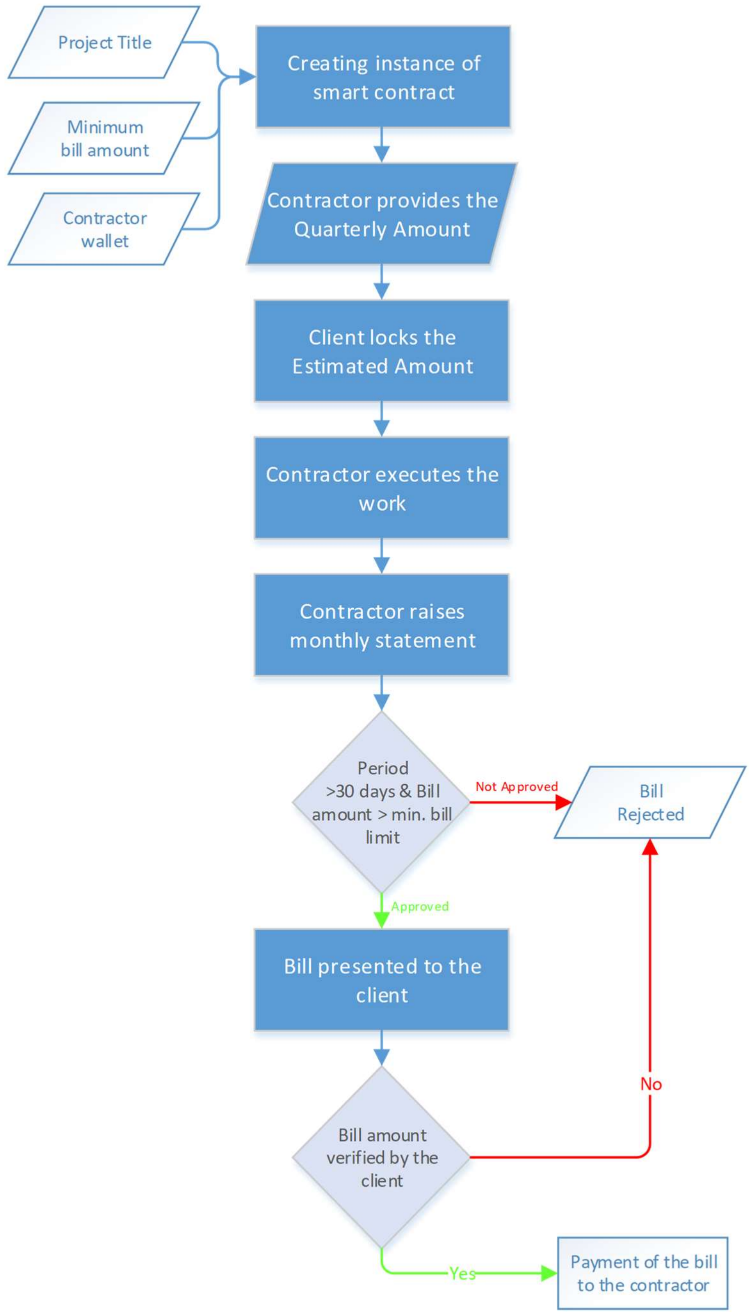

Figure 3.4: Smart Contract Working

The solidity language was used for the development of the smart contract. essentially there were two smart contracts developed. The name of the first smart contract is CreateDappinstance.

As its name suggests this contract is being used for creating the instance of the main smart contract for the respective project by taking the prerequisites data from the user.

```
pragma solidity ^0.4.17;

contract CreateDappinstance {
    address[] public deployedDapps;

    function createDapp(uint BA, address cont, string PN)
public {
        address newDapp = new dapp(BA, cont, msg.sender, PN);
        deployedDapps.push(newDapp);
    }
```

The main contract is by the name of getDeployedDapps. It’s essentially containing 5 functions whose breakdown is described. For storing the bill information, a struct datatype was used that contains the metadata of the bills such as bill status, billing month, etc.

```
    function getDeployedDapps() public view returns
(address[]) {
        return deployedDapps;
    }
    //this function contains the arrays of all the deployed
contracts!!!
}
contract dapp {
    struct Bill {
        uint invoiceNumber;
        string month;
        uint amount;
        bool complete;
    }
    Bill[] public bill;
    uint public BidAmount;
    address public contractor;
    address public client;
    string public ProjectName;
    uint public estimatedQuarter;
    uint public whichno;
    uint public time;
```

The first function is a constructor function that doesn't need to be called as it automatically gets called whenever the contract gets deployed by someone. This function essentially configures the dApp instance by providing relevant data to the smart contract.

```
// 1st function of initilization
      function dapp(uint BA, address cont, address clie,
string PN) public{
        BidAmount = BA;
        contractor = cont;
        client = clie;
        ProjectName = PN;
    }
```

