
Exploring the Potential of Smart Contracts in the Business Industry

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Conceptual Formulation

Master Thesis for Mr./Ms. Mario Akhnoukh

Student number 581310

Topic: Exploring the Potential of Smart Contracts in the Construction Industry

Introduction

In recent years, the advent of blockchain technology has paved the way for the development of smart contracts, digital agreements that can be programmed to automatically execute certain actions when certain conditions are met. These smart contracts have the potential to revolutionize the way businesses operate by reducing costs, increasing efficiency and transparency, and reducing the need for intermediaries. However, while the potential of smart contracts is widely acknowledged, their adoption in the construction industry has been limited so far.

This thesis aims to explore the potential of smart contracts in the construction industry and to identify the challenges and opportunities for their implementation. Smart contracts are self-executing contracts with the terms of the agreement between buyer and seller being directly written into lines of code. They enable transactions to be processed automatically when certain conditions are met, removing the need for intermediaries, and reducing the risk of fraud.

In recent years, various construction companies have shown interest in incorporating smart contracts into their operations. However, there is still a lack of understanding of the full potential of this technology and how it can be effectively implemented in different construction aspects.

Research Questions

1. How can smart contracts be effectively utilized in the construction industry to improve efficiency and reduce costs?
2. What are the challenges facing the adoption of smart contracts widely in the construction sector?
3. What are the merits and demerits for using smart contracts in construction?
4. What is the current status of smart contracts with respect to construction?

Objectives

- To investigate the current state of smart contract adoption in the construction industry
- To identify the challenges and opportunities for the implementation of smart contracts in different construction contexts.

- To analyze the potential benefits and drawbacks of using smart contracts in the construction industry.
- To provide recommendations for companies on how to effectively implement smart contracts in their operations.

Methodology

- This research will be conducted using a combination of literature review and case studies.
- The literature review will focus on existing research on smart contracts and their potential use in the construction industry.
- The case studies will involve precise details about projects and companies that are currently using or experimenting with smart contracts in their operations.
- The data collected will be analyzed using a combination of qualitative and quantitative methods.

Expected Contributions

This research will provide insights into the current state of smart contract adoption in the construction industry and identify the challenges and opportunities for further adoption.

It will also provide a detailed analysis of the potential benefits and drawbacks of using smart contracts in the construction industry.

Finally, it will provide practical recommendations for companies on how to effectively implement smart contracts in their operations.

Significance

The research will provide valuable insights into the potential of smart contracts in the construction industry and will contribute to the body of knowledge on the topic.

The recommendations provided will also be useful for companies looking to adopt smart contracts in their operations, potentially leading to increased efficiency and reduced costs for construction projects and companies.

Overall, this study aims to explore the potential of smart contracts in the construction industry and to identify the challenges and opportunities for their implementation. Through a combination of literature review, a case study, and a survey, this research will provide valuable insights into the current state of smart contract adoption in the construction industry and provide practical recommendations for companies looking to adopt smart contracts in their operations.

Time Scale

Activity	Start	End
Conceptual Formulation Final Draft	April 2022	June 2022
Research	June 2022	September 2022

Literature Review	September 2022	November 2022
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Resources:

- Metropolia Library Website: <https://metropolia.finna.fi/>
- HTW Berlin Library Website: <https://bibliothek.htw-berlin.de/>
- Elsevier Website: <https://www.elsevier.com/>
- Springer Website: <https://www.springer.com/gp>
- Blockchain Platforms such as Ethereum, Hyperledger Fabric, Stellar, NEM & Polkadot

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Abstract

In 2018, construction was responsible for more than 6 percent of global GDP, and this number is expected to rise to 14.7 percent by 2030. However, the construction sector is hampered by several obstacles that prevent it from evolving into a simpler, quicker, and more lucrative enterprise. Many of these hurdles may be overcome with the use of smart contract technology, which boasts advantages like increased security, accelerated processing, and transparent transactions throughout the whole construction sector. Insights into the application of "smart contracts" within the construction industry are explored in this study to determine the efficacy of this technology in the industry.

The research makes use of a number of different approaches to arrive at findings that contribute to the scientific community. The value that "smart contracts" may bring to various facets of construction is discussed and analysed via the use of two case studies and a survey. Prior to the case studies and survey chapters, a literature review and a chapter outlining blockchain and smart contracts and their applications in the construction industry are included.

After years of study, a plethora of initiatives have been set in motion to bring the revolutionary blockchain technology to various segments of the construction industry. According to the findings, new software and hardware are being tested and deployed in the field. According to the results of the first case study, using the breakthrough technology, known as PLASMA, has the potential to drastically cut down on building projects' durations and budgets. In the second case study, it is obvious how the application of smart contract technology plays out in the real world. Payment automation on a building site using sensors and blockchain technology proved effective, with an error rate of under 5%. Finally, the poll found that over 70% of respondents think "smart contracts" technology would become commonplace in many facets of the construction industry.

Keywords: Smart contracts, blockchain technology, PLASMA, payment automation

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List of Abbreviations

AEC	Architecture, Engineering, and Construction
BIM	Building Information Modelling
BRE	Building Research Establishment
CDE	Common Data Environment
CID	Unique Content Identifier
DAG	Directed Acyclic Graph
DAO	Decentralized Autonomous Organization
DApp	Decentralized Application
DfMA	Design for Manufacturability and Assembly
DOI	Digital Object Identifier
DPoS	Delegated Proof of Stake
EOA	Externally Owned Accounts
ERC	Ethereum Request for Connect
ETH	Ethereum Native Cryptocurrency
EVM	Ethereum Virtual Machine
EVM	Ethereum Virtual Machine
GDP	Gross Domestic Product
GDPR	General Data Protection Regulation
GUID	Globally Unique Identifiers
GUID	Globally Unique Identifiers
HVAC	Heating, Ventilation, and Air Conditioning
ICT	Information and Communication Technology
ID	Identification
IEEE	Institute of Electrical and Electronical Engineers
IFC	Industry Foundation Classes
IOT	Internet of Things
IPFS	Internet Protocol File System
IPFS	Interplanetary File System
JSON	JavaScript Object Notation
KPI	Key Performance Indicator

LoC	Letter of Credit
MMC	Modern Methods of Construction
P2P	Procure to Pay
PDF	Portable Document Format
PoS	Proof of Stake
PoW	Proof of Work
QR	Quick Response
RFID	Radio Frequency Identification
RMC	Ready-Mixed Concrete
RPC	Remote Procedure Call
UAV	Unmanned Aerial Vehicle
UGV	Unmanned Ground Vehicle
UK	The United Kingdom
UKRI	UK Research and Innovation
URI	Unified Resource Identifier
USA	The United States of America

1. Introduction

Smart contracts are digital agreements that may be designed to automatically carry out particular activities when certain criteria are satisfied, and their development has been facilitated by the ascent of blockchain technology in recent years. By cutting down on overhead, boosting productivity and openness, and decreasing reliance on middlemen, smart contracts have the potential to radically alter the way organisations are functioning. Despite smart contracts' promising future, their use is still relatively uncommon in the building sector.

The aim of this research paper is to examine the feasibility of using smart contracts in the building sector, as well as to analyse the advantages and disadvantages of doing so. A smart contract is an electronically recorded and automatically carried out agreement between a purchaser and a vendor. They allow for automatic processing of transactions under specific conditions, cutting off the need for middlemen while also lowering the possibility of fraud.

There has been recent interest among construction firms in using smart contracts. However, there is currently a dearth of knowledge about this technology's potential and how it might be efficiently utilized in various building contexts.

1.1. Background

The global economy depends heavily on the construction industry, which contributed over 6% of the world's GDP in 2018 and is projected to increase to about 14.7 % by 2030. However, this industry has endured years of criticism for its low output, subpar performance, and slow innovation. As industries become more digitalized and as the amount of useful data increases exponentially, information and communication technology (ICT) breakthroughs are currently transforming practically every business. The adoption of ICTs to increase productivity and efficiency has had a large positive impact on other industries, including automotive, aerospace, and aviation. However, the fields of architecture, engineering, and construction (AEC) are lagging behind in terms of adopting new digital technologies.

The development of smart contracts is being investigated more and more as a factor of the digital revolution of the building industry. Building Information Modelling (BIM) adoption can be facilitated by smart contracts, which have the capability to assist tackle a number of significant difficulties in the building industry, including contract conflicts and payment issues. The construction business frequently has contract disagreements. Contradictions, inaccuracies, or ambiguous wording in construction contracts might make them difficult to enforce. The current widespread use of paper-based, also known as traditional contracts, makes it difficult to monitor changes and record execution. Customers and vendors can act improperly, and contracts can be enforced poorly, because there is no foundation for claims and disputes. Smart contracts provide a way to guarantee immutability by keeping track of and publicly displaying any changes. Problems with making payments are also growing. Payments on schedule and a steady stream of cash flow are dependent on the effective completion of construction projects. Problems like as non-payment, late payment, or incorrect payment contribute to construction delays, increased expenses, decreased performance, and conflicts. Fresh progresses in the field of smart contracts have made it feasible to implement trustworthy, automated payment systems. Adoption of BIM is challenging because of issues with technological progress. Among the challenges to adopting and using BIM more successfully are the risks connected with information security and intellectual property ownership. Using someone else's BIM model might infringe on their intellectual property rights without their knowledge. As a result, the proprietorship of digital data in "BIM" becomes a permanent issue that can be resolved by implementing smart contracts in building projects. In the meantime, information security may also be guaranteed because BIM allows for the tracking of any changes.

Blockchain in construction is highlighted in recent papers and academic writing, where smart contracts are frequently referred to or treated as a part of the blockchain. One of the "most significant aspects" of the "blockchain", smart contracts are regarded as a bind, component, layer, or feature. The smart contract, however, has a distinct interpretation, connotation, and value to the construction sector as a driver for pertinent mechanisation and a vital modernization for digital transformation.

The implementation of smart contracts in this context is still in its infancy. In its first phases, a technological application may encounter a number of problems, such as difficulties in determining its efficacy and roadblocks posed by management and technology. Explaining the benefits and pointing out the challenges of “smart contract” development, from their infancy to their full maturity, is therefore of great value.

1.2. Research Problem

The application of software known as "smart contracts" in the building trade is a relatively recent innovation that holds the promise of boosting productivity while also cutting expenses. The use of this technology in the construction industry is still in its infancy, despite the many advantages that may be gained from employing smart contracts. As a result, the fundamental objective of this line of inquiry is to study the appropriate application of intelligent contracts within the building and construction sector so as to boost productivity and save expenses.

In order to accomplish these objectives, the primary focus of this investigation will be on investigating the many different applications of “smart contracts” in the building sector. In addition, this research will investigate the hurdles that stand as roadblocks to smart contracts' widespread use in the construction industry. These obstacles include legal and regulatory concerns, as well as technological and cultural opposition. In addition, the use of “smart contracts” in the building division will be evaluated, along with the possible advantages and hazards connected with the utilization of this technology, as part of this research project's evaluation of the pros and demerits of employing smart contracts.

The study aims to answer the following research questions:

- 1- How might smart contracts be used to maximize efficiency and save expenses in the building sector?
- 2- What barriers prevent the widespread utilisation of smart contracts in the building industry?
- 3- When it comes to building, what are the pros and downsides of implementing smart contracts?

4- When it comes to construction, what is the present state of smart contracts?

In conclusion, the reason for doing this study is to investigate the present state of smart contracts in the building sector, namely their degree of adoption, the extent to which they are being implemented, and their potential for future expansion. This study's overarching objective is to shed light on how smart contracts can be utilised productively in the building business to improve efficiency and cut expenses, as well as to highlight the challenges and opportunities associated with this emerging technology. Specifically, the research will focus on the construction industry.

1.3. Objective

Two of the many possible meanings of "smart contracts" in the building sector are highlighted here: 1) "Smart contracts" are one technology that can help advance the digitization of construction agreements; and 2) The digitization of construction agreements is only one-use case for smart contracts; other uses include controlling for quality and compliance, tracking the supply chain, and refining the CDE, "Common Data Environment". On the basis of these two meanings, it is vital to differentiate "intelligent contracts" from "smart contracts" or "iContract" in order to better comprehend the technological contribution and implement "smart contracts" in applicable structure aspects in accordance with domain-specific requirements. The technological provision of smart contracts is investigated, and the blockchain is analysed as a platform that guarantees the correct deployment and execution of these contracts in a secure setting.

As previously stated, smart contracts are not restricted to promoting the digitization of building contracts. Smart contracts contribute to the technological upheaval of the building sector. In this context, it is stated that transience and lack of reproducibility are significant obstacles. Almost invariably, construction projects are one-of-a-kind endeavours with specific objectives that involve specialised design and delivery strategies. There is traditionally a high barrier to replicating successful building projects; however, the reasoning and mechanism in smart contracts (such as acceptance norms of quality and payment necessities) may be readily reprocessed and redistributed across different projects.

Meanwhile, the proliferation of “digital twins” of the built environment increases the likelihood that these and other construction project and company procedures may be automated. Smart contracts, with their capacity to activate and regulate data streams on a secure digital stage, might encourage the development and deployment of digital twins in the building sector, which ultimately can improve the efficacy of smart contracts through increased automation. However, “smart contract” implementation in the building sector is only getting started. It's important to find out if the smart contract makes a difference or if it's just an illusion. Understanding the upsides and downsides of smart contracts is crucial.

1.4. Methodology

This research work employs a miscellaneous-methods tactic to explore not just the research topic but also the research questions. The research will utilize both literature reviews and case studies to give a thorough comprehension of smart contracts and their potential applications in the construction industry. The literature study will be completed by reading through relevant academic and industry publications to learn more about the existing condition of smart contract research in the building business. This literature analysis will concentrate on determining the advantages, disadvantages, and possibilities related with the utilization of smart contracts in the building sector, in addition to the variables that impact their acceptance.

In addition to the evaluation of the relevant literature, case studies will be carried out in order to collect data from businesses that are either actively utilizing smart contracts in their operations or are experimenting with using them. These case studies will provide specific information on the projects and businesses, as well as their experiences and the results obtained from utilizing smart contracts. Case studies will be used to give a more in-depth knowledge of the possible advantages, problems, and possibilities related with the enactment of smart contracts in the construction business. In addition, they will assist in the identification of the variables that impact the application of smart contracts in the building sector. Some examples of these elements include technological preparedness, legal and regulatory frameworks, and cultural attitudes.

A mix of qualitative and quantitative approaches will be used to investigate the information that was gleaned from reading the previous research and carrying out the case studies. The qualitative data will be assessed using a method called “thematic analysis” so as to discover recurring ideas, patterns, and trends in the data. To locate links between variables and to test hypotheses, the quantitative data will be evaluated with statistical methods such as regression analysis and correlation analysis.

Overall, this approach, which makes use of a variety of methodologies, will result in a thorough knowledge of smart contracts and the building sector's potential applications for these types of agreements. The research will be able to determine the benefits, problems, and possibilities connected with the utilization of smart contracts in the building business by combining an assessment of the relevant literature with case studies. In addition, the examination of data through the lens of qualitative as well as quantitative approaches will result in a more in-depth comprehension of the elements that impact the realisation of “smart contracts” in the construction sector. The findings of the research work will contribute to the current body of information on “smart contracts” in the construction sector. Additionally, the findings will be valuable for practitioners, policymakers, and scholars interested in this area.

1.5. Significance

This research will contribute to the existing body of information on the subject while also providing insightful new perspectives on the possibilities presented by smart contracts in the building and construction sector.

The supplied ideas will also be valuable for businesses that are wanting to implement smart contracts in their operations, which may possibly lead to greater efficiency and decreased costs for construction projects as well as for the businesses that are working on them.

The overarching purpose of this work is to investigate the applicability of “smart contracts” to the building sector and to analyse the obstacles and possibilities associated with putting them into practice. This research will provide valuable insights into the status of the technology adoption in the building sector through

a combination of a literature review, a case study, and a survey. It will also provide practical recommendations for businesses that are looking to implement smart contracts in their operations. The research will provide valuable insights into the potential of smart contracts in the sector of construction and will contribute to the body of knowledge on the topic.

The recommendations provided will also be useful for companies looking to adopt smart contracts in their operations, potentially leading to increased efficiency and reduced costs for construction projects and companies.

Overall, this research work targets exploring the potential of smart contracts in the construction business and to identify the challenges and opportunities for their implementation. Through a combination of literature examination, case studies, and a survey, this research will provide valuable insights into the status of smart contract utilisation in the field of construction and provide practical recommendations for companies looking to adopt smart contracts in their operations.

2. Blockchain and Smart Contracts Technology

2.1. Blockchain Technology

Blockchain is a decentralized digital ledger system that enables the secure and translucent transmission of information and value minus the requirement for middlemen such as banks or governments. Blockchain was developed by Satoshi Nakamoto and is referred to as the "Internet of Value." The fundamental premise underlying blockchain is that it is an ever-expanding list of documents, which are referred to as blocks, that are linked and safeguarded through the use of encryption. (Golosova & Romanovs, 2018)

The transaction data, a timestamp, and a cryptographic hash of the former block are involved in each new block that is added to the chain. Because any modification of a block in the chain will be quickly identified thanks to the hash function, it is not possible to alter the data that is contained in the blockchain. (Golosova & Romanovs, 2018)

Due to the fact that blockchain technology is decentralized, there is neither a central authority nor a governing institution. As a result, it is exceedingly difficult to hack or corrupt. Instead, the network is maintained by a set of users who are collectively referred to as nodes. These nodes are responsible for validating and authenticating transactions that take place on the network. (Golosova & Romanovs, 2018)

After being added to the chain, transactions on the blockchain are recorded in a way that is both visible and immutable. This implies that once a transaction is attached to the chain, it cannot be altered or removed. Because of this, the blockchain technology is ideally suited for usage in sectors such as the financial industry, the administration of supply chains, and voting systems, all of which place a premium on transparency, security, and accountability. (Bahga & Madiseti, 2016)

Cryptocurrencies such as Bitcoin and Ethereum, which utilise blockchain as its foundational technology, are largely responsible for bringing widespread attention to the blockchain technology. However, blockchain technology has the potential to be used in a wide variety of different contexts, including the

authentication of identities, the management of digital voting systems, and the creation of smart contracts. (Bahga & Madiseti, 2016)

In a nutshell, “blockchain” is a digital ledger system that is decentralized, transparent, and secure. It enables the safe movement of information and money without the participation of any middlemen. It has the power to provide better security, transparency, and accountability, all of which have the potential to transform many different sectors and applications. (Litviņenko & Āboltiņš, 2017)

The blocks inside the Blockchain are organized in a linear sequence, and new blocks are assigned to the chain at predetermined intervals. The information that is contained in the blocks is determined by the “blockchain” system; nevertheless, the time records, transactions, and “hash values” are consistent across all versions of Blockchain. The cryptographic “hash” of the block which came before it is included in each new block, as it is explained in figure 1 below. Because the information contained in the hash is created automatically, it is not possible to modify any of the data confined inside the “hash”. In this scenario, the verification of the block that came before it and the safety of the whole Blockchain are strengthened with each subsequent block. The Blockchain will be a more secure and dependable system when there are more blocks in the chain. (Fernandez-Carames & Fraga-Lamas, 2018)

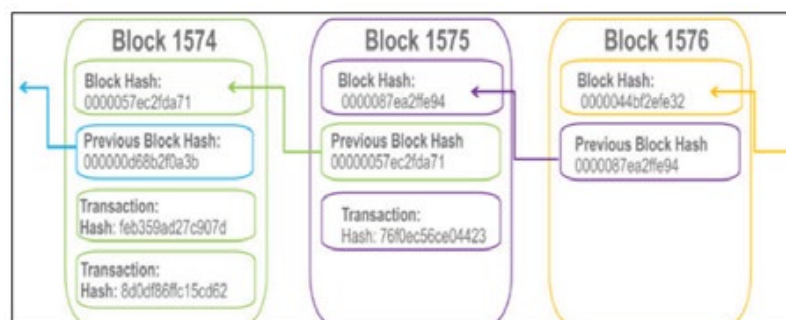


Figure 1. The hash value sequence in the Blockchain

2.1.1. Advantages

The “blockchain” technology has the prospective to help make the corporate world, the authority, and the logistical systems more trustworthy, dependable, and safe. Because it may assist in accomplishing the aforementioned objectives across a variety of contexts and settings, this technology offers several

significant advantages. Undoubtedly, the Blockchain technology has a few drawbacks, the majority of which are connected to the expenses incurred and the steps required to put the technology into practice. The effective use of the technology is contingent on a wide variety of various conditions, including backing from the government and legislative bodies. There is no doubt that the Blockchain represents a new kind of database. (Bahga & Madiseti, 2014)

One of the most pressing issues in the economy is linked to the financial industry, and this technology may provide a solution. In this case, we must make two independent purchases without a middleman. Just how does this blockchain thing operate, and how can it help with this problem? Every block in the Blockchain is a eternal recording of certain data in its own right. Each of these blocks is linked to the others on this blockchain in some fashion. To keep the Blockchain reliable and secure, the proof-of-work system is implemented. It becomes exceedingly difficult, if not impossible, to edit or delete blocks once they have been put to a Blockchain. You'll need a supercomputer capable of massive computations if you want to join the Blockchain. Individuals called "miners" do the task of calculating the hash value for each fresh block. (Bahga & Madiseti, 2014)

The distributed network, trusted chain, transparency, irreversible and indestructible system are the primary benefits of the blockchain system. In turn, the primary drawbacks of the "blockchain" are its high consumption rate of energy, the challenging process of assimilation, and the massive expenses associated with its implementation. (Bahga & Madiseti, 2014)

The fact that this technology operates as a decentralized network is the primary advantage it offers. Why is it so significant to our everyday lives? It is not essential to collaborate with the third-party administrations or with the middle administrator, which is a certainly easy response to this topic. This means that intermediaries are unnecessary for the system to function, due to the fact that all contributors in the blockchain are the ones who choose the options. When a system works together with third-party figures, there is a possibility that the databank will be hijacked, or the data may fall into the unwanted hands. Because of this, it is imperative that each system safeguards its database, since it is risky that the record may end up in the unwanted hands. The process of

ensuring the safety of the record might require a long time and could incur significant costs. If the Blockchain technology is used, this problem may be circumvented since each transaction on the Blockchain has its own proof that it is genuine and authorisation to carry out the necessary restrictions. Additionally, this entails the possibility of independent verification and processing of the transactions. Every transaction is added to the distributed ledger, where it is immutable and cannot be altered or removed. The data included inside the ledger is viewable by all parties involved in the Blockchain. The following parts focuses on the trustworthiness, immutability, and transparency of the Blockchain. (Bahga & Madiseti, 2014)

Two or more strangers who are willing to trust one another are required for “Blockchain” to be reliable. The primary focus here is on the genuine and not pointless exchanges that take place between these nameless individuals. It is possible to further raise the level of confidence by increasing the number of processes and records that are shared. (Songara & Chouhan, 2017)

The immutability of the data is ensured by having each transaction validated and recorded in a distributed ledger. Once the transaction has been added to the Blockchain, it will no longer be able to alter or delete the information associated with it. It also relies on the type of system being used; for example, if the system is centralized, its components can be altered or eliminated at the discretion of a single individual. If, on the other hand, the system is distributed, like the “blockchain”, then every operation that is added to the “blockchain” is replicated on all of the computers that are part of the “blockchain” network. Because of this advantage, the Blockchain technology cannot be modified and cannot be destroyed. Users of a blockchain are vested with the authority to govern any and all information and transactions on the network. When an intruder has the far-fetched computing power essential to be able to modify or delete the material on all computers, including those that are part of the “blockchain”, prior to the recording of the next block, it is possible for them to change or delete the information that has been entered into the Blockchain. If there are just a few computers participating in the “blockchain”, then the technology is less secure and less transparent. On the other hand, if there are a large number of

computers participating in the “blockchain”, a safer system, and more transparent technology are present. (Songara & Chouhan, 2017)

The promise of total transparency offered by the blockchain is accomplished in the process of cloning transactions. Following the same pattern as before, all Blockchain network computers will have a copy of every transaction. Because all transactions are visible to all members, this also means that all acts within the Blockchain are broadcast to everyone using it. Nobody is capable of displaying such insensible behaviour. (Song et al., 2016)

The Blockchain was built in such a manner that it is able to identify any issues and make the required adjustments to fix them. Because of this benefit, the blockchain technology's capability for traceability stands out. Each user that connects to the “blockchain” is handed a one-of-a-kind characteristic that is connected to his account, which is how the system achieves its high level of security. The unbroken bond of the “cryptographic hash” is another feature that contributes to the blockchain's invulnerability and durability. Whenever a fresh block is formed, it becomes vital that a hash value be generated for it. There is no room for question that the fresh hash incorporates the earlier one's value. Hashes often include information such as block ID, previous hash value, time block was formed, user ID, miner level, and Merkle Root, among other things. Past transaction history and associated hashes are kept there. The node-key generates this hash automatically, with no human intervention required. In this case, changing the cryptographic hash or any of the data it represents is impossible. (Song et al., 2016)

Participants in the system see an increase in both clutter and complexity as a direct result of the various ledgers. Because all transactions are added to a central, shared ledger, the implementation of blockchain tech results in an overall reduction in the complexity of the ecosystem. (Light, 2019)

The processing time may also be reduced, which is the last advantage. Historically, the processing and initialization of the transaction inside financial institutions might take a significant amount of time. The usage of the Blockchain technology helps minimize the time required for the processing and initializing

greatly. This time may be cut down from about three days to few minutes or even seconds by using the Blockchain. (Light, 2019)

2.1.2. Challenges

If the blockchain has benefits, then this technology must also have drawbacks, or perhaps a better word would be difficulties. The incredible consumption rate in energy of the blockchain is the primary drawback of this technology. preserving a up to date ledger requires the use of electricity, hence this is a necessary expense. At the same moment that a new node is established, it immediately begins communicating with all of the other nodes in the network. It is via this process that transparency is achieved. Miners throughout the network are working hard to validate transactions by finding solutions to many puzzles in such short time. They are consuming a significant percentage of the available computer power. Every node provides extraordinary degrees of fault tolerance, ensuring that there is no downtime, and helps to make the data that is recorded on the blockchain permanently immutable and immune to censorship. However, these operations use both time and power, which is a waste because it is unnecessary for each node to do so in order to reach consensus. (Light, 2019)

Because each transaction is required to be indicated using a “cryptographic” technique, an incredible measure of computational power is required for the calculation procedure to sign. This presents a hurdle for the blockchain. It is one of the factors that contributes to the high values of energy consumption. (Light, 2019)

The subsequent issue that may arise with the Blockchain is the opportunity for the chain to become shattered. Transactions in the new chain will not be accepted by the nodes since they are still using an older version of the software. This new chain will have the exact same history as the previous chain, which was built using antiquated software. The term for this thing is the fork. The “soft fork”, and the “hard fork” are the two different varieties of forks that are available. (Songara & Chouhan, 2017)

The latest set of rules for the protocol blocks are implemented when the soft fork takes place. The nodes get updates in order to comply with the soft fork

requirements. If a block, which was validated prior to the activation of the “soft fork”, defies the new regulations introduced by the “soft fork”, the block will not be remaining in a valid state after the deployment of the soft fork. As an illustration, the soft fork reduces the maximum size of a block to 500 kilobytes, when earlier it was 1 megabyte. This indicates that blocks of a size greater than 500 kilobytes will not be legitimate in the fresh chain after the upgrades have been implemented. (Songara & Chouhan, 2017)

Because of the hard fork, the set of rules governing the blocks in the protocol has been loosened. The soft fork methodology and this procedure are identical, except the value and outcome of the soft fork process are in the other direction. For instance, the hard fork will raise the maximum size of a block from 1 megabyte to 2 megabytes. Even though the block has never been part of the chain before, it can still be included in the chain provided it satisfies all the criteria for inclusion outlined in the hard fork's set of rules. (Songara & Chouhan, 2017)

A further issue with the Blockchain is maintaining a healthy balance among the nodes number and keeping transaction fees low for consumers. At the moment, there is a shortage of nodes, which prevents the Blockchain from functioning fully and effectively. In this scenario, the fees are greater since the nodes earned bigger rewards; yet the transactions are executed more slowly because the nodes do not exert a great deal of effort. (Bahga & Madiseti, 2014)

