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CREATING SMART CONSTRUCTION CONTRACTS STRUCTURE WITH THE HELP OF BUILDING INFORMATION MODELLING

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
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BY

AVO BARAN ERKENEK

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ABSTRACT

CREATING SMART CONSTRUCTION CONTRACTS STRUCTURE WITH THE HELP OF BUILDING INFORMATION MODELLING

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The number of countries where BIM is mandatory to be used in projects is increasing day by day because of its data intensive structure. In addition to improving coordination and collaboration in the projects, BIM helps the stakeholders to visualize the project and make more accurate estimations at the preconstruction stage. In the process, some of the problems previously encountered are solved by adapting BIM system into the project but there are still many problems to be solved by using other technologies in the construction sector. Especially legal disputes which result from uncertainty in contract terms and disagreements in delivery and payment processes can be solved by automatizing the payment process and eliminating the intervention of human beings within the progress. Smart contracts can execute the terms of contracts with the project information through BIM and computer codes embedded in the blockchain system. In this study, a sample workflow model to combine smart contracts and BIM models is proposed by combining the information gathered from the literature on this subject and the results of research conducted with experts. Each component and step of the proposed workflow was explained in detail with their alternatives. The parameters and details

needed from BIM models for its efficient implementation were determined. Then, the pros and cons of the proposed workflow model and the usability of these technologies in the payment processes were evaluated, and the limitations of using these technologies were explained.

Keywords: Smart Contracts, Blockchain, Building Information Modelling, BIM

ÖZ

YAPI BİLGİ MODELLERİ YARDIMIYLA AKILLI İNŞAAT SÖZLEŞMELERİ YAPISI OLUŞTURMA

Erkenek, Avo Baran
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İçinde bulundurduğu zengin veri yapısı nedeniyle projelerde Yapı Bilgi Modellemesi (BIM) kullanılmasının zorunlu olduğu ülke sayısı her geçen gün artmaktadır. Projelerde koordinasyonu ve iş birliğini geliştirmenin yanı sıra BIM, paydaşların projeyi görselleştirmelerine ve inşaat öncesi aşamada daha doğru tahminler yapmalarına yardımcı olmaktadır. Bu süreçte daha önce karşılaşılan sorunların bir kısmı BIM sisteminin projeye uyarlanmasıyla çözülmektedir ancak inşaat sektöründe hala diğer teknolojilerin kullanımıyla çözülebilecek birçok sorun vardır. Özellikle sözleşme maddelerindeki belirsizlikten, ödeme süreçlerindeki uyuşmazlıklardan kaynaklanan problemler, akıllı sözleşmeler kullanılarak otomatik hale getirilebilir ve insan müdahalesi ortadan kaldırılarak çözülebilir. Akıllı sözleşmeler, BIM ve yazılım teknolojileri aracılığıyla proje aktivitelerinin bazıları otomatik bir şekilde yürütülebilir. Bu çalışmada, bu konu ile ilgili literatürden elde edilen bilgiler ve uzmanlarla yapılan araştırma sonuçları bir araya getirilerek akıllı sözleşmeler ile BIM modellerinin birleştirilmesi için örnek bir iş akışı modeli oluşturulmuştur. Önerilen iş akışının her bir bileşeni ve adımı alternatifleri ile detaylı olarak anlatılmıştır. BIM modellerinin verimli bir şekilde kullanılabilmesi için ihtiyaç duyulan parametreler ve detaylar belirlenmiştir. Ardından önerilen iş akışı

modelinin artı ve eksi yönleri ile bu teknolojilerin ödeme süreçlerinde kullanılabilirliği değerlendirilmiştir ve bu teknolojilerin kullanımında karşılaşılacak olan sınırlandırmalar anlatılmıştır.

Anahtar Kelimeler: Akıllı Sözleşmeler, Blokzincir, Yapı Bilgi Modellemesi, YBM

Dedicated to my beloved family and friends, who encouraged me to strive for excellence.

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ABBREVIATIONS

BIM	Building Information Modelling
LOD	Level of Development
PBA	Project Bank Account
TPS	Transactions Per Second

CHAPTER 1

INTRODUCTION

In the construction industry, delayed payments harm all of the stakeholders financially, and damage the trust between the parties (Manu, Ankrah, Chinyio, & Proverbs, 2015). The distrust-based relations between the stakeholders cause bids to rise and in connection with the total cost of the project, since they are afraid of bankruptcy due to delayed payments (Amoako, 2011). According to Ramachandra & Rotimi, (2014) problems related to delayed payments are seen as one of the most important problems of the construction sector.

Most of the problems related with payment issues are caused by payers intentionally or arbitrarily not paying or delaying payment (Hillebrandt, Hughes, & Murdoch, 1998). According to Tran & Carmichael (2012), employers or contractors, who are managing multiple projects simultaneously, are deliberately delaying their payments to finance other projects. This has become a very common strategy in the construction industry. On the other hand, due to the long duration of the activities carried out in the construction sector, regular cash flow is very important, the expenses of the contractors and subcontractors should be covered as soon as possible (Ameer-Ali, 2006).

In fact, as an alternative solution to this problem, called Project Bank Accounts (PBA), had the opportunity to be tried in a few projects in UK. This proposed payment system aims to secure payment process by taking the control of payments from employers and contractors and give it to the bank to ensure that payments can be made on time directly to the all project stakeholders. According to UK Cabinet Office (2012), Project Bank Accounts are ring-fenced bank accounts which can manage the supply chain by making the payments on time and separately to all of

the stakeholders of the project. For PBA system, the employer can deposit the entire project price or the first progress payment amount to be paid. Then, the approved amounts will be released from the PBA to the contactor and subcontractors by considering the breakdown structure stated at the beginning of the project (Macaulay & Summerell, 2019). In this way, both payments are accelerated and sub-contractors are not victimized in case of bankruptcy of the contractor (Biddell, 2015). Although the PBA system is actually a very advantageous system, it has been used in very few projects yet due to set-up and management costs (Griffiths, Lord, & Coggins, 2017). Nevertheless, according to Li, Greenwood, & Kassem (2019), PBA system is a useful option for the solution of the payment problems in construction sector and the system can be set with in the blockchain in the next stages.

Blockchain is a technology developed to manage data among network participants in a decentralized way (Anuradha, Yamini Gupta, Udayasree, & Tabassum, 2017). In this way, the data is encrypted, and the transactions made can be kept safe from infiltration and intervention with the methods of cryptography. All the data can be stored on blockchain and are duplicated multiple times for each participant. Blockchain system was actually developed for Bitcoin, the first decentralized cryptocurrency, but after the invention of smart contracts, the system provided an alternative solution for several industries the opportunity of automatic execution of contract conditions.

Smart contracts are basically code-based computer programs that run within the blockchain to execute the defined contract clauses automatically by using digital assets of the project parties (Szabo, 1996). In other words, most of the clauses and certain details are involved in smart contracts in a similar way with the conventional contracts. A smart contract is a digitalized set of agreements represented in a code and being self-executed by computers once certain conditions are met (Ciotta *et al.*, 2021; Dolgui *et al.*, 2020; Feng *et al.*, 2019; Mik, 2017; Sheth & Subramanian, 2019; Solaiman *et al.*, 2021). The code is stored and replicated in the form of a Blockchain (Dolgui *et al.*, 2020). The computer network can self-execute the contract in the form when the subsequent transactions are stored as a block of data at the end of

Blockchain (Mik, 2017). The main difference is the contract information is defined by the programming code. The main purpose of adapting smart contracts into various industries is automatizing the processes which traditionally require the intervention of a human. The structure of smart contracts basically contains if-then rules for specific contract clauses and according to the progress, contract requirements are fulfilled automatically. As these processes progress in a way that all project stakeholders can follow and be informed, therefore trusting is not required. In short, the smart contracts aim to provide a transparent, traceable, and efficient payment environment for various industries. In addition to that, in the process of automating the clauses related with payment activities, an opportunity arises to make these clauses simpler and more transparent at the beginning of the project. Furthermore, detailed documentation need and complex interactions of the stakeholders results with some difficulties in verifying payment claims and setting the relations between the tasks and payments.

In the smart contracts, the payment transactions are made by using the cryptocurrencies which are not in a physical form and created through blockchain encryption process. The transaction amounts can be embedded in the smart contracts system and after the related activity is done by the responsible stakeholder, then blocked payment amount within the contract can be released (Ahmadisheykhsarmast and Sonmez 2018). In addition to popular cryptocurrencies such as Bitcoin and Etherium, which vary greatly in value, there are also cryptocurrencies with fixed values. Thanks to their fixed values, the fluctuations can be avoided and become more usable in contracts.

On the other hand, the construction sector is one of the sectors where the technology uptake is relatively slower compared to others. It can be said that the increasing use of BIM has been taken as a bold step that can be associated with the utilization technology so far. Building Information Modeling is the process of creating a interoperable digital model where the physical and functional properties of a structure are represented (Smith,2007). Number of countries mandating the use of BIM is increasing as the number of publications about BIM advantages and the

number of projects that time and cost savings achieved with the use of BIM are increasing. Main purpose of using BIM in a project is much more than designing and building the project. The purpose of BIM is to make easy to access the information and to prevent false steps at any point in building lifecycle (Anderson *et al.*, 2012). In order to access information for a BIM model, the BIM model should be constantly updated, detailed, and improved. BIM is the first step for this period of innovation, but of course for this step all project stakeholders need to contribute to the process. Supporting processes are changing and these new technologies don't fit into the previous processes (Hardin and McCool, 2015). Despite this, the BIM system has contributed to the achievement of successful results in many projects, together with the companies that do not avoid using technology and are open to such challenges. For this reason, companies that see this contribution are more willing to include new technologies in the construction sector.

After deciding to use BIM methodology in a project, the expected benefits from the BIM system in a project should be clarified by the employer at the beginning of the project and a BIM execution plan is prepared accordingly. There are several standards and guidelines which clarifies the BIM uses, in other words, the objectives of using BIM in a project. In these standards and guidelines, BIM uses are classified according to project stages.

At first phase, planning phase, the main aim is estimating accurately project duration and the budget needed with the help of BIM models. For the design phase, BIM uses mainly focus on design coordination and engineering analyses that can be performed with the data in the BIM models. For the construction phase, the main objective is updating the BIM models with information coming from field engineers and manufacturers and using these updated BIM models for assisting all the project stakeholders in decision making processes. The last phase is operation and maintenance phase in a project life cycle. In this phase, as a prerequisite, the BIM models should be modeled in high detail during the design phase and updated regularly during the construction phase with data from the field staff and manufacturers because only this way they can be used effectively as a record model.