The second function is for the contractor where the estimate of the quarterly amount is provided by the contractor to be used by the smart contract for knowing the financing needs of the project.

```
    //2nd function

    function giveQA(uint estimatedQ) public {
        require(msg.sender == contractor);
        estimatedQuarter = estimatedQ;
    }
```

The third function is in continuation with the second function, where the client deposits the project's funds into the smart contract following the estimate given by the contractor. This function compares the incoming amount with the transection with the estimates provided. If the incoming amount represented as msg.value is greater than equal to the provided estimated than the system proceeds.

```
// 3rd function of funding
    function funds() public payable{
        require(msg.sender == client);
        require(msg.value >= estimatedQuarter);

        whichno = 0;
        time = block.timestamp;
    }
```

The fourth function is for the creation of the bill. Upon the work completion and invoice gets submitted to the smart contract from the BIM environment. The smart contract will apply the preliminary checks on the bill amount and upon approval the process proceeds.

```
// 4th function of bill creation
    function createBill(uint invoiceNumber, string month, uint
amount) public {
        require(msg.sender == client);
        require(this.balance >= amount);
        require(block.timestamp >= time + 20);
        require(amount >  5*BidAmount/100);
        Bill memory newBill = Bill({
            invoiceNumber: invoiceNumber,
            month: month,
            amount: amount,
            complete: false
        });
        bill.push(newBill);
        time = block.timestamp;
    }
```

The fifth and final function is for the payment of the bill amount to the contractor. Once the preliminary checks were passed by the bill, it'll await the final confirmation from the clients. Once the client approves the bill, payment will get available for the contractor.

```
// 5th function of payment
    function pay(uint index) public{

        Bill storage Bbill = bill[index];

        require(msg.sender == contractor);
        require(!Bbill.complete);

        if(this.balance > estimatedQuarter/2) {
            contractor.transfer(Bbill.amount);
            Bbill.complete = true;

        } else {
            contractor.transfer(Bbill.amount);
            Bbill.complete = true;
            client.transfer(this.balance);
            estimatedQuarter = 0;
        }}
```

For the development of an interactive front end on top of the Dapp, data pertinent to smart contracts needed to get extracted from the blockchain and to be shown on the webpage for getting a better understanding of the project. For the said purpose, a distinct function on solidity was coded that fetches the relevant data from the blockchain that can then be called and shown on the front end.

```
//retreve information

        function getSummary() public view returns (
      uint, uint, uint, string, address, address, uint
      ) {
        return (
          BidAmount,
          this.balance,
          bill.length,
          ProjectName,
          contractor,
          client,
          estimatedQuarter
        );
    }
    function getRequestsCount() public view returns (uint) {
        return bill.length;
    }}
```

For the creation of the front end of the Dapp, next.js was used which is an open-sourced JavaScript framework. Next.js wraps up the react framework and builds a bunch of functionalities around it. Next.js have features like server-side rendering, routing, hot module reloads (HMR), etc hence making the next.js by far the easiest and most robust approach for developing Dapp's front ends. A front end of a Dapp constitutes a dashboard that provides preliminary information about the project as shown in figure 4.2 and several other landing pages for approving, claiming, and viewing bills. Web3 npm package is of paramount importance in developing a Dapp. Through the web3 library, developers get programmatic access to the Ethereum network, which is important for extracting data from the blockchain and accessing functions of the smart contract. Web3 must be configured using a provider. The provider tells the web3 from which wallet and from which network it is supposed to communicate with the network.

3.5 Payment to the Contractor

A separate MySQL database was created to host the data related to generated invoices. The data fields of this database consist of invoice number, month, commutative amount, payable, and net-payables. To upload the invoice on the Dapp, a connection between the MySQL database and the input form of the Dapp was created by using the serverless-MySQL library. Controlled input tags were created in the Dapp so that data get fetched directly from the database. Only the final net-payable amount along with the metadata was pushed on the Dapp from the database. Upon passing the initial screening of the smart contract, the bill gets presented to the client on Dapp for final verification. If the client approves the bill, the bill gets uploaded onto the blockchain and the bill amount gets available for the contractor to claim into its wallet otherwise bill gets rejected. So, in this way, a control mechanism for accepting or rejecting the invoice is concocted.