When new blocks are added and the necessary amount of computer power grows, this indicates that the blockchain has expanded. Not all of the nodes have the capacity to supply what is required. There are two issues: the first is a smaller ledger, which compromises the data integrity and transparency of the Blockchain since the nodes cannot carry a full copy of the Blockchain; the second issue is that the Blockchain is becoming a more centralized structure. (Bahga & Madiseti, 2014)

The Blockchain has a significant drawback in the form of its exorbitant expenses. The energy consumption accounts for the vast majority of the transaction's typical cost, which ranges from 75 dollars to 160 dollars on average. The previous section discussed one of the factors that contributed to the current

predicament. The hefty initial capital expenses associated with Blockchain technology are the second factor. (Bahga & Madiseti, 2014)

2.2. Smart Contracts

A computerized transaction protocol is known as a smart contract. Its goal is to recreate legally enforceable contracts via the use of a code that is executed on a public blockchain system. Smart contracts technology is computerized. The software was capable of having clauses and instructions programmed into it. Because the software runs automatically whenever the predetermined contractual criteria are satisfied, smart contracts can operate as a form of self-enforcing agreements. In addition, digital transaction information, such as the transaction value, may be encoded in smart contracts, and after the instructions for the contract have been fulfilled, the data can be sent automatically between the parties involved. To put it another way, the sum that is owed is secured via smart contracts in a manner that prevents any one party from gaining access to the funds. If the predetermined conditions are met, only then will the agreed-upon payment amount be sent to the parties' accounts. Because of its binary basis, which implies that outputs and inputs are identical and that the function of the contract parameters is dependent on the compliance of specified scope, the smart contracts are authoritative. (Crosby et al., 2016)

Because it is a decentralized technology, blockchain does away with the requirement for additional intermediaries such as banks, notaries, and exchanges. Additionally, it lessens the likelihood of fraudulent payments occurring owing to the inherited characteristics and dispersed attributes of smart contracts. Being distributed implies that the results of each contract are checked for accuracy by all of the parties who make the network up. Therefore, a lone individual is incapable of coercing the contract into letting go the cash since other users on the network would detect the effort and flag it as invalid if it succeeds. In other words, confirmation from all of the parties is required in order to carry out any transaction within this system. In addition, the transaction costs associated with smart contracts are reduced, and the level of confidence between the parties to the contract is increased. In addition, the technology

underlying smart contracts and blockchains are incontrovertible. This implies that as soon a smart contract has been formed, it can certainly not again have its terms altered in any way. Because of this, applying changes to the code or the smart contract is nearly challenging. It is impossible to conduct a transaction using digital data in a smart contract, such as a payment, without employing cryptocurrency, which is a form of digital or virtual coinage designed to function as a transaction mechanism. It does this by utilizing encryption, which not only helps to keep transactions private and verifiable but also helps to maintain control over the creation of new types of cryptocurrencies. (Fedorchak, 2018)

By leveraging the resources of both the blockchain and smart contracts, a reliable setting for financial transactions might be created using the combination of the two. This article examines how the construction sector might benefit from the advancements of smart contracts and blockchain, and it also analyses the potential resolutions for collapses within the industry that these technologies could provide. A great number of contracts are made between different parties within the building business. The written contracts can take many different forms, including those between an owner and a provider, between a contractor and subcontractors, between a contractor and providers, and so on. Because of this, the business model of this sector is predominately based on contracts, and as a result, there is a significant need for innovative contracting software in order to resolve contractual disagreements and address payment issues in the sector. (Fedorychak, 2018)

2.2.1. Smart Contracts & Traditional Contracts

Conventional contracts, known as paper-based contracts, are the effect of parties engaging in negotiations with one another, going through phases of drafting, requiring the assistance of attorneys, and other such activities. These contracts are designed to present parties with obligations that are necessary to deliver a certain task. The conventional contract is coded in a computer environment to produce smart contracts, which function in the same way as traditional contracts in that they set the responsibilities of the parties involved. In contrast, smart contracts merits place them in a position of superiority over

conventional paper contracts in terms of the fulfilment of contract payment conditions. (Crosby et al., 2016)

Because smart contracts are digitized and based on code, there is no longer a requirement for stakeholders to be physically present in order to create the provisions governing payments; instead, virtual manifestation of the coalitions is sufficient. In addition, a wet signature is being phased out in favour of a digital signature in the means of verifying and signing the terms of the contract stipulations. (Mason, 2017)

Because there is no need for liaison involvement in the smart contract approach, overhead expenses and financing costs are substantially slashed. In addition, costs related to notarization and administration associated with the means of pursuing transactions are reduced. In addition, the cost of transactions involving cryptocurrencies like as “Ethereum” ranges from zero dollars to four dollars at most, which is an extremely cheap cost when related to the fees that banks charge for transactions. (Mason, 2017)

The digitally encoded contract provisions that are recorded in blockchain for smart contracts. Since the contract provisions are private and can only be seen by the parties to the agreement, it is impossible to change the code or otherwise alter the clauses of the contract. The utilisation of “smart contracts” leads to the establishment of a safe and confidential environment, which in turn leads to a decline in the figure of fraudulent contract claims. (Cardeira, 2018)

Because the terms of smart contracts are carried out in a precise manner according to their coding, no place exists for abstruseness inside them. Because the “smart contract” is defined in “blockchain”, all of the data pertaining to the transaction, including the amount of the transaction, reasons for the payment, as well as the transaction date, are registered within a “node” of the system of “blockchain”, which leads to a drop in the number of clashes and ambiguities. (Cardeira, 2018)

Taking use of the benefits offered by smart contracts might dramatically cut the number of payment disputes that occur in the construction business. It is a desirable solution that can save money and time by automating specific components of the execution of building projects. The payment technique during the

phase of procurement of the project is typically the point at which overruns in both costs and timelines are experienced. In addition, parties involved in the project frequently struggle with a further payment issue known as late progress payments. The next chapter will discuss the notion that has been offered regarding the use of smart contracts to reduce the number of payment issues that are experienced in the construction business. (Naughter, 2018)

2.2.2. Challenges

As a relatively new kind of technology, smart contracts are now confronted with a number of difficulties, including those relating to legality, dependence on resources that are located "off chain," immutability, scalability, and consensus mechanisms. (Khan et al., 2021)

Legal Issues

Another important facet of the difficulties presented by smart contracts is the question of legality surrounding them. For instance, the "European General Data Protection Regulation" (GDPR) states that individuals acquire the permission to be forgotten, which is in conflict with the irreversible character of "smart contracts" that are enabled by blockchain technology. Some other legal matters can be mentioned, some of which include the following: (1) It is challenging to maintain compliance with all requirements because Each nation has its own laws and rules; (2) It is challenging to represent legal provisions or conditions in smart contracts in a way that is suitable and measurable for a computer to execute.; and (3) Authorities are interested in the controlled and widespread usage of blockchain technology. (Khan et al., 2021)

Reliance on "off-chain" Resources

Off-chain resources are those resources that are not stored on the blockchain itself. Numerous smart contracts need obtaining information or parameters from these resources in order to be fulfilled. Oracles are utilized as trustworthy third parties for the purpose of achieving this goal. Oracles obtain information that is

stored “off-chain” and then send out that information into the “blockchain” at predefined intervals. The usage of pre-existing oracles, despite the fact that they have undergone extensive testing, may result in the introduction of a “point of collapse.” For instance, an oracle may be unable to disseminate the required information, may supply inaccurate data, or may cease operations entirely. Therefore, before there can be a broad adoption of smart contracts, it is necessary to guarantee that they can accommodate the contingencies. (Levi & Lipton, 2018)

Immutability Issue

Smart contracts are distinguished by a number of key characteristics, one of which is their immutability. As soon as a smart contract has been activated, the computer code behind it will not be altered by the parties involved. But there is a downside to the immutability notion in smart contracts, and that is the fact that if there are any faults in the code, the immutability characteristic of a smart contract prohibits its fixation. This is the fundamental reason why this is considered a “downfall” of the concept. In a similar vein, it is not feasible to edit a smart contract in a straightforward manner in the event that certain conditions arise, such as when the parties to a commercial transaction come to an agreement to alter the terms of the transaction, or when there is a shift in the legal landscape. In order to solve the immutability problem, it is necessary to have in-depth evaluations of the smart contract carried out by industry professionals prior to the contract's deployment in a blockchain. These assessments might potentially be rather costly. (Khan et al., 2021)

Because of the irremediable nature of the blockchain, which is another constraint of the blockchain technology that has an effect on the smart contracts, once a “smart contract” has been implemented, it cannot be modified. In addition, any blockchain node can be hacked or utilized in an inappropriate manner to submit inaccurate data, which will then be permanently recorded on the blockchain. This data cannot be changed. (Khan et al., 2021)

Scalability Issue

For many blockchain networks, scalability is the most pressing issue at the moment. When contrasted with “VISA”, which can handle up to twenty-four thousand transactions per second, the “Ethereum” blockchain, for example, can only authenticate only fourteen transactions in a second, making it much slower than Visa. In point of fact, the scalability problem results in congestion on the network, higher commission rates for transactions, and a lengthening of the amount of time that must pass before the transactions can be confirmed. In the near future, considerable research that focuses on raising the number of transactions that may be managed by “smart contract” platforms is going to be necessary so as to solve the scalability issue. However, the verification of transactions is contingent on the consensus mechanism that is implemented by the platforms for smart contracts. Therefore, the scalability of smart contracts is dependent on consensus procedures, that is another challenge associated with them. (Khan et al., 2021)

Problem of Consensus Mechanism

The consensus process is the most important component of blockchain networks for keeping all three properties—decentralization, scalability, and security—in balance at the same time. There are currently various methods for reaching consensus, such as “Proof-of-Work” (PoW), “Proof-of-Stake” (PoS), and others. While the “Proof of Work” method does make the blockchain more secure, it must waste resources in the process. As a result, many companies have moved away from the Proof-of-Work algorithm and toward other consensus methods, which offer the promise of cheaper fees for transactions and lower energy costs associated with the process of producing blocks. In light of this, subsequent research may make use of novel consensus methods, such as “Proof-of-Activity” (PoA) or “Delegated Proof-of-Stake” (DPoS), in order to evaluate them and, ultimately, enhance the level of quality that they offer. (Khan et al., 2021)

3. Literature Review

In 1994, Szabo coined the expression "smart contract" to describe "an electronic contract protocol that carries out the terms of an agreement". Payment terms, liens, secrecy, and enforcement are all necessary components of a legally binding contract. In order for a contract to be considered "smart," it must reduce the amount of time and energy spent on transactions, as well as the amount of money lost to fraud, spent on arbitration and enforcement, and any other fees associated with the transaction. At the close of 2013, "systems that autonomously move digital content thus according arbitrarily predefined criteria" (smart contracts) were implemented on the "Ethereum" blockchain. Since then, smart contracts have been able to be leveraged to construct application-specific logic. Smart contracts may accommodate complex requirements, allowing developers to create robust decentralized apps with integrated domain-specific features. Blockchain applications can save data in a key-value format that is particular to a certain domain by developing and implementing smart contracts for that domain. As a result, besides production control, law enforcement, E-government, and healthcare may all benefit from using these contracts. Decentralized applications (DApps) and autonomous organizations (DAOs) are two concepts that have emerged because of the widespread use of smart contracts (DAO). Often thought of as an application of smart contracts with a user interface front end, a "DApp" is a computerized program that proceeds on a decentralized peer-to-peer network. When the smart contract is implemented on a blockchain, they may be managed independently of the DApp's creators. Idealistically, a "DApp" would operate autonomously, becoming a DAO. A DAO makes decisions autonomously based on smart contract rules, with all supervision and guidelines recorded on the blockchain. By using the DAO, autonomous, decentralized, transparent, and competent operations can be reached. (Szabo, 1994)

The notion of intelligent contracts in the construction sector has evolved over time. The term "smart contracts" is "used interchangeably for the typed program and the legally enforceable contracts," specifically "smart contract codes" and "smart legal contracts," according to a definition from 2015. The construction sector currently lacks a unified description of smart contracts. They are

sometimes characterized as "codes for a smart contract" or both in the literature. Evidently, construction researchers have high expectations for the digitization of building contracts. Mason (2017) advocated using "Automated contracts", when a contract tries to regulate itself as a means of avoiding human oversight. An "intelligent contract" (or "iContract"), which may "handle itself with the means of a hybrid legal clause", has been proposed as the next stage in the digitization of construction covenants. After some time, the term "intelligent contract" came to mean "an application of those smart contracts that strive to strictly correspond with conventional contracts". Li and Kassem (2021), (McNamara & Sepasgozar, 2021)

3.1. Planning Phase of Construction

During the planning phase of a construction project, the most noticeable manifestations of blockchain integration are smart contracts and construction coins. Numerous experts have identified smart contract as one of the most effective blockchain-based solutions in the building sector, with one stating, many of the issues plaguing this sector of the economy might be ameliorated with the use of this blockchain technology. This technology, if successfully developed, may be applied not just in the phase of planning, but in all project-related phases of the building project lifecycle. The fact that Construction Coin stores complete record of past transactions stored in blocks, thereby preventing information falsification and tampering, has far-reaching implications. Currently, "Construction Coin" is only a currency for payment, but it has far-reaching significance because it prevents information falsification and tampering. Some construction coins, such as (HDAC), "Hyundai BS&C's Hyundai Pay", are currently in the development phase and commercialization is anticipated within the foreseeable. (Kim et al., 2020)

3.2. Blockchain & BIM

Blockchain technology can also be integrated with BIM models through many phases of a project. A few of these phases are designing phase, phase of bidding, implementation phase, and operating phase. (Belle, 2017)

In regard to the design phase, it is possible to communicate and distribute all of the details of the project through a centralized digital service thanks to the design levels preparation that is based on BIM methodologies. The inclusion of these digital methods with the decentralised blockchain database renders it possible to produce a process that is truly collaborative and narrows the break between digital data modelling and the management of project information, which is produced mainly in sheets. Details pertaining to administration, finances, and coverage are included here. Through the use of smart contracts, automated payments may be linked to model data, ensuring a thorough execution of engineering and architectural service contracts and, by extension, the respect of the needs of all parties. In this light, the traditional BIM model is no longer considered to be a cloud-based, third party-controlled hub for centralized data exchange. Instead, it is seen as a platform for decentralized data sharing, wherein each user has absolute and unchangeable sovereignty over their own data. (Belle, 2017)

Informational stages comprise conceptual, schematic, detailed, and contract papers within the design process. Designers share this data with Contractors and Client. In this phase, blockchain may be utilized as a distributed network to set up a trustworthy link for consumers, contractors, and other stakeholders to share files. With the utilisation of a blockchain and its related chain, “smart contracts” may make financial transactions more open and swifter. During the project's preliminary stages, several design packages must be defined. In addition, services are used to smart contracts as a method of executing transactions in accordance with the business plan and delivering on the project's tasks on time. (Dakhli et al., 2019)

The suggested Blockchain architecture is applicable in a linear path from the first to last stages of construction. Understanding the role of financing and information-sharing mechanisms in the building development is facilitated by this

structure's design, which in turn advances knowledge of blockchain and its technology that is state-of-the-art. Considering transaction fees, paperwork, and building permissions, as well as the elimination of third parties, a combination of blockchain and BIM can lead to substantial savings. (Celik et al., 2023)

Figure 2 shows how a Blockchain system might facilitate communication and collaboration amongst several design disciplines during the planning stage, and it identifies the following activities:

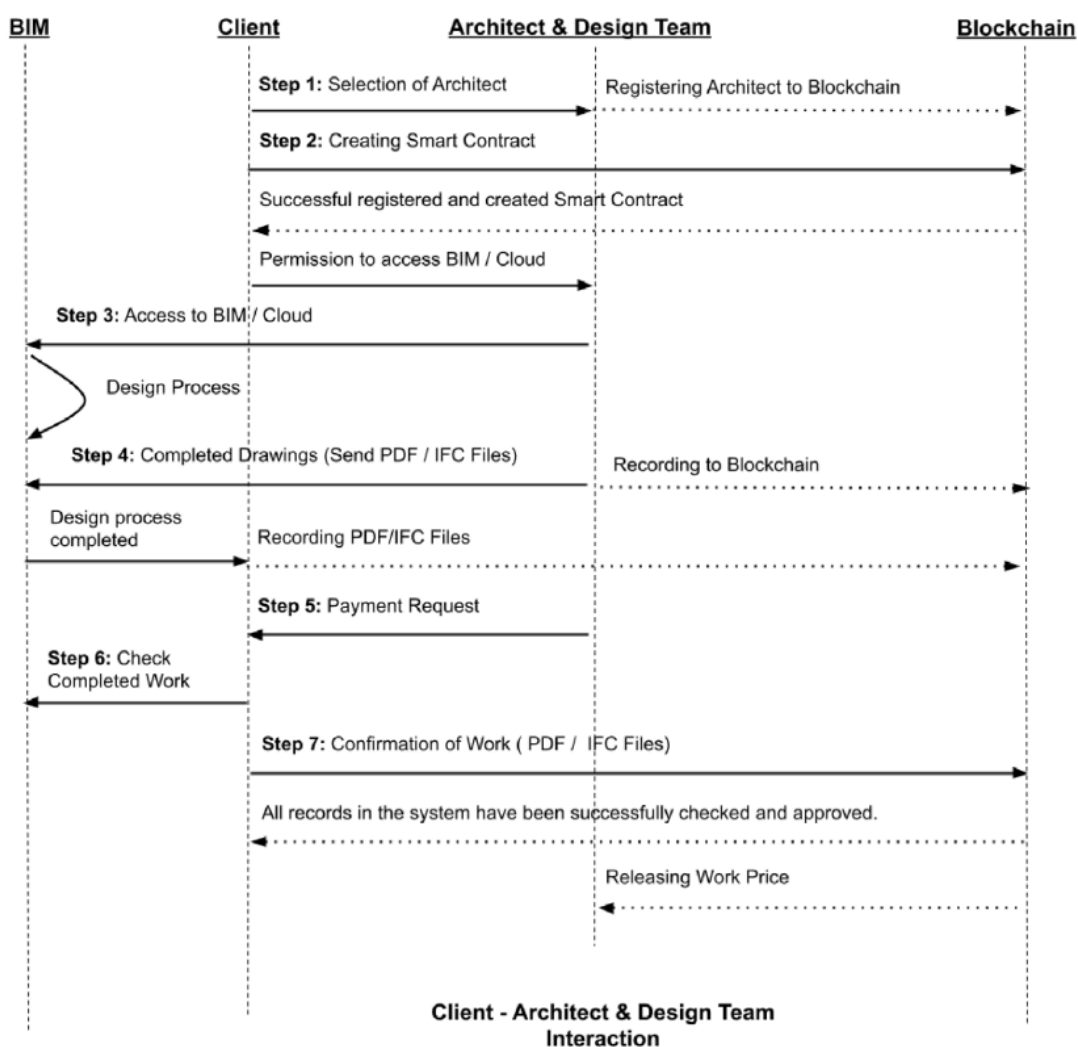


Figure 2. Design Team and Client's Blockchain Structure

1. A deal is reached with a qualified designer who will preserve their involvement in the development.
2. Digital details, such as hash and digital address, will be sent between the Client and the Architect so as to initiate the smart contract creation

process. When the smart contract is set, it will be uploaded to the blockchain, and the registration procedure will begin.

3. The designer will be given access to the BIM/Cloud system so that he or she may contribute to the project's designs.
4. The architect will send the client a preliminary version of the project. The Client will review the document and provide comments on whether or not it meets their needs for the project. The Architect will then finalize the blueprint after considering all comments. When the process of design is complete, the designer will export the model to a BIM configuration and provide the client with an IFC-format file.
5. Once the architect has verified that the drawings are complete, he or she can submit a request for payment.
6. The Client will send the money so that we may verify the drawings. If the architectural design doesn't require any further revisions from the Client, the procedure ends when the Client signs off on it.
7. The customer will upload the PDF/IFC design files to the Blockchain network to create a fixed record of the data's history. After the Architect has been paid, the smart contract may notify both parties and add the transaction to the blockchain. (Celik et al., 2023)

All of these transactions are recorded on the same Blockchain network, allowing smart contracts to be activated for payment and progress reporting on projects. Today's building sites use methods extremely similar to this one. Each work sequence and its associated payments made in the field for authorization and completion of the job are logged and monitored thanks to the underlying automated and immutable layer of Blockchain. This will allow for the processing of payments from the account specified for the project, and the establishment of a clear flow of value at the base of the supply chain. (Celik et al., 2023)

As for the bidding phase, the mere existence of a distributed ledger, within which all data is maintained in a manner that is visible, permanent, and accessible, helps to control any misunderstanding that may emerge due to the many inconsistencies that arise throughout the procedures for tendering goods and services. The adoption of digital tools offered by a distributed platform, which is characteristic of the Blockchain technology, would make it feasible to store all

the primary tender documents in an unchanging manner. This would include the information models presented both by the client and by the bidders. The process that has been explained above ensures that the client's released tender papers are both unchangeable and completely open to public scrutiny. All of the participants have access to the processes and standards that will be used to evaluate the bids. This ensures that the rationale for the awarding of the contract is transparent and removes any possible room for operational confusion. All the participants will have the opportunity to view all of the bids and evaluate them in light of the predetermined award criteria. This will ensure that there is efficient competition and give all parties involved the prospect to observe all of the bids. The client will only be able to access the bids at the conclusion of the phase in which they are received. (Graham, 2019)

While regarding construction phase, the production of models in both 4D and 5D dimensions makes it possible to update and monitor the progress of the building phase. The BIM model enables us to gain a realizing of the current stage of the building tasks, and the continuous recording of information enables us to gain an understanding of the causes of any delays or cost overruns and to track individuals responsible for causing them. In this manner, the customer is able to exercise control over the real operations that are progressing, and the rapid and open sharing of information regarding the building site is made possible. The use of blockchain technology through the building task is also helpful in influencing the supply chain. Resources that reach at the construction site are tracked along their entire journey, and as a result, in the event that there are flaws or delays in the construction, one is able to review each stage of the processing that was saved on the blockchain database and then linked to it on in the inside through the BIM model. In conclusion, the accurate performance of the Smart Contract is enabled by the record of information on the supplies and the progress of the task. Because of the relationship that exists between the information model, also known as the progress of the activities, and the computed contract, it is possible for automated payments to be delivered whenever a milestone that was established by the work program is completed. (Di Giuda et al., 2019)

After the phase of construction of the project has been finished, the as-built model of the structure may be created. This model will include all of the information that is relevant to each component that was designed and built. The deployment of a BIM model that is based on blockchain technology makes it easier to adhere to the bases of a circular economy for the entirety of the asset's life cycle. Some of the building component data that was acquired during the implementation phase and kept in the distributed record can provide assistance for future maintenance, replacement, and dismissal actions that will take place during the operational phase. Because the BIM model can be used as a database of materials thanks to the ongoing conservation of components and maintenance status updating, this makes it feasible to assist a significant decrease in waste and contributes to a more environmentally friendly built environment. Additionally, the existence of system terminals that are outfitted with smart layouts enables one to conceive of the possibility of executing a Smart Contract for the purpose of doing maintenance tasks on plant devices within the building. In point of fact, once the treatment has been carried out, the maintenance worker will be able to input the activity that has been carried out into the machine. This will certify that the Smart Contract terms have been met, which will then cause the money to be released automatically. (Di Giuda et al., 2019)

3.3. Smart Cities & Blockchain

Many initiatives may be seen in the design and operations and maintenance stages of the smart city and logistics fusion uses of new technologies like blockchain. It is expected that blockchain technology in its many incarnations would be used in the building and upkeep of smart cities. Some customs and distribution management applications are among those in the logistics sector where blockchain is already in use. Several initiatives can be seen in both the development and operation/maintenance stages of the well-known fusion applications of emerging technologies like blockchain in smart city and logistics. It is expected that blockchain technology in its many incarnations would be used in the building and upkeep of smart cities. Some blockchain solutions have

already been implemented in the logistics industry, particularly in customs and distribution management.

Another idea, known as the Internet of Things (IoT), has been developing in conjunction with smart cities. The number of connected technologies and gadgets is advancing at such a dizzying rate that, in the not too distant future, we may come to view them as being precisely located in the core of the solutions for smart cities. As a result, it is extremely important to meet the security requirements and improve the service quality of a wide variety of Internet of Things applications. Devices connected to the internet of things provide several advantages to society; nevertheless, many organizations and corporations are still hesitant to adopt them. In recent years, the vast majority of Internet of Things devices have been put to use as messaging applications due to their user-friendly features and centralized communication structures.