Focus in operation and maintenance phase is effectively monitoring assets and maintenance by using the record model.

It has been discussed that the data embedded in BIM models, which are useful in many of the project management processes, can also be used for automation of contract clauses. Building Information Modeling (BIM) due to its data-intensive nature and the level of details presented in an appropriate model is an excellent way to connect different sections of the work to a smart contract. Smart contracts can be implemented with the help of data in the BIM models to automate the process of construction. In other words, smart contracts have access to project information through BIM. Shou, Wang, & Wang, (2015) stated that BIM is a useful tool for smart contracts to use it as a database and on the other side, the blockchain technology of the smart contracts are useful to keep records of the modifications done in BIM models during the design and construction phases. Moreover, blockchain helps to identify both changes and the users making the changes with its details by using the recordings and the data in it (Stougiannos & Magneron, 2018).

There are several researches and suggestions about the adoption process for smart contracts and how BIM models can be used in this process. After deciding on the clauses that are going to be implemented in smart contracts, the needs of parameters, information and detail which can be transferred from the BIM models should be clarified. Thus, in the design phase of the project, the responsible people can change their workflow according to the needs of smart contracts infrastructure. In addition to that, both field staff and manufacturers can drive the data needed for smart contracts. In other words, after clarifying the payments planned to be made by using smart contracts, project stakeholders should be informed about the data required and level of detail of the BIM elements for smart contract process. In order to enlighten this process, the employer should decide on the payments to be made using smart contract, the platform on which the smart contract will be created, and the information to be obtained from the BIM model.

The payment process cannot be automatized completely, especially, in the adoption process, therefore the information that can be obtained easily from the BIM model should be defined in the contract documents to guide the stakeholders at the beginning of the project. Also, the approval process for the payments of a system with smart contracts and BIM should be examined to clarify the workflow. In other words, the needed level of development which defines the geometric information, structured data and reliability of BIM elements should be clarified. In addition to that, the required BIM development level (LOD) in order to execute of smart contracts efficiently should be defined. Furthermore, the payment process in the platforms selected should explained in detail for the project stakeholders which are planned to be involved.

1.1 Problem Statement

There is a need for a change in the payment processes in order to prevent the problems experienced in the construction sector due to delayed or short payments. These problems experienced in the payment processes have caused many companies to go bankrupt and resulted with a trust problem in the sector. This distrust between the companies in the construction sector causes calculations on worst-case scenarios and accordingly high bids. This situation not only creates an uncomfortable working environment for contractors and subcontractors, but also causes projects to be built at higher costs for the employer.

It is thought that this problem can be solved by separating the payment processes from the initiative of the decision makers and automating them. By making this automated process transparent at the same time, it is desired to help establish a stronger and easier bond of trust between the project stakeholders. In order to solve this problem, alternative solutions such as "Project Bank Accounts" were produced in which payments are made automatically by the bank in the amounts defined at the beginning of the project, but they did not receive much demand in the construction sector.

On the other hand, it has been concluded that the projects should proceed together with the BIM infrastructure in order to produce solutions to the needs such as interdisciplinary coordination, an accurate cost and quantity estimation, and a single information source that can be used in the project processes, which were previously encountered in the construction industry. It is aimed that these problems experienced in payment processes can be solved by including technology in the process. In accordance with this purpose, the use of smart contracts, which is a system where payments are made automatically with precoded programs, has been mentioned in the literature. It is anticipated that these technologies can be a solution to this disrupted environment of resentment, since every transaction made on the blockchain platform, where smart contracts are located, is recorded and a transparent information flow is promised within the system.

1.2 Aim and Objectives

The main question of the research of this study is how the problems encountered in payment processes in construction industry can be solved by means of BIM and smart contracts. The objectives of the research listed below:

- To understand the issues with existing traditional contracts and their deficiencies for payment purposes
- To establish the theoretical foundation for the use of structured information from BIM with smart contracts
- To develop and evaluate a prototype workflow where BIM and smart contracts are integrated

In accordance with these objectives, the literature was examined for the problems encountered in payment processes in the construction industry and suggested solutions to these problems are investigated. BIM, smart contracts and blockchain terms that are aimed to solve these problems were searched in the literature in detail.

In addition, the information on the transition from traditional contracts to smart contracts in the literature was reviewed.

After the review in the literature, with the help of an interview in line with the information obtained from the literature, a survey was conducted with people who are experts in the sector. A sample study model was proposed in line with the results obtained from the literature and the results of the research. The proposed workflow was explained in detail with the requirements of the workflow, relations between components of the workflow and alternatives of its components.

It is aimed to provide information that will enlighten the companies targeting this transition by evaluating the pros and cons of the proposed technologies. At the same time, the limitations of the payment processes to be created by using these technologies were evaluated.

1.3 Research Methodology

The methodology in this thesis consists of 4 parts as shown in the figure below.

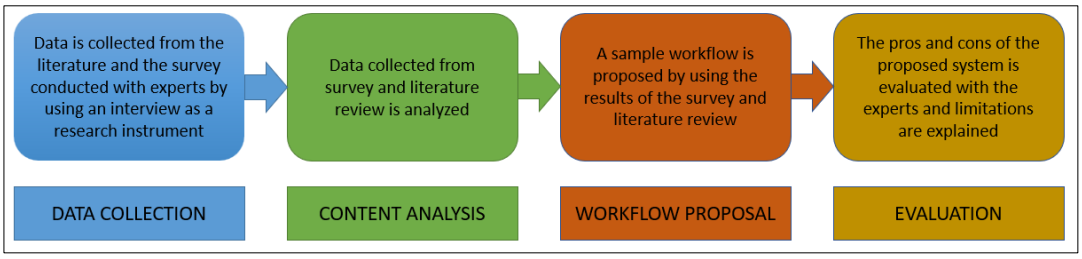

Figure 1.1 Methodology of the Thesis

As shown in the figure, data about the transition from traditional contracts to smart contracts, problems encountered in payment processes in the construction industry and suggested solutions to these problems and detailed information about BIM, smart contracts and blockchain was collected from the literature as the first step. Also, in data collection step, a survey was conducted with the experts by using interview as a research instrument.

After the data collection phase, in the second phase, the data collected from survey and literature review is analyzed to create an optimized workflow. Then, a sample workflow is proposed by using the results of the survey and literature review. At the last step, the pros and cons of the proposed system is evaluated and limitations are explained.

1.4 Research Outline

In the first stage of the research, a comprehensive literature review on payment problems in the construction sector was made. Causes of payment problems and problems arising from late or short payments were reviewed. The proposed solutions for these problems were examined and the solutions that can be provided with technology to these problems were evaluated. As a result of the literature review, it has been determined that an effective solution to guarantee the payments to be made in the construction sector has not been found yet. In the literature, considering the solutions that smart contracts and BIM models aim to generate for the problems in the construction sector, it is aimed to solve the problems related to payments by establishing a common system. Although many studies in the literature indicate that smart contracts and BIM models will be used together to solve payment related problems, only few detailed studies have been made on a detailed workflow model and the details and alternatives of the parts within the scope of this system.

By considering this unclarity on the topic, it is decided that a survey to be done on this subject and an exemplary workflow to be created can be a guide for those who want to pioneer this change for the sector. A survey is conducted with the experts in with the help of an interview, then the results are analyzed. The information collected from survey and literature review are used to create a workflow proposal which combines smart contracts and BIM models. In the sample workflow, the data that can be obtained from BIM models for smart contracts and the level of detail required for the models to be efficient for the system are mentioned. In addition to that, the alternatives of blockchain environment that the contracts can be created with and the

usage costs and language of them are explained and presented. Lastly, the types of wallets that can be used in smart contracts and the types of coins that can be used for the transactions made within the smart are examined and presented.

At the end of the study, the pros and cons of the proposed work flow were evaluated. The limitations that may be encountered during the implementation of the system were discussed. The research framework of this study is shown schematically in the figure below.

The rest of the paper will continue with Chapter 2 which contains the literature review of the study. The literature review starts with the information about the transition from traditional contract to smart contracts. Thereafter, the problems related to payments and solutions suggested to these problems in the construction industry are mentioned. At the end of Chapter 2, blockchain, smart contracts and building information modelling terms in the literature are investigated in detail. In Chapter 3 the survey conducted with the experts is explained and the results of the interview made to identify the opinions of experts are discussed. In Chapter 4, the proposed workflow is explained with its components and alternatives. Chapter 5 contains the discussion on the proposed workflow and technologies mentioned in the study to identify their advantages and limitations. At the end of the study, in Chapter 6, the conclusions obtained as a result of the study are summarized.