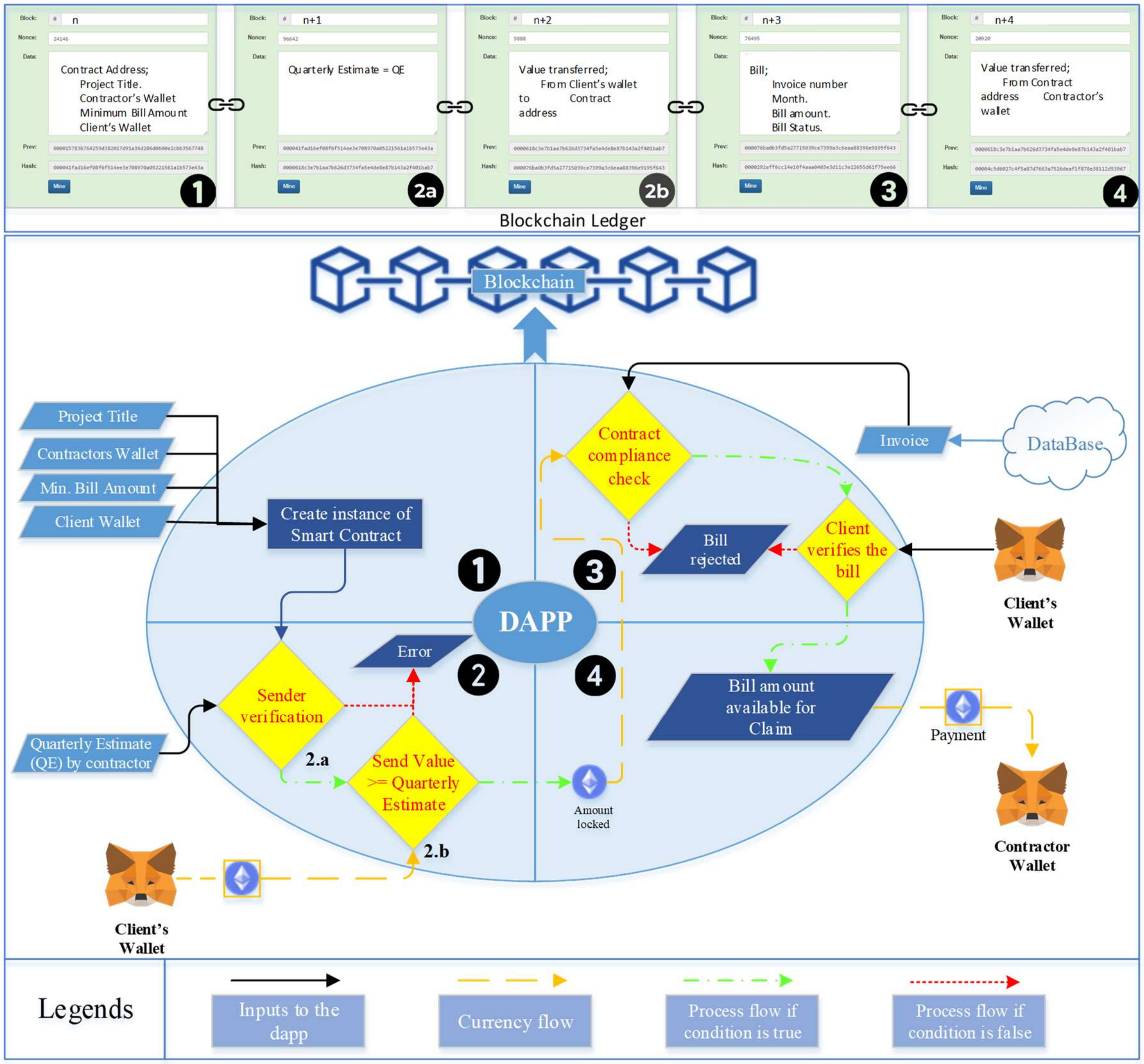

Figure 3.5: The payment administration on Payment DApp can be divided into four steps. In step 1, the client creates the instance of a smart contract for the project—step 2 consists of two processes. In the 2a process, the contractor will give its estimate, and subsequently, the client submits funds on the DApp in 2b. In step 3, the invoice is uploaded on the DApp, and checks are applied to it. Once the checks are passed, the bill amount will be available for the contractor to claim in step 4. Every activity on Dapp leaves its trace on the blockchain ledger.

CHAPTER 4: ANALYSIS AND RESULTS

4.1 Case Study Project

The developed system was applied to a real construction project for validation. The case project was a commercial building of 2440 m^2 area constructed in Pakistan. The contract cost of the project was 1.8 million USD, and the FIDIC red book was being used as a contract document. Initially, the BIM model of LOD 350 was developed for the case project as shown in Figure 4.1: BIM Model. Revit 2022 software was used for BIM modeling. A model of the sub-structure and super-structure was developed from the CAD drawings. MEP items were not modeled in the BIM due to a lack of quality data. The BIM model includes a total of 5584 objects including rafts, retaining walls, columns, beams, slabs, structural steel, and façade. The columns and beams were modeled as a single BIM element while footings and slabs were modeled as per the pour schedule. So that the BIM model precisely depicts the as build conditions on the actual site. The unit cost of each element was included in the model. So, by multiplying the quantity by the unit price stored in the BIN model, the total cost of the element gets computed. Then all this element data was imported into the primavera P6 software for scheduling and a cost-loaded schedule was obtained.