Due to the costs that are involved with centralized clouds, several IoT elucidations are fairly pricey. When such a framework is not established by the merchants, the cost emits through intermediaries. In traditional applications, it is frequently believed that all of the intelligent devices are trustworthy and willing to cooperate with one another. In reality, however, Internet of Things devices may operate in a hostile manner with the intention of interrupting the services provided by the network. The breaches of privacy protection that are present in electronic voting systems, in particular, lead to a significant concern in which unauthorized individuals may commit a variety of electoral frauds in order to manipulate the results of the vote. As a result, one of the potential challenges is going to be to differentiate between the good IoT devices and the bad IoT devices to set up a genuine communication environment. In addition, to stop data from being altered in the future after it has been gathered by smart devices, a distributed ledger called a blockchain is kept updated with the blocks of every legal Internet of Things device. The need for transparency, which is being expressed in an ever-increasing number of ways, may be satisfied through the utilisation of the blockchain technology. In addition, it has the capability of ensuring transparency and security among the devices, even when IoT items may be hacked by attackers. This is because any alteration with the data can be immediately noticed by the system. In addition, the Blockchain

technology may be applied to the tracking, organization, and support of communications. This is accomplished by saving the data from a multitude of devices and simplifying the creation of parties without the need of a centralized cloud. (Rathee et al., 2021)

3.4. Supply Chain Management and Smart Contracts

The blockchain technology can make supply chain management more efficient and effective for businesses. When integrated with, for instance, Internet of Things (IoT) devices, it might provide dependability, traceability, and accurate information, facilitating the automatic movement of information and materials across the supply. In addition, it provides five advantages for establishing the following aspects about a product: its nature, its quality, its quantity, its location, and who currently owns it. The data associated with these variables, from the source material to the final sale, is then stored on the blockchain. (Saber et al., 2019)

There are a wide variety of players involved in the construction sector, and these players need to work closely together in order to be successful. The construction sector has been reluctant to adapt to technological improvements, but blockchain technology offers various implementations that have potential futures. One of these applications is the addition of smart contracts to blockchain. At this time, the construction sector is not making significant headway with regard to the utilisation of smart contracts and blockchain technology. The industry as a whole and its players have low levels of confidence in their ability to bring about change, and the industry as a whole has poor levels of technological literacy. Despite the paucity of research in blockchain applications in the building sector, the studies that have been conducted suggest that there is room for growth. Actors will be capable of cooperating thanks to the deployment of smart contracts more readily, and projects will be able to be broken up more quickly without requiring any manual administration. In addition to this, there is the automated settlement and clearing out of trades that take place between actors. (Bjorklund & Vincze, 2019)

The research by Lanko, Vain, and Kaklauskas is one example of a study that has addressed the use of “blockchain technology” in the building business, more especially the “ready-mixed concrete” (RMC) industry (2018). In the course of their research, the authors studied the possibility of enhancing the delivery of ready-mix concrete by employing RFID technology in conjunction with blockchain technology and exploring the possibilities offered by smart contracts. Increased confidence between parties, better supply chain efficiency, and the potential for robotic ready-mix concrete delivery are just a few of the benefits. If blockchain technology is adopted on a global scale, it has the potential to build trust between parties and boost transparency. This, however, is contingent on the development of a worldwide blockchain, something they admit is “idealistic” in today’s building industry. In addition, they claim that a globally decentralized system, also known as a global blockchain, will dramatically increase effectiveness in the supply chain, eliminate superfluous linkages, and lower the downside impact that a human influence can have on the supply chain. In conclusion, they state that the deployment of smart contracts, RFID technology, and “blockchain technology” will cause a rise in automation, a reduction in losses caused by human influence, a reduction in misinformation, and the elimination of trust issues that are currently present in the supply chain. This effect can be seen throughout the supply chain, both further upstream and further downstream. (Bjorklund & Vincze, 2019)

Mason and Escott’s (2018) study was yet another investigation into the utilisation of smart contracts in the building business in the British market. They came to the conclusion that in order for there to be any possibility of broad deployment of smart contracts and blockchain technology, there has to be understanding of the technology as well as consensus on the utility of it. This is a prerequisite for any potential success in this endeavour. According to the findings of their investigation, building companies have extremely poor levels of expertise concerning the technology that is being used. In addition, the businesses that were questioned on the feasibility of utilizing smart contracts in the building sector expressed a low level of optimism regarding this matter. Mason and Escott (2018) came to the conclusion that the technology must first reach a certain level of maturity before it can be beneficial. In addition, Mason’s (2017) research

uncovered nine characteristics that need to be addressed before the use of smart contracts in the construction industry can be considered a feasible option. The precise characterization of the problem, the identification of unsatisfactory regions within the construction sector, and the development of a unified implementation plan for the technology were the most critical elements. (Apte & Petrovsky, 2016)

3.5. Smart Contracts in Project Management

The benefits of blockchain technology extend, also, to the field of project management. Blockchain technology can be implemented in various sectors. Many cases of use are investigated in order to determine the actual contributions that blockchain technology may make to the administration of projects. Research revealed that the regarded contributions of the blockchain to project management can be broken down into four primary categories. These categories are as follows: establishing trust; enhancing communication; reducing the number of disputes and claims; and eliminating fraud. Based on the research of cases of use, it appears that blockchain technology has a significant potential to make significant contributions to the administration of projects in a variety of ways. (Sonmez et al., 2021)

Trust is a significant component to the success of any project undertaken in the construction business. The use of blockchain technology can facilitate the development of trust between parties involved in a project by producing a record that cannot be altered and is completely open to public inspection. Since everyone working in the project has access to the same information and can be certain that it is correct, this might be beneficial in reducing the likelihood of disagreements and misunderstandings occurring. When there are several parties engaged in a construction project and it is spread out across a vast geographic region, it can be difficult to maintain effective communication, which is a vital element of every construction endeavour. The use of blockchain technology has the capability to enhance communication by providing all involved parties with a safe and open forum in which they may exchange information and work together on a project. (Sonmez et al., 2021)

In the construction sector, conflicts and claims are a frequent occurrence, and they frequently stem from misunderstandings or arguments over the terms of a contract or the scope of a project. The creation of an immutable and transparent record of all transactions and activities linked to the project can be one way that blockchain technology can contribute to a reduction in the number of disagreements and claims that arise. This may be helpful in preventing misunderstandings and ensuring that all stakeholders are kept up to date about the development of the project as well as any changes to the scope of it. There is a big issue with fraud in the construction business, which results in the annual loss of billions of dollars due to fraudulent actions. The use of blockchain technology can assist in the prevention of fraud by producing a record that cannot be altered and is completely open to inspection of all the transactions and activities that are associated with the project. This can assist in the identification of fraudulent actions in a timely manner and help avoid their occurrence in the future. (Hargaden et al., 2019)

3.6. Payment, Procurement, and Smart Contracts

One of the phases of a building project that requires a significant amount of time is the procurement phase since it involves many contracts. As a result of the possibility that the buyer and seller have never managed to complete a transfer of funds together in the past, it is necessary for there to be confidence between the parties involved, or for third parties such as notaries, banks, intermediaries, etc. to establish that confidence. Third parties, such as banks, can more easily create confidence between parties with the help of a document known as the LoC, a letter of credit. When a bank agrees to provide a seller an LoC, it is guaranteeing that the seller will be paid after the delivering conditions have been completed and the goods has been turned over to the buyer. A letter of credit typically involves four parties: the buyer (applicant), the seller (beneficiary), the lender (issuing bank), and the lender's financial partner (advising bank). The requirement of the procurement process and how it works is demonstrated with the help of an illustration taken from the procurement phase of the building sector. (Eker, 2018)

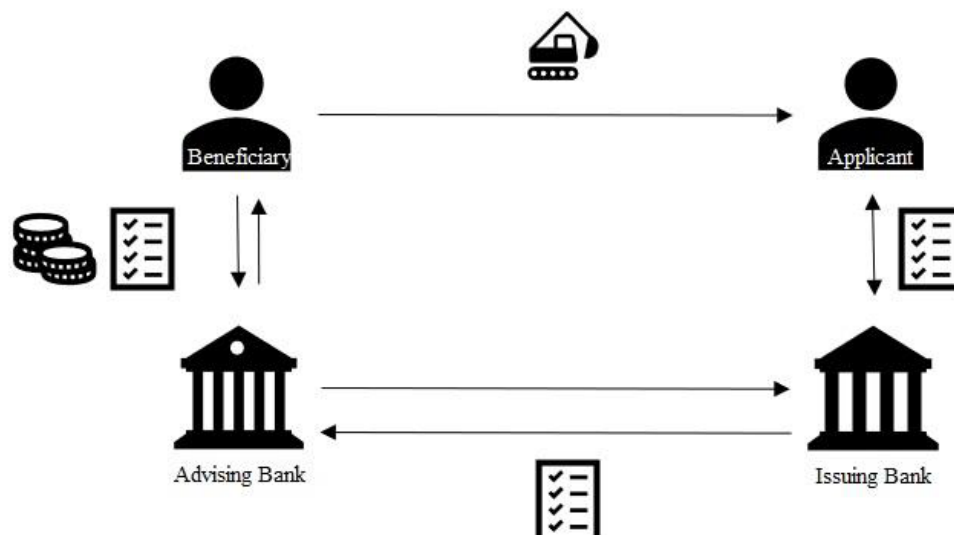


Figure 3. Letter of Credit Document Process

According to what is shown in Figure 3, party A (the applicant) is interested in importing a piece of machinery, whereas party B (the beneficiary) is the machinery's exporter. To begin, the two parties must create a contract and reach an agreement on the terms and conditions that will be included in the LoC form. The LoC is requested by the A party from the issuing bank in the presence of the Y party. The paperwork for the LoC is created by the issuing bank in accordance with the terms that have been agreed upon, and it is then forwarded to the advising bank. The issuing bank has a legal responsibility to pay the total amount of the transaction on the date that was previously agreed upon. The advising bank verifies that the LoC document is accurate and communicates with the B party on the parameters outlined in the LoC. B party is responsible for notifying the advising bank that all of the terms and conditions outlined in the LoC have been satisfied after the machinery has been delivered to the A party. The letter of credit is then forwarded to the issuing bank by the advising bank, and the issuing bank checks to ensure that all of the requirements outlined in the letter of credit document have been satisfied. Through the advising bank, the payment will be made to the B party. The delivering party (A) is given the delivery documentation when the issuing bank has confirmed receipt of payment from the delivering party (A). (Eker, 2018)

Although the LoC helps to reduce payment risks within a transaction, it is not without its drawbacks. The LoC procedure may be lengthy and costly, costing as much as 4 percent of the entire price of the products bought in bank fees alone. (Reilich, 2018)

Due to the decentralized nature of the technology behind the smart contract, intermediaries like banks may no longer be necessary throughout the transaction process. When smart contracts are used during a project's procurement phase, the parties to the contract can utilize machine learning to automatically determine when and how much money is owed. The smart contract includes the price of the equipment, materials, or other goods that must be paid for. The system might also be programmed with the date payment is due. Smart contracts are transparent, allowing both parties to ensure that the agreed-upon payment amount is safely stored away in the system until the agreed-upon payment date. As the product is ordered away, the exporter might notify the importer using the smart contract. In addition, the importer may inform the exporter of the delivery of the required products. The amount payable will be instantly transferred to the exporter's bitcoin account thanks to the self-executing functionality of the smart contract as soon as both parties validate the programmed requirements within the system. One possible upside of using smart contract technology in the buying process is the one listed below. Since there is no third party to negotiate terms, like a bank, there is no requirement for a letter of credit (LoC). As a result, the substantial costs associated with pursuing the procedure, including payments to mediators and administrative costs, are greatly reduced. Smart contracts have several benefits during the procurement phase of construction, including expedited approval and payment transactions, protection against payments being withheld, and a secure payment setting. (Cardeira, 2015)

3.7. Smart Contracts Primary Benefits in Construction

If the capabilities of smart contracts are adapted to the needs of the construction sector, it is envisaged that they will be able to resolve or significantly

mitigate a number of critical issues and offer a considerable boost to the progress of the project. The following is an overview of these potential primary benefits:

3.7.1. Payments

One of the most significant issues that plague the construction sector is payments. It is anticipated that the most major benefit of using smart contracts would be the elimination of issues pertaining to payments. The smart contracts for the project are written in the form of coding and are composed of the milestones and activities. When these predetermined activities and milestones are completed, the blockchain system enables smart contracts to be activated by sensors, which enables those contracts to make instant payments. This affords construction projects the ability to reduce the likelihood of conflicts about payments, which are one of the most common types of issues that arise with traditional contracts. One of the most significant issues that plague the construction sector is transactions. It is estimated that the most major benefit of using smart contracts would be the elimination of issues pertaining to payments. The normal sequence of steps to make a payment successful through the construction industry is factually explained in the following figure 4. (Blycha, 2018)

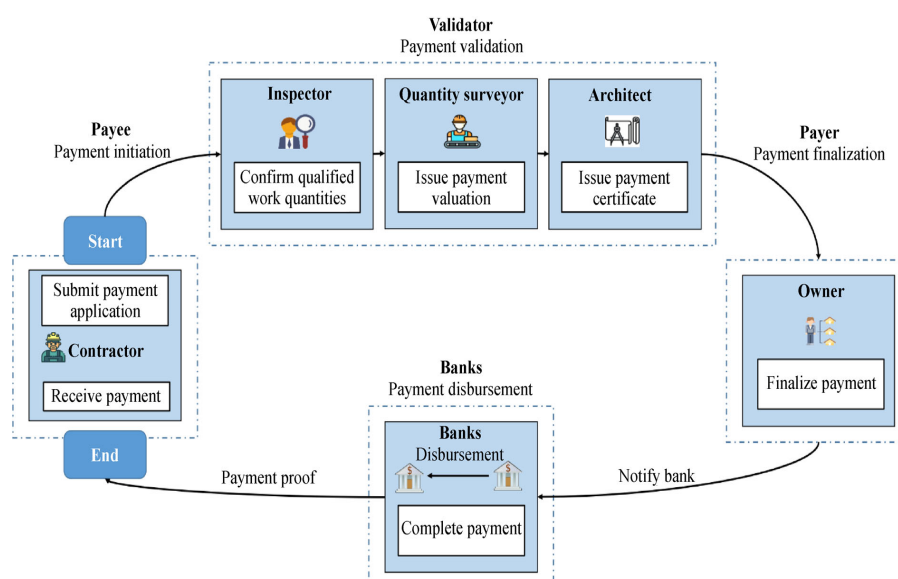


Figure 4. Normal steps sequence for a successful payment through the construction industry

The manner in which a contractor is paid for work that has been completed as per an agreement is depicted in the figure that was just presented. The procedure begins with an inspection from the consulting side of the project, which is then followed by quantity surveying, which in turn authenticates the done quantities of finished jobs with their respective pricing. At that point, the calculations necessary to determine the revenues of the contractor are finished. When this condition is met, and only then, a payment certificate may be produced. This allows the owner to complete the payment and inform the bank that is responsible for distributing funds to parties in the form of payments. When all of the preceding steps have been successfully completed, the payment procedure will come to an end when the money is transferred to the bank account of the contractor. (Blycha, 2018)

3.7.2. Cost and Time

Smart contracts eliminate the need for human oversight and involvement in the transaction execution process. As a result, the contract's expenditures for monitoring and carrying out the terms of the agreement are unnecessary. The transaction fees paid in smart contracts are also far lower than the fees paid to the bank in conventional contracts. Similarly, they head off any potential tension between the two parties. Because of this, they help cut down on project costs and timeframes. (Ahmadisheykhsarmast & Sonmez, 2018)

3.7.3. Contingent Probability of Error

Errors in the manufacturing of contracts are eliminated when codes are used to create smart contracts, and the process of creating these codes is automated. They also prohibit individuals from interpreting a contract in a manner that is inconsistent with one another. As a result, they provide the possibility of lowering the number of mistakes caused by humans while also eliminating the need for human interaction. (Mason & Escott, 2018)

3.7.4. Backup, Archiving and Safety

When it comes to traditional contracts, the parties are responsible for archiving and backing up the data individually. On the other hand, smart contracts take advantage of aspects of blockchain technology such as digital archiving, backup, and cryptography. The data pertaining to the project is immediately accessible to all parties involved in the blockchain network, and they can save it in their own archives. In addition, the data is encrypted using cryptography on each individual block. As a result, the undertaking is somewhat insulated from any potential assaults. (Smart Contracts, 2017)

3.7.5. Bankruptcy Avoidance

When traditional contracts are used, one of the primary reasons why construction businesses go out of business is because they fail to make timely payments to the involved groups in the project, which leads to a decline in the quality of cash flows at the respective businesses. It is anticipated that smart contracts would safeguard project stakeholders from personal bankruptcy, guarantee the money for the project, make sure that payments to suppliers and project stakeholders other than the customer are timely produced, and guarantee that payments are made on time. Additionally, the instant realization of payments will alleviate cash flow issues that are currently being experienced by businesses. (Cardeira, 2016)

Automating the payment process is one of the ways that "smart contracts" can help to avoid businesses from going bankrupt. When two or more parties come to an agreement, those parties have the ability to stipulate the conditions under which payments will be paid, as well as the terms of payment. For instance, if a company is in the process of delivering a product or service to a client, the smart contract may be programmed to immediately initiate payment upon the accomplishment of predetermined milestones, such as the handing over of finished work or the shipment of items. This may help to guarantee that businesses receive their payments on time, which in turn can assist them in avoiding issues with their cash flow and the possibility of going bankrupt. (Cardeira, 2016)

Another way that smart contracts can prevent bankruptcy is by providing transparency and accountability. Smart contracts are designed to be transparent and accessible to all parties involved in the transaction. This means that all parties can see the terms of the agreement, the conditions under which payments will be made, and the status of the transaction in real-time. This can help to prevent disputes and misunderstandings, as all parties have access to the same information. Additionally, smart contracts can help to ensure that all parties are held accountable for their obligations under the agreement. For example, if a party fails to make a payment as specified in the smart contract, the contract can automatically trigger penalties or other consequences, which can help to ensure that all parties fulfil their obligations. (Altay & Motawa, 2020)

In conclusion, the increased efficiency and scalability that smart contracts offer can be an asset in the fight against bankruptcy. Contracts that are "smart" can be pre-programmed to carry out a broad variety of activities automatically. These activities can vary from the relatively straightforward processing of payments to the administration of assets and supply chains. This can assist firms in streamlining their operations and lowering their costs, both of which can help improve their overall financial health and minimize the likelihood that they would declare bankruptcy. (Altay & Motawa, 2020)

4. Case Study 1: Vinci and Skanska Blockchain Tool

Skanska is a well-known corporation that works all over the world in the building and development industries. The firm has a long and illustrious history, dating back to 1887, and has developed into one of the most important participants in the building and construction sector. The corporate headquarters of Skanska can be found in Stockholm, Sweden; however, the firm has activities in over 80 sites throughout the globe, including the United States of America, Europe, and Asia. (Gibson, 2022)

Building construction, civil engineering, the development of infrastructure, and commercial property development are some of the primary areas of competence that the organization possesses. Skanska is well-known for its dedication to environmentally responsible as well as socially responsible business practices. The firm makes it a priority to guarantee that the communities in which its projects are situated, as well as the surrounding environment, benefit from the work that it does. (Gibson, 2022)

As for Vinci Construction UK, it is a long-standing construction firm with its headquarters in the United Kingdom. It is a subsidiary of the broader Vinci Group, which conducts business in more than one hundred countries throughout the globe. Since its founding in 1946, Vinci Construction UK has maintained a dominant position in the competitive construction industry in the United Kingdom. (Gibson, 2022)

The firm provides a comprehensive variety of services, such as building and maintenance, in addition to civil engineering and administration of facilities. Its undertakings span a wide variety of fields, including commercial and industrial work in addition to educational and healthcare endeavours. Vinci Construction UK is dedicated to delivering projects of the highest possible quality that are also sustainable and friendly to the surrounding environment. (Gibson, 2022)

The importance that Vinci Construction UK places on technological advancement and innovation is one of the company's most notable qualities. Building Information Modelling (BIM) and off-site manufacturing are just two examples

of the cutting-edge technology that this organization use in order to boost productivity and cut down on waste. This strategy has made it possible for the organization to successfully complete difficult tasks in a more timely and precise manner. (Gibson, 2022)

4.1. Introduction

Recent developments in blockchain technology have the capability to revolutionise the construction sector by enhancing transparency and enhancing efficiency. Historically, the building industry has been sluggish to accept new technologies, but these developments have the ability to change that. Both Vinci and Skanska are prominent participants in the construction business, and together they have formed a partnership to develop a blockchain-based tool with the goal of improving the effectiveness and openness of the administration of building projects. This project was undertaken with the intention of developing a tool that would simplify processes, lessen the likelihood of errors and disagreements, and strengthen communication between various stakeholders. (Electricbloomhosting, 2019)

Beginning in March 2018, a project that would last for two years and be funded by the United Kingdom's Research and Innovation organization sought to develop a proof-of-concept version of a toolkit that would be referred to as PLASMA. This toolkit was intended to enhance the efficacy of the building process regarding planning and supply chain management. (Electricbloomhosting, 2019)

It is built on a blockchain platform and has the goal of increasing construction productivity. This will be accomplished by improved project planning, enhanced cooperation within the supply chain, and data assessment of supply chain and IoT data.

Planners are given the ability to develop and numerically practice several project delivery situations, such as sequencing, critical routes, and logistics, with the use of this application. This mitigates risk by taking into consideration

context-specific constraints and "pinch spots" in the supply chain, such as locations where additional capacity or automation might enhance overall efficiency.

PLASMA also makes it possible for firms throughout the supply chain to collect, distribute, and retain data that is resistant to tampering without the requirement for centralized control and administration. The gadget allows for change management and progressive payments to be performed using smart contracts, and it allows monitoring of components such as work accomplishment via current IoT-based data options. Additionally, the tool allows tracking of aspects such as task completion. (Electricbloomhosting, 2019)

Furthermore, the technology will also make it possible to generate quantifiable key performance indicators (KPIs) that are unique to construction supply chains. These KPIs will identify best practices and the span of performance throughout the industry. KPIs may be linked to and used as benchmarks for a wide variety of tried-and-true methods for performance enhancement as well as forward-thinking technologies like robots and mechanization.

A spokeswoman for Vinci stated, "It is difficult material, and the idea is to demonstrate 'proof of concept,' and then work towards producing a tool that provides savings of 25 percent at the end of it". The project as a whole is evidence of Vinci's commitment to improving construction processes and moving the industry forward via innovation. (Electricbloomhosting, 2019)

According to Sam Stacey, head of the Transforming Construction Challenge UKRI, The Industrial Strategy Challenge Fund supports innovative projects like PLASMA, which play an essential role in hastening the sector-wide transition. Because of this, the building industry will be capable of engaging closely with smart inventors to test out novel approaches to constructing that can reduce costs without sacrificing quality. (Electricbloomhosting, 2019)

4.2. Description

The Vinci-Skanska blockchain tool is a safe and secure platform for managing construction projects. It makes use of blockchain technology to create an unchangeable record of all transactions and modifications made to the project. The application is equipped with a number of features that facilitate the automation of operations and the enforcement of agreements between parties. These features include real-time tracking, smart contracts, secure document management, and payment administration. (“*VINCI Construction UK*,” 2019)

Smart contracts are a type of executable contract in which the terms of the agreement are written directly into computer code. They contribute to the removal of the requirement for intermediaries and assist to lessen the likelihood of errors or disagreements occurring. The Vinci-Skanska tool makes use of smart contracts in order to automate important operations and ensure that parties adhere to their agreements.

Another important function that is included in the Vinci-Skanska solution is secure document management. The blockchain serves as a repository for all construction-related documents, including contracts, invoices, and change orders. This creates an immutable record of all construction-related transactions and modifications. (“*VINCI Construction UK*,” 2019)

The Vinci-Skanska tool includes a number of useful features, one of which is real-time tracking. It gives project managers the ability to monitor the development and performance of their projects in real time, which helps them to spot possible problems and take remedial action much more rapidly.

The tool has a payment administration system, which is another key function. The platform includes a payment management system that enables project managers to monitor and handle payments in an open and organized manner that is both efficient and transparent. (“*VINCI Construction UK*,” 2019)

4.2.1. PLASMA

When the partners were testing PLASMA with the Singapore Port Authority, that's when they made the major breakthrough. They found that the scenario-creation and task-sequencing capabilities of PLASMA could save time and administration by automatically planning for and notifying a site team about any international tariffs that they may be incurring. This is in contrast to manually monitoring or paying them after the fact, both of which are administrative burdens. In addition to making preparations for these tariffs, PLASMA could also investigate the country of origin of their shipments. Companies are placing a greater emphasis on knowing the origin of their products as the industry adjusts its focus from finding the lowest cost and quickest delivery to finding the best overall value. (Gibson, 2022)

The digital "toolbox" was developed in response to requests from customers, and the team saw its potential. PLASMA had the capability of providing rich data regarding supplies, starting at the very beginning of their voyage, continuing throughout their movement, and eventually informing teams about their safe and undamaged arrival, as well as giving back any defects or flaws that occurred along the road. The partners eventually discovered that the instrument they had at their disposal was about a great deal more than just the current standing of a contractor's order. It is possible to follow a whole supply chain, which would create more transparency about the products that are acquired. (Gibson, 2022)

4.2.2. Innovation

With its manufacturing and modular optioneering tool, PLASMA promotes uniformity in constructing approaches. Optioneering is guided by data and gives the end user with a variety of alternatives based on a level of rigour comparable to that of engineering procedures. Building on Skanska's "flying factories" concept (which enables off-site production through temporary and adaptable facilities), the partners sought to push the limits of data-driven, intelligent supply chain management. The application will map and plan construction projects using Design for Manufacturability and Assembly (DfMA). Due to the nature of

DfMA, building projects may utilize a platform-based strategy, repeatable, streamlined procedures, and a manufacturing regime. The primarily self-service digital platform has been created with user testing/feedback/input to allow industry professionals to adopt data-driven procedures and make educated decisions. Currently, the optioneering part of PLASMA is being tested on Skanska's £160 million Blossom Street site, which employs a combination of offsite and contemporary building techniques. (Gibson, 2022)

4.2.3. Operation and Interface

A smart and digital "SatNav," PLASMA collects data during the whole lifespan of a structure and then communicates it both up and down the supply chain. It accomplishes its goals by doing data analysis on the information collected by on-site sensor networks and supply chain tracking systems. The data then creates a 360-degree view of the entire build, allowing for the planning of the most effective program, the identification of the most suitable suppliers, the incorporation of modern methods of construction approaches (MMC), and the suggestion of workflows that have the smallest carbon footprint. (Gibson, 2022)

Within the application, project teams have the ability to place orders, generate invoices, and send requests to the whole supply chain. This keeps everyone apprised of the status of the project as well as its interdependencies. Digital records of all transactions make it possible for suppliers and contractors to view received orders and take appropriate action on them. The data is continually updated with the most recent information from the sites and providers. Additionally, members of the project have the ability to contribute supporting information, such as compliance with health and safety regulations, routes and bottlenecks that could delay orders, or do damage to orders. If a supplier causes a delay in the supply chain, the tool will be able to rapidly recommend alternate solutions in order to keep the project on track. (Gibson, 2022)

The tool is also capable of carrying out smart contracts and authorizing rapid payments, hence boosting trust and confidence all throughout the supply chain in addition to being secure. PLASMA generates a registration and

authentication for any individual who has a need for access and control on the system. This might vary from client to supplier to site manager, and each party's access will be tailored to meet their respective requirements. Because PLASMA is a mobile application, all that is required to use it is a computer or a phone. PLASMA may be put to use right away because it does not require any new equipment purchases on the part of clients or contractors. Building upon BRE's tag and track tool, the mobile app includes barcodes and QR codes to enable tracking, as well as the uploading of documents and photographs and the linkage of them to order numbers. The contractor would be able to submit and track orders, while the supplier would be able to log in to examine the orders that they have received and need to process. It is also compatible with existing systems that are used by the partners, which means that PLASMA has consistent components, but it may also be customized according to the requirements of the project. Because of their adaptability and creative approach, the partners have been able to mould and reshape the solution in accordance with the discoveries that have been made along the process. (Gibson, 2022)

4.3. Methodology

The project team began the process of developing the Vinci-Skanska blockchain tool by conducting in-depth research of the construction sector and identifying significant pain points that may be alleviated by utilizing blockchain technology. After that, they collaborated on the design of a platform that would accommodate the requirements of all parties involved, such as the owners, the contractors, and the suppliers.

Blockchain technology was used in the development of the platform, which also includes smart contracts and secure document management tools that are embedded into the code. In addition to this, the team carried out comprehensive testing to guarantee that the system was both safe and straightforward to use.

4.4. Discussion

The Vinci-Skanska blockchain technology has the ability to completely transform the construction business by making it more transparent, efficient, and affordable all at the same time. The application can contribute to a reduction in the likelihood of blunders and disagreements by making use of blockchain technology, which creates an immutable record of all modifications and transactions.

Additionally, the platform contains a number of capabilities that, when combined, can serve to simplify workflows and enhance communication between various stakeholders. For instance, the real-time tracking function helps project managers to swiftly spot potential problems and take remedial action, while the payment management system provides transparent and efficient processing of payments. Both of these benefits are made possible for project managers.

4.5. Results

Although it is still in the early phases of development, the Vinci-Skanska blockchain tool has already received excellent feedback from industry professionals and stakeholders. This is despite the fact that it is still in the early stages of development. The application has the potential to considerably enhance the effectiveness and transparency of the administration of construction projects, which may result in cost reductions and improved outcomes for all parties involved. PLASMA has the ability to reduce the costs associated with the supply chain by 25 percent and the timelines associated with projects by 28 percent, with the goal of increasing productivity by 15 percent by the year 2025. (Gibson, 2022)

Moving forward, the team working on the project intends to continue honing the platform's existing capabilities while also adding new ones in order to solve more challenges faced by the construction sector. It is possible that in the future, the blockchain tool that was developed by Vinci and Skanska may become a standard tool for the administration of building projects. This would require sustained investment and development.

5. Case Study II: Smart Contract Payment System in a Construction Project in the USA

5.1. Introduction

In recent years, blockchain and smart contract technologies have garnered a great deal of interest, presenting creative solutions to several sectors. Blockchain is a distributed ledger technology that enables safe and transparent data sharing via a decentralized network between various participants. When predetermined circumstances are satisfied, smart contracts automatically execute the terms and conditions of an agreement between two or more parties. The integration of these technologies has the potential to change several businesses, including the construction field, by delivering, among other benefits, effective and secure payment procedures.

The construction sector is notorious for its complexity and fragmentation, which frequently leads to contract disputes and delays. The typical payment process in the construction sector requires several intermediaries, such as banks, payment processors, and other stakeholders, resulting in time-consuming and expensive payment procedures. In addition, the lack of transparency in the payment process frequently results in disagreements between parties, which further delays the payment process. (Hamledari & Fischer, 2021)

In the construction business, the introduction of blockchain-enabled smart contracts and reality capture technology can dramatically enhance the payment process. When established circumstances are satisfied, smart contracts can automatically execute the terms and conditions of an agreement between two or more parties, removing the need for mediators. This saves administration costs and accelerates payment processing, leading to more efficient payment system.

Additionally, the implementation of blockchain technology in the construction sector provides a safe and transparent method for executing contractual commitments, so fostering greater stakeholder engagement and confidence. Blockchain is a distributed ledger system that keeps data in a decentralized network, therefore assuring the data's immutability and tamper-resistance. This provides

a clear and safe method for storing data, hence lowering the likelihood of stakeholder disagreements. (Hamledari & Fischer, 2021)

In the construction sector, reality capture technology solutions such as 3D scanning and photogrammetry may also considerably enhance the payment process. These technologies offer parties with accurate and timely information on the development and delivery of the project, hence boosting transparency and decreasing the likelihood of disagreements. By having access to real-time data, stakeholders may discover deviations from the original plan and make the required modifications, resulting in a more efficient building process.