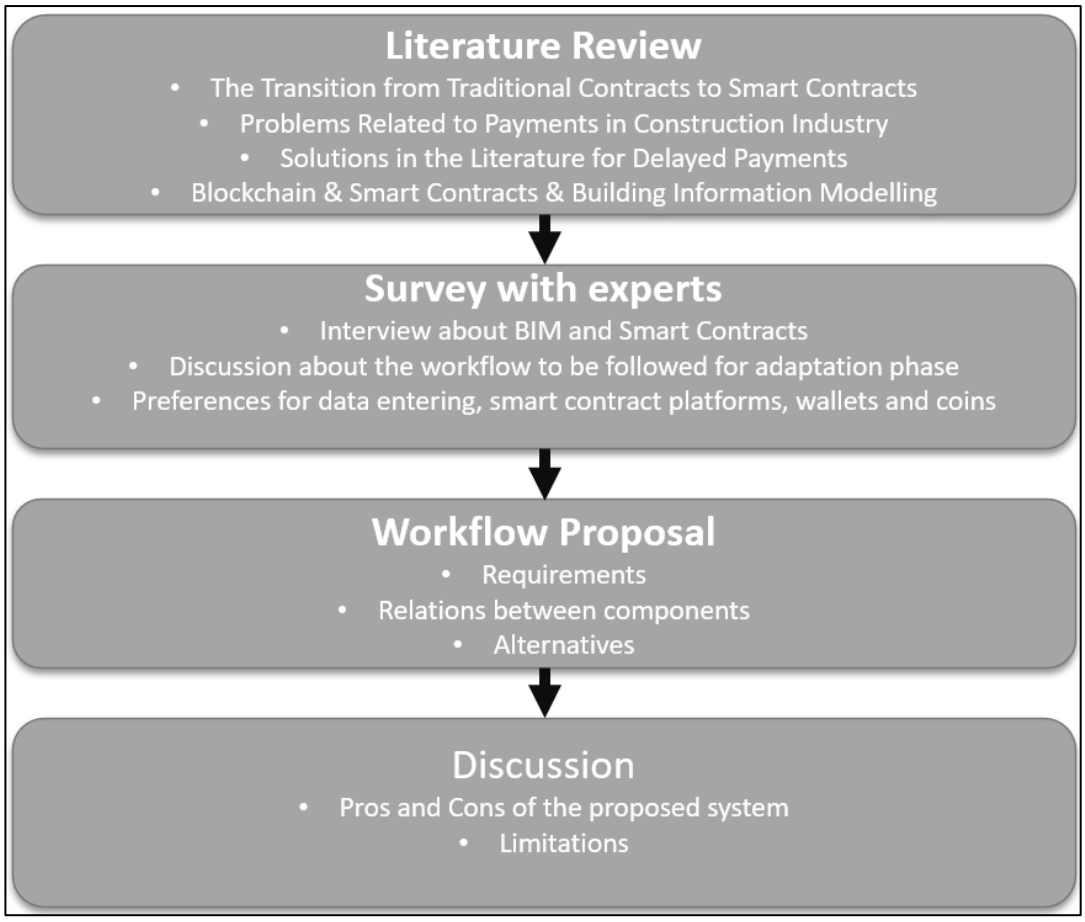

Figure 1.2 Research Framework

CHAPTER 2

LITERATURE REVIEW

2.1 The Transition from Traditional Contracts to Smart Contracts

In order to identify the contract formalization in general, the structure of a construction contracts should be examined. The key concepts of the contracts can be listed as parties, activities and clauses in general. Parties are representing all of the organizations and people (stakeholders) in the project's lifecycle. Activities are the tasks and services that should be done during projects and as a last component, the clauses are the statements in the contracts which clarify the responsibilities, permissions and prohibitions of the stakeholders (Luo *et al.*, 2019).

Also, the workflow of the payments is clarified with its responsible parties and responsibilities in the contracts. Although the payment process differs from contract to contract, in most cases the payment process begins with the request of the Contractor. The contractor submits a payment application and the inspector company is responsible for confirmation of the qualified work quantities. After the confirmation of the inspectors, quantity surveyor issues payment valuation. Then, the engineer issues the payment certificate for the Employer to finalize the payment (Luo *et al.*, 2019).

In the form of the smart contracts, the target is to transform the activity, responsible party, condition, action and the resultant event into a code which has an if-then structure. An example formalization of a workflow within codes is shown in the Figure below.

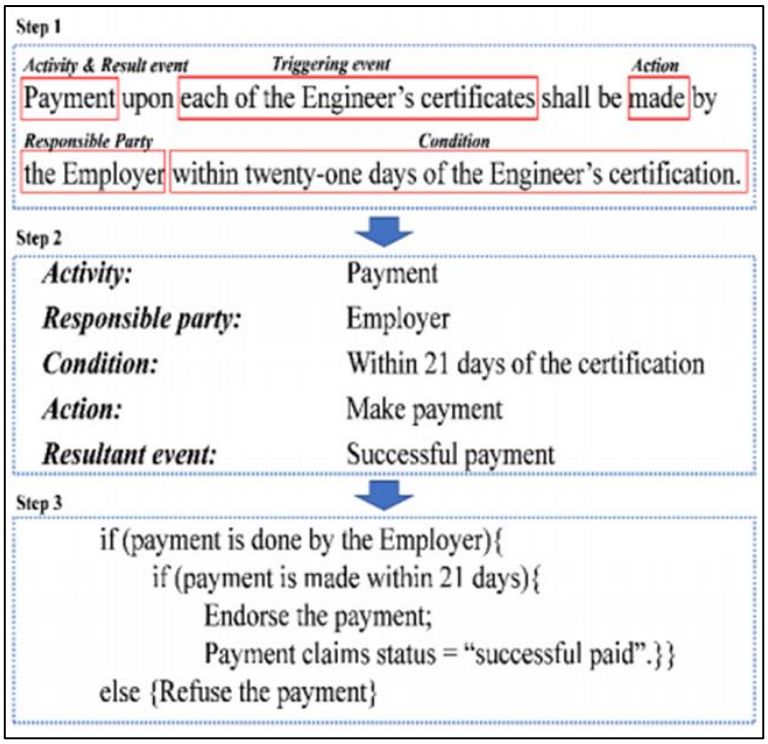

Figure 2.1 Example formalization of a workflow within codes (Luo *et al.*, 2019)

The issue to be decided in the transition to this automatization is which clauses should be automated and at which point we need manual inputs. Because of the complexity and legality of a construction contract, a smart contract will not be able to replace a construction contract completely. For the scope of smart contracts, the starting point should be the payment-related activities (Ye *et al.,* 2020). BIM can play an important role of this automatization process with its data related with quantities but there will be still need of manual inputs for confirmations and controls to have a final consensus before the finalization of the payments.

Each "if code" can be triggered by its responsible stakeholder after all the responsibilities are completed under their own control. The formalized workflows can be modified according to the conditions and the controls before making the payments as shown in the Figure below.

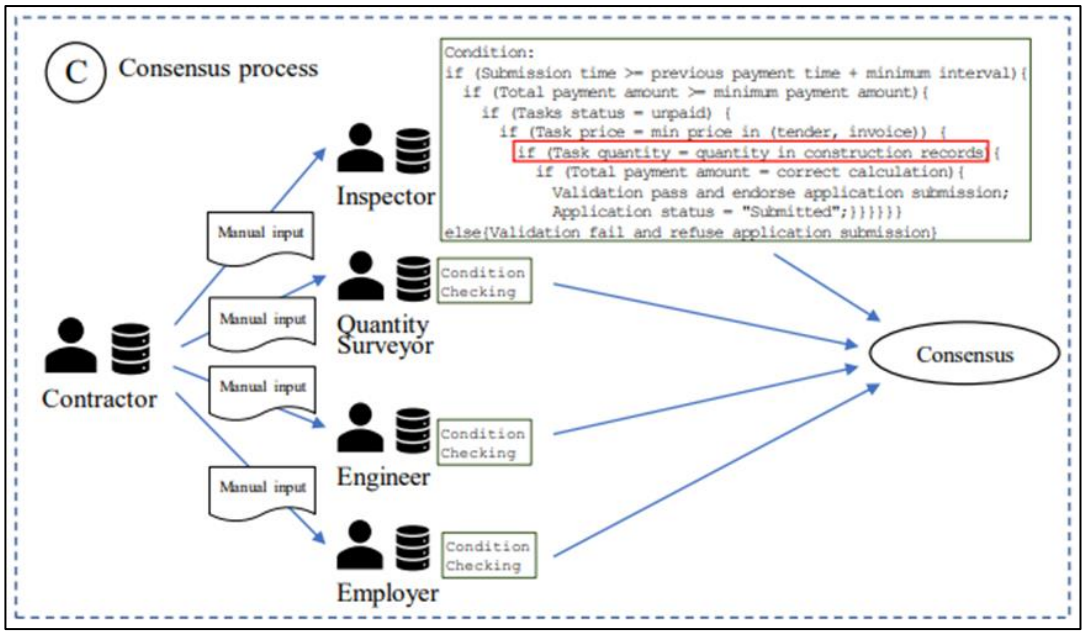

Figure 2.2 Condition checking for several stakeholders (Luo *et al.*, 2019)

Considering the list of obligations, the code should include when, where, and how the contractor will be paid and what for. Then, smart contracts should also consider the deadline upon the occurrence of certain events so that it can be checked whether the activity that is going to be paid meets the deadlines or not. In addition to that, the responsibilities for request, control and approval processes should be included for all of the project stakeholders (Mason, 2017). For example, one of the sub-contractors can request a transaction for the work executed, but only the general contractor can endorse and approve that transaction. While coding the contract clauses, both work and cost breakdown structure should be examined in detail.

In smart contracts, making a revision transaction workflow can be more complex than traditional contracts. Since the number of software engineers experienced in this field will be less in the adoption process and change requests can only be met by them, it may be preferable to automate the terms that require less change. In addition to that, short term delay of payment or work that should be performed can be tolerated by considering long term relations between the stakeholders in current applications. This tolerance provided is very hard to be included in smart contracts,

because of that the clauses that is planned to be automatized should be preferred by considering the low ratio of the flexibility.

Also, it should not be forgotten that for smart contracts currently no legal binding available, the companies may have to wait for the new laws of construction related with smart contracts to be released. At this stage, the academic studies and exemplary projects will be the start for this transition (Altay and Motawa, 2020). It is also stated that smart contracts can be best used for repetitive agreements and not unique complex agreements, particularly where the contract is susceptible to change throughout the life of the contract (Kassem *et al.,* 2018). Also, because of the new disorganizations that may arise, a semi-automated system is suggested in the short and medium term. In a semi-automated contract, the execution and verification of obligations are done by peers inside the network, but the blockchain network controls the results of their actions upon verification (Shojaei *et al.,* 2019). In most of the studies, it is stated that at the implementation stage of the smart contracts, small and simple-scale projects are better options to foresee possible limitations and the to experience the losses at a low level (Altay and Motawa, 2020).

2.2 Problems Related to Payments in Construction Industry

Today, the issue that causes litigation and disputes between the parties in many construction projects is related to the problems experienced in payments. (Sambasivan & Soon, 2007). Many contractors have trouble meeting construction costs when payments are delayed. This situation not only causes conflicts, but also the speed of the work slows down and delays occur on the delivery of works. Delay in payments for a contractor affects also the subcontractors' works with this contractor, therefore the workers either quit the job or slow down until they get paid. The duration of the project is negatively affected by the late progress payments made to the contractor and subcontractors. (Lessing, Thurnell, & Durdyev, 2017) Even when the payment is made late, the time lost and the team split cannot be compensated in most cases. Due to the possible uncertainty in payouts, contractors

decide to hire fewer workers than they can actually hire, in order to avoid the need for dismissal in case of a problem with payments in the future (Abdullah, Abdul Azis & Abdul Rahman, 2009).

Payments made in construction projects must be made on time, not only between the employer and the contractor, but also between the contractor and many subcontractors. Payment made on time for the contractor does not mean that subcontractors get paid on time (Cheng, Soo, Kumaraswamy, & Jin, 2010). Due to the wide scope of construction projects, usually the contractor agrees with many subcontractors and distribute the payments received from the employer according to the amounts in the agreement made with the subcontractors. This multi-tiered structure of the payment process causes the problems in the payments (Griffiths *et al.*, 2017). For instance, a delay in payment for a contactor affects the payments of all subcontractors. For this reason, the payments should be made on time by the employers and contractors. Delayed or short payments adversely affect the cash flow planned by the contractor, causing him to become financially unable to continue the work; inability to pay subcontractors and suppliers. Hence, all of the parties are affected from the delayed and short payments (Mei Ye & Abdul-Rahman, 2010).