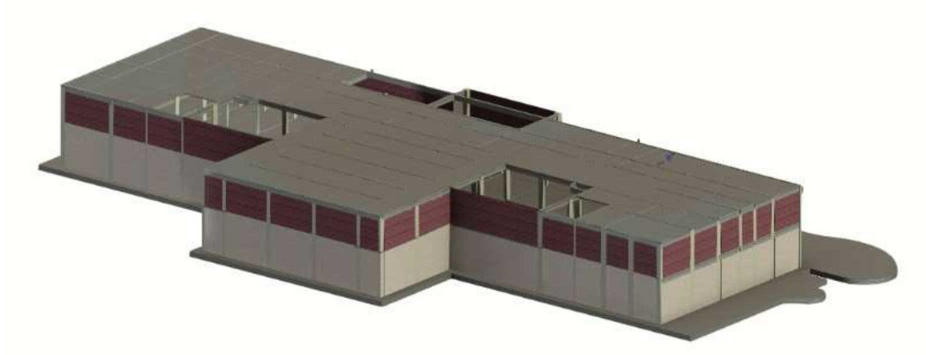

Figure 4.1: BIM Model

For this case study, an instance of the smart contract was created. The smart contract was provided with the information of project title, client and contractor's wallet, and minimum bill amount. The metamask wallets were hypothetically assigned to the contractor and the client. The deployment cost of the smart contract for the case project was 0.00178 Ether or $2.76. At the beginning of the quarter, the contractor provides its estimated work amount. The client locks this amount in the smart contract and the contractor executes the construction work. Upon completion, the request for progress payment for July 2022 was initiated by the contractor as shown in figure 4.3. The amount of work done was $40,148. The total deduction amount was $7,026 which includes 10% retention money and 7.5% tax. The net-payable amount was $33,122. At an exchange rate of 1568.432 eth /$, an IPC of 21.117 ethers was presented to the client on Dapp for approval. The client verifies the bill with his metamask wallet as shown in Figure 4.4: Bill verification from the client and upon verification, the smart contract gets invoked and the bill amount became available for the contractor to claim into its metamask wallet. The contractors claim the bill amount. Transaction on the Ethereum blockchain took about 20 seconds to complete and gets published on the blockchain ledger figure 4.6. Upon receiving the payment in Ethers, the contractor can convert it into its local currency.