However, the use of these technologies necessitates considerable adjustments to the construction industry's present processes and procedures. The involved parties must be prepared to adapt to the new and accept the advantages that new technologies provide. Training and education on the advantages and disadvantages of these technologies are also essential to the effective deployment of these technologies.

In conclusion, the introduction of blockchain-enabled smart contracts and reality capture technology in the construction business might, among several other benefits, transform the payment process. Smart contracts eliminate the need for intermediaries, hence decreasing administrative expenses and accelerating payment processing. The application of blockchain technology facilitates the execution of contract terms in a safe and transparent manner, hence improving stakeholder confidence and collaboration. Reality capture systems give stakeholders with precise and timely data on the progress and completion of work, hence boosting transparency and decreasing the likelihood of disagreements. The successful use of these technologies necessitates considerable modifications in the present processes and procedures of the construction industry, as well as education and training on their advantages and hazards.

5.2. Description

Existing research proves conclusively that smart contracts may improve construction payments. The implementations of smart contracts discussed in this article reduce a portion of the payment processing overhead; nonetheless,

many workflows still trust in intermediary operations (e.g., reviewing, manually submitting, and confirming payments applications). The aforementioned workflows offer potential for centralization, service rejections, and harm the execution guarantee. In addition, current smart contract apps cannot enable the usage of reality capturing on-site. (Hamledari & Fischer, 2021)

The purpose of smart contracts is not the mere digitalization of payment application, as automation may be done through various means. To reap the benefits of its key decentralization characteristic, the configuration of the smart contract solution must be tailored to the industry problem. The key value proposal for smart contracts is allowing for trustable mechanisation and "traceable confidence" in transaction data by eliminating intermediary workflows and providing assurances and consistency.

Implementation in the physical world is crucial to the technology's acceptance of practitioners of the AEC, who currently have questions regarding the automation potential of this technology. In order to solve the aforementioned restrictions, this paper concentrates on the implementation of its suggested solution in the actual world. (Sheng et al., 2020)

5.3. Methodology

Each payment made as work progresses on a building represents a shift in focus from goods to money. The authors, drawing on the philosophy of John Searle, make a distinction between two categories of facts that are relevant to the handling of financial transactions. 'Brutal facts' and 'institutional realities' are two terms used to describe these types of information. Construction progress and product flow are described by the former; cash flow is described by the latter, and its status is subject to human agreements, the observer's decision, and the observer's judgment. Payment terms and contractual agreements are examples of institutional factors that play a role in the construction industry. In this text, "reality" and "physical reality" mean the same thing: the unfiltered truth (i.e., product flow). When discussing institutional truths, we talk about "social reality" (i.e., cash flow).

To streamline the construction industry's payment processes, many procedures must be digitized as scripts and run on computing resources. Among these are the evaluation of on-site observations, the pricing of finished work, and most significantly the actual signing of contracts and the processing of financial transactions. Someone participating in the project must perform the computational codes and communicate the outputs to the banks before any transactions can take place. Due to the client-server architecture's introduction of single points of failure, payment processing is prone to difficulties such as denial of service, manipulation with historical data, and knowledge asymmetry, making this type of automation unreliable. Therefore, the same constraints of current payment systems also apply to such automation. (Sheng et al., 2020)

In order to remedy this, this study employs Blockchain-enabled smart contracts, which lend more trustworthiness to automated payment processing by ensuring the fulfillment of contractual obligations and doing away with the need for a centralized client-server architecture. All blockchain prospectors (i.e., full nodes) individually enact the contract script, calculate the results, and build consensus regarding the financial transactions, accrued expenses, and receivable accounts; this is how a smart contract memorializes the contractual agreements between project teams in a distributed manner on blockchain. (Hamledari & Fischer, 2021)

However, the trustworthiness of "smart contracts" depends on the robustness of the consensus algorithms that control the blockchain they are built upon. Public, private, and consortia blockchains each have their own unique consensus procedures (i.e., private blockchains managed by an authorized consortium of organizations). Project stakeholders in private and alliance chains play the role of explorers, carry out the contract's instructions, and come to an agreement on the status of the world as it actually exists; however, Such private blockchain applications run the danger of antitrust violations because users may collude in a way that undermines the decentralized nature of the consensus process. There are exceptions to the rules of immutability, irreversibility, and guarantees of execution.

The smart contract developed for this study is deployed on a public blockchain, where no one participant has control over the underlying consensus method or

the execution of the contract's software. The two most well-known permissionless networks, in terms of both popularity and hash rate, are the Bitcoin and the Ethereum blockchain technologies. Since the former has better programming language and can enable general advances inside the decentralized software ecology, it was employed to create the technique. (Sheng et al., 2020)

As has been shown so far, the implementation of smart contracts operating on public blockchains decentralizes not only the administration of payments but also the recording of cash flow, therefore granting trustworthy access to the social reality of a project. However, the use of smart contracts alone is not sufficient to facilitate payment automation because the technology is not connected to the events that occur in the actual world (physical reality), and it is unable to create a link between the states that occur off-chain and those that occur on-chain. This is one of the most significant obstacles that must be overcome before smart contracts can be used effectively in construction management applications.

Using various reality capture technologies, this research provides a solution to this problem by providing the smart contract with an "eye" in the actual realm (also known as an "oracle"). In this context, the phrase "reality capture" refers to the practice of utilising perception, machine intelligence, and BIM for the purposes of, respectively, collecting, evaluating, and recording the state of the physical reality present at construction project sites. (Sheng et al., 2020)

The relevance of reality capture to the automation of payment processes comes in two forms: First, it enables the state transitions of the blockchain to be conditioned on events that really occur in the world. Second, it introduces impartiality, which means that the evaluation of the work turns into autonomous of the spectator. This improves the trustworthiness of the entered data that is supplied to the smart contract and ensures uniformity both between projects and throughout the life cycle of each project. This is an improvement over previously used methods, such as manually recorded progress reports, which place a burden on the dependability of automation of payments as a result of their dependence on the part of spectators and their somewhat more speculative interpretation of factual facts. This is because manually reported progress reports are reported by individuals rather than by machines. (Hamledari & Fischer, 2021)

Once it has been effectively captured, the reality has to be securely shared among the participants in the project in order to build an acceptable understanding of the bare stats. Only then can the physical reality be used by a smart contract to move cash. The Interplanetary File System (IPFS) is utilized in this research to bring about the creation of a content-addressable and decentralized file sharing solution. The most important feature of the IPFS is called content addressability, and it allows information about projects to be referred off- and on-chain based on what it is (the content), rather than where it is located (location). Each data case, such as a BIM that is as built, is assigned a one-of-a-kind identification that is computed with cryptographic hash algorithms. This identifier is subject to change after each time the data object is updated. The addressability of the content is essential to the operation of the smart contract used in this research work, as it enables the creation of linkages to physical reality that are both immutable and safe on the public blockchain. This strategy is in contrast to location-based data referencing, which involves retrieving project-related information from centralized data servers depending on the place at which it was last saved. (Sheng et al., 2020)

Figure 5 depicts how “smart contracts”, “IPFS”, “reality capture technologies”, and “public ledgers” are integrated to realize digitalization of payments. This interprets the progression at job sites (Product flow, figure 2a) into construction progressive payments (Cash flow, fig 2c) without relying on current centralized, intermediary, and resource-strenuous processes such as invoice gathering and payments application/certification.

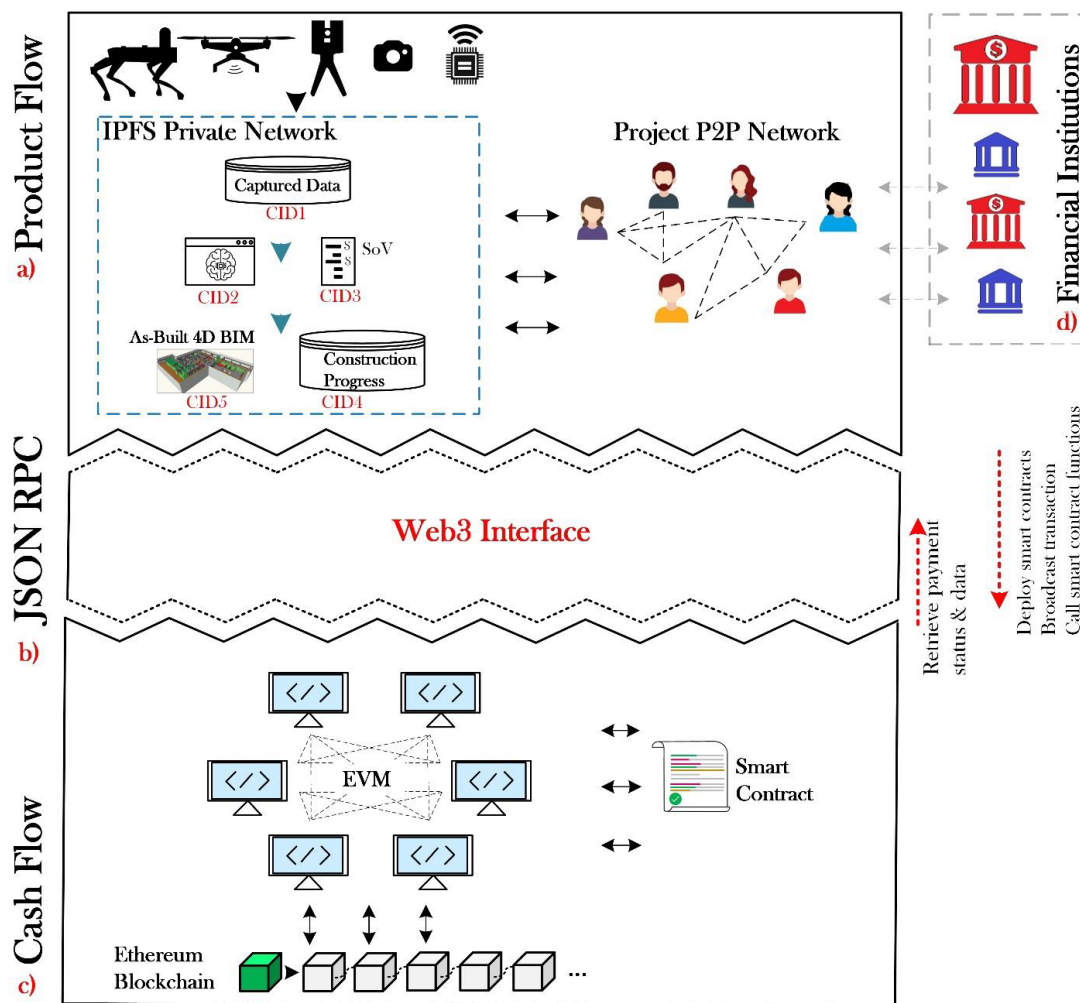


Figure 5. Independent Payment Upon Completion of Construction: a) Products are tracked on an internal IPFS server network, b) information transfer is facilitated using the JSON RPC interface, c) Smart contracts help regulate financial flow, d) peripheral financial institutions.

The off and on-chain contents of the suggested technique each get their own section below, which expands on the previous one in terms of the design considerations that went into making them. In section 5.3.1, the process of capturing the product flow and storing it safely in a distributed way is broken out in depth. The architecture of the smart contract that is utilized for payment automation is discussed in Section 5.3.2, along with how it makes use of progress data to accomplish on-chain payment resolution. (Das et al., 2020)

5.3.1. Product Off-Chain Action

The first step toward effective payment automation is gaining an accurate and up-to-date understanding of the ways in which the physical reality (also known as product flow) is evolving. As part of this research, the progression of building

is evaluated utilizing reality capture systems that are either humanly handled (for example, laser scanners) or installed on robotic systems (e.g., unmanned aerial vehicles with equipped camera). In order to determine the proportion of work that has been completed for each of the several scopes of work, the data that was gathered is analysed by machine intelligence. This can be accomplished in one of two ways: either by identifying the components (such as columns, studs, and panels for insulation), or by determining the stage of development for construction parts. The level of detail of the advancement check results may change based on the type of machine intelligence technique that was employed. These results can be made available either per GUID, globally unique identifiers, or per a bigger work scope, for example one or many structure floors. The resultant data on the project's development is automatically added to the as-built version of the 3D and 4D building information model. This results in the creation of an integrated method that is driven by data, through which the physical reality of a work site may be directly utilized to value the work that has been accomplished. (Das et al., 2020)

After the progression of the job has been gathered and analysed, it is categorized and priced utilizing the project's associated codes for cost. This procedure structures the flow of products so that it may be used by smart contracts. This phase is not without its obstacles, but they are manageable: 1- The product drift cannot be saved on blockchain because on-chain storage is outrageously costly; 2- Data storage on blockchain poses a risk to the authenticity of project data owing to the traceability of the public blockchain for Ethereum; 3- The involved parties in a project need a method for referencing the nearly identical data over the project's lifecycle without repeating files between platforms and organizations; and 4- The proper documentation for the product flow utilised in processing of payments need to sustain audible signatures.

In order to get around these problems, the study advises using a "P2P" network for the project and an addressable content file transfer for product flow off-chain archiving. On a private IPFS network, the most important data, such as the timetable of value, data of the progress, as-built BIMs, and required scripts for analysing the state of building activities, are saved (Figure 3a). (Das et al., 2020)

The Internet Protocol File System (IPFS) divides files into blocks, which are then kept in an acyclic graph directed by Merkle as key-value pairs (DAG). When compared to the Merkle tree, the Merkle DAG is distinguished by the absence of a balancing requirement. The Merkle DAG employs a multi-hash checksum, which not only protects against tampering but also allows for content addressing. A CID, short for unique content identifier, is created for each file when it is first stored to IPFS. This CID may be utilised to get the file back from the network. Since the CID of a file is derived from its “SHA-256” hash, it is subject to modification if there is a change to the file that it refers to. For instance, every time a BIM that is an as built model that is being utilised for the cost estimation of work is updated to integrate fresh progress data, it will immediately be assigned a new CID. (Das et al., 2020)

The IPFS capacity to position and restore files based on "what" they are rather than "where" they are saved is the source of the content addressability that the IPFS provides. Every IPFS peer—or, in the “IPFS” private case, every participant in a project using IPFS—is connected to the identical data structure described earlier. First, a content identifier which is created on one point may be utilised by a different point to get the exact file at any point in the project's lifespan. Second, a file will always be associated with the same content identifier, not depending on who publishes it, when it's published, or the number of times it's submitted. Both of these statements are true.

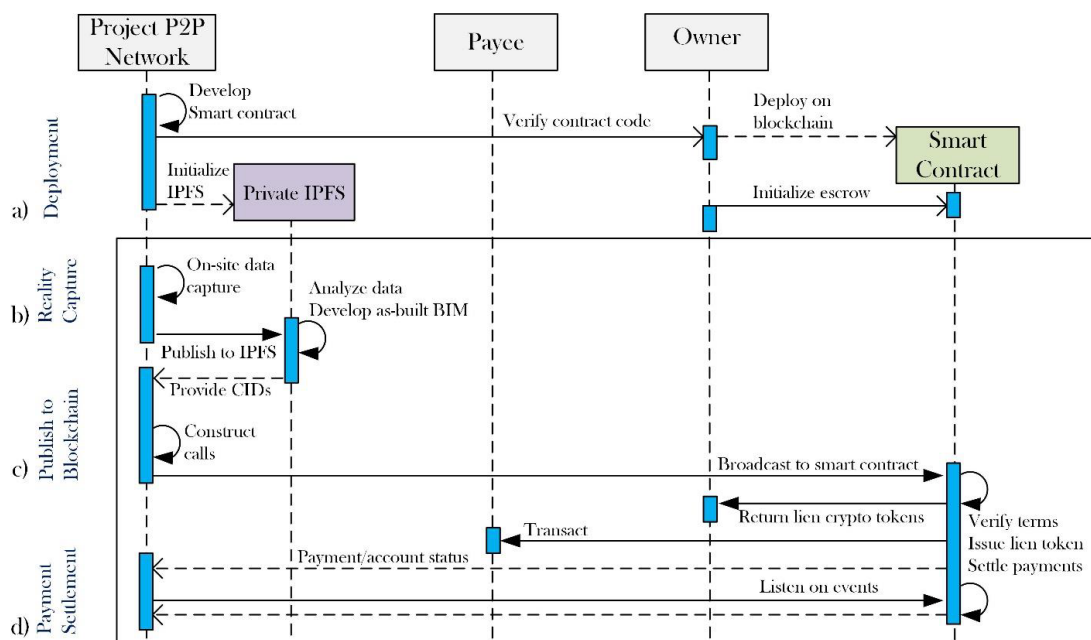


Figure 6. Process flowchart for autonomous transactions based on smart contracts: a) blockchain-based smart contract implementation, b) on-location capture of reality, c) info on development being published to a blockchain, d) settlement of funds on-chain.

Off-chain product flow documentation and subsequent smart contract use in this work rely heavily on the "IPFS" file system. First of all, project participants use permanent CIDs, such as "QmXvTCjaxAW4YHnnQMePU1kahvJ1s8jEEu-YRwPNppDUFxn", instead of positions on a server of the project to obtain data of utmost importance utilised in payment processing. This is done so that IPFS can be used. By doing so, a unified perspective of the flow of the product is created, duplicated instances are avoided, and consistency is guaranteed. Secondly, it connects the on and off-chain parts by including the content identifiers that correspond to key project details in processing of payments in the state transitions that are recorded on the public blockchain. These CIDs are conveyed to the "smart contract so that they can be incorporated in state transitions (Figure 6b-c). The basic data used in processing of payments is only accessible to project members and would be incomprehensible to a public reader of the blockchain called Ethereum who is not even a part of the private IPFS network. Thirdly, Due to its reduced sensitivity to network downtime and tamper resistance (which stops stakeholders from altering history), material that has been updated to safeguard payment automation from potential assaults is more secure. These two properties combine to make content addressability less vulnerable to these types of threats. (Das et al., 2020)

5.3.2. On-Chain Cash Flow

To be effective, management of on-chain cash flow must do two things: firstly, settling payments amongst participants of the project in agreement with the off-chain movement of products, and secondly, Transferring lien rights along with payments. If a contractor isn't paid for their work, they can file a mechanical lien to protect their financial interest in the property.

It is difficult to achieve these two goals in a payment system that is both autonomous and decentralized for the following reasons: First, Banks and other similar financial entities are only marginally involved in the suggested approach (Fig. 2d), and they have no hand in overseeing the money coming in; Money is an institutionally unambiguous indicator that requires the support of disintermediated third parties; second, general contractors currently acquire conditional lien withholdings in the course of drafting payment applications; and third, cash.

The solution to these problems is the implementation of a smart contract that, utilizing Ethereum's cryptocurrency, also known as ETH, and an inconvertible token, settles payments autonomously and transmits lien rights in accordance with their individual terms. Tokens, often known as crypto tokens, are digital representations of rights to a certain asset or use (e.g., ownership and monetary value). This functionality is also known as the smart property feature, and it entails the distribution of power over an asset to the holders of a token. The ERC-20 and the ERC-721 are the two standards that are used the most frequently for designing crypto tokens. These standards are used to describe transferable and non-transferable tokens, respectively. According to the off-chain product flow saves, each right of a lien is distinct and matches with a certain work scope. This information may be found in these records. The possession right of the token, and consequently the authority to the base that is the physical asset, is controlled through the smart contract, and the transaction is registered on the Ethereum blockchain. As a result, this work makes use of the criterion of ERC-721 to generate the inconvertible "LIEN" token in order to symbolize the lien rights to a piece of real estate.

The "smart contract" that will be detailed in more detail on this page must be implemented by the project owner (Figure 4a) into the "Ethereum virtual

machine” (EVM). As shown in Figure 3a, the smart contract address of the account is both verifiable and payable; as an escrow account, it bases its outputs on conditions, such as the disbursement of funds and assignment of liens, on information about the project's actual physical state. In particular, the outputs depend on whether or not the smart contract is content with the actual state of the project (Figure 4b-c). Accounts associated with contracts are unable to begin transactions solely by themselves; rather, EOA, known as externally owned accounts, which are managed by project responsible parties, are required in order to activate smart contract capabilities. The progressive construction progress is determined by the capture solution of reality (Figure 3b), and the off-chain component of the method (which is described in section 3.1) assigns a value to the work based on the project's schedule of values, the geometry and semantics of the building elements (which are obtained through BIM), and the data of percent of accomplishment. The procedure reveals the construction's progressive development. It can be very detailed, as in the case of as-built modelling at the level of individual building elements, or very broad, as in the case of progress evaluation based on a percentage of the total competition for the work on numerous structural components. Both of these scenarios are possible (e.g., electrical work 80 percent complete).

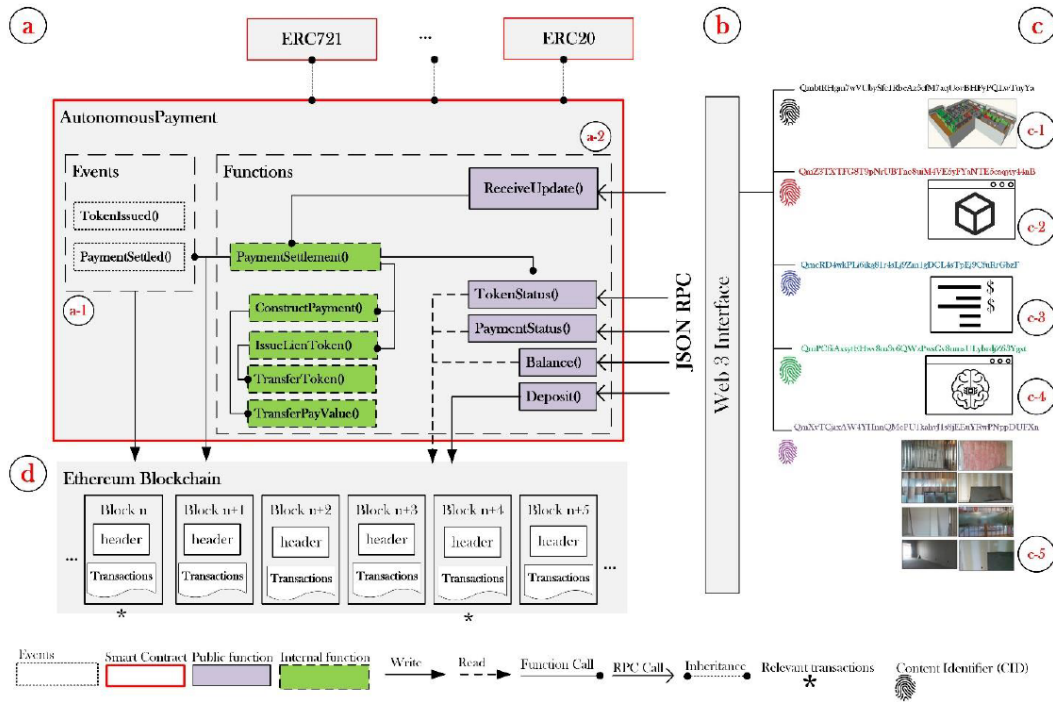


Figure 7. Integration of the P2P network with the smart contract architecture for hands-off financial transactions: a) contract framework, b) “RPC of JSON”, c) Created Identifiers (CIDs) from the IPFS private network, d) transactions recorded on “Ethereum’s” distributed ledger.

The client from the side of off-chain creates a transfer of funds which is communicated to the smart contract (Figure 6c) through a JSON-encoded RPC, short for remotely accessible procedure call (Figure 5b). Content identifiers of input data used in the valuation of incremental progress are sent in this transaction with the work value, the public key of the private contractors carrying out the valued work, and the value of the job itself. The latter consists of a BIM that is as built, schedule of amounts, and CIDs for the element list and GUIDs. This information is then sent in a broadcast to the public function of the smart contract labelled "ReceiveUpdate" (Figure 7a-2), which validates that the data has been appropriately structured before it activates the internal operations necessary to begin the on-chain payment settlement.

The function upgrades the smart contract aspects by lettering the changes to the current blockchain; it retains a record of processed payments and the documentation of components corresponding to those payments; it validates the address of the node posting the changes versus the addresses of the nodes in the project's P2P network. This is a very important step to do in order to avoid

having to pay the same amount again. The usage of event logs is a different approach that may be taken to attain the same purpose. In the second situation, it is essential for an off-chain client to compile a list of the payments that have been made. A project P2P network is responsible for operating this client. The "ReceiveUpdate" feature will cause other internal processes to be initiated, and these procedures will then manage payment settlement after they have been activated.

"PaymentSettlement," "ConstructPayment," "TransferPayValue," "IssueLienToken," and "TransferToken" are the names of some of the internal activities. These functions can only be carried out inside the confines of the smart contract (Figure 7a). The project's logic and input variables are brought up to date whenever there is a modification to the contractual provisions that govern the project, and they are then exposed to digital verification by all of the parties engaged in the project.

After the public function "ReceiveUpdate" has activated the private code for "PaymentSettlement", the latter function will check the balance of the "smart contract" account before triggering the private functions "IssueLienToken" and "ConstructPayment" to create the payment that will compensate the beneficiary and issue a new LIEN ticket demonstrating the lien rights related with the priced work. "ReceiveUpdate" is the function that will trigger "PaymentSettlement," and " (Figure 6d). The "TransferPayValue" function is responsible for sending the stated amount of ether-based payment to the "ConstructPayment"-designated contractors who were accountable for the task.

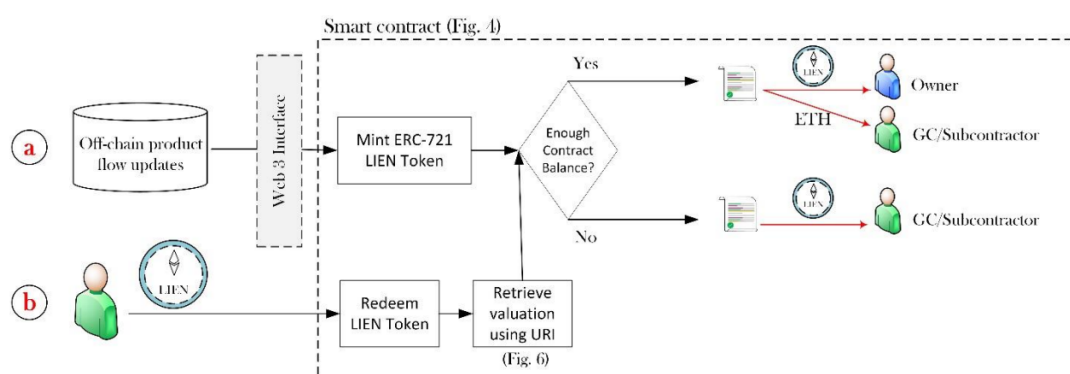


Figure 8. The use of ERC-721 in the assignment of liens: a) Upon receipt of updated information, LIEN tokens will be issued and payments will be settled, b) A subcontractor's use of a LIEN token to redeem a lien

The lien token contains the payment metadata, which includes the building parts references and the value of the payment. Also included in the token is the payment itself. The unified resource identifier (URI) of the ERC-721 token is populated with the CID relating to the building parts for which the right is transmitted to accomplish this goal. Following the completion of the payment settlement process, the owner receives the appropriate lien token, which was sent to them using the “TransferToken” method (Fig. 8). If the available credit is insufficient, the ticket will be sent inevitably to the responsible service providers for the job (Figure 8a). Then the contractor will be provided with the right to the work that is outlined in the product flow recorded data and is accessible through content identifiers. Once the smart contract address has sufficient credit, the ticket that is according to the ERC-721 can be sent there to be robotically converted to its value (Figure 8b): By using its URI and detecting from the saved data given by the smart contract, the token's value may be retrieved, which corresponds to the product flow modifications that triggered the payments.