Especially in the construction sector, cash flow plays a very important role in the overall operation, as projects are costly and take a relatively long time. Any delay in the project or in the cash flow can have a variety of effects on both the project and all of the stakeholders (Mei Ye & Abdul-Rahman, 2010). There is a period between when a contractor incurs costs and when he receives payment. If this period is extended, it will force the contractor to find more funds to cover his expenses (Odeyinka & Kaka, 2005).

It is known that many contractors have to take loans from banks at the beginning of the project in order to carry out the work and they have to pay interest on these loans. One of the biggest problems caused by late payments is the interest on the borrowed debt. As such, contractors depend heavily on regular progress payments from employers during construction to repay their debts to banks.

2.3 Solutions in the Literature for Delayed Payments

Asking the contractor for interest (claim) is one of the possible solutions for late payment caused by the employer. If it is stated as a right in the contract, the contractor can stop or slow down the work. Also, it is even possible to terminate the work after notifying the employer.

Griffiths *et al.* (2017) stated that the problems related to payments in the construction industry can be solved with the Project Bank Account system. They stated that by providing a secure payment system, delayed progress payments can be prevented and the payment period can be shortened.

Project Bank Accounts is an alternative solution which is offered by National Audit Office to solve the problems in the cash flow in construction projects by giving the control of the payments to the bank to distribute the payments to the contractor and subcontractors in the amount approved, on time and at the same time as shown in the Figure below.

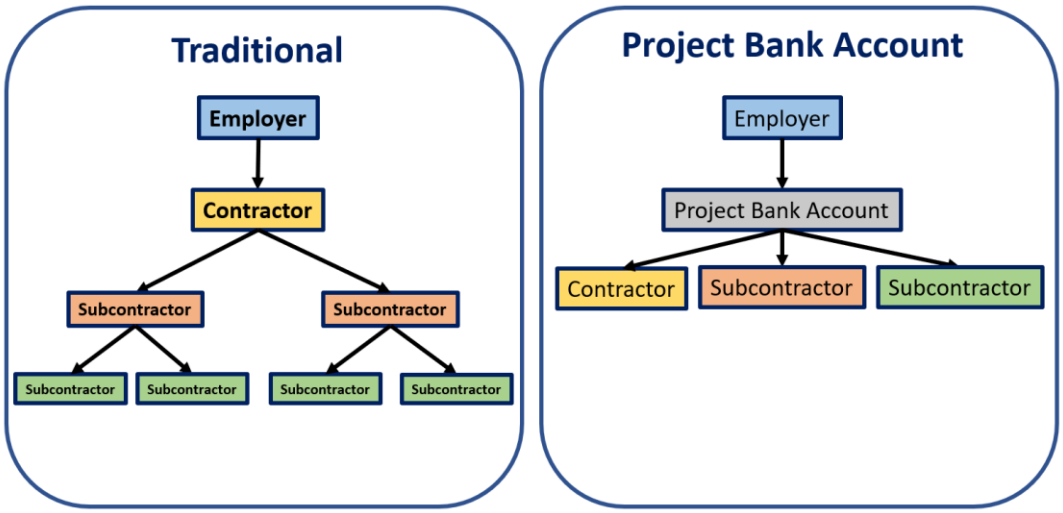

Figure 2.3 Traditional Cash Flow and Project Bank Account

Unlike the traditional payment system, in the PBA system the employer deposits the monthly payment into the system in advance before the works are started. A detailed and up-to-date payment plan is used to keep the account balance positive, so that the

employer usually foresees the amount needed to be paid to the contractor and subcontractor for each month of the project or interim payment and keeps the required amount of money in the system.

The progress payment documents prepared during the set-up of the PBA system, the progress payment breakdowns between both the employer and the contractor and between the contractor and the subcontractors are taken into account. The due payment deposited into the PBA by the employer is sent to all parties at the same time, taking into account the breakdowns specified in these documents. After the payment is certified, no one has to wait for payment from anyone, so that trust is established between the parties and the work proceeds without a problem in the cash flow (Towey, 2013).

Thanks to PBA, payment problems are solved, but according to Price (2011), PBA is not a fully accepted system by companies yet due to the set-up expenses of the system, the costs of managing the system, the training of personnel in the adaptation process, the employer and contractor not wanting to lose control over the money flow, and the system has not yet been tested in very few projects. PBA has so far only been used in a few public projects in the UK and Australia.

2.4 Blockchain in the Literature

Blockchain, as a distributed ledger, was originally invented to create a peer to-peer digital currency but on the other side it is can be useful for the other sectors. A distributed ledger is a simple database of transactions. If all transactions are processed and stored by one organization, then it is called centralized network like in a bank. In blockchain system, decentralized system is used, transactions are processed and stored across many different computers, known as nodes.

Blockchain was recognized as the core technology of Bitcoin from the very beginning of the process, but it was actually a technology that was generally intended to be used as a digital cash exchange system (Anuradha *et al.*, 2017). Every

participant in the blockchain network maintains the records of every transaction made, which is an important feature for reliability (Sultan, Ruhi, & Lakhani, 2018). Every transaction on the blockchain is recorded using a timestamp (hash and hash of previous block), thus users can verify and track previous records by accessing them (Zheng, Xie, Dai, Chen, & Wang, 2018).

As a distributed ledger technology, blockchain can be used as the basic infrastructure for automating the consequences of each transaction and recording of project progress (Shojaei *et al.*, 2019). Each block in a blockchain system comprises a record of information or a transaction that is locked in chronological sequence and encrypted to protect the data (Fortney, 2019). In other words, in this automated process, thanks to the blockchain system, all of the stakeholders have the archived and crypted data with the backups (Altay and Motawa, 2020).

Each block of the blockchain contains the data, hash, and hash of the previous block. Data such as transaction amount, sender and receiver information are stored in the block. When this block is created, a unique hash is calculated using cryptographic methods. In addition, since each block refers to the hash of the block before it, any change made in any block depends on the others (Christidis & Devetsikiotis, 2016).

In addition to that, unlike today's siloed data development, in blockchain based systems, the data can be transferred and followed between the stakeholders and collaborative environment can be created. In other words, in the blockchain system, every transaction requires consensus and project funds managed by the stakeholders instead of single person or organization.

Blockchain 1.0 is designed to decentralize the payment system provided for the well-known digital currency Bitcoin, but later, when this need for digital money turned into a digital finance need, Blockchain 2.0 was developed to meet this need (Swan, 2015). Blockchain 1.0 has created an environment that allows individuals to make secure and fast payments directly over the internet all over the world without the need for intermediaries such as banks. Unlike other currencies, Bitcoin's money supply was limited, preventing institutions such as the central bank from regulating

the money supply (Efanov & Pavel, 2018). Blockchain 2.0 aims to take this to the next level by creating a decentralized market that allows not only the simple payment transaction but also the transfer of the assets via the blockchain (Wang *et al.*, 2017).

In the use of Bitcoin, money transfers from one person to another could be made without any problems, but there was no feature such as setting conditions for the transfer to take place. Etherium created an environment for programming to set conditions and clauses for transactions (Wood, 2014). In the later process, many different platforms were developed where smart contracts could be created.

There are three categories of blockchain which can be listed as public, private and consortium. Any individual or organization all around the world can be a part of the system of public blockchain Bitcoin, which can be cited as one of the most popular examples of the public blockchain. For the public blockchains, as the number of anonymous participants increases, the reliability of the network increases.On private blockchains, an invitation is needed in order to participate. Private blockchains are systems in which participants in the network can be restricted from accessing information. In this system, only pre-defined participants can make every transaction or access every information (Wang *et al.*, 2017). Because of the importance of transaction confidentiality, private permission based blockchain is better option compared to the public permission based blockchain solution in the AEC industry. Consortium blockchains are combining the public and private blockchains depending on transactions (Ye *et al.*, 2018). In the consortium blockchains, a selected server defines predetermined rules to the system and these rules determine the access controls and visibility of the data in the system (Viriyasitavat & Hoonsopon, 2019).

The network members of smart contracts should be known, but transactions may be private unless a stakeholder has permission to view them, in contrast to the blockchain networks used by Bitcoin, where network members are anonymous and transactions are public. In other words, the stakeholders know who they are dealing with, but the detail of each transaction is known only to the parties involved in that transaction (Shojaei *et al.*, 2019).

The studies in the literature also examined which currency unit should be used in the smart contracts. There are several suggestions about using cryptocurrencies like Ether as it is prone to be used in blockchain system. On the other side, by considering the risk factor of the fluctuations in cryptocurrencies price, the cryptocurrencies which have a fixed value in transaction can be more feasible for the project stakeholders.

In addition to the solutions offered by blockchain technology in many issues, several limitations and challenges of the system have been emphasized in the literature. In the early stages of blockchain technology the proof of work (PoW) method is used for the validation which is known as mining process. In this verification process of PoW, miners have to do a lot of trial and error in order to solve the cryptographic puzzle. This becomes an advantage for the miner whose computational power is more powerful because that miner is more likely to solve the cryptographic puzzle required for the new block. Miners are racing to acquire more and more powerful equipment in order to earn more miner reward, causing larger amounts of electricity to be consumed by machines during the mining process. Consequently, blockchains that use proof-of-work method to verify transactions create an environmentally unfriendly system as they require too much computational resources and consume too much electricity. In addition to that, as the number of participants and transactions in the network increases, the demand for transactions will increase, so a verification process will constantly be processed for each transaction. This will prolong the validation period and slow down the transaction process (Law, 2017). In other words, increasing the number of transactions results with a need of larger storage space and which also means slower transaction speed (Ammous, 2016). Furthermore, miners come together in miner pools to increase their hashing power and chances to receive more mining reward and minor pools makes the blockchain more centralized as opposed to decentralized.

As an alternative method to solve the problems cause by proof of work method, proof of stake technique is proposed. The basic idea of proof of stake method is using an election process in which the node is chosen according to the amount of deposit coins

for validation of next block instead of letting everyone compute against each other with mining as in proof of work. In other words, a node has to deposit a certain amount of coins into network as stake to became a validator. Instead of hashing power, in proof of stake method, the size of the stake determines the chance of the validator to be chosen for the new blocks. Thus, the proof of stake method uses considerably less energy than proof of work method. In addition to that, validators can lose a part of their stake if the approve fraudulent transactions and the amount of the stake should be higher than the validation reward to force them to do their validation correctly. Despite all, proof of stake method needs some needs some developments for selection algorithm of the next validators. The selection criteria cannot be only the amount of the stake to avoid rich nodes get chosen more frequently and there are several studies to propose the alternatives to overcome this issue. At present, each method has its own advantages and disadvantages.