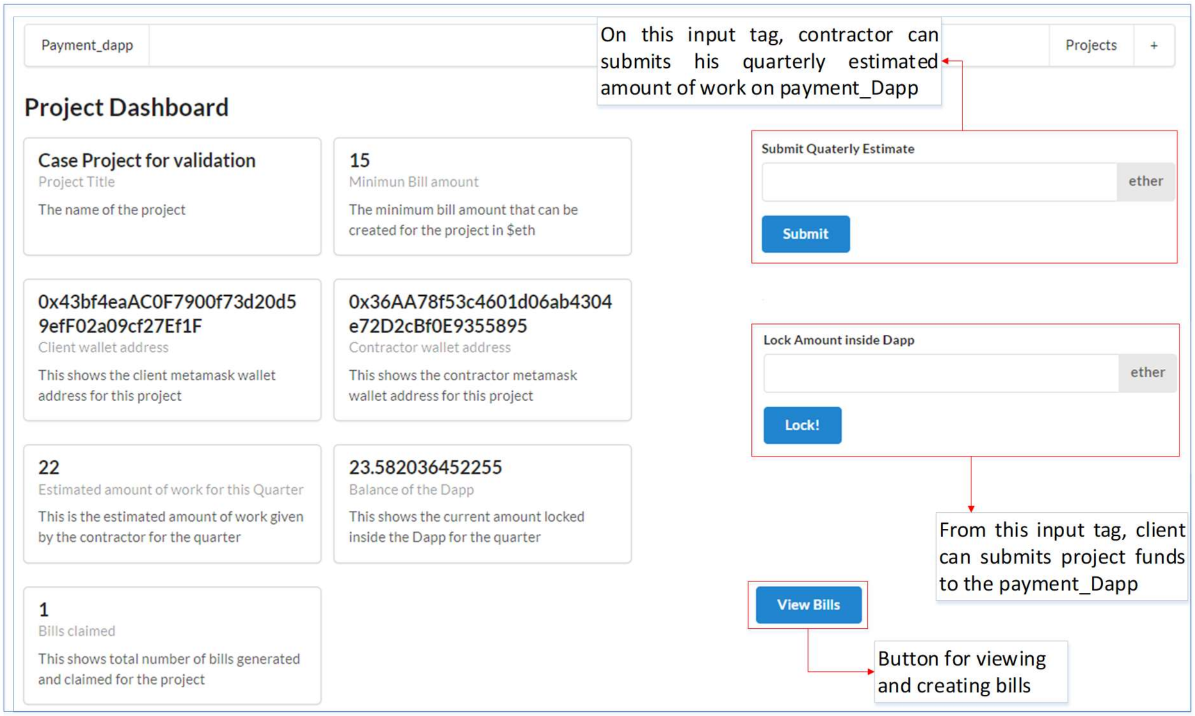

Figure 4.2: Dashboard of the case project on Dapp

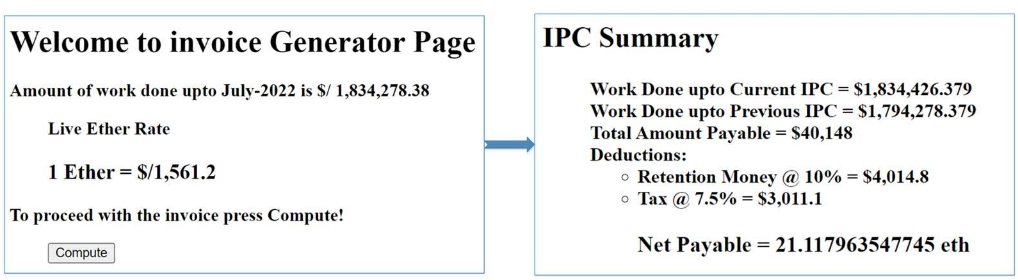

Figure 4.3: PHP module for generating invoice

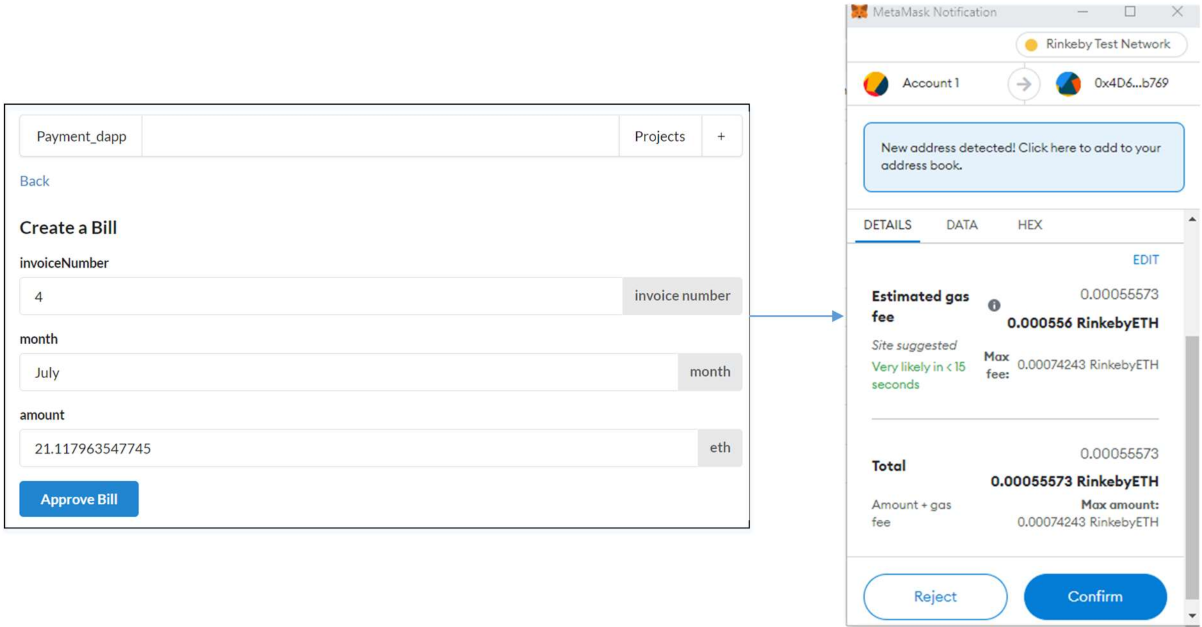

Figure 4.4: Bill verification from the client on Dapp interface

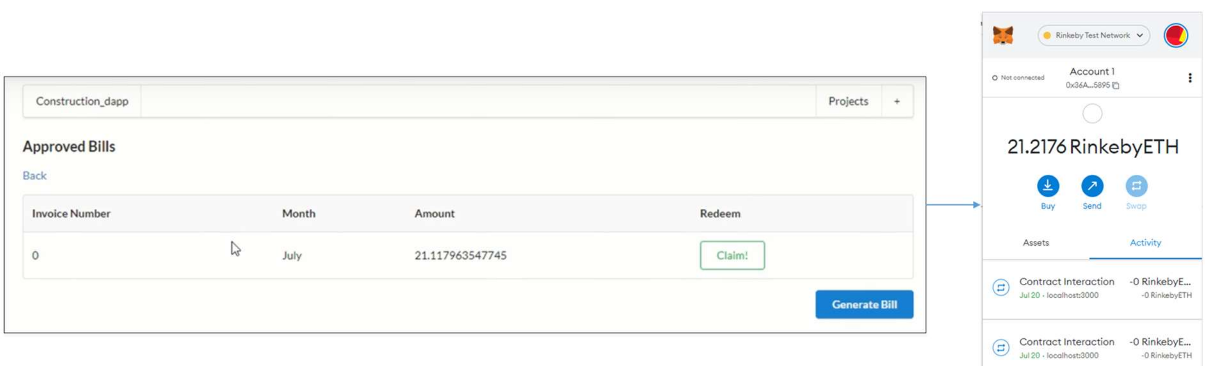

Figure 4.5: Payment to the Contractor on Dapp interface

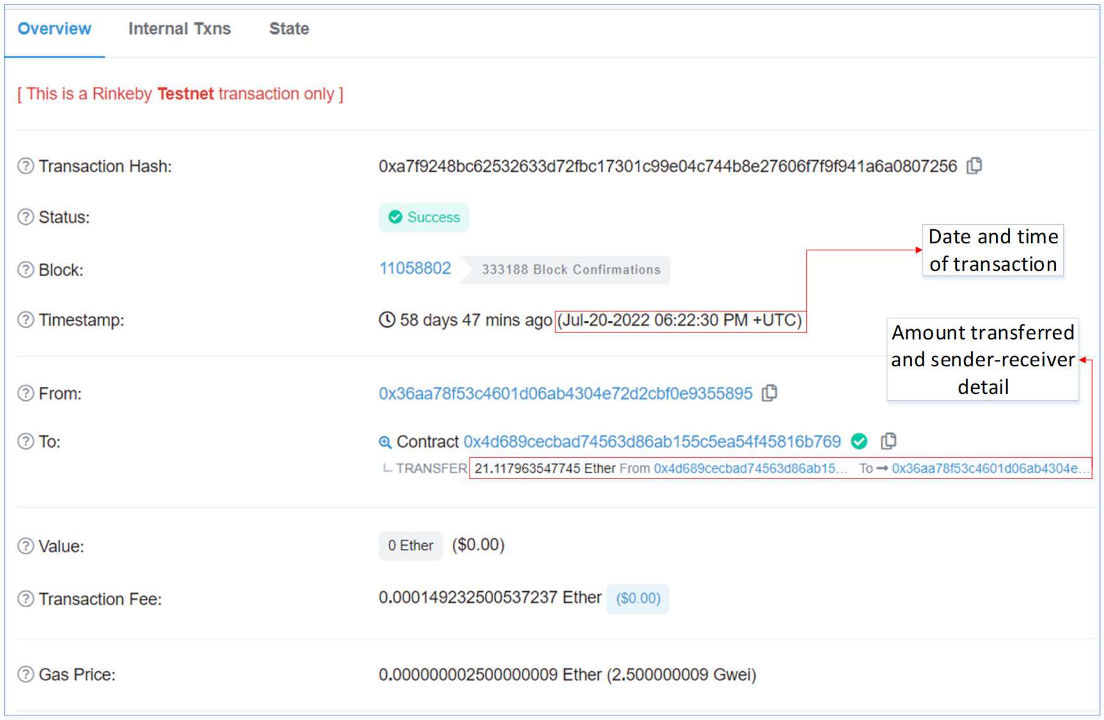

Figure 4.6: Payment receipt on the blockchain ledger

4.2 Expert Validation

To assess the working of the Dapp, a survey was conducted constituting of the professionals working on the case project. A total of 13 professionals participated in this survey. The participant includes 3 Quantity surveyors, 2 planning engineers, 2 procurement managers, 2 site engineers, 2 project coordinators, and 2 deputy directors. Six participants had 5 years or less experience, 3 participants had experience ranging between six and 10 years, and 4 participants have experience of 11 years or more. Firstly, a short presentation was given to the project participants in which the working of the system was explained to them and a short introduction to blockchain and BIM technologies was given as a preamble. Then the participants were asked to quantify their knowledge as "low", "medium", and "high" about BIM and blockchain technology. For BIM 41.7% of participants ranked their knowledge as "high", 41.7% as "medium", and 16.7% as "low". The response for blockchain comprises 58.3% as “medium” and 41.7% as “low”. The data of the participants are summarized in Table 4.1. In the second stage, participants were asked to evaluate the likely benefit achieved by using the payment Dapp for progress payments. Eight questions were included in the survey and these questions were formulated in a way to discover that the novel developed payment Dapp addresses the limitations of the traditional payment system. Questions were to be answered by a five-point Likert scale. Options of the scale range from “strongly agree”, “agree”, “neutral”, “disagree”, and “strongly disagree”. The questions and the responses are summarized in Table 4.2.