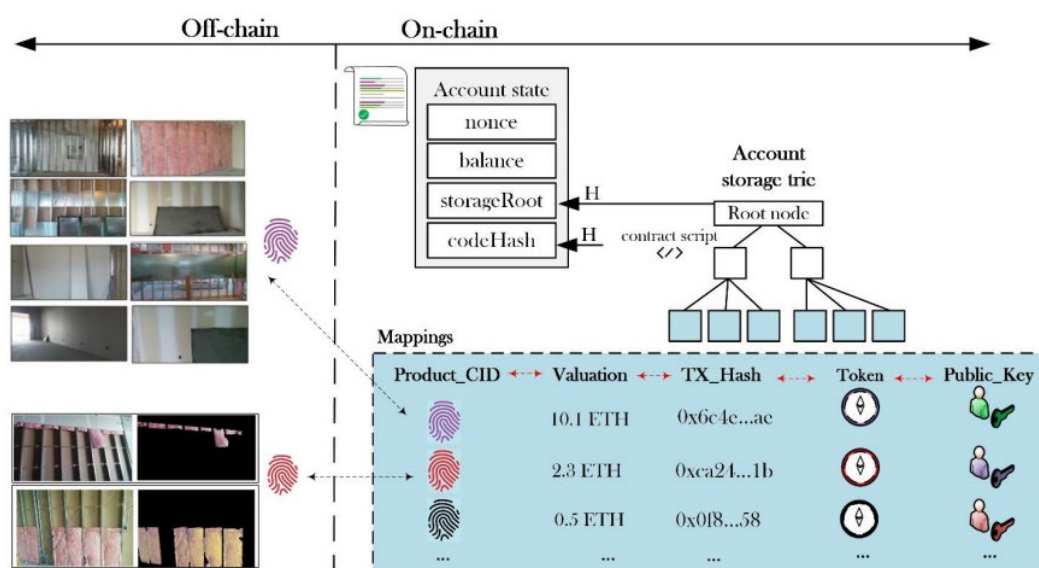


Figure 9. The mappings between product flow (CIDs and the value) and cash flow are documented on-chain via the smart contract (corresponding transactions on blockchain, corresponding LIEN token, and the public key of payee)

Figure 9 depicts the data structures of the blockchain that allow for the recovery of the aforementioned info; the smart contract instantly writes to the Ethereum blockchain, and the parameters of the contract may be recovered from the Account Storage Trie (accessible from State Trie under each block header). This results in the creation of a number of mappings between, among other things,

specific instances of product content identifiers, values, LIEN tickets, public key addresses of beneficiaries, and the payments that correspond to those CIDs and valuations. When any of the two factors listed above is available, these mappings make it possible to retrieve information on cash and product flow. For instance, if the owner is analysing a transaction in which a contractor is paid, they have the ability to get the relevant product flow data. It is possible to access the related data of the progress and the work scope assessment by using the URI that is associated with an ERC-721 token. Because CIDs offer enduring references to information that is kept on the IPFS network that this project utilizes, these mappings also establish a connection between off-chain and on-chain records.

5.4. Experimentation

The solution that was proposed to be based on smart contracts was implemented in Solidity version 0.6.2. Both web3.py and “Infura” were utilized, one in the establishment of the RPC module and the other in the facilitation of inquiries on the state of the Ethereum blockchain. (Ye & König, 2020)

On two separate commercial building sites, progress payments were processed using this manner. Payments were performed on the test network for Ethereum, and an IPFS network, private, was set up for use by the participants in the project, which included the proprietor, the general contractor, and other service providers. The descriptions of every project are included in Table 1, together with the trades number for which transactions were completed and the categories of construction items that were captured in reality. The collection of data took place over the course of a period of four weeks at A-Project, which is located in the province of Ontario in Canada. The gathering of data took place at the location of Project B in California (United States) for a period of five months. (Ye & König, 2020)

Table 1. Locations of the two building sites used in the study

Project	Location	No. of Floors Inspected	Building Floor Area (sq.ft)	Subcontractors Number	Building Elements
A	Ontario, Canada	1	40,000	4	Partitions
B	California, USA	4	200,000	3	HVAC, Plumbing, Partitions

A camera-equipped UAV, known as unmanned aerial vehicle (Figure 7a) was used to carry out the data capturing at Project A, which resulted in digital pictures (Figure 7b); a laser scanner attached on a UGV, known as unmanned ground vehicle (Figure 7c) was used to encapsulate the state of construction advancement at Project B. Figure 7a–c Unmanned aerial vehicles (UAVs) and unmanned ground vehicles (UGVs) (Figure 7d).

The tests that were planned to evaluate whether or not it would be possible to use the suggested approach are listed in Tables 2 and 3, respectively. In the tests that were conducted for Project A, test 1, and Project B, test 2, different real-time capturing sensors, capturing solutions, data formats, and data analytics tools were used. In addition, the (A) test had a more granular product flow (Table 3), with progress data being made accessible for each of the 104 inspected building elements that were connected to BIM. The product flow of the second test, meanwhile, has a little granularity and delivers an aggregate percentage of completion. These differences are included with the intention of assisting in the evaluation of the suggested method's generalisation as well as its usefulness in commons progress monitoring methods. (Ye & König, 2020)

Table 2. Created tests to measure the efficacy of the smart contract platform

Test	Project	Data Capture	Sensor	Data Formats	
				BIM	Schedule
1	A	UAV	Camera	IFC	IFC
2	B	UGV	Laser Scanner	.nwd, .rvt	XML

Table 3. The regularity and specificity of payments

Test	Payment Frequency	Product Flow Granularity	Site Visit Duration
1	Bi-weekly	High	4
2	Monthly	Low	20

In each of the studies, the general contractor was the one who brought the robot to the place where the work was being done. This requires a person to attach the real-time capturing scanner on the robotic platform and then return the robot to a secure destination once the data has been collected. The basic data on the robot's progress was manually removed from its memory card, and then it was given to the case study authors (test 1) as well as an outside seller (test 2).

During the first test, various digital photographs taken by a UAV were uploaded to a computer with a vision-based system in order to create the different stages of completion for the interior partitions. An automated technique was used to combine the progress data into 4D building information models (BIMs) based on industry foundation classes (IFC). There was no need for human intervention in the data analyses or the in-BIM documenting of the progress. In the second test, an independent third party was responsible for processing the point clouds that were recorded by the UGV. the algorithms utilized by the vendor or the degree to which they are automated were not known; nonetheless, it is assumed that the process requires a considerable amount of human participation. During test 2, no as-built BIMs were generated. (Ye & König, 2020)

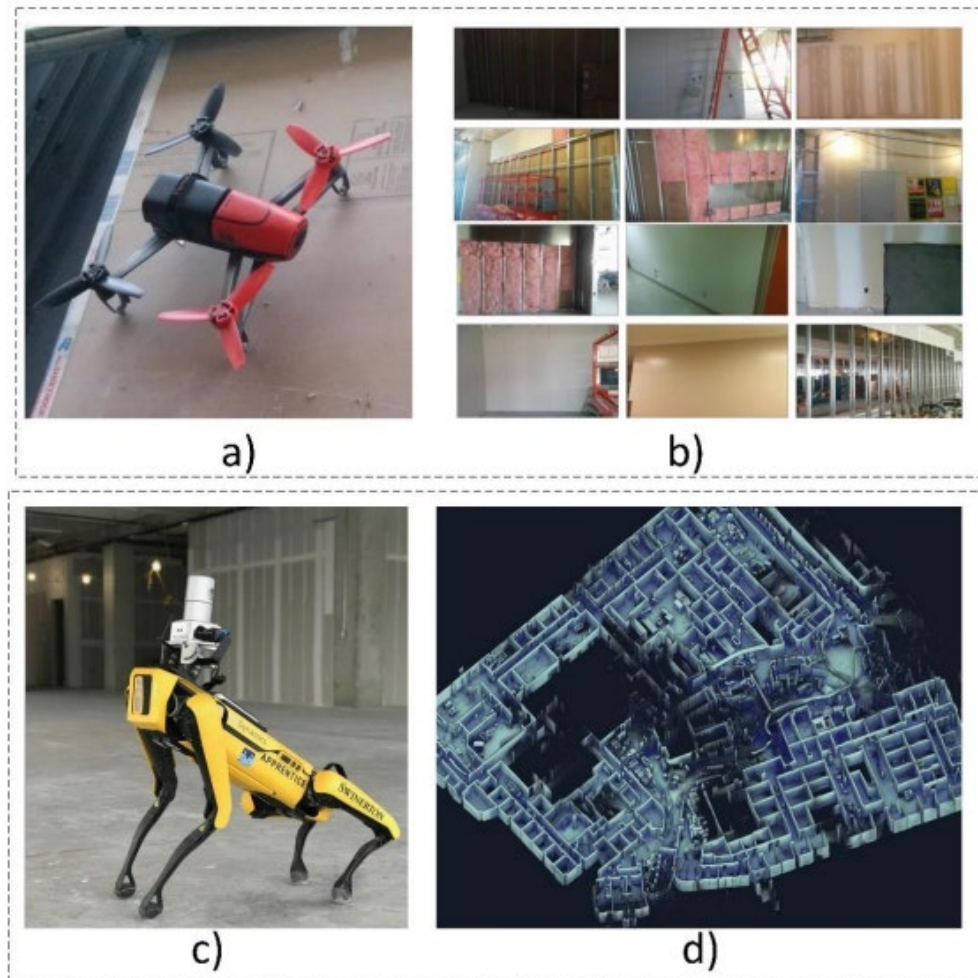


Figure 10. Experimental reality-capture equipment: a) “Multicopter” with four rotors for aerial photography and videography, b) UAV-photos, c) scan with a laser on a UGV, d) recorded point cloud by UGV

Throughout each test, data on progress, as-built BIM (where available), and supplementary files utilised in assessing the work done all were sent to a private IPFS system. This is where the content identifiers are repeatedly formed. The CIDs are sent to the smart contract by one of the P2P nodes using the RPC module; the functioning of the smart contract (shown in Figure 6d) did not require the participation of a person.

In Table 4, the outcomes of the tests that were carried out are detailed, including the length of time required for processing each cycle of payment, the precision of the remote scanning method as well as the proposed solution that is based on smart contracts, and the cycles of payment total number. In order to determine whether or not the results of the method, counting the transactions in, and the progress evaluations were accurate, manual verification was

performed. The proportion of components, that the precision state could be reliably determined, is the metric that is used to define the accuracy of the remote sensing solution (i.e., informed as-built state is matching to the on-site condition, it was manually confirmed). Since the external supplier does not physically validate the situation on-site, and because they do not publicly reveal the accuracy of their platform, the accuracy of reality capturing is not accessible for test 2. When it comes to the processing of payments, a transaction is regarded to be accurate if the monetary amount that was transmitted by the smart contract, the receiver, and the included information (such as CIDs) are all consistent with the reality of the situation. After each transaction was checked by hand, there were no discrepancies found in the manner in which the payment resolution of the smart contract was processed. Also, the transactions for the entirety of the work scope that was detailed in the progress reports have been satisfactorily settled. (McNamara & Sepasgozar, 2021)

Table 4. Performed tests results

Test	Payment Cycles No.	Blockchain Transactions No.	Processing Time per Payment Cycle (Average)		Accuracy (Average)	
			Reality Capture	Payment Processing	Reality Capture	Payment Processing
1	2	10	9 minutes	5 minutes	95%	100%
2	5	20	5 hours	4 minutes	-	100%

The payment processing durations that have been recorded each cycle (Table 4) are consistent within all tests since the solution founded on smart contract utilises the results of the remote scanning method and is oblivious to the inner workings of the data analytics tools utilised for progress evaluation. On the other hand, the time of retrieving for the real-time capturing might be very different depending on the sensor and progress tracking method that is used. When compared to digital pictures, the Point cloud analysis using computer vision (test 2) takes much more time (test 1). The time it takes to gather the

data and prepare the data is not included in the processing times that are shown in Table 4. (McNamara & Sepasgozar, 2021)

5.5. Results

The following parts will provide a discussion of the findings obtained from the case study. The findings section and the reasoning section are the two parts that make up the results section. The findings section is the first part of the results section and is where the data is translated into an analysis and understanding of the limitations and challenges of the entire process of the study. The reasoning section is the second part of the results section and is where the final conclusion of the study is discussed and shown as the final part of the case study. (Li et al., 2019)

5.5.1. Findings

This research shows that bridging the gap between the physical and social worlds is an essential step toward fully automating financial transactions. Without depending on payment software or other conventional procedures, the suggested technique effectively arrived at progress payments (social reality) from observations of task site circumstances (physical reality). This effort substantially decentralizes the various phases of the payment processing. However, not every process step can be decentralized, nor is it always preferable to do so. (Li et al., 2019)

Smart contracts can enable the decentralized implementation of contractual accords in an autonomous system, making the server-client paradigm obsolete, although a few steps in the preparation of the inputs and analysing the outcomes still involve human interaction. This is especially true when deploying robotic reality capture systems in the field and sending data from data gathering devices to analytics frameworks. These steps are carried out by a select group of people in a centralized fashion. Although these processes may be automated, doing so would not necessarily enhance the security of automated payments. In the event of inaccurate malfunctions or data capture, human

engagement may assure the on-site data collecting quality and allow for quick modifications. (Li et al., 2019)

In spite of the fact that the suggested smart-contract-based suggestion was shown to be very precise (Table 4), it is critically important that the input data (generated by reality capture technologies) be precise in order to provide dependable and trouble-free financial transactions. For 5% of the building components in the first test (Table 4), for instance, the progress was misidentified (e.g., a wall that was painted was categorized as a wall with plaster on). The conclusion was that 5% of payments, those connected to misidentified items, were either handled later than planned or processed earlier than intended. (Zhang et al., 2020)

Still, this precision can be superior to the inspector's subjective assessment of manually recorded progress statistics. The delay in the 5% of pay-outs for which the progress was misidentified is not related to the overall value of the job. The payments are recorded either by construction element or cost code, depending on the precision of the progress data. The level of competition cannot exceed one hundred percent in any scenario. If a contractor was overpaid or underpaid in the past, the smart contract will adjust future payments to reflect the actual amount owed. (Zhang et al., 2020)

Which reality capture method is used also impacts the variety of tasks that may be paid for all at once. In the first experiment, payment processing was carried out on a granular element scale (e.g., framing completed for a certain wall). Test 2's progress reporting format from the external vendor prevented this, however. The reality capture approach, rather than the smart contract, appears to set the minimum time between payments; the second can execute payments as regularly as data becomes available on progressive building progress. From a technological aspect, payments may be handled within a few days following on-site observations, which includes the processing timeframes (Table 4), the duration of robotic data collecting at locations, and the time it takes to prepare the data. For a cash-strapped business, such as engineering and construction, where payment often takes three months, with declining performance with time, this has serious ramifications. (Zhang et al., 2020)

The pioneering publications of Nick Szabo on the topic identify three desired properties of smart contracts, one of which is increased openness. These are: 1- openness, 2- confidentiality, and 3- testability. By contrast, under the smart contract-based approach, payments current state and the finished processes can be straightforwardly asked from the account made for the contract for each scope of work and with no counting on gatekeepers, making it much easier for subcontractors to pinpoint the cause of payment delays. This improves the post-hoc capacity to observe. More can be observed ex ante because of the availability of prior contacts, which boosts trust formation. (Turk & Klinc, 2017)

The removal of intermediaries guarantees the confidentiality of the conversation. For instance, when dealing with external financial institutions, private information such as cash flow in the supply chain is isolated and moved to the periphery (Figure 5d). The authenticity functionality is supported through integration. Participants in the project can utilise the off-chain data keeping and on-chain referencing to confirm prior payments and their link to data gathered on the job site, the analysis script, and the valuation timetable. All calculations made by a smart contract, as well as the subsequent cash flow, are permanently linked to the source data, allowing for auditing and verification at any time. In a world where trust is hard to come by due to conflicting commercial goals, this helps build it. (Turk & Klinc, 2017)

5.5.2. Reasoning

The stresses placed on the construction industry's supply chain by the coronavirus epidemic have greatly hastened the sector's ongoing shift toward digitalization. Fixing the payment system's flaws is crucial for a smooth evolution into the new normal. (Turk & Klinc, 2017)

To achieve true payment independence, we must automate formerly manual processes including payment application creation, review, and submission. It is believed that the decentralization and assured execution afforded by smart contracts made possible by blockchain technology overcome these constraints. (Ham et al., 2016)

Despite the benefits it might provide, widespread use of the technology in financial transactions is hampered by the absence of a connection between digital currency transactions recorded in a blockchain and the actual world. Interconnection of digitalized progress data, facilitated by reality capture systems and BIM-based performance evaluation, and smart contract procedures is proposed as a way to boost the viability of smart contracts applications and make better use of the conceptually rich progress data captured on modern construction sites. (Ham et al., 2016)

In this paper, a smart contract-based method was presented to handle the handoff between on-site inspections and interim payments automatically. This innovative approach eliminates the need for stakeholders to submit payment requests, instead rewarding them whenever machine learning analyses of field data show even a little improvement. Two commercial construction projects employing the suggested technology showed that proper payment processing using smart contracts is possible. Smart contracts and reality capture were shown to be critical components of an accurate payment system. (Hamledari & Fischer, 2021)

The use of smart contracts in financial transactions is still in its infancy and has yet to gain widespread acceptance. Smart contract standards and formal verification, data fusion to improve product flow accuracy, and hybrid model creation for simultaneous on- and off-chain payment settlement are all areas where further research is needed. (Hamledari & Fischer, 2021)

6. Survey

6.1. Introduction

The results and analysis of a survey that was carried out online to investigate the applicability of smart contracts in the building and construction business are presented in this chapter. Significant progress has been made in a variety of industries thanks to the widespread use of digital technology, and the building and construction business is not an exception to this rule. Smart contracts, which are built on blockchain technology, have emerged as a viable way to solve the problems and inefficiencies that are common in the procedures of traditional contract administration.

The purpose of this survey was to obtain views and viewpoints from construction industry experts in order to gain a better understanding of their awareness, attitudes, and experiences in relation to smart contracts. We will be able to identify the possible advantages, problems, and possibilities related with the implementation of smart contracts in building projects if we look at the data that was acquired through the survey and analyse it. This analysis will contribute to the body of information that is already available and give helpful recommendations for industry practitioners, legislators, and researchers who are looking to improve contract management systems in the construction sector.

6.2. Objectives

This poll had two main goals in mind when it was designed:

One of the primary goals of this study is to determine the degree of familiarity and comprehension of smart contracts that exists among building business experts. The purpose of the survey was to determine whether or not the respondents were knowledgeable about smart contracts, whether or not they were familiar with blockchain technology, and whether or not they were aware of the possible benefits and uses of smart contracts in building projects.

Identifying the potential benefits, problems, and possibilities related with the use of smart contracts in the building business is the second objective of this

study. The purpose of the survey was to collect information from participants on their thoughts, experiences, and expectations surrounding the utilization of smart contracts. This purpose is to offer a full grasp of the practical consequences of integrating smart contracts into the building business by investigating the possible benefits as well as the potential drawbacks of doing so.

This survey's goals were designed to add to the body of work on the viability of smart contracts in the building sector. Those in the construction business, as well as politicians and researchers, might use the data to better understand how smart contracts can help them expedite contract management procedures, increase transparency, and boost overall efficiency.

The subsequent sections will be devoted to the analysis of the survey data, which will directly address these objectives and make it possible to conduct a comprehensive investigation into the levels of awareness, perceptions, and experiences associated with smart contracts in the building business.

6.3. Methodology

6.3.1. Design

The methodology of the survey was an essential component in the process of gaining insightful data on the application of smart contracts in the building and building business. This subsection offers an overview of the most important aspects and factors that went into the design of the survey, with the goal of guaranteeing its reliability and relevance to the study goals.

The creation of a detailed questionnaire was the initial stage in the process of planning and creating the survey. Extensive study was done in order to locate the pertinent subjects and questions that would supply the required information to fulfil the research objectives. The basis for the design of the survey instrument was laid with a comprehensive analysis of the available literature, reports from the industry, and the opinions of industry experts concerning the application of smart contracts in the building sector.

The questionnaire included both closed-ended and open-ended items in an appropriate proportion to ensure a good balance. It was possible to conduct quantitative research thanks to the use of closed-ended questions, which enabled the evaluation of the participants' degree of awareness, knowledge, and comprehension of smart contracts. We used Likert scales to determine the degree to which respondents agreed or disagreed with various statements pertaining to the possible advantages and disadvantages of using smart contracts. The knowledge of the participants with blockchain technology and their thoughts on the subject's applicability to the building and construction business were evaluated through the use of questions with multiple-choice answers.

6.3.2. Sampling

The study was directed toward construction industry professionals who work in a variety of roles, such as project managers, architects, engineers, contractors, and subcontractors. In order to guarantee that there was a wide variety of points of view represented among the participants, they were chosen using a mix of the convenience and snowball sampling procedures. The incorporation of construction industry experts who have worked on large-scale infrastructure projects as well as more intimate building endeavours received a lot of focus throughout the hiring process.

6.3.3. Data Collection

The survey was carried out via the internet with the use of a well-structured questionnaire that had been developed for the sole purpose of gathering information on smart contracts in the building and building business. The construction of the survey instrument was guided by a thorough assessment of the relevant literature as well as the comments of industry experts. The participant's access to the online platform was made easier and more convenient by its intuitive design, which included a user-friendly interface.

The questionnaire for the survey had both closed-ended and open-ended items in varying proportions. Those with closed-ended responses allowed for

quantitative analysis, but questions with open-ended responses gave participants chances to offer their ideas, experiences, and suggestions in a more in-depth manner. Six weeks were allotted for the gathering of data, and throughout that time, reminders were emailed on a consistent basis to ensure the highest possible response rate.

The survey instrument's validity and reliability were put to the test by way of a pilot study, which was carried out with the assistance of a select few experts from the building and building sector. The survey instrument was able to undergo modification and enhancement as a direct result of the input obtained from the pilot participants. The completed questionnaire had internal consistency that was up to the required standard.

6.3.4. Data Analysis

In the next sections of this chapter, a thorough analysis of the data that has been collected, is offered. This investigation will make use of quantitative and qualitative methods, employing suitable statistical procedures and theme coding in order to extract insightful conclusions from the replies to the survey. In reference to the study objectives and research questions presented in Chapter 1, the findings will be addressed.

Insights on the perceived benefits, obstacles, and future uses of smart contracts in the construction sector by studying the findings of the poll are to be mentioned. Additionally, the analysis will provide recommendations for industry stakeholders, policymakers, and researchers on how to leverage the capabilities of smart contracts in order to improve contract management processes, enhance transparency, mitigate risks, and streamline operations in construction projects.

In general, this survey study functions as an important supplement to the current body of literature, giving empirical facts and practical insights to the continuing discussions around the potential of smart contracts in the building business.

6.4. Participants, Perceptions, and Progress

6.4.1. Participant Demographics

This subheading offers a summary of the respondents' demographic information that was gathered for the study on the applicability of smart contracts in the building sector. To evaluate the findings for their representativeness and their potential to be generalized, it is necessary to have a solid understanding of the characteristics of the people who participated in the survey.

The study was directed toward construction industry professionals holding a variety of jobs, such as project managers, architects, engineers, contractors, and subcontractors. The participation of such a varied pool of individuals was essential to achieving the goal of gaining an in-depth comprehension of the myriad of viewpoints and experiences connected to smart contracts in the context of building projects.

In order to successfully recruit participants, we utilized a sample strategy that was a hybrid of the convenience and snowball sampling methods. Convenience sampling gave for simple access to potential participants, while snowball sampling made it possible to include additional people by having initial respondents suggest their friends. By taking this method, our goal was to elicit responses from a sizable cross-section of construction industry experts who came from a variety of educational and professional settings.

The study attempted to establish demographic diversity among the participants by taking into consideration a variety of characteristics, including age, gender, educational background, and professional experience. We wanted to ensure that we had a representative sample that would offer a thorough picture of the attitudes and experiences linked to smart contracts in the construction sector, so we included participants from a variety of demographics in our study. This helped us achieve our goal.

Participants were chosen for the workshop on the basis of their prior experience working on construction projects of varied sizes and scopes. The purpose of this inclusion was to collect a wide variety of opinions from construction industry workers working on a variety of construction endeavours, ranging from large-

scale infrastructure projects to more intimate building endeavours. This variety would help to a more thorough knowledge of the possible uses of smart contracts as well as the obstacles involved with using them in a variety of situations within the construction sector.

During every stage of the data collecting process, we worked hard to ensure that everyone was included and to communicate with experts who came from a variety of different backgrounds. We wanted to reduce the possibility of bias and improve the survey's capacity to be generalized, thus we took into account a wide variety of demographic parameters.

The demographic information of the people who took part in the study will be taken into consideration in the subsequent sections while doing the analysis of the data that was gathered. Through conducting this study, we will be able to determine whether or not there are any differences or patterns in the views, experiences, and expectations connected to smart contracts in the construction sector across the various demographic groups. By doing so, we are able to obtain a detailed picture of the ways in which characteristics such as age, gender, educational background, and professional experience may impact opinions about smart contracts and their possible adoption in building projects.

6.4.2. Awareness and Understanding of Smart Contracts

Within the context of the construction sector, this paragraph offers a summary of the participants' general degree of awareness and comprehension about smart contracts. In order to get an accurate picture of the level of awareness now present within the sector, it is vital to test the participants' level of expertise and familiarity with smart contracts.

The purpose of the poll was to determine whether or not the respondents were familiar with smart contracts and how much they understood about the block-chain technology that underlies them. To evaluate the respondents' level of familiarity with smart contracts, closed-ended questions were devised. For example, respondents were asked whether or not they were aware of smart contracts prior to taking part in the survey. In addition, the participants' knowledge of

blockchain technology and how it relates to the building and construction business was investigated through the survey.

Questions based on a Likert scale were included in the survey so that researchers could gauge respondents' levels of awareness and comprehension. The participants were asked to assess the degree to which they agreed or disagreed with statements that related to the possible uses and advantages of smart contracts in building projects. The purpose of these statements was to determine whether or not the participants understood how smart contracts might simplify contract management procedures, improve transparency, and reduce risks in the construction business.

6.4.3. Perceived Benefits and Challenges

This chapter focuses on the participants' opinions of the benefits and obstacles related with the implementation of smart contracts in the building sector. Specifically, this paragraph examines the participants' views towards the construction industry. In order to evaluate the practicability of using smart contracts in building projects and determine the possible impact they may have; it is essential to have a solid understanding of the perceived benefits and drawbacks of using such contracts.

The questionnaire consisted of a series of closed-ended questions that asked participants to indicate the degree to which they agreed or disagreed with statements that linked to the possible advantages of smart contracts. These remarks covered a wide range of topics, including greater confidence among project stakeholders, better contract transparency, increased efficiency in contract administration, decreased instances of conflicts and delays, and improved contract management efficiency. By doing an analysis of the replies to these questions, we will be able to gather insights into how individuals in the building business see the benefits of using smart contracts.

In a similar vein, the poll investigated the perceived difficulties or roadblocks associated with the utilisation of smart contracts in building projects. Participants were asked to rate their level of agreement or disagreement with

statements related to potential obstacles, such as concerns about data security, legal and regulatory issues, technological complexities, and resistance to change. Participants were also asked to rate their level of resistance to change. By analysing these comments, we will be able to determine the perceived obstacles that may prevent broad adoption of smart contracts in the building sector.

Open-ended questions, in addition to closed-ended questions, were included in the survey. These questions gave respondents the opportunity to elaborate further on the perceived benefits and difficulties associated with the topic at hand. These qualitative responses provide a deeper understanding of the participants' perspectives, allowing for nuanced insights and potential considerations that may not be captured by closed-ended responses alone. Alternatively stated: these qualitative responses allow for more nuanced insights and potential considerations.

The purpose of this research is to find common themes and patterns related to the perceived benefits and obstacles of using smart contracts in the construction field by analysing the comments provided by the participants. This research will present a detailed review of the advantages that are thought to be offered by smart contracts, such as an increase in efficiency, a reduction in conflicts, and an improvement in transparency. During the same time, it will provide light on the various issues and impediments that need to be addressed, including concerns surrounding data security, legal repercussions, and technological complexities.

We are able to acquire useful insights into the possible influence that these digital agreements may have on the construction sector if we investigate the alleged benefits and difficulties associated with smart contracts. These results will provide industry experts, policymakers, and researchers with information regarding the potential and considerations related with the implementation of smart contracts in building projects. In the end, the study will contribute to strengthening processes for contract management, reducing risks, and increasing overall efficiency in the construction business.

6.4.4. Barriers to Adoption

In this part, the focus is on identifying and analysing the obstructions that stand in the way of broad implementation of smart contracts in the building sector. To distinguish the issues that need to be overcome in order to encourage the use of smart contracts in building projects, it is principal to first have an understanding of the obstacles that stand in the way.