2.5 Smart Contracts in the Literature

A smart contract is a computerized transaction protocol which implements the terms and conditions in a contract automatically (Szabo, 1996). In other words, smart contracts are self-executing contracts, where the terms of the agreement between the client and contractor are written directly in lines of computer code. Smart contracts are a type of contract in which common contract terms such as payments and legal obligations agreed upon by the relevant parties are written in the form of computer codes and run at a unique address on the blockchain (Pratap, 2018).

In the set-up process of a smart contract, the parties must first identify and determine the necessary conditions that must be met for the exchange to take place. When and how conditions are triggered must be set. The triggering can be done by the stakeholders within the contract or by predefined milestones. The conditions that are agreed upon and that are desired to be applied automatically within the blockchain are written in codes using programming languages and uploaded to the blockchain.

There are two types of accounts on the blockchain: External Account (EOA) and Contract Account. Contract Accounts are the accounts in which smart contracts are stored on the blockchain. The conditions required for the execution of the transactions are defined as the codes in the contract account and they are managed by these contract codes (Aung & Tantidham, 2017). The value transaction is possible between the external accounts and from an external account to a contract account by creating and cryptographically signing a transaction using their private key (Law, 2017). Users should use an external account to create a transaction with a Contract Account in order to initiate a smart contract, then this transaction can be encrypted by the private key of the initiating users and transmitted to the nodes throughout the blockchain. Other users can validate the originality of the transaction using generated public key (Smart Contracts Alliance, 2016). After more than 50 percent of users identified on the network verify the transaction, the transaction is linked to the blockchain and the code defined under the smart contract fulfilled, also all outcomes are recorded.

As mentioned before, computational resources are needed for proof-of-work mechanism and these resources consume a certain amount of electricity in order to carry out transactions, so every transaction carried out in order to award the miners has a transaction fee (Rosic, 2017). The initiator of the transaction needs to pay the miners. Moreover, in smart contracts, a transaction fee is paid not only for the transactions, but also for the installation of the smart contract (Wedrowicz, 2018).

According to Ahmadisheykhsarmast and Sonmez (2018), providing payment related solutions by using smart contracts can solve the disputes regarding payments in procurement phase and monthly progress payments in the industry. The transaction amounts can be embedded in the smart contracts system and after the related activity is done by the responsible stakeholder, then blocked payment amount within the contract can be released. The embedded funds cannot be transacted among the parties until the predefined conditions of the smart contact are satisfied. Thus, the use of smart contracts and cryptocurrencies has the potential to create a guaranteed payment system (Cardeira, 2015). Thanks to smart contracts, payment processes can be

automated and payments can be accelerated, thus the parties can reduce the risk of disputes arising from late payments (J Mason & Escott, 2018).

Blycha (2018) stated that information such as the date of delivery of materials delivered to the construction site or the amount of material reaching the site can be recorded in the blockchain. This has given rise to the idea that blockchain can be used not only in payments but also in the supply chain management of the construction projects. In addition to that, it has been stated that in construction projects, payments for procurement can also be added to smart contracts in order to ensure the payments of the manufacturers and to eliminate the need for letter of credit. According to this suggestion, the payments to the manufacturer can be made automatically with the delivery of the materials into the construction site (Ahmadisheykhsarmast and Sonmez, 2018). Furthermore, the use of blockchain for payments also creates an advantage in terms of transaction fees. Especially in international projects, payment transaction fees are quite costly, but for payments made through blockchain, the transaction fee is kept the same all over the world. Not only the payment transaction fees are low, but also the transaction process can be completed in seconds on the blockchain, while it takes two to three days between international banks (Khandaker, 2019).

There are also several challenges about smart contracts and blockchain mentioned in the literature should be resolved before the wider adoption of them. The use of smart contracts may be a technology that may cause concern for many companies before the legal foundations are fully established (Hu *et al.*, 2018). Not only are there legal inadequacies, but smart contracts also have issues regarding enforceability and controllability, as no approval has yet been given by a government for smart contracts. Smart contracts need to be regulated within the scope of legal regulations and government controls. Furthermore, since the nature of smart contracts and blockchain is not to keep data confidential, the need for certain transactions and certain information to be seen only by certain stakeholders cannot be fully met in smart contracts. It is anticipated that this situation may cause problems among stakeholders regarding confidentiality (Bahga & Madisetti, 2016).

One of the advantages offered by smart contracts is an automatic system without the need for human intervention, but the intervention of coders is required for this system to be set correctly. Especially since there are not many case studies or standards in the adaptation process to smart contracts, coders play an important role. The role of coders is very important because once smart contracts are executed on the blockchain, it will not be possible to make any corrections or updates, as it will be against the nature of the blockchain. In addition to this issue, contract clauses related to payments can be written in code in smart contracts, but not all kinds of clauses can be written as in traditional contracts. In short, limitations such as the dependence on the success of the coders and the inability to convert all contract clauses to smart contract format may affect the motivation of companies in the transition process.

Smart contracts require data to be entered by third parties to understand whether the conditions for making payments are met. The payment process of smart contracts proceeds automatically on the payments side but requires reliance on third parties for control of the conditions (Gatteschi *et al.*, 2018). The need for the trust between project parties, which is aimed to be solved with smart contracts, is solved with the automatization of payments, but then the need for trust arises for condition checking by third parties.

2.6 Building Information Modelling in the Literature

Building Information Modeling is the process of creating a digital model where the physical and functional properties of a structure are represented (Smith,2017). By using BIM software, 3D model of each discipline can be modelled with the data needed for the project such as the date of delivery to the site or the date of construction, costs, dimensions *etc*. Thanks to BIM, problems that may be encountered can be noticed in advance by building the project virtually before it is physically built. In other words, the main purpose of using BIM in a project for is much more than designing and building the project. The purpose of BIM is to make easy to access the information and to prevent the false step (Anderson *et al.*, 2012).

In order to access correct information from a BIM model, the BIM model should be constantly updated, detailed, and improved. BIM model should contain all elements needed as database with its last form and the information within these elements should be updated starting from first day of design phase until the last day of construction phase (Messner *et al.*, 2019).

In the creation process of BIM models, first 3D geometric elements of a project should be modeled in the desired detail level (LOD) and then the data needed should be embedded according to the information requirement requested from the employer. If the 3D model elements are associated with the calendar of the project, then model can be considered as 4D model. In addition, if cost data is added to the element models, this model is transformed into a 5D model. This 5D BIM model created can provide the stakeholders both time and cost parameters to predict how much cost will arise at each stage of the project, and the project stakeholders can take precautions against problems that may be encountered in the project flow.

There are several studies in the literature stating the expected benefits of using BIM models in the construction industry. According to Azhar (2011) expected benefits from BIM models can be listed as creating drawings and visualizations needed faster, using the information defined in BIM models in the analysis of different disciplines, making cost analysis easily, resolving problems that may be encountered in the field beforehand and operating the facility to be built within the information embedded into BIM models. Similarly, according to the research conducted by Mesároš and Mandičák (2017), the expected benefits of using BIM are reducing the time spent in the design phase, reducing the project cost, and providing the accessibility of all of needed information and documents. In the study conducted by Olbina and Elliot (2019), more detailed benefits have been mentioned on the same issues such as improving logistics planning during construction, reducing safety problems in the field, reducing material waste, obtaining more accurate results in determining critical activities in planning. In summary, the basis of all these listed expectations is to finalize projects with cheaper costs in a shorter time and creating a database which

can be useful for all of the stakeholders during the planning, design, construction and operation stages by using the information in BIM models.

In the literature, many studies stated that BIM models, which have become a database on issues such as cost estimation and planning, can also be used in payments. In other words, quantity information, schedule and cost information in the project can be transferred from BIM models to the blockchain and smart contracts. Thus, progress payments can be prepared using the BIM model and paid using blockchain and smart contracts.

2.7 Insights Gained from the Literature

It has been mentioned in the literature that delayed payments cause high bids to be given by the contractors due to the fear of bankruptcy at the tender stage. It has been stated that this situation causes employers to build projects at higher costs. In order to eliminate the need for trust, several solutions were proposed. For instance, in the Project Bank Account solution, which is a escrow type service, payment transactions are taken from the initiative of the project stakeholders and given to the bank prior to the commencement of the job to ensure availability of fund after completion. However, it has been mentioned that this proposal is preferred in very few projects due to the set-up and management costs.

Automation of payment processes has recently been discussed in order to solve delayed or incomplete payments. In this discussion, two new terms, blockchain and smart contracts, have been introduced. At the same time, it is mentioned that the data intensive structure in BIM models can be used as an information source in a system that is planned to be created. It has been discussed that the blockchain platform provides decentralized data management. Also, the data is recorded after encrypting with cryptographic methods on each user's server to provide more reliable system than a centralized data management like in banks. It is mentioned that the blockchain platform was used only for digital currency exchange at first stages, but later on, with

the inclusion of smart contracts into the system, it turned into a platform where contract conditions can be defined. Furthermore, the transactions made on the blockchain platform have a transaction fee called gas, and this fee varies according to the number of transactions and the size of the information to be recorded in the blockchain within the scope of the transaction. However, it has been stated that the transaction fees are much more reasonable in the blockchain compared to the transaction fees charged by banks, especially with international banks. As another advantage, it is mentioned that the transactions can be completed within minutes within the blockchain, while it takes days at international banks.

Smart contracts are basically defined in the literature as a set of digitized agreements represented in a code that works within the blockchain. In the form of smart contracts, the goal is to transform the activity, responsible party, condition, action, and resulting event into code with an if-then structure and the code of the smart contract is stored in the blockchain environment. The main purpose of recommending its use is shown as automating processes that traditionally require human intervention. Transaction amounts can be embedded to the predefined conditions and embedded amounts cannot be transacted until predefined conditions are met. Therefore, it has the potential to create a guaranteed payment system where trust is not required. Payment is made using cryptocurrencies in the smart contracts. Besides popular cryptocurrencies like Bitcoin and Ethereum, there are also cryptocurrencies with fixed values. In the literature it is mentioned that the fluctuations can be avoided with the use of cryptocurrencies with fixed values.

In order to get expert opinions, the issues discussed in the literature and the issues that have not yet been discussed in the literature were turned into questions and shared with experts in the next chapter. Examples are given in the literature for the use of smart contracts, both for payments for construction activities and for material payments. Issues such as which payments can be made with smart contracts in construction contracts, which criteria are important when choosing a smart contract platform, or which method the experts will prefer to transfer data to the smart contract were discussed with the help of online interviews with experts.