Table 4.1: Summary of survey participants

no.	Designation	working for	Years of experience	Understanding of	
				BIM	Blockchain
1	Quantity Surveyor	Contractor	8	Good	Low
2	Site Engineer	Contractor	12	Good	Medium
3	Assistant Quantity Surveyor	Client	21	Medium	Medium
4	Quantity Surveyor	Client	11	Good	Medium
5	Planning Engineer	Client	3	Medium	Medium
6	Site Engineer	Contractor	3	Medium	Medium
7	Procurement Manager	Contractor	3	Medium	Low
8	Procurement Manager	Client	6	Good	Low
9	Planning Engineer	Contractor	1	Low	Low
10	Deputy Director	Client	17	Good	Medium
11	Project Coordinator	Contractor	3	Good	Medium
12	Deputy Director	Client	8	Low	Low
13	Project Coordinator	Contractor	2	Medium	Medium

Most of the participants agreed or strongly agreed with the statements that the proposed system will help in accelerating the payment process (92.3%), will help end financial misconduct

(84.6%), and will make the process of audibility and traceability easier (92.4%). 61% of the participants agreed with the statement that the security of payments issue gets solved with the proposed system. 53.9% of participants agreed or strongly agreed with the statement that the proposed system ends the need for information-intensive paperwork and the rest were neutral about it. The majority of the participants (53.8%) were neutral on the statement that the proposed system is lesser prone to human error. However, 76.9% agreed with the statement that the system will have an overall positive effect on the payment culture.

In the last part, participants were asked to highlight the major limitation of the developed system and suggest any potential modifications to make the system more pragmatic. 46.2% of the participant were skeptical of the system because of the use of cryptocurrencies as they lack a legal or regulatory framework. 23.1% of participants point out the price fluctuation of cryptocurrency is the major limitation that renders the system ineffectual. Two participants point out the lack of satisfactory procedures for assessing work quality as a potential limitation. Lastly, suggestions were asked from the survey participants to improve the system. Most participants suggest excluding the use of cryptocurrency for progress payments. Other suggests developing invoices by some other means as most of the time actual work done lags the schedule and secondly, error in the Revit model may disturb the whole procedure. One participant suggests that the system needs to be integrated with other systems to work effectively in a real-world complex environment.

Table 4.2: Questions of the survey and responses of the participants

no.	Question	Strongly agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly Disagree (%)
1	The proposed system ends the need for information-intensive paperwork for IPC generation. (Digitization of the invoicing process)	38.50%	15.40%	46.20%		
2	The proposed system is lesser prone to human error.		46.20%	53.80%		
3	The proposed system help in resolving security of payments/trust issues among the involved parties.	46.20%	15.40%	15.40%	15.40%	7.70%
4	The proposed system will help accelerate the payment process.	61.50%	30.80%		7.70%	
5	The administrative burden can be lessened on the organization by this payment system.	23.10%	46.20%	30.80%		
6	This payment system will help end financial misconduct (corruption) in the construction industry.	30.80%	53.80%	15.40%		
7	This system will help in payment auditability and traceability.	46.20%	46.20%	7.70%		
8	Overall this system would have a net positive effect on the construction industry and will help improve the payment culture.	23.10%	53.80%	23.10%		