The poll consisted of a variety of questions that were developed with the express purpose of eliciting responses concerning the challenges and restrictions that experts see as being associated with the use of smart contracts. The participants were asked to assess the degree to which they agreed or disagreed with statements that were connected to a variety of possible roadblocks. These statements encompassed factors such as a lack of awareness and understanding of smart contracts, concerns about data security and privacy, uncertainties regarding legal and regulatory requirements, technological complexities, resistance to change, and the requirement for industry-wide standardization. By doing an analysis of the replies to these questions, we will be able to acquire a better understanding of the perceived barriers that is positioned in the way of the well-known use of smart contracts in the building sector.

In addition, participants were given the opportunity to submit further comments and explanations addressing the challenges they see in connection to the implementation of smart contracts through the use of open-ended questions. These qualitative comments provide useful insights into the unique issues that participants encounter or predict, providing for a fuller knowledge of the barriers and potential considerations that may be taken into account.

Through the analysis of the replies provided by the participants, we want to find common themes and patterns connected to the obstacles that stand in the way of the widespread utilization of smart contracts in the building and construction sector. This analysis will offer a detailed overview of the issues and hurdles that professionals experience or perceive as hindrances to using smart contracts. This overview will be provided as a result of this analysis. It will give insight on

reasons that inhibit the widespread application of smart contracts, such as worries about the security of data, legal uncertainty, and opposition to change.

We may obtain useful insights into the specific difficulties that need to be solved in order to enable the integration of “smart contracts” in the building sector if we examine the obstacles to adoption that are preventing it from being adopted. The conclusions of this study will enlighten industry experts, politicians, and researchers about the challenges that need to be conquered in order to encourage the efficient usage of smart contracts. The analysis will contribute to the development of strategies and initiatives that will facilitate the widespread adoption of smart contracts in construction projects by addressing these barriers, fostering awareness, enhancing education, addressing regulatory concerns, and promoting industry-wide collaboration. All of these goals will be accomplished in order to facilitate the widespread adoption of smart contracts.

6.4.5. Factors Influencing Adoption

In this part, we will investigate the elements that play a role in determining whether or not smart contracts become widespread in the construction business. In order to determine the drivers and influencers that contribute to the adoption and realization of smart contracts in building projects, it is essential to have a solid understanding of the elements that are at play here.

The questionnaire included a number of questions whose purpose was to investigate the variables that participants consider to be influential in the decision-making process regarding the utilization of smart contracts. The participants were asked to assess the degree to which they agreed or disagreed with statements that were connected to a variety of potential reasons. These remarks covered a wide range of topics, including things like the perceived advantages, technology maturity, corporate culture, industry norms and practices, legal frameworks, financial concerns, and the availability of supporting infrastructure. By examining the replies to these questions, we will be able to acquire insights into the perceived elements that impact the choice on whether or not to embrace smart contracts in the construction business.

Open-ended questions, in addition to closed-ended questions, were included in the survey. These questions gave respondents the opportunity to elaborate further on the aspects that they felt were most influential in terms of adoption. These qualitative responses provide a deeper understanding of the participants' perspectives, allowing for nuanced insights and potential considerations that may not be captured by closed-ended responses alone. Alternatively stated: these qualitative responses allow for more nuanced insights and potential considerations.

By analysing the replies provided by the participants, our goal is to discover common themes and patterns linked to the factors that affect the smart contracts adoption in the building field. Upon completion of this investigation, a complete summary of the most important drivers and influences that experts take into consideration when making choices about the deployment of smart contracts will be presented. This research will offer light on a number of aspects, including the perceived advantages of smart contracts, the preparedness of companies to accept new technologies, the impact of industry norms and practices, the influence of legal frameworks, and the financial consequences of adoption.

We can obtain useful insights into the dynamics and considerations that shape the decision-making process around smart contracts in the construction sector if we conduct an investigation into the elements that influence adoption and see how they affect adoption rates. These findings will inform industry professionals, policymakers, and researchers about the key factors that need to be addressed and leveraged to promote the wider adoption of smart contracts. These findings will inform industry professionals, policymakers, and researchers about the key factors that need to be addressed and leveraged. The analysis will contribute to the development of strategies and initiatives that aim to increase awareness, address technological readiness, promote a supportive organizational culture, shape regulatory frameworks, and overcome any barriers that hinder the adoption of smart contracts in construction projects. These goals will be accomplished by fostering knowledge, addressing technological readiness,

promoting a supportive organizational culture, and overcoming any barriers that exist.

6.5. Results

In this section, the results of the survey are reported. The actual number of responses is 33. The survey consists of 2 sections; the first section contains 5 questions related to the demographics of the participants. Age, where participants live, the highest education level, what their field of expertise is. The results of the first section are discussed next.

For the question: “What is your age?”, all participants answered withing the ranges provided.

What is your age?
33 responses

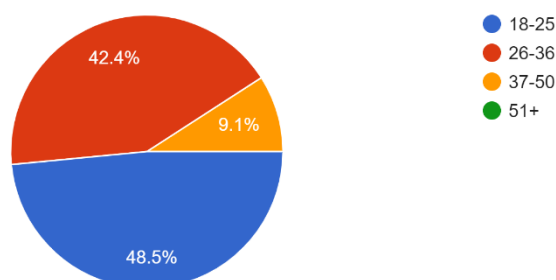


Figure 11. Section 1 – Question 1

Among the 33 participants who took part in the survey, 16 were from the ages 18-25, while 14 were from the ages 26-36. 3 participants were from the age group 37-50.

For the question: “Where do you live?”, also, all participants took part in answering the question.

Where do you live?

33 responses

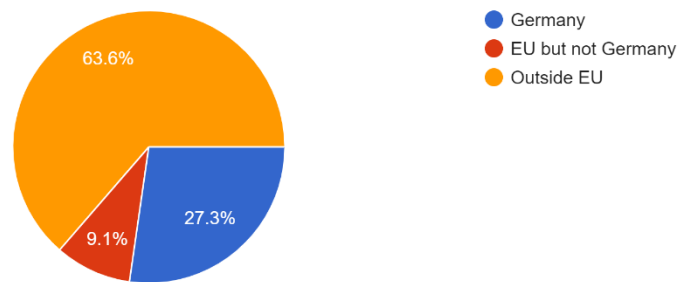


Figure 12. Section 1 – Question 2

Most of the participants were from the areas outside the European Union with an exact number of 21 participants. 9 survey respondents live in Germany, while the remaining 3 participants live in EU countries outside of Germany.

For the question regarding highest education acquired, the following results were gathered.

What is the highest educational level you reached?

33 responses

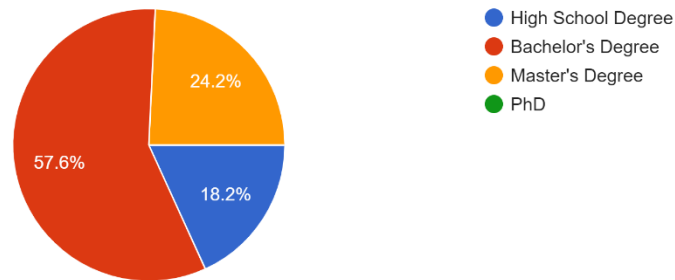


Figure 13. Section 1 – Question 3

Bachelor's degree holders took first place with 19 participants, while master's degree holders who answered the survey, were 8 participants. High school degree holders composed 6 answers of the total number of respondents.

For the question regarding the field of expertise, the following data was collected.

In which field do you have experience? (multiple picks are accepted)

33 responses

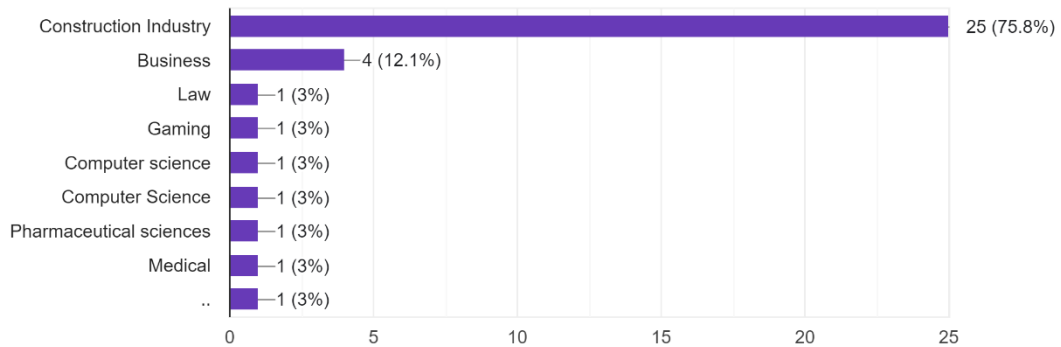


Figure 14. Section 1 – Question 4

75.8% of the respondents came from the construction industry. 3% came from law, while 12.1% came from business industry. Participants from other industries took part in the survey, such as gaming, computer science, and medical and pharmaceutical sciences.

For the question about the current role of participants if they work in construction, the collected data is as follows:

If you have experience in the construction industry, what is your current role?

33 responses

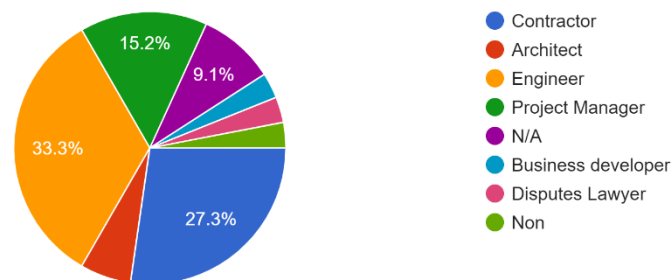


Figure 15. Section 1 – Question 5

Contractors formed 27.3% of the participants, while engineers composed 33.3% of the respondents. 15.2% of the participants were project managers, and 6.1% of the respondents were architects. 3% formed disputes lawyers, and finally, around 12% were not from the construction industry.

The next part discusses the survey questions regarding the utilisation of smart contracts in the building business. This section consists of 22 questions that are collecting data regarding the possibility of using smart contracts in the construction field, the best qualities of the new technology, the challenges facing the technology and its reasons, and what can be done to get smart contracts to be used more within the construction industry.

For the questions regarding familiarity of smart contracts concept, and prior experience with using smart contracts technology in a construction project, the following results were collected:

3% of the respondents were very familiar with the concept of smart contracts, while 27.3% have not heard of the technology. 18.2% heard of it but were not very familiar with the concept, while 18.2% were familiar with the technology to some extent. The data can be viewed clearly in the figure 16 below.

3% of the participants have used smart contracts multiple times in construction projects, while 12.1% of the participants did not and do not plan to use smart contracts technology in the future. 9.1% used the technology just once in their sector. 12.1% were not involved with the technology application, while 63.6% have not used the technology but plan to in the future. The results can be seen in figure 17 below.

Are you familiar with the concept of smart contracts?

33 responses

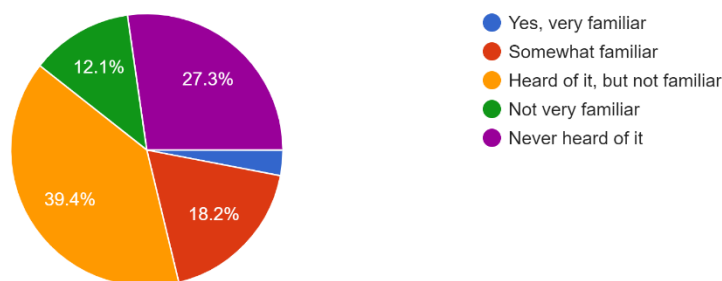


Figure 16. Section 2 – Question 1

Have you ever used smart contracts in a construction project?

33 responses

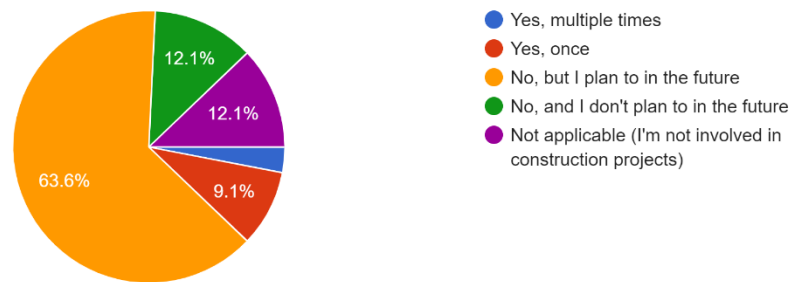


Figure 17. Section 2 – Question 2

The next couple of questions inquire about the opinions of the participants regarding the potential of smart contracts to streamline the building realm, and if smart contracts would be more efficient than traditional contracts with respect to the construction sector.

27.3% were very positive regarding the streamlining of the construction industry, while 6.1% did not believe that this technology could streamline the construction business. 48.5% were neither with nor against on that matter as can be viewed in figure 18.

When comparing smart contracts to traditional contracts, 21.2% believed that smart contracts are significantly more efficient than traditional ones. Also, 39.4% agreed that smart contracts are more likely to be more efficient than traditional contracts. 39.4% were not very sure about the comparison as shown in figure 19.

Do you think smart contracts could help streamline the construction industry?

33 responses

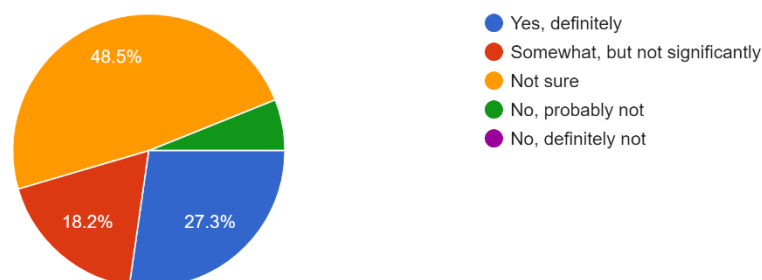


Figure 18. Section 2 – Question 3

Do you think smart contracts would be more efficient than traditional contracts in the construction industry?

33 responses

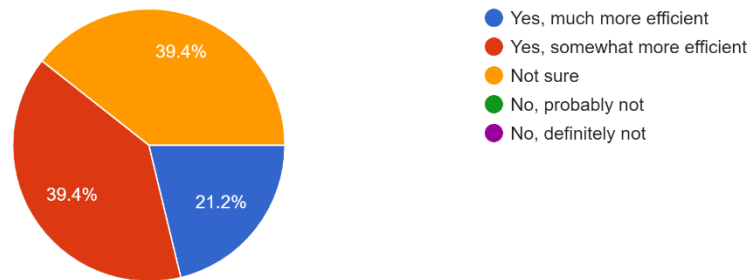


Figure 19. Section 2 – Question 4

The next question unravels what concerns participants have when about using smart contracts in the building realm. As seen in figure 20, 63.6% of participants chose lack of familiarity with technology as a main concern. In second place, security risks form a somewhat significant concern for 45.5% of participants. Uncertainty about legal validity, and lack of standardization both came in third place with a score of 36.4% of participants. Only 3% of the participants mentioned the endangered existing job system.

What concerns do you have about using smart contracts in the construction industry?

33 responses

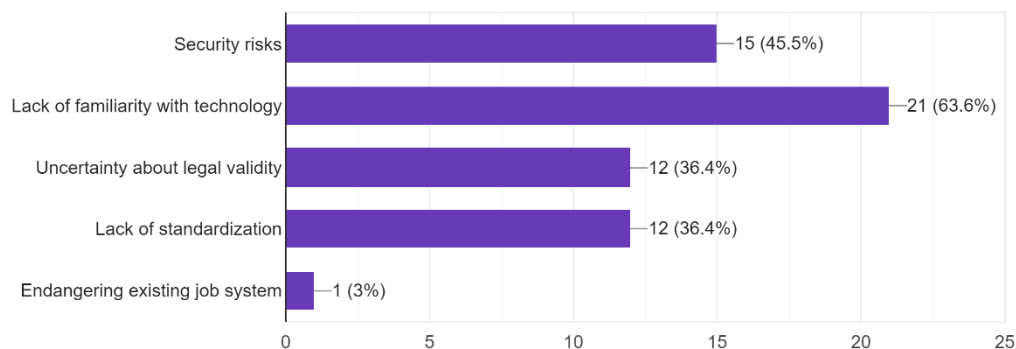


Figure 20. Section 2 – Question 5

The following question poses a major point regarding the topic of the thesis, how smart contracts would benefit the construction industry. In figure 21, 75.8% of the participants agreed on faster contract execution being the top benefit for the construction sector. Reduced administrative burden came in second with

54.5% of the participants agreeing on it as major benefit for construction. Improved transparency was regarded as a less-significant benefit of smart contracts in the building business with a score of 45.5%. Enhanced security was considered the least significant benefit for implementing smart contracts technology in the construction sector with a score of only 30.3%.

How do you think smart contracts could benefit the construction industry?

33 responses

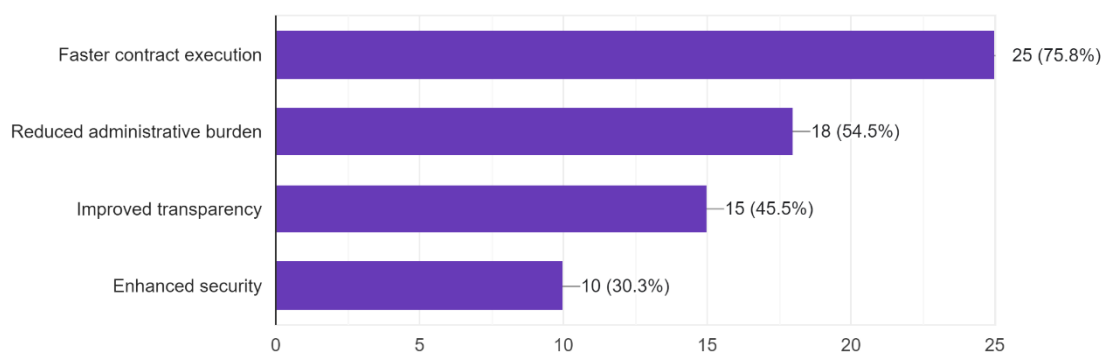


Figure 21. Section 2 – Question 6

How smart contracts can help reduce disputes in the building sector, is the topic for the next question. Figure 22 shows that 48.5% of the participants agreed on increased transparency being the best way to help reduce disputes. 21.2% of participants agreed on improved communication as way to help with the disputes. Also, streamlined dispute resolution processes was thought to be the best way by 18.2% of the participants. Only 12.1% of the participants thought enforced contractual obligations are the best way to help reduce disputes in the construction sector.

How do you think smart contracts could help reduce disputes in the construction industry?

33 responses

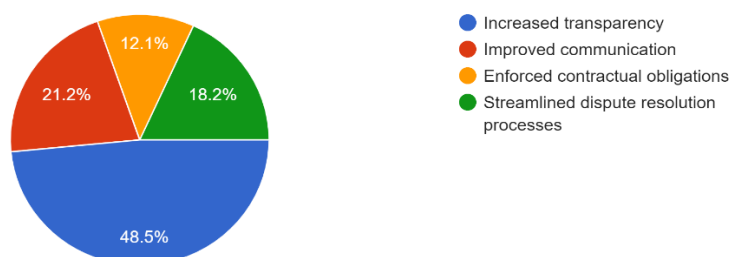


Figure 22. Section 2 – Question 7

When the respondents were asked if they would trust a smart contract more than a traditional contract, 42.4% responded by not sure, while 21.2% were confident about using a smart contract, and 33.3% agreed provided that it was backed by reputable provider. Only 3% would not trust the smart contract over the traditional contract. The results can be seen in figure 23.

Would you trust a smart contract more than a traditional contract?

33 responses

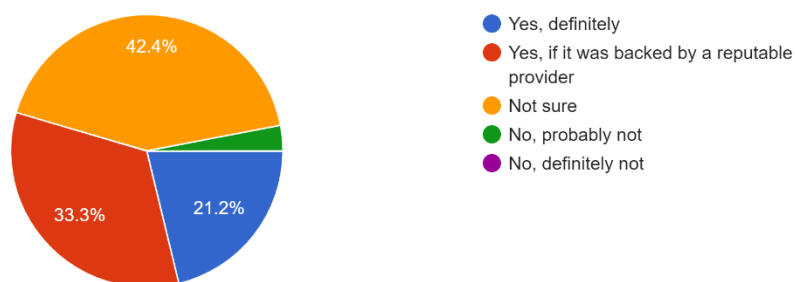


Figure 23. Section 2 – Question 8

The question after discusses the opinions of participants about what the key features of smart contracts that make them useful for the construction industry. In the figure below (figure 24), 51.5% believe that automation is the top key feature for a smart contract that make it most useful. 21.2% agree that self-execution is the best feature to be used in the construction industry. 18.2% believed that transparency is the most useful feature in the construction sector, while only 9.1% of the respondents agreed that enforceability is the top feature.

What do you think are the key features of a smart contract that make it beneficial for the construction industry?

33 responses

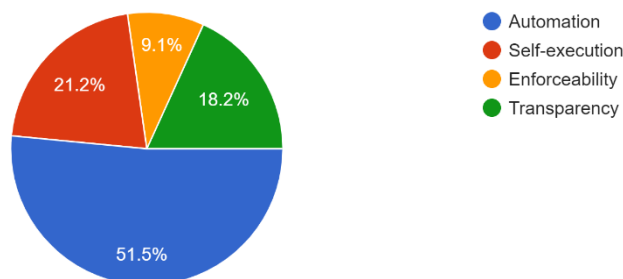


Figure 24. Section 2 – Question 9

When the participants were asked about what improvements needed to be made to smart contracts to make more useful in construction, 48.5% agreed on better integration with existing systems as the most needed improvement. 18.2% thought that enhancing security measures, same as for improved standardization, is of most importance, while only 15.2% required greater flexibility to be the improvement needed the most as can be viewed in figure 25.

What improvements do you think need to be made to smart contracts to make them more useful in the construction industry?

33 responses

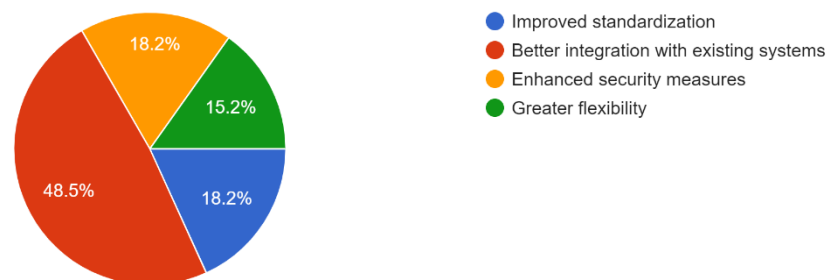


Figure 25. Section 2 – Question 10

For the question about the preference of participants for using contracts in a construction project, smart or traditional, 60.6% agreed they have neutral tendencies regarding the subject. 30.3% would choose smart contracts if they are available. 6.1% would go to a traditional contract first, while 3% would never go for a smart contract in a construction project. See figure 26.

Would you prefer to use smart contracts or traditional contracts in a construction project?

33 responses

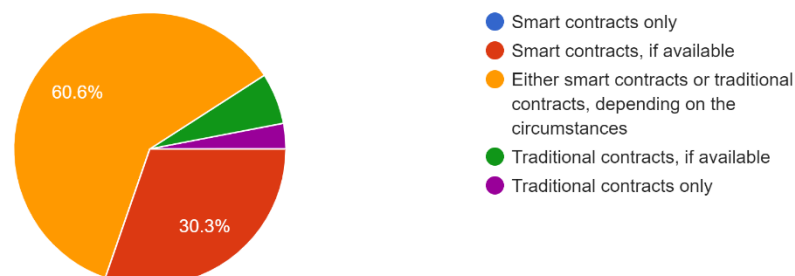


Figure 26. Section 2 – Question 11

When the participants were asked about their opinion if smart contracts could help with the payment processes in the construction industry, 30.3% were incredibly sure that smart contracts would help payment processes. Also, 48.5% believed that it would help only if it was properly implemented. On the other hand, 3% did not agree that smart contracts would help payment processes. Figure 27 shows that 18.2% were not sure about the matter.

Do you think smart contracts could help with payment processes in the construction industry?
33 responses

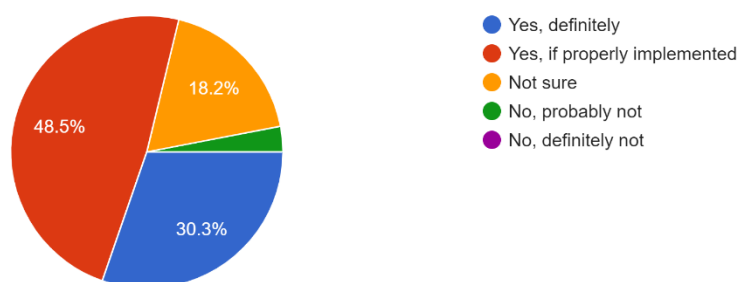


Figure 27. Section 2 – Question 12

Following up on the previous question, participants were asked about the factors that help smart contracts improve payment processes. 63.6% of respondents agreed that improved payment tracking is the top factor. 51.5% of respondents believed that faster payment processing is the most important factor. The participants who believed that enhanced payment security is the most important factor were 33.3%, while those for reduced payment disputes were 36.4% as shown in figure 28.

How do you think smart contracts could help improve payment processes in the construction industry?
33 responses

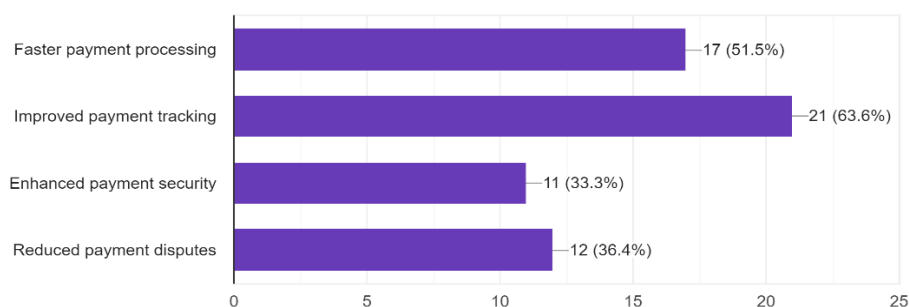


Figure 28. Section 2 – Question 13

As for the question if smart contracts were thought to be a disruptive technology in the construction industry, 21.2% were very optimistic and were definitely sure. 36.4% were agreeing but in a less confident manner. 39.4% were not sure if smart contracts technology is a disruptive technology. Only 3% were not in favour of the subject as shown in figure 29.

Would you consider smart contracts to be a disruptive technology in the construction industry?
33 responses

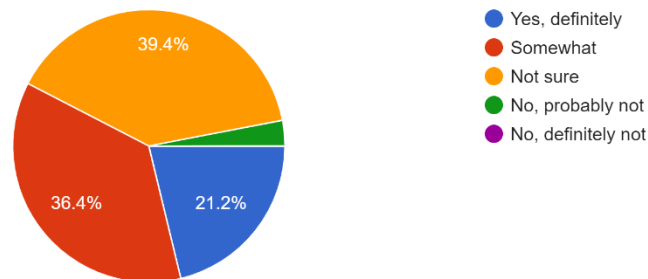


Figure 29. Section 2 – Question 14

When the participants were asked about the impacts smart contracts could have on the role of lawyers in the construction industry. In figure 30 below, 39.4% of the participants believed that a reduced need for legal review would be the most significant impact, while 48.5% agreed that a shift in focus towards contract coding and implementation would be the most significant. Only 12.1% did not think of a relatively noticeable impact for smart contracts on construction business.

What impact do you think smart contracts could have on the role of lawyers in the construction industry?

33 responses

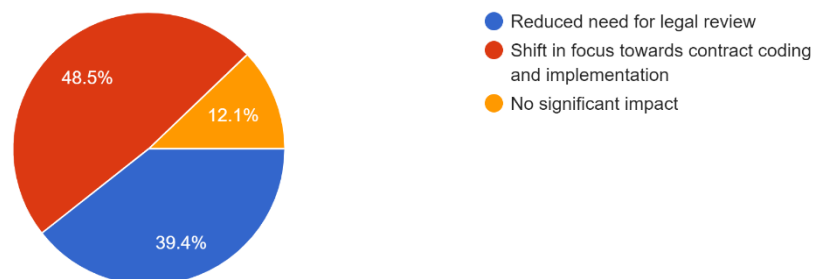


Figure 30. Section 2 – Question 15

As for the question if the utilisation of smart contracts would require significant changes to the current legal framework governing construction contracts, 12.1% agreed that significant changes would be necessary, while 60.6% agreed that only some changes would be needed. 27.3% were not sure about the matter, as can be seen in figure 31.