CHAPTER 3

SURVEY ON SMART CONTRACTS AND BUILDING INFORMATION MODELLING WITH EXPERTS

In this section, the survey conducted with the experts is explained and an interview as a research instrument to identify the opinions of experts is presented. The questions used within the interview are structured according to the literature review. For companies that aim to transfer from traditional contracts to smart contracts, the information needed to be chosen, the issues that need to be solved and the issues that need to be clarified were made into questions and shared with the relevant experts. In order to make the survey results to efficient, experts with at least limited knowledge about BIM, smart contracts and blockchain were included in the survey. Experts who had the opportunity to work in at least one project in which BIM methodology is used and also have ideas about smart contracts and blockchain were included in the study. The participants were reached through an announcement on the website of an engineering company employing approximately 500 engineers.The research was conducted online. After the answers of the participants were recorded as notes in the online interviews, the answers were graphed. The questions asked in the interview were listed and shared in the appendix section. First of all, the information obtained from the literature review were shared with the respondents in order to give them an idea about the concept that is planned to be created. After presenting the concept and information obtained, the participants were asked to answer the interview set for them.

The answers given to these interview questions consisting of 13 participants in total were examined and the ideas obtained were interpreted. Respondents were asked about their current job role, years of experience, and level of knowledge about BIM, smart contracts, and blockchain. The answers given to these questions are examined in this section.

First of all, the participants were asked what they think about the use of BIM in their construction projects. All of the participants have been in different roles in at least one project designed and constructed using BIM. Participants were first asked a few questions to learn their opinions about the use of BIM in the construction projects, and then questions about smart contracts and the planned workflow to be created were asked.

General information about the respondents are given in the figure below.

			Level of Knowledge	
No. of Respondant	**Current Job Role**	**Years Of Experience**	**BIM**	**Smart Contracts & Blockchain**
1	BIM Engineer	6	High	Low
2	Project Manager	12	Intermediate	Intermediate
3	Construction Manager	16	Low	Low
4	Contract Manager	11	High	High
5	Tender Manager	15	Intermediate	High
6	R&D Manager	13	High	Intermediate
7	BIM Manager	9	High	Intermediate
8	Project Coordinator	10	High	Intermediate
9	Technical Office Engineer	6	Intermediate	Low
10	Contract Manager	14	Intermediate	High
11	Project Coordinator	9	High	Intermediate
12	Project Manager	10	Intermediate	Intermediate
13	Project Coordinator	8	Low	Low

Figure 3.1 Information About Respondents

3.1 Interview About Building Information Modelling Usage

In order to get more detailed information about the participants' opinions on the use of BIM, they were asked in which project phases they found the use of BIM beneficial.

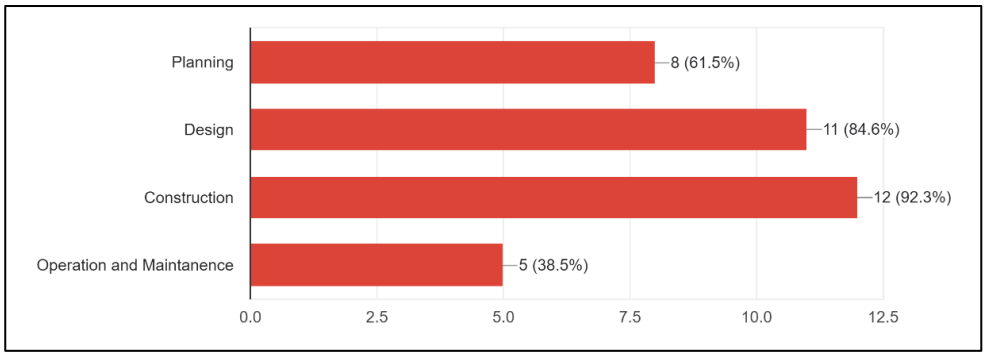

Figure 3.2 The project phases that respondents found beneficial

According to the participants, BIM models contribute a lot to the process during construction. The order of contribution according to the respondents is followed by the design and planning stages in the results. According to more than half of the participants, BIM models are not useful in the operation and maintenance phases, but when evaluating these answers, it should be taken into account that most of the BIM models that have been created cannot be created at the level of detail required to be useful in the operation and maintenance phase. In other words, this situation does not show that BIM models are not useful at the operation and maintenance stage, but it may mean that BIM models do not have a level of detail that can be useful at this stage.

Afterwards, the participants were asked which BIM uses they considered more important and useful in connection with the previous question.

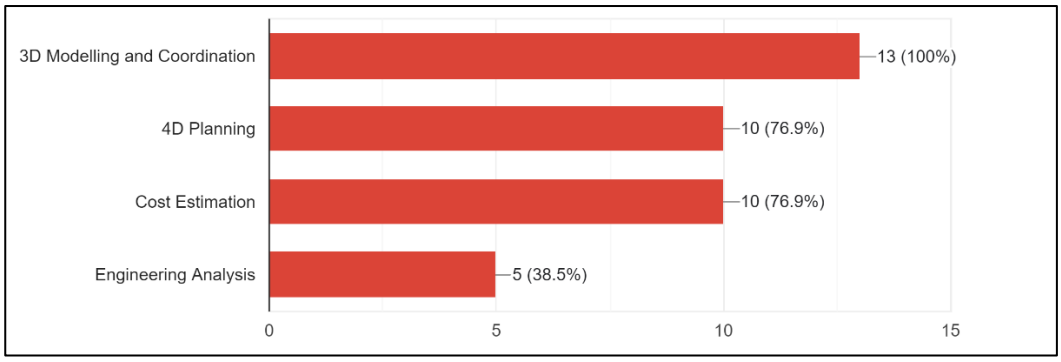

Figure 3.3 BIM uses that the respondents found useful

Participants think that the use of BIM, together with 3D modeling, is a very important and useful tool that allows different disciplines to coordinate before taking action in the construction site. At the same time, the participants report that together with the time and cost information defined to the BIM model, the model opens up the way of project stakeholders in terms of planning and cost analysis. Some of the participants declared that the prepared BIM models could not be used in the engineering analysis program or that BIM models were not needed for these calculations.

3.2 Interview About Smart Contracts

After learning the general ideas of the participants on BIM, it was asked whether they believe that the automatic payment processes planned to be created with the smart contract suggested in the literature could bring a solution to the problems experienced in the payments in the construction sector. 11 of the 13 respondents (84.6%) who participated in the survey think that a system created by smart contracts can provide solutions to these problems.

When asked which payment items they prefer to be made using smart contracts in a situation where some of the payments can be transferred to the smart contract, all of the participants think that the payment of the construction activities can be made using smart contracts, among the options such as construction activities and procurement activities. While most of the participants stated that there is no need to use smart contracts for payments made during the operation and maintenance phases, they also stated that a system installed at the field entrances which can be activated with the entrance of the employees (badge, face scanning or finger scanning) could make automatic payments by calculating the working hours.

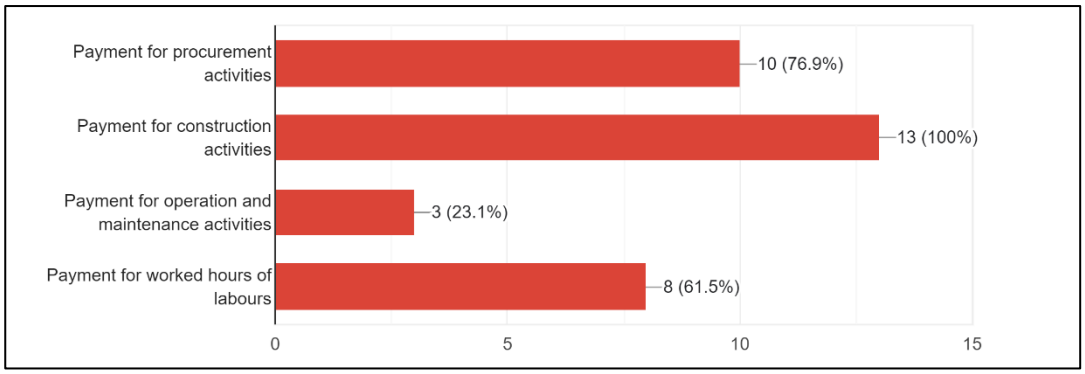

Figure 3.4 Payments which transferable to smart contracts

Respondents were asked in which way they preferred a workflow in which data was entered into smart contracts.

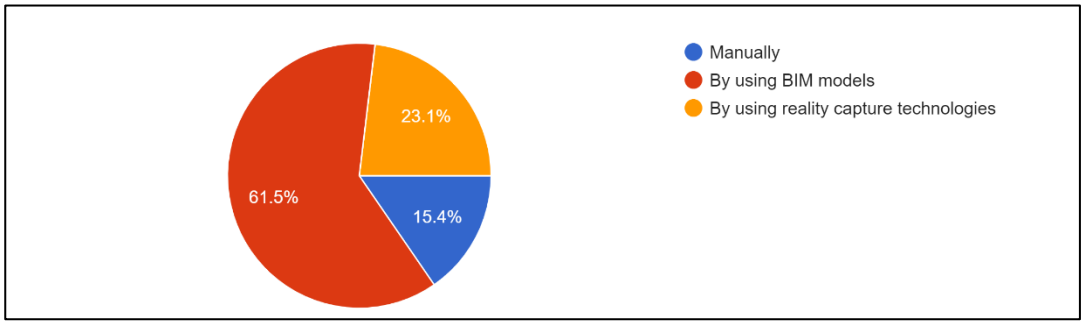

Figure 3.5 Preferences for data entering

According to the results, more than half of the participants stated that since the use of BIM is already beneficial to the project, it can also be beneficial in transferring information to the smart contract. Only 15.4 percent of the participants think that information entry should be done manually because they think that mistakes can be made in the transfer of information. On the other hand, participants who think that technology can completely automate the process think that information entry and, if necessary, some controls can be done using reality capture technologies.

The participants were asked which factors would play an important role for them when it comes to the transition to a platform where smart contracts are used. When the answers given are examined, it is seen that the most important criterion when choosing the platform is the transaction fees, and then the security factors and the

transaction speed are also the criteria which is critical for selection of the platforms according to the respondents.