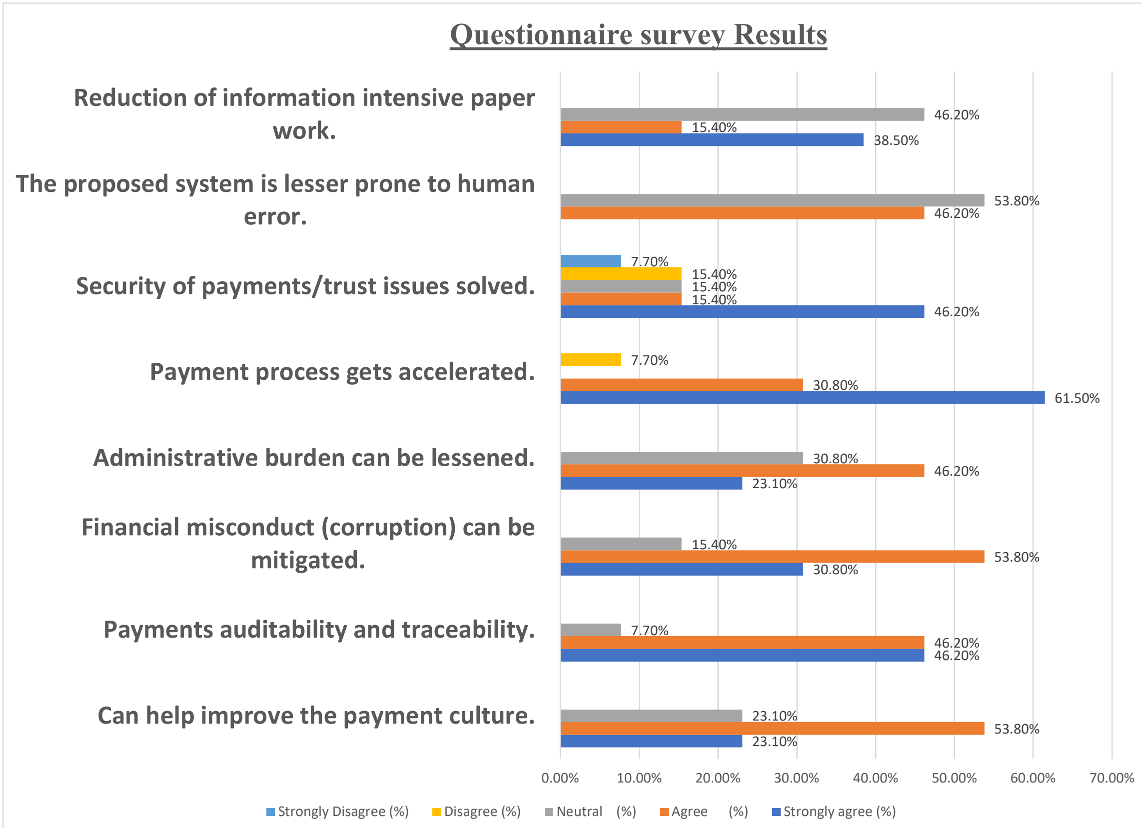

Figure 4.7: Questionnaire Survey Results

CHAPTER 5: CONCLUSION

5.1 Discussion

This research work contributes to the literature by addressing the major constraints in the path of mass adoption of blockchain and smart contracts for payment administration which are the data flow from the BIM environment to the smart contract (McNamara & Sepasgozar, 2018) and standardized template for smart contract. The developed Dapp addresses the security of payment issues by acting as an escrow account and ensures the prompt release of funds to the contractor upon approval of the client. The smart contract template can be molded to be used in any nature of contract ranging from lumpsum to unit-price to GMP etc. The developed system eliminates overheads associated with the payment process. The proposed system provides a slick mechanism for integrating the project schedule with the financing requirement which is an important consideration for the project's successful completion (Lee et al., 2012; Alavipour & Arditi, 2018) and would bolster discipline in the payment process by compelling the client for effective utilization of funds. The survey results also hunch that majority of the respondents have a positive opinion of the proposed system.

This paper presents an on-hand decentralized application (Dapp) for the construction industry to be used for payment administration. The smart contract of the Dapp was deployed on the rinkeby Ethereum test net. A BIM model is acting as a digital BOQ and is used for the generation of the monthly invoice. A method of sending the invoice from the BIM environment to the Dapp has also been established. Security of the payment along with red tape came to be the biggest downside of the traditional payment system. The developed system is capable to address all the major limitations of the traditional payment system. The Dapp stores the work amount from the client and ensures the contractor of remuneration upon completion of payment provisions. Subsequently, acting as a trustworthy intermediary and mitigates mistrust and misgiving between the contractual parties. The system creates an environment of trust and transparency and overall brings efficiency to the system. The results of the case study also recommend that majority of the construction professionals have a constructive demeanor toward the proposed system.

5.2 Limitation

The payment DApp computes the invoice using the BIM model, where the information of quantities and rates of the building members gets stored. In case of a change of scope or claims, one must manually add or modify the BIM model which can be a conundrum. So, the payment Dapp works best when the scope of the project is meticulously defined such as in the case of the design-build-bid project delivery method. Also, the system utilizes cost-loaded schedules but generally, construction activities don't go as per the baseline schedule. So, the schedule needs to be updated regularly for the system to work properly. These are the potential limitations of the system. The BIM model for the case study building was developed using CAD drawings as the BIM wasn't practiced on the case project. Also, the MEP and finishing works weren't included in the model. So, the model may be susceptible to inaccuracies.

The lack of legal infrastructure and fluctuation in the price of cryptocurrency remains a major deterrence in the adoption of the system. These issues can be addressed by the use of stablecoins (Calcaterra et al., 2019) or the use of coins pegged against real-world commodities (Hamledari & Fischer, 2021c). Also, there is a propensity that with the inflow of smart money and institutional money in crypto market capitalization, these digital coins will get mature and there will be a drop in price volatility. Ideally, such a cryptocurrency with a utilitarian use case, which offers efficient scalability, high transaction per second volume, and speed, grows steadily without creating a bubble, and finally regulates itself in such a manner that it avoids anyone to accumulate coins to such an extent that it creates a phenomenon of crypto whale which can single-handedly disturb the liquidity of the market. Such a coin can offer a permanent fix to the regulatory and volatility issue. This may be feasible given the extensive collaboration of gentry that withholds the idea of decentralization.

5.3 Further Research

In the developed system satisfactory mechanism for ensuring the quality of the project is missing. In future studies, work on addressing this inadequacy can be done. One prominent solution to this is to integrate IoT technology with the blockchain. So using IoT with blockchain for payment administration can be a prominent research area of the future. The biggest perk of web 3.0 is the concept of data ownership. This is a revolutionary concept and research can be conducted on exploring the use of non-fungible tokens also known as NFTs in the construction industry. In construction projects, the final payment is subject to most disputes. So work of development of such a smart contract that addresses the smooth settlement of final payment can also be a good future study. A future study on the design and development of the decentralized autonomous organization (DAO) for payment administration can be conducted. A DAO presents a major potential as it offers a much more flexible architecture. A DAO-based payment system will be applicable throughout the life span of the project and can settle complexities that engirdle the invoices as it can restructure its code and is self-regulatory.

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