Do you think the use of smart contracts would require significant changes to the current legal framework governing construction contracts?

33 responses

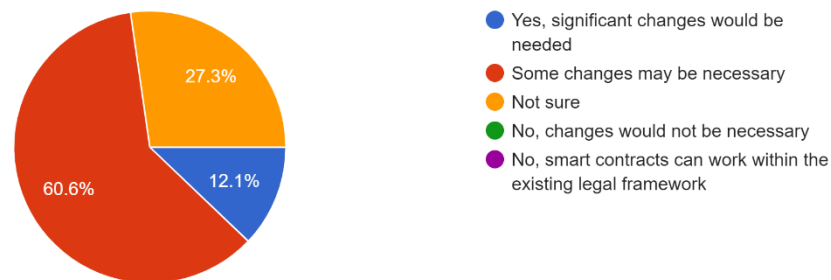


Figure 31. Section 2 – Question 16

Regarding the question if smart contracts would help with risk management in the construction industry, as can be viewed in figure 32, 51.5% agreed that with proper implementation, smart contracts could help with risk management. 18.2% were very confident that risk management would be positively affected by smart contracts technology, while 27.3% were not quite sure about the matter. Only 3% were not approving of the fact that smart contracts would help with risk management.

Do you think smart contracts could help with risk management in the construction industry?

33 responses

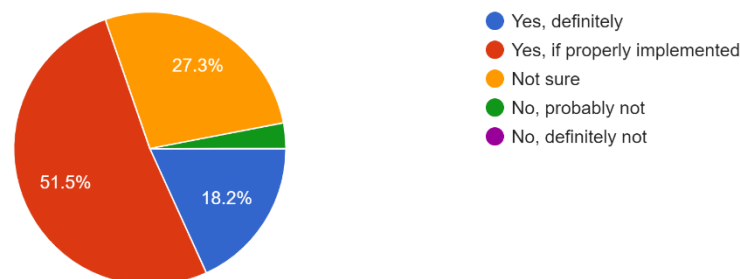


Figure 32. Section 2 – Question 17

Following up on the previous question, participants were asked about how they think smart contracts would help risk management. In figure 33, 48.5% of the participants agreed that enhanced risk mitigation measures are going to be boosted when using smart contracts. 27.3% of the participants agreed on better risk sharing arrangements. 21.2% viewed that improved risk assessment is the main factor that could help risk management. Only 3% did not believe that smart contracts can be applied in risk management.

How do you think smart contracts could help with risk management in the construction industry?

33 responses

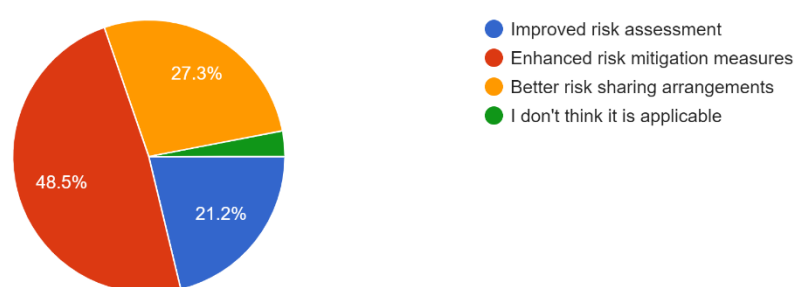


Figure 33. Section 2 – Question 18

When the participants were asked if smart contracts could help improve the quality of construction projects, 15.2% totally agree with the question. 39.4% agree but with the condition of being properly implemented. Also 39.4% were not sure whether the quality would be boosted or not with smart contracts. On the other hand, 1% of the participants disagreed with the question, and 1% strongly disagreed with the question. The data can be seen in figure 34.

Do you think smart contracts could help improve the quality of construction projects?

33 responses

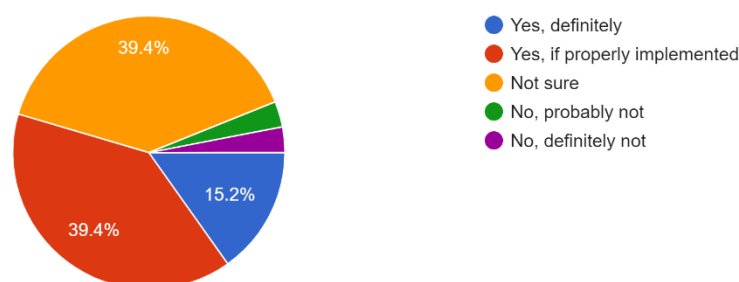


Figure 34. Section 2 – Question 19

The participants were asked about the role of the government and regulatory bodies play in promoting the use of smart contracts. 51.5% agreed that the regulatory bodies should develop standards for smart contracts implementation. 42.4% agreed that the government should provide guidance and education on smart contracts, while only 6% agreed that the government should offer incentives for companies to adopt smart contracts, as shown in figure 35.

What role could the government and regulatory bodies play in promoting the use of smart contracts in the construction industry?

33 responses

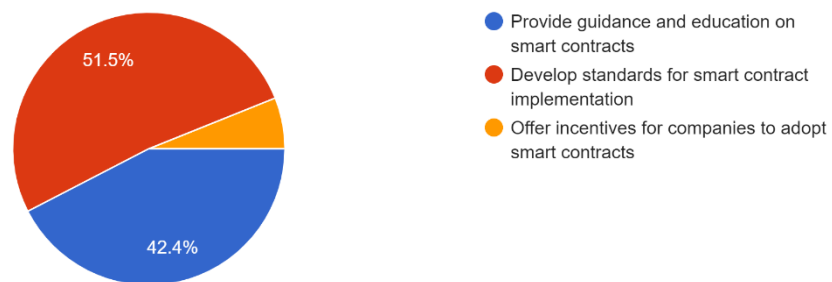


Figure 35. Section 2 – Question 20

The following question discussed what the most significant barriers to the widespread adoption of smart contracts in the construction industry are. As shown in figure 36, lack of awareness and understanding of smart contracts, same as resistance to change from traditional contract processes achieved a score of 69.7% of the participants. While concerns about security and legal validity, same as lack of standardization, scored 45.5% of the participants.

What are the most significant barriers to the widespread adoption of smart contracts in the construction industry?

33 responses



Figure 36. Section 2 – Question 21

The last question discussed participants how much they agree with smart contracts technology would be widely used among many disciplines in the construction industry. 15.2% fully agreed, and 51.5% agreed that smart contracts would be adopted across many disciplines. 30.3% of the participants were neutral about the subject. On the other hand, only 3% disagreed with the subject of the question as shown in figure 37.

Do you agree that smart contracts technology will be widely used among many disciplines in the construction industry?

33 responses

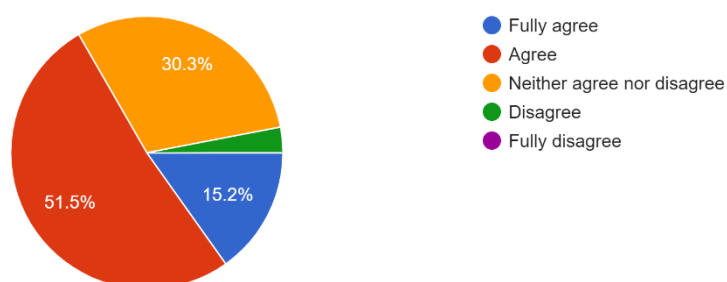


Figure 37. Section 2 – Question 22

That concludes the survey results section, where all the questions results were reported. The final parts of the thesis will include the results chapter, where a summary of the results of all the chapters included in the thesis is provided, and a conclusion chapter, where the results are translated into information and useful data to provide an outcome of the author's research towards the potential use of smart contracts technology in the building field.

6.6. Analysis

6.6.1. Section 1

The results provide a clear picture of the age distribution of the respondents, providing valuable demographic insights. It reveals that people from all walks of life participated in the study, with the majority of respondents falling between the ages of 18 and 25 and 26 and 36. It also suggests there are fewer people in the sample between the ages of 37 and 50. Understanding the construction industry's generational views and probable attitude variations towards smart contracts might benefit from this data.

The findings give a snapshot of the participants' global distribution, with the bulk of respondents located outside the EU, followed by those in Germany and other EU nations. Knowing the geographical range of the survey helps researchers, policymakers, and implementers zero in on certain areas for in-depth study, targeted policy change, or stricter oversight.

The findings also shed light on the participants' educational backgrounds, revealing that the vast majority of them have at least a bachelor's degree. This data may be used to infer the average education level of the population and put respondents' knowledge of smart contracts into perspective. This allows for a more nuanced assessment of the educational variety among the participants because it displays a lesser number of master's degree holders and responders with only a high school education.

As for area of expertise, the bulk of respondents' jobs may be deduced from the data; most are in the construction business. This indicates that the poll was taken by a knowledgeable group of people interested in building. Having people from fields as diverse as law, business, gaming, computer science, and the medical and pharmaceutical sciences take part in the survey enriches the overall quality of the data collected.

Contractors, engineers, project managers, architects, and disputes attorneys are just some of the examples of current occupations in construction that may be gleaned from the data. With this information, researchers may learn more about the thoughts and feelings of people working in various construction-related fields. Important players in the adoption and execution of smart contracts in building projects may also be identified.

These results provide a thorough picture of the sample population by revealing information on their demographics, geographic representation, education, expertise, and current roles. Having this background knowledge will help shape future smart contract-related studies, policies, courses, and cross-industry partnerships.

6.6.2. Section 2

The findings provide light on the respondents' level of acquaintance with smart contracts and their thoughts on the applicability of the technology to the construction sector, among other things. Here are the most important takeaways about the relevance of the findings:

Regarding smart contracts expertise, the findings reveal the respondents' degree of comfort with smart contracts. Comprehension the current knowledge gaps and the need for educational programs to raise awareness and understanding of smart contracts in the construction sector is greatly aided by the data shown here. The fact that many people in the study did not know what smart contracts were also serves to draw attention to possible implementation hurdles.

About adoption and usage, the findings provide light on the respondents' past exposure to and future plans for utilizing smart contracts in building projects. This information is useful for assessing the existing degree of adoption and pinpointing challenges and openings for further adoption. There appears to be a rising interest and possibility for increasing use of smart contracts, since a large proportion of participants have not utilized them but expect to in the future.

Participants' views on the advantages they foresee for smart contracts are instructive. The stated benefits, such as quicker contract execution, decreased administrative load, more transparency, and higher security, offer a clear grasp of the expected benefits that smart contracts may bring to the construction sector. Future deployment methods may be informed by this data, and areas where the technology can have the most impact can be highlighted.

The findings illuminate the uncertainties and hurdles surrounding smart contracts in the building sector. Lack of familiarity with technology, security risks, uncertainty about legal validity, and a lack of standardization are just some of the concerns that have been identified. This information is crucial for addressing potential obstacles and developing strategies to mitigate risks and increase acceptance among stakeholders.

Regarding changes to job duties and regulations, the views of participants on the effects of smart contracts on the function of attorneys and the legal

framework controlling construction contracts provide light on possible obligations and the need for alterations to the legal environment. To guarantee a seamless incorporation of smart contracts within the existing legal framework, this data may direct talks and partnerships between legal professionals, industry players, and regulatory agencies.

The findings provide light on participants' perspectives on the use of smart contracts in risk management and the enhancement of the quality of building projects. By gaining an appreciation for these vantage points, we can better pinpoint the use cases for smart contracts and direct our efforts toward improving risk management, risk allocation, and project quality as a whole.

Perspectives from participants on the role of government and regulatory agencies in encouraging the adoption of smart contracts stress the need for clear standards, advice, education, and possible incentives. This knowledge may be used to better promote smart contract usage in the building sector through legislative talks and other activities.

In regard to adoption obstacles, the highlighted adoption obstacles, such as a lack of understanding, reluctance to change, security concerns, and the need for standardization, provide light on the problems that must be solved before smart contracts may be used on a global scale. When these roadblocks are identified, specific solutions may be developed to remove them and make smart contracts a more natural part of the building process.

The optimistic outlook of the participants on the broad implementation of smart contracts in the construction sector is an encouraging sign of the field's future growth and development. To realize the full potential of smart contracts in building, this knowledge might motivate more study, cooperation, and creativity.

In short, the findings provide useful information that can be used to decisions, policies, educational efforts, and industry-wide partnerships aimed at boosting the efficient adoption and use of smart contracts in the building sector.

7. Results

This chapter comprises of four different sections; first section discusses the final result the literature review chapter; second section reveals the results for the first case study, Vinci UK and Skanska blockchain tool; third section reviews the results for the second case study, smart contract payment system in a construction project in the USA; and fourth section discusses the summarized result for the conducted survey about the potential of smart contracts in the industry of building.

Regarding the first section, the literature review chapter discusses multiple topics where smart contracts add significant values to across the different fields inside the building realm. The journey of smart contracts started in the 1990s when Nick Szabo first came up with the idea and started this lifechanging trend.

Many sources confirm that smart contracts can be used in the planning phase of projects in the form of smart contracts and construction coins. Construction coins can effectively store all payments and transactions information and history in blocks, so that they can prevent tampering with information. Furthermore, blockchain technology can also be used hand in hand with BIM (building information modelling). This technology can be used through different project phases such as design phase, bidding phase, construction phase, and operation phase. Automation of payment, and data exchange environment on a peer-to-peer level are among the top benefits that using smart contracts with BIM enable. In addition, having a distributed ledger allows for the sharing for documents in a secure environment, that is unchanging, where documents review is to be done in manner that is accurate and secure. That can be done in the bidding phase.

The smart contract system with the blockchain technology can easily record and monitor all construction details, when applied to a BIM model with a 4D or 5D integration into the model. This allows for accountability and cost control over the project in the construction stage. Smart contracts are applied in supply chain management when integrated with IoT. The technology allows for secure transfer of information in a system where hacking is nearly impossible. This system can be used in the transfer of materials from one place to another with

ease while controlling the transactions as the contract tracking shipments will definitely be carried out, sending a payment to the responsible partner as soon as IoT sensors inform of the cargo whereabouts. This can be applied to ready mix concrete business, as payments can be organised with delivery of concrete trucks to construction sites.

In project management, smart contracts allow for trust between parties through opening the contract to the public and everyone can see the terms and conditions coordinating every party in the project. This is extremely important when disputes occur, and such contract will definitely eliminate many disputes if properly applied.

Finally, a smart contract is a technology that is being explored and fitted out to existing applications and projects, the top benefits for smart contracts are archiving and safety, payment automation, and eradication of errors that could happen due to failure to apply contract terms.

The second section discusses the first case study, which is the blockchain tool developed by Vinci UK and Skanska. This tool is an application that can allow for control, verification, collaboration, and viewing between all parties involved in a project. The application contains clearance levels that lets parties with higher involvement in the project to sections and data that is not accessible to some of the other parties. The application has the potential to considerably enhance the effectiveness and transparency of the administration of construction projects, which may result in cost reductions and improved outcomes for all parties involved. In addition, cost reductions associated with supply chain by 25% and timelines by 28%, while increasing productivity by 15%.

The third section examines the second case study, which is an actual experiment done on an existing construction site that has used smart contracts in order to automate payments and transactions through a smart contract system that uses unmanned ground and aerial vehicles to scan and detect progress across the project. The case study took into account two construction sites which vary in size and equipment. The case study reported a number of inaccuracies of 5% in some building components. That lead to 5% of inaccuracies in payments because of misclassification of certain items.

Overall, the experiment showed that smart contracts implementation is real and can be used significantly in construction projects, some inaccuracies occur, but the generally, the method was successful.

The fourth section was the survey directed for the exploration of the potential of smart contracts in the construction industry. The survey was carried out online and showed responses of 33 participants. The participants group that took part in the survey were from different areas around the world. The survey showed many positive answers regarding the effect and change the smart contracts technology can have. On the other hand, some responses were not sure about if smart contracts can actually significantly impact on the construction industry. In general, the responses showed that there are many benefits to the use of the technology in construction. Faster payment, reduced disputes, and payment tracking are the top benefits of the smart contract technology in the construction business.

A major part of the participants believed that smart contract technology would improve the quality of the construction industry. Also, most of the participants agreed that legal bodies and the government should help with standardization of smart contracts and its technology to fit the current state of technologies. Finally, most of the respondents agreed that the smart contracts technology will be widely used, sooner or later, among various disciplines in the construction industry.

8. Conclusion

Based on the results acquired from different chapters across the author's research, conclusions were formed in way that answers the research questions which were formulated at the beginning of the journey of the research. The study had 4 research questions that were mentioned in the objective of the master's thesis.

The first question is a direct question about how smart contracts could be utilised in the construction industry to improve efficiency and reduce costs. In order to answer this question, how smart contracts would be implemented into the industry is of essence. Through payment tracking, payment automation, documentation control and sharing, it is made more efficient to go through the normal tasks of the construction industry, as represented in the second case study. When the smart contract system is attached to BIM technology, or IoT devices, the results tend to be more fruitful.

The construction industry can have its costs reduced significantly by implementing smart contracts technology, when the disputes are looked at from a cost point of view. The disputes are incredibly less frequent when using smart contracts. Another aspect that can improve the costs in construction industry, which is the automated payments. Due to the insane risk of bankruptcy in the construction business, when using smart contracts, automating payments can protect companies from that risk, making it less costly than bankruptcy.

According to the survey conducted shown in chapter 6, automation, self-execution, transparency are the key features that are beneficial to the construction industry.

The second research question inquired about the challenges facing the adoption of smart contracts in the construction business. The most significant concerns facing users about smart contracts are lack of familiarity with the technology, in other words, new technology, security risks, and lack of standardisation. Some of these concerns are being mitigated in the recent years, but some remain a little bit in an ignored zone. The most significant barriers to the adoption of smart contracts are lack of awareness and understanding of smart contracts,

resistance to change from traditional contracts to smart contracts, and concerns about security and legal validity.

Inaccuracy of sensors that transmit data to the smart contract is a serious problem and cannot be eliminated fully, due to human error that will always exist on construction projects. The only true solution to this problem is to try and keep the inaccuracy errors at a minimum.

The third question inquires about the merits and demerits of using smart contracts in construction. Best benefits regarding smart contracts are payment automation, reduction in legal disputes, protection against bankruptcy, security and backup, and cost and time savings. Among the benefits of smart contracts are the possibility of integration with different systems such as BIM, IoT, and systems in smart cities.

A significant demerit of the smart contract technology is the unchangeable nature of a smart contract. When a smart contract is built, it cannot be changed or edited, making change of plans after the construction of the smart contract out of the question.

Another demerit is that blockchain platforms can validate significantly less transactions per second compared to other platforms, such as VISA. In point of fact, the scalability problem results in congestion on the network, higher commission rates for transactions, and a lengthening of the amount of time that must pass before the transactions can be confirmed. The last demerit worth mentioning, is the off-chain resources. When the smart contract system requires data entries from outside the online system of the contract, as data from sensor, the possibility of errors increase as the off-chain resources increase.

To answer the fourth research question, which is about the current status of smart contracts in the construction field, how much improvement across the recent years can indicate how fast the technology is growing, and if the growth curve is inclining or declining. Over the years, since the start of the concept by Nick Szabo in 1997, incredible approaches have been made and relatively numerous research papers have been made. The two case studies mentioned in this research work are convincing of the fact that smart contracts technology is growing and will keep spreading. Countless applications are being developed

using blockchain technology, as well as on the field experiments to try and minimise the gap between the off-chain and on-chain resources.

Finally, based on the survey data gathered, more than two thirds of the participants agreed that smart contracts will keep spreading and be widely used in various aspects of the construction industry.

Declaration of Authorship

I hereby declare that the attached master's thesis was completed independently and without the prohibited assistance of third parties, and that no sources or assistance were used other than those listed. All passages whose content or wording originates from another publication have been marked as such. Neither this thesis nor any variant of it has previously been submitted to an examining authority or published.

Berlin, 13/06/2023

Location, Date

Mario Akhnoukh

Signature of the student

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10. Appendix A – Survey Questions

Survey questions and choices as sent to participants to perform the survey using Google Forms.

Master's Thesis Survey: Smart Contracts in Construction

We are conducting a survey to explore the potential of smart contracts in the construction industry. Smart contracts are self-executing contracts that are coded on a blockchain network. They have the potential to revolutionize the construction industry by automating the contracting process, reducing paperwork, and increasing transparency. Your participation in this survey will help us understand the current perception of smart contracts in the construction industry and identify potential challenges and opportunities.

*** Indicates required question**

1. What is your age? *

Mark only one oval.

- 18-25
- 26-36
- 37-50
- 51+

2. Where do you live? *

Mark only one oval.

- Germany
- EU but not Germany
- Outside EU

3. What is the highest educational level you reached? *

Mark only one oval.

- High School Degree
- Bachelor's Degree
- Master's Degree
- PhD
- Other: _____

4. In which field do you have experience? (multiple picks are accepted) *

Check all that apply.

- Construction Industry
- Business
- Law
- Other: _____

5. If you have experience in the construction industry, what is your current role? *

Mark only one oval.

- Contractor
- Architect
- Engineer
- Project Manager
- Other: _____

Master Thesis Survey

Technical information of interviewees are being collected in this section

6. Are you familiar with the concept of smart contracts? *

Mark only one oval.

- Yes, very familiar
- Somewhat familiar
- Heard of it, but not familiar
- Not very familiar
- Never heard of it

7. Have you ever used smart contracts in a construction project? *

Mark only one oval.

- Yes, multiple times
- Yes, once
- No, but I plan to in the future
- No, and I don't plan to in the future
- Not applicable (I'm not involved in construction projects)

8. Do you think smart contracts could help streamline the construction industry? *

Mark only one oval.

- Yes, definitely
- Somewhat, but not significantly
- Not sure
- No, probably not
- No, definitely not

9. Do you think smart contracts would be more efficient than traditional contracts in the construction industry? *

Mark only one oval.

- Yes, much more efficient
- Yes, somewhat more efficient
- Not sure
- No, probably not
- No, definitely not

10. What concerns do you have about using smart contracts in the construction industry? *

Check all that apply.

- Security risks
- Lack of familiarity with technology
- Uncertainty about legal validity
- Lack of standardization
- Other: _____

11. How do you think smart contracts could benefit the construction industry? *

Check all that apply.

- Faster contract execution
- Reduced administrative burden
- Improved transparency
- Enhanced security
- Other: _____

12. How do you think smart contracts could help reduce disputes in the construction industry? *

Mark only one oval.

- Increased transparency
- Improved communication
- Enforced contractual obligations
- Streamlined dispute resolution processes
- Other: _____

13. Would you trust a smart contract more than a traditional contract? *

Mark only one oval.

- Yes, definitely
- Yes, if it was backed by a reputable provider
- Not sure
- No, probably not
- No, definitely not

14. What do you think are the key features of a smart contract that make it beneficial for the construction industry? *

Mark only one oval.

- Automation
- Self-execution
- Enforceability
- Transparency
- Other: _____

15. What improvements do you think need to be made to smart contracts to make them more useful in the construction industry? *

Mark only one oval.

- Improved standardization
- Better integration with existing systems
- Enhanced security measures
- Greater flexibility
- Other: _____

16. Would you prefer to use smart contracts or traditional contracts in a construction project? *

Mark only one oval.

- Smart contracts only
- Smart contracts, if available
- Either smart contracts or traditional contracts, depending on the circumstances
- Traditional contracts, if available
- Traditional contracts only

17. Do you think smart contracts could help with payment processes in the construction industry? *

Mark only one oval.

- Yes, definitely
- Yes, if properly implemented
- Not sure
- No, probably not
- No, definitely not

18. How do you think smart contracts could help improve payment processes in the construction industry? *

Check all that apply.

- Faster payment processing
- Improved payment tracking
- Enhanced payment security
- Reduced payment disputes
- Other: _____

19. Would you consider smart contracts to be a disruptive technology in the construction industry? *

Mark only one oval.

- Yes, definitely
- Somewhat
- Not sure
- No, probably not
- No, definitely not

20. What impact do you think smart contracts could have on the role of lawyers in the construction industry? *

Mark only one oval.

- Reduced need for legal review
- Shift in focus towards contract coding and implementation
- No significant impact
- Other: _____

21. Do you think the use of smart contracts would require significant changes to the current legal framework governing construction contracts? *

Mark only one oval.

- Yes, significant changes would be needed
- Some changes may be necessary
- Not sure
- No, changes would not be necessary
- No, smart contracts can work within the existing legal framework

22. Do you think smart contracts could help with risk management in the construction industry? *

Mark only one oval.

- Yes, definitely
- Yes, if properly implemented
- Not sure
- No, probably not
- No, definitely not

23. How do you think smart contracts could help with risk management in the construction industry? *

Mark only one oval.

- Improved risk assessment
- Enhanced risk mitigation measures
- Better risk sharing arrangements
- Other: _____

24. Do you think smart contracts could help improve the quality of construction projects? *

Mark only one oval.

- Yes, definitely
- Yes, if properly implemented
- Not sure
- No, probably not
- No, definitely not

25. What role could the government and regulatory bodies play in promoting the use of smart contracts in the construction industry? *

Mark only one oval.

- Provide guidance and education on smart contracts
- Develop standards for smart contract implementation
- Offer incentives for companies to adopt smart contracts
- Other: _____

26. What are the most significant barriers to the widespread adoption of smart contracts in the construction industry? *

Check all that apply.

- Lack of awareness and understanding of smart contracts
- Resistance to change from traditional contract processes
- Concerns about security and legal validity
- Lack of standardization
- Other: _____

27. Do you agree that smart contracts technology will be widely used among many * disciplines in the construction industry?

Mark only one oval.

- Fully agree
- Agree
- Neither agree nor disagree
- Disagree
- Fully disagree

This content is neither created nor endorsed by Google.

Google Forms

11. Appendix B – Survey Responses

Responses as they were received from Google Forms.

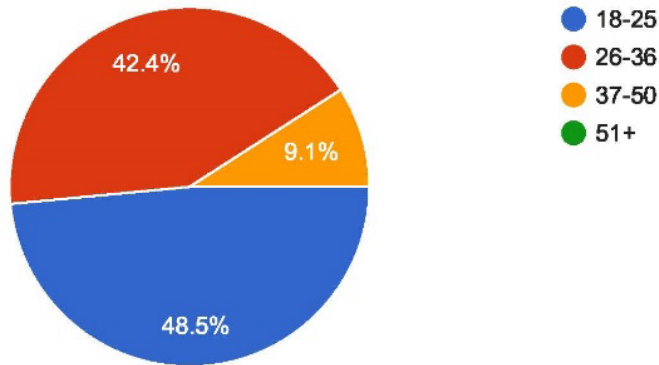
Master's Thesis Survey: Smart Contracts in Construction

33 responses

What is your age?

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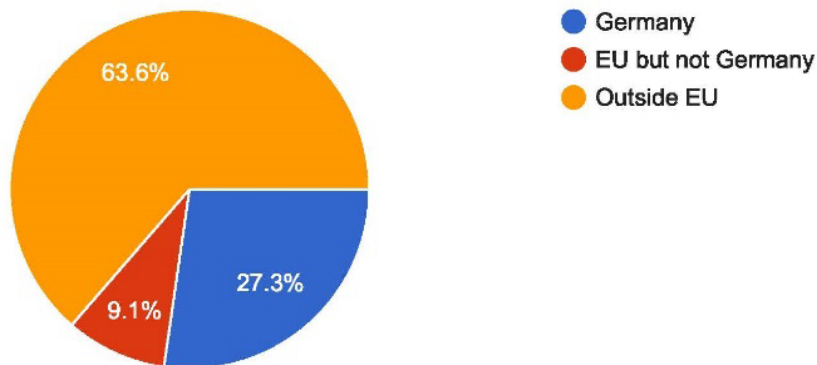
33 responses



Where do you live?