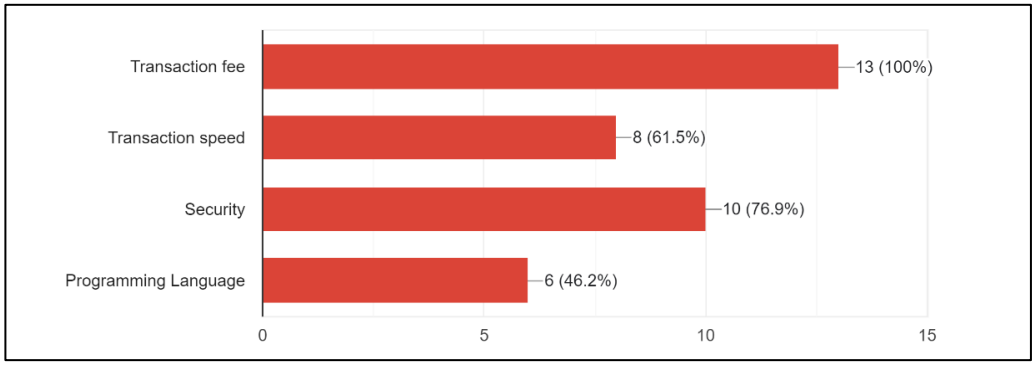

Figure 3.6 Important factors for smart contract platform selection

Afterwards, the participants were asked whether they would prefer stable coins, whose value is pegged to a fiat currency, or cryptocurrencies, which are popular on the blockchain, for payments made through smart contracts. It is stated that if cryptocurrencies are preferred, each payment amount of the smart contract will be made by proportioning the fiat money value to the cryptocurrency used. Only 2 of the 13 participants stated that they prefer to use popular cryptocurrencies in payments and to make payments using these cryptocurrencies by calculating the value against fiat money for each approved payment. However, in this case, the amount transferred to the contractor need to be converted into the desired fiat currency as soon as possible to not to be affected by the fluctuations.

As a last question, when the participants were asked whether they would prefer to use online web wallets where their wallet information is saved on a different server, 92.3 percent of the participants stated that they would not agree to share their wallet information. For this reason, the times to be selected when installing the system should be carefully examined on which server the information is stored.

3.3 Discussions About Survey Results

The results of the survey shows us that experts generally have positive thoughts about smart contracts and BIM. Furthermore, it is noticed that they believe that with this integration, the problems arising from the payments in the construction sector can be solved. Also, it is stated that the participants think that it takes time for the system to adapt to the plans and decisions that change frequently in the construction industry, and that variable decisions in this adaptation process will force the technical team to update the system. However, if the adaptation process is overcome with determination, it is thought that taking the control of the payments from the initiative of individuals and companies and making them automatic can prevent the problems experienced in the sector.

In addition to the fact that the participants find the implementation of BIM very useful during the construction phase, it can be seen clearly that they also find it reasonable to make payments for the construction activities by using smart contracts. In addition, the participants find useful the models that are coordinated in 3D with the use of BIM and in which time information is defined for 4D planning. In other words, the BIM models, which the participants find useful, is an adequate database for payments to be made under the smart contract.

In the next section, it is aimed to present the alternatives and components of a workflow which combines smart contracts and BIM for the companies targeting this transition by using the ideas obtained as a result of this research with the experts.

CHAPTER 4

PROPOSED WORKFLOW OF SMART CONTRACTS WITH BIM

In this section, a sample workflow of an application of smart contracts with help of BIM is proposed. Each component of the sample workflow is detailed with explanations of alternatives.

4.1 Proposed Workflow Overview

In the proposed system, the employer should prepare the BIM model of the project at the concept design phase and the smart contract which includes the contract items to be paid with the information to be obtained from the BIM model elements for the tendering stage. In addition, at least a document which describes how the BIM model elements and smart contract codes are matched in the tender documents should be shared by the employer with the contractors for information purposes. After the tender process is finalized, the BIM model should be updated simultaneously with the progress in the construction phase and arranged in accordance with smart contract codes and shared with all project stakeholders on the cloud server.

BIM models are used to provide accurate information about the quantity and planned time as an input for the smart contracts. Thanks to the BIM models, the contractor can parametrically classify the items that are completed in the field in a different schedule category and export them quickly. In order to ensure that the BIM model can be viewed and accessed by any stakeholder in the project from anywhere, it is suggested to store BIM models in the cloud servers in the proposed system. Since it is aimed to create a reliable infrastructure that can be tracked by the project stakeholders for every change in the system that is being established, by keeping the models in the cloud servers, the changes made on the published BIM models can be tracked through the versions in the same model. In addition to that every change

(deletion, renaming, moving) performed on the cloud servers can be recorded within the servers.

While preparing the code structure of the smart contract, the quantity and time information coming from BIM models must be classified in the same way with the clauses defined in the smart contract in order to match the price of the relevant element in the contract.

The price of the items to be paid through smart contracts will be defined in the smart contract. By using the quantity and time information obtained from the BIM model and the payment request are transmitted to the smart contract by the contractor, then the smart contract matches the prices defined in the smart contract with the quantities sent. After calculating the total amount to be paid by multiply the quantities with relevant prices defined, it should be transmitted to the employer as a request.

Then, the employer should define the actual dates of the activities within the smart contracts to calculate the difference due to delay (if there is any) by using the planned dates information exported from the BIM model for the relevant items.

During the evaluation phase of the payment request, the employer can use the features of the BIM software to examine the request sent by the contractor in the 3D model, and compare the work done in the field with the demanded amount. In order to fully automate this control process, procedures in which robotic reality capture technologies such as laser scanners and drones automatically calculate the work done by detecting the current state of the structure have been proposed. The construction progress can be captured by using these technologies and compared with the BIM model to control the requested amount of the interim payment requested by the contractor (Hamledari & Fischer, 2021). A similar technology proposal on this subject is made by Shojaei (2019), a system in which the automatic payment of the materials supplied to the field is made by scanning the QR code at the field entrance was proposed. Since it is difficult to automate the whole process in the transition process, the employer may need to manually perform certain checks in the first

attempts, but in the future, different technologies can be included in the process and a fully automated payment flow can be achieved.

If the employer approves the amount to be paid after evaluating, both the information transmitted from the BIM model to the smart contract and the payment transaction made can be recorded in the blockchain. Thus, both the amounts paid and the information obtained from the BIM model will be recorded in an encrypted manner.

It is recommended that these payment transactions be made with the wallets of stable coins in order not to be affected by the variability of other crypto currency values against fiat currencies. The stable coin type to be used will vary depending on the blockchain in which the smart contract that can be used is created. Instead of using stable coin, this system can be established by calculating the value of an unstable coin against fiat money in each payment. In this case, it should be defined that the smart contract should make a payment by reading the crypto currency rate of the fiat currency to be paid before each payment.

The recommended workflow for this adaptation phase is described in the figure below.

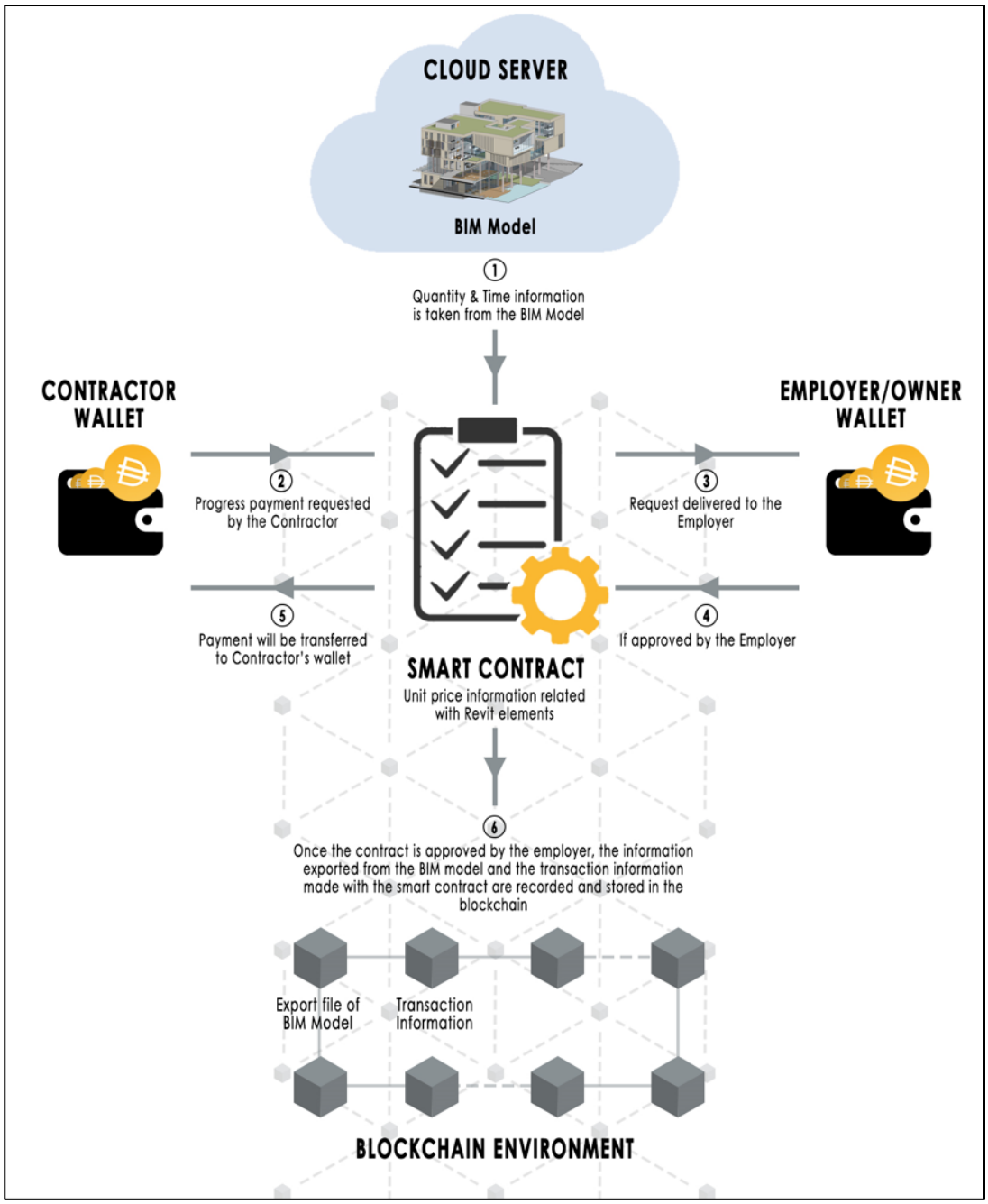

Figure 4.1 Proposed workflow of using smart contracts with BIM

4.2 Building Information Models

The purpose of including BIM models in the system is to be used as an information source to transfer project-related quantity and planned time information to smart contracts. A BIM model that is coordinated with different discipline models at the tendering stage of the project and ready to be updated with the progress in the field will prevent the contractor from losing time while preparing the progress payment manually and the employer controlling it.