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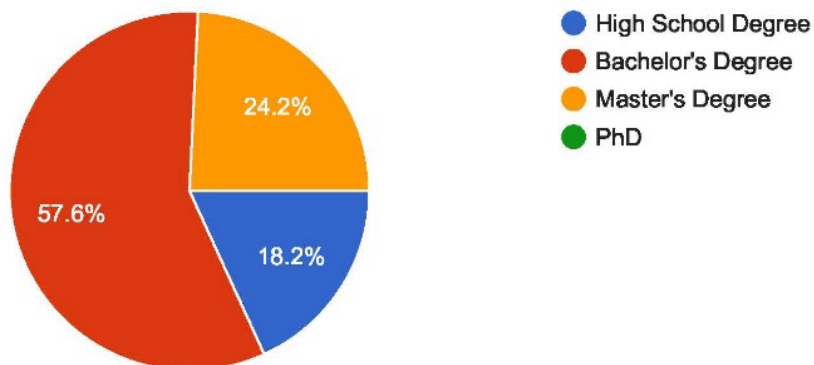
33 responses



What is the highest educational level you reached?

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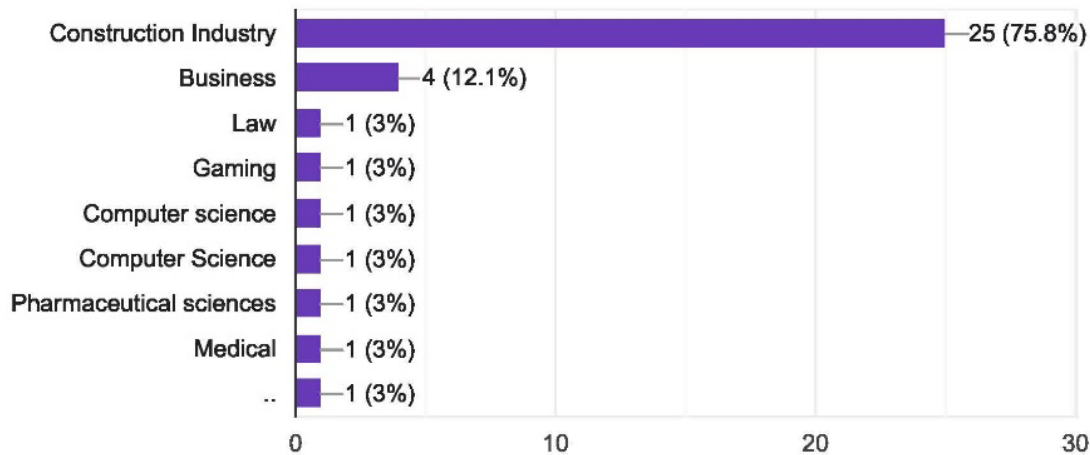
33 responses



In which field do you have experience? (multiple picks are accepted)



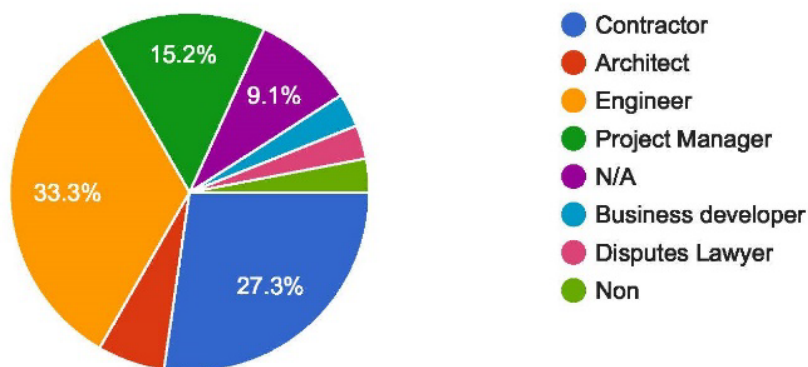
33 responses



If you have experience in the construction industry, what is your current role?



33 responses

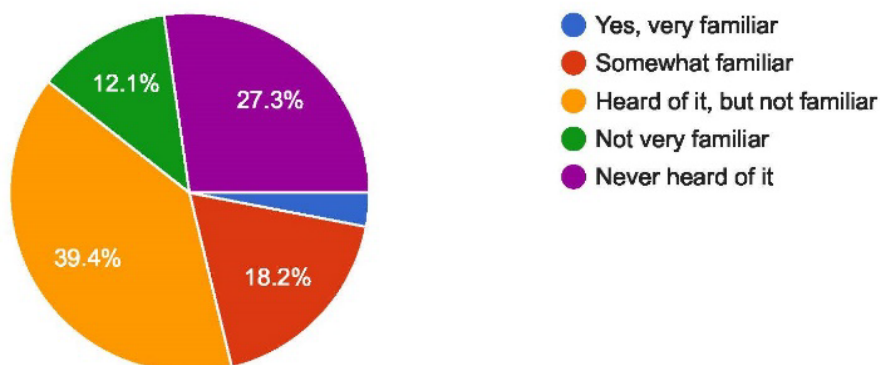


Master Thesis Survey

Are you familiar with the concept of smart contracts?



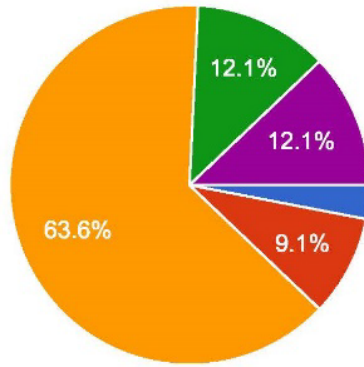
33 responses



Have you ever used smart contracts in a construction project?



33 responses

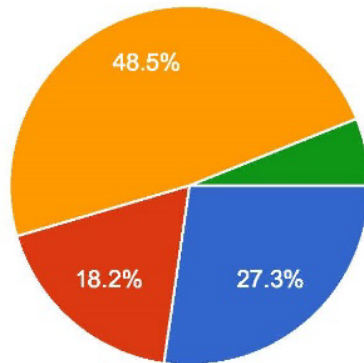


- Yes, multiple times
- Yes, once
- No, but I plan to in the future
- No, and I don't plan to in the future
- Not applicable (I'm not involved in construction projects)

Do you think smart contracts could help streamline the construction industry?



33 responses

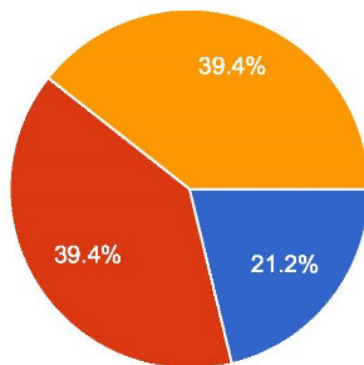


- Yes, definitely
- Somewhat, but not significantly
- Not sure
- No, probably not
- No, definitely not

Do you think smart contracts would be more efficient than traditional contracts in the construction industry?



33 responses



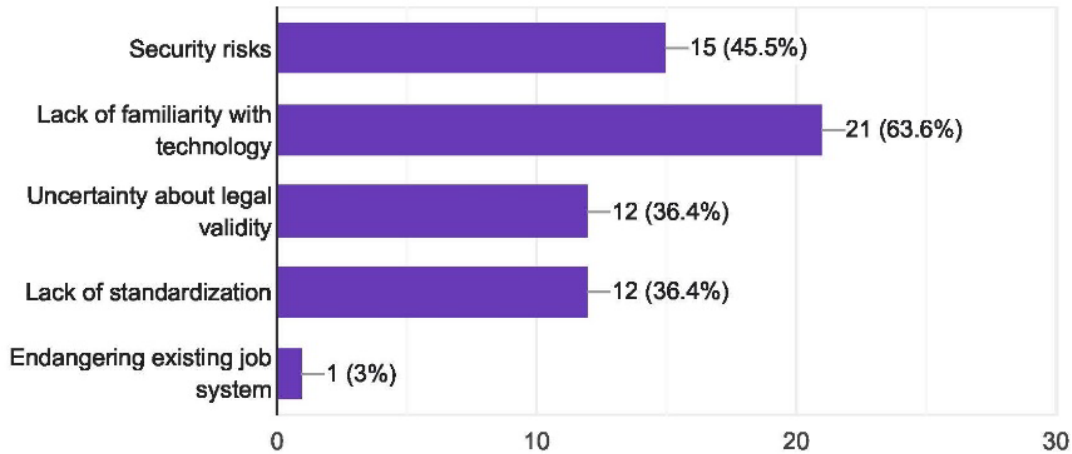
- Yes, much more efficient
- Yes, somewhat more efficient
- Not sure
- No, probably not
- No, definitely not



What concerns do you have about using smart contracts in the construction industry?



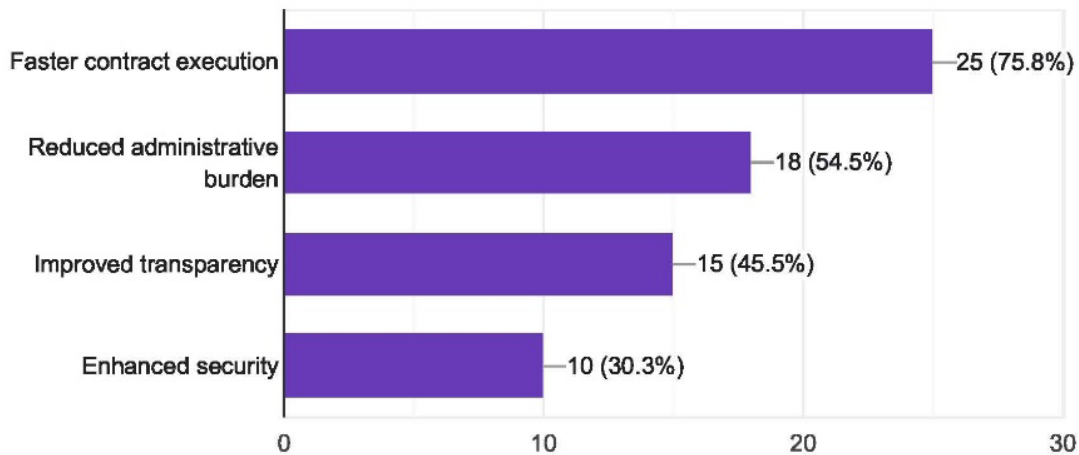
33 responses



How do you think smart contracts could benefit the construction industry?



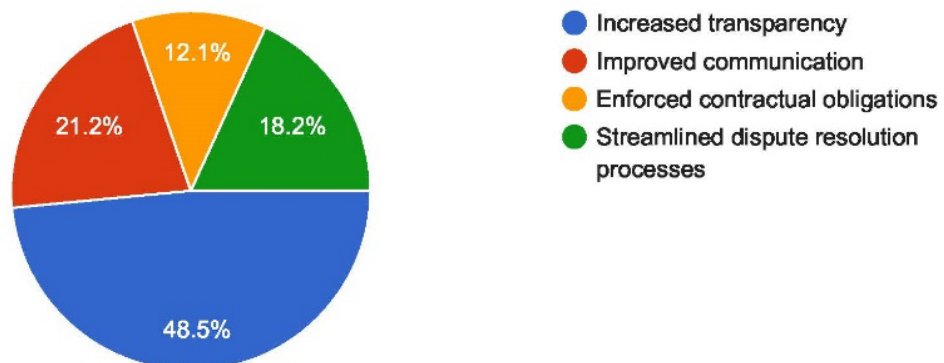
33 responses



How do you think smart contracts could help reduce disputes in the construction industry?



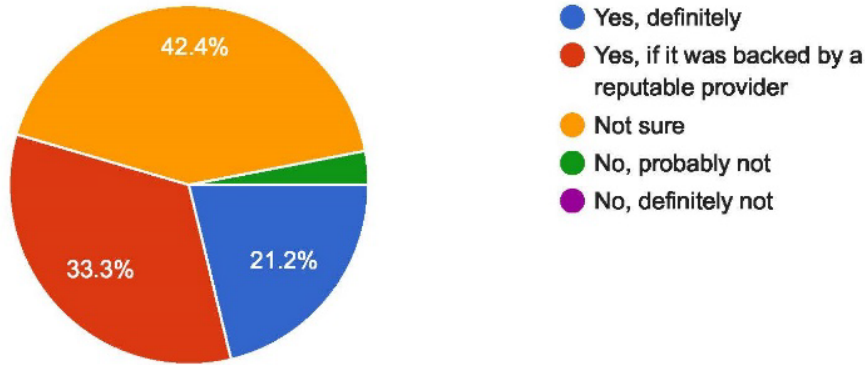
33 responses



Would you trust a smart contract more than a traditional contract?



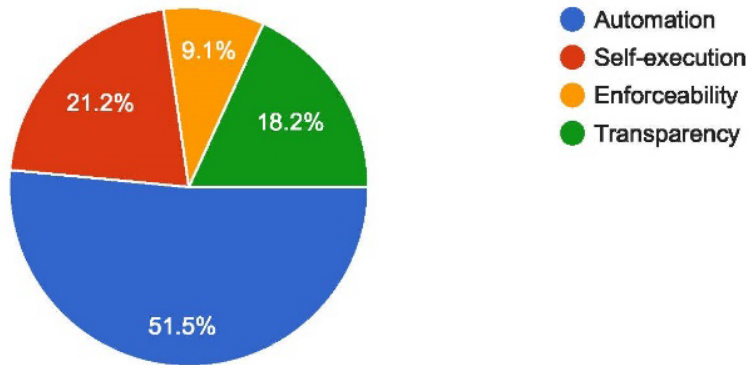
33 responses



What do you think are the key features of a smart contract that make it beneficial for the construction industry?



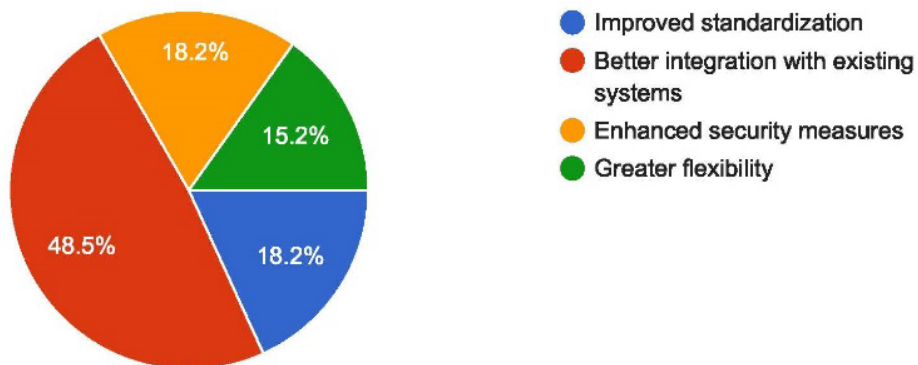
33 responses



What improvements do you think need to be made to smart contracts to make them more useful in the construction industry?



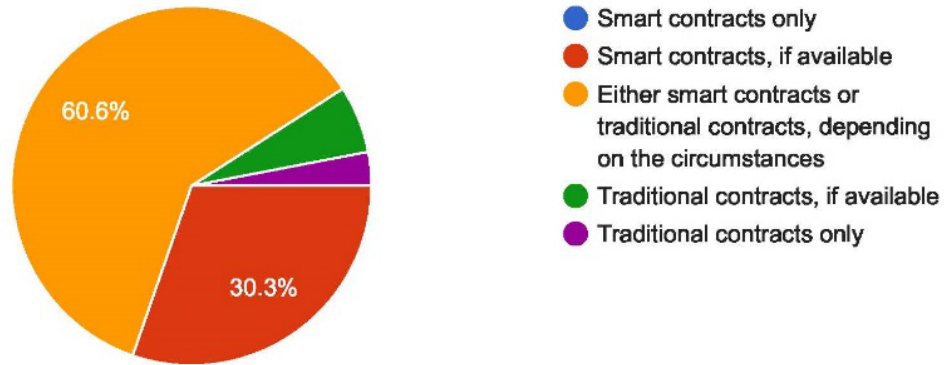
33 responses



Would you prefer to use smart contracts or traditional contracts in a construction project?



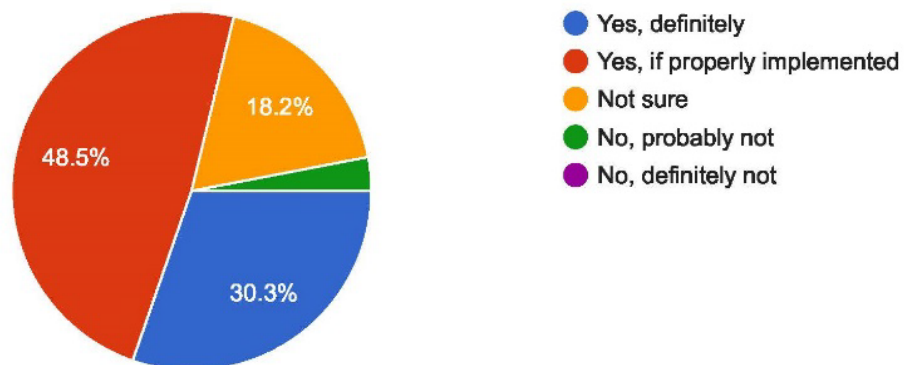
33 responses



Do you think smart contracts could help with payment processes in the construction industry?



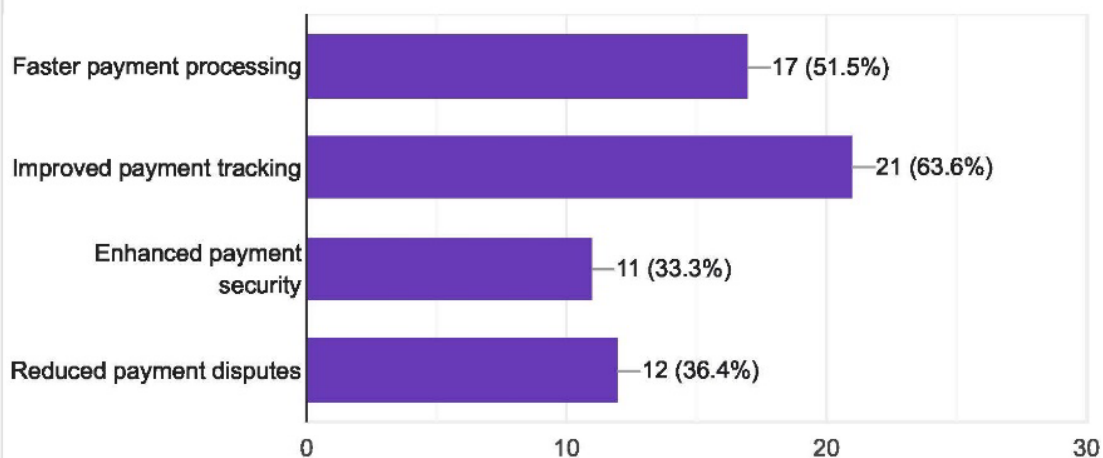
33 responses



How do you think smart contracts could help improve payment processes in the construction industry?



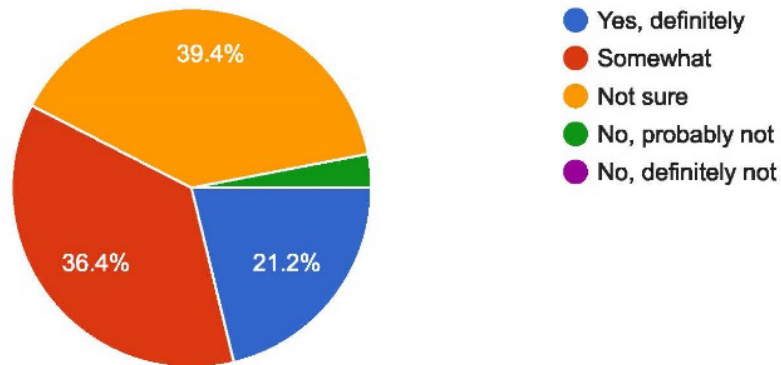
33 responses



Would you consider smart contracts to be a disruptive technology in the construction industry?



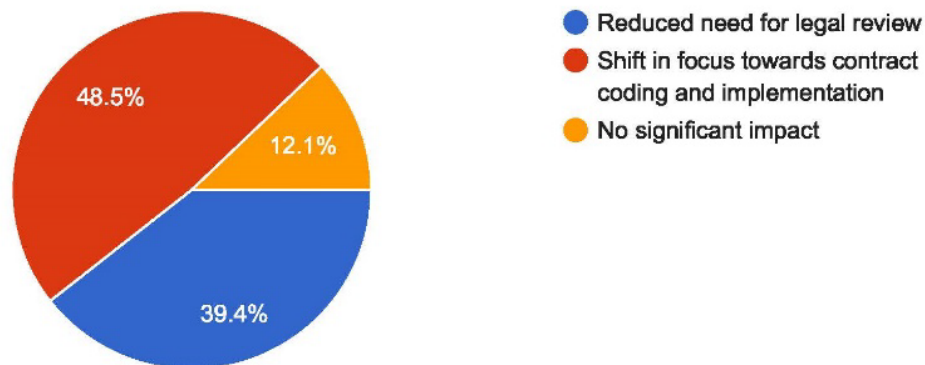
33 responses



What impact do you think smart contracts could have on the role of lawyers in the construction industry?



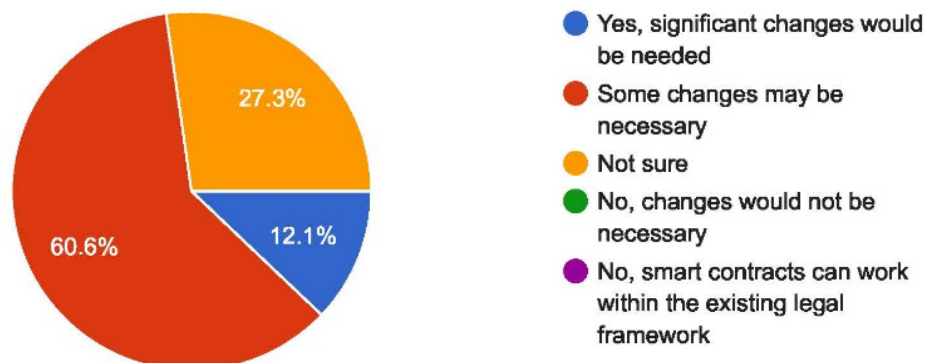
33 responses



Do you think the use of smart contracts would require significant changes to the current legal framework governing construction contracts?



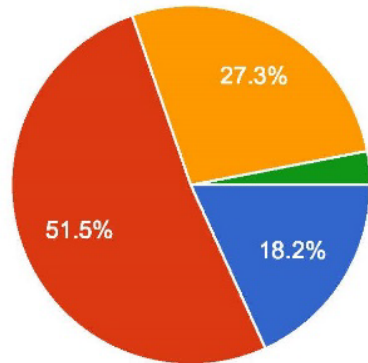
33 responses



Do you think smart contracts could help with risk management in the construction industry?



33 responses

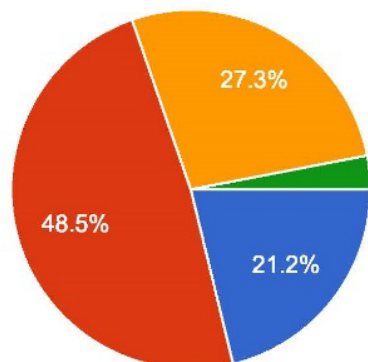


- Yes, definitely
- Yes, if properly implemented
- Not sure
- No, probably not
- No, definitely not

How do you think smart contracts could help with risk management in the construction industry?



33 responses

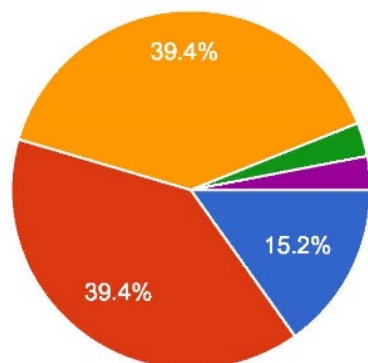


- Improved risk assessment
- Enhanced risk mitigation measures
- Better risk sharing arrangements
- I don't think it is applicable

Do you think smart contracts could help improve the quality of construction projects?



33 responses



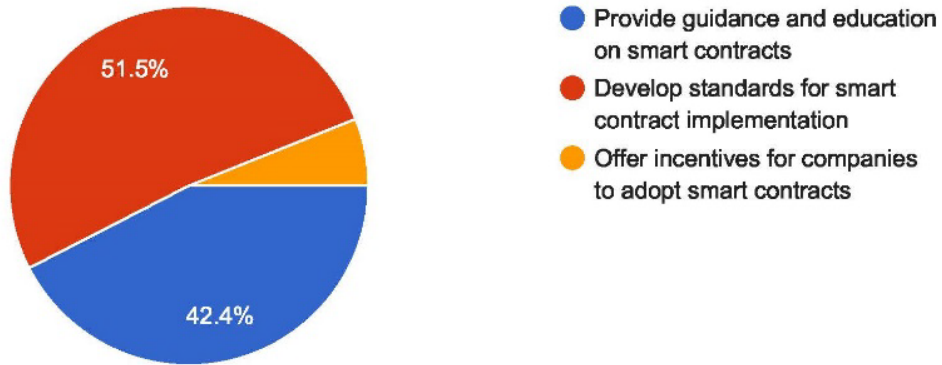
- Yes, definitely
- Yes, if properly implemented
- Not sure
- No, probably not
- No, definitely not



What role could the government and regulatory bodies play in promoting the use of smart contracts in the construction industry?



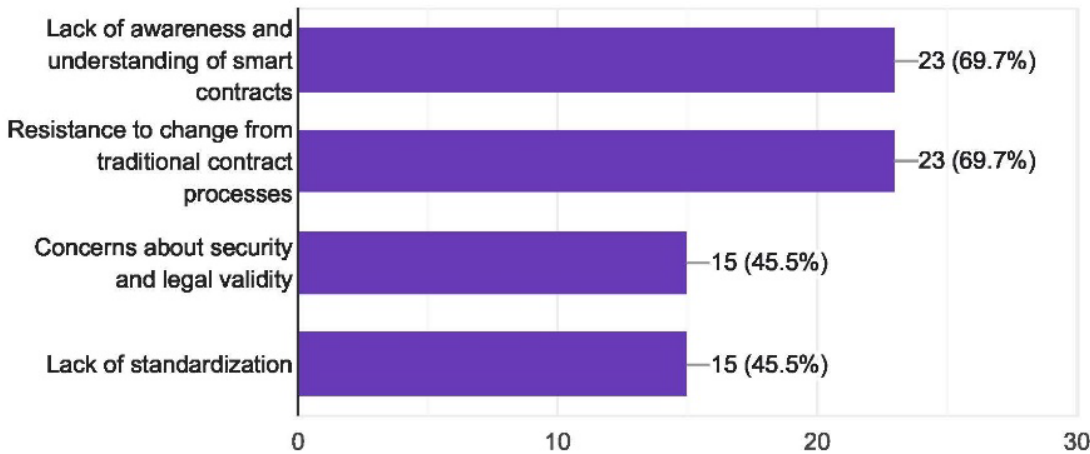
33 responses



What are the most significant barriers to the widespread adoption of smart contracts in the construction industry?



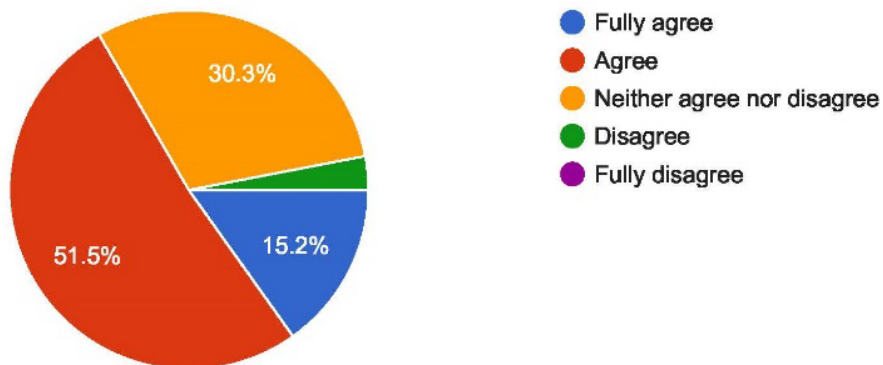
33 responses



Do you agree that smart contracts technology will be widely used among many disciplines in the construction industry?



33 responses



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