The BIM models that are planned to be used in the proposed workflow should accurately provide the quantity information for the items defined in the smart contract and whose payment is planned to be made automatically. Therefore, models must be above a certain level of detail.

The AIA (American Institute of Architects) committee used the LOD (Level of Development) concept in the building information modeling protocol named 'E202-2008 Building Information Modeling Protocol' published in 2008. According to this document, LOD levels are were handled in 5 groups and LOD levels are; LOD 100, LOD 200, LOD 300, LOD 400 and LOD 500. As the level of detail increases, the information in the model element such as area, height, volume, location become more accurate. Today, BIMforum, which is used as a resource in many BIM execution plans and model progress matrices and is working in the field of Building Information Modeling as the US branch of Building Smart International, is also working to standardize LOD concepts. The institution cooperating with AIA has developed the LOD concepts initiated by AIA in line with the needs, added the LOD350 level and removed the LOD 500 and defined the LOD levels with visuals. This document is updated every year according to the needs and feedbacks and is constantly updated.

According to BIMforum LOD specification, LOD100 means representing a model element with a symbol or other generic representation in the BIM model. It shows the existence of a component but not its shape, size, or precise location. When the

level of detail rises, a model element with LOD200 can be defined as a generic system, object, or assembly with approximate quantities, size, shape, location, and orientation within the model. Non-graphic information is also inserted in the model element. LOD300, the next step, means the model element is graphically represented as a specific system, object or assembly in terms of quantity, size, shape, location, and orientation within the model. Unlike previous detail levels, the quantity, size, shape, location, and orientation of the element as designed can be measured directly from the model without referring to non-modeled information. If a model element is upgraded from LOD 300 to LOD 350, parts necessary for coordination of the element with nearby or attached elements should be modeled. These parts will include such items as supports and connections. Finally, in order to reach LOD 400, a model element should be represented with detailing, fabrication, assembly, and installation information. This means the model element is modeled at sufficient detail and accuracy for fabrication.

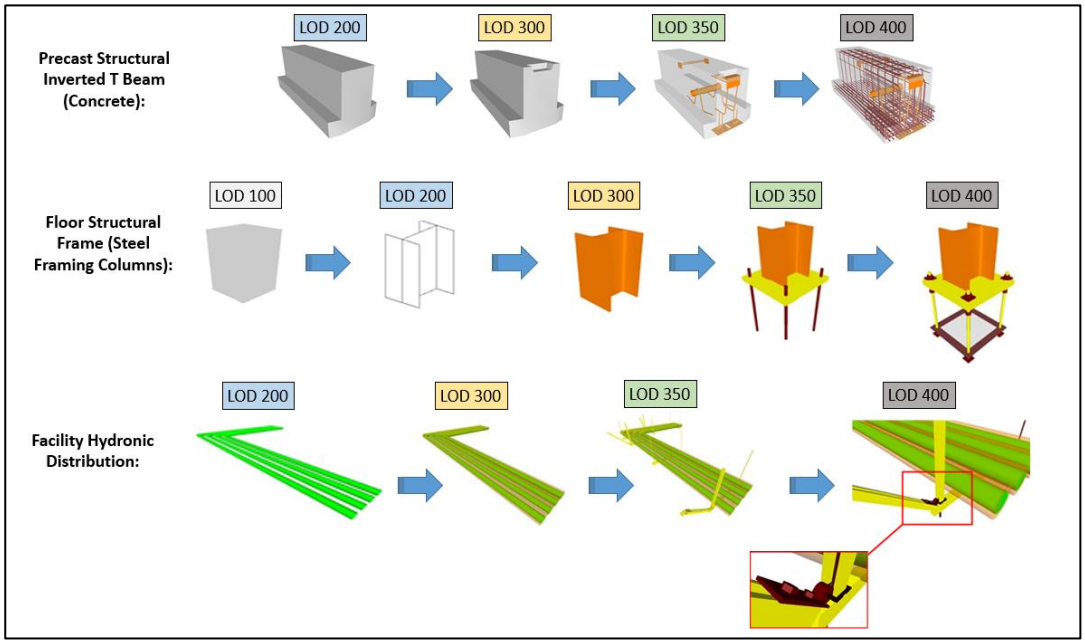

Figure 4.2 Examples of changes in LOD level transitions (BIMFORUM, 2019)

In the figure above, the evolution in the appearance of the elements as the level of detail increases is illustrated by a few examples. These improvements shown are not only geometric information but also non-graphic information.

Due to its effect on the payments which are planned to be made automatically, according to the detail levels specified in the standards, the detail level of BIM models should be at the minimum LOD350 level in order to provide the accurate information and quantity directly from the model. If the employer plans to make the payments for more detailed and small items of the project through the smart contract using the BIM model, the BIM model may need to be at the LOD400. However, in order to model the BIM model at this level of detail, it may be necessary to decide on the brand and model information of the elements. While the standards that must comply with the materials to be used at the tender stage can be specified, in most countries, it is prohibited to include material and model information in contracts as per the competition laws. Therefore, BIM models can provide smart contracts with detailed quantity information where material and model information are not required.

Quantity information that may be needed in smart contract payments, such as the volume of concrete to be poured, the surface area of the formwork to be used, and the weight of the reinforcement to be used must be parametrically defined in BIM elements. At the same time, the time parameters that will affect the payment amounts to be made, such as the planned and actual completion dates of each activity to be paid.

The proposed workflow is structed for the unit price projects; therefore, the components of the BIM models should be modeled in a way that can provide quantity information defined unit prices, and also in a way that the contractor can request his progress payment partially. In other words, BIM models should be able to provide quantity information for each work item which are defined in the smart contract and the model elements should be divided in such a way that it can reflect the steps in the contractor's progress into interim payments. For example, the modeled reinforced concrete model should be modeled as separate parts for each floor so that the

contractor can request the payment separately for each floor. Thus, there will be no restriction such as making monthly payments, and the contractor will be able to demand payment of the work done within two months or a shorter period, if he wishes. Thanks to BIM models, you can filter your work in the model and prepare the relevant quantity and send it to the employer.

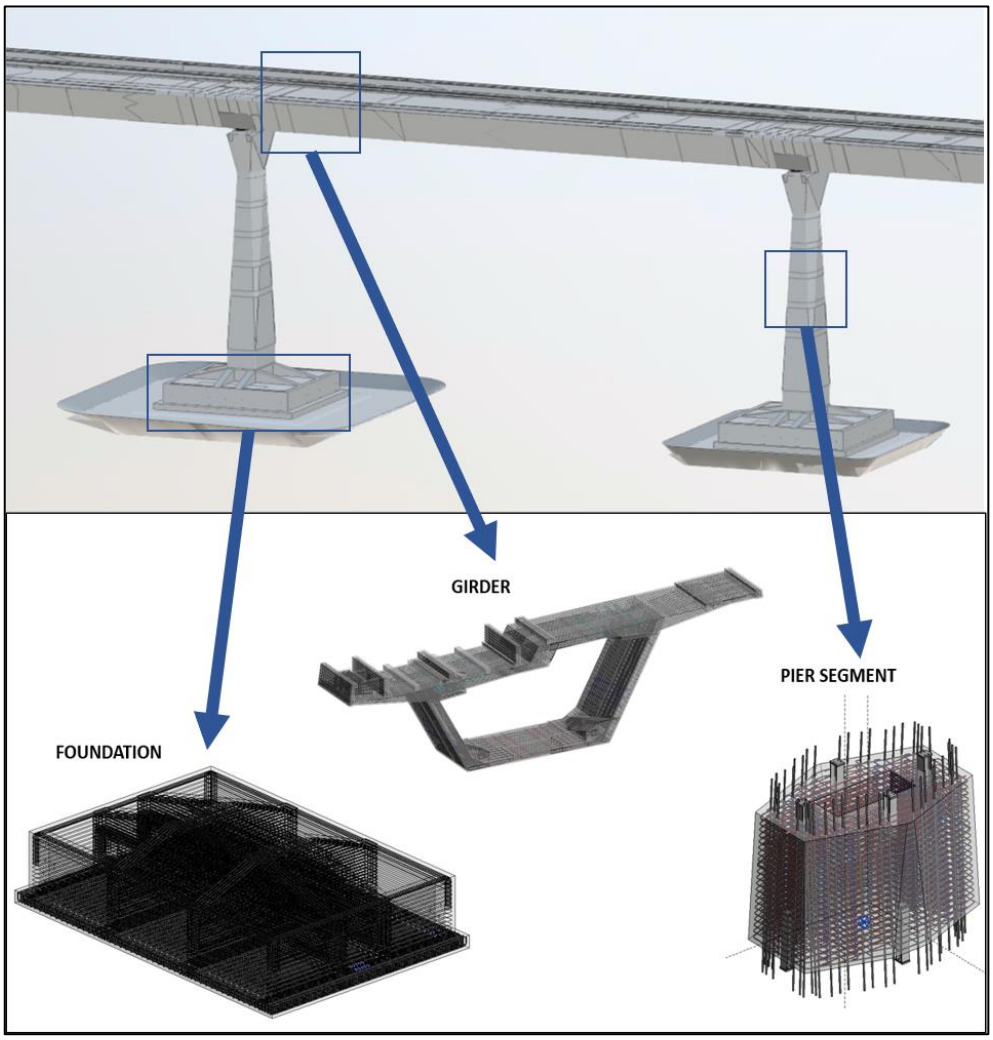

Figure 4.3 Complete Bridge Model and Separated Parts

In the figure above, a bridge project model is shown as an example. The model elements of the bridge project were modeled piece by piece considering the work program prepared for the project. Since the model elements are modeled by considering the progress stages of the work done in the field, the contractor will not

have any problems in getting the quantity information of the work done at any stage as output.

In the prepared BIM model, the parameters that are planned to be transferred to the smart contract should be determined within the BIM Execution Plan of the project and this parameter should be embedded to the relevant BIM elements.

In order to record the quantity and time information obtained from the BIM model and transferred to the smart contract in a secure encryption system, it is recommended to save this information as a hash in a block in the blockchain database of the project in the proposed workflow.

4.3 Smart Contract

The purpose of using smart contracts in the proposed system is to take over the role of the bank in payments made, and to execute payment procedure with a decentralized system that all project stakeholders can follow up. Here, basically, the commission taken by the bank for payments and the preparation of payment request reports to be sent to the banks will be prevented. Most importantly, this system will create a reliable environment in which all the project stakeholders will be able to monitor whether the money they will receive for their executed work is embedded by the employer in the system and the money embedded in the system cannot be taken out of the system without the permission of more than half of the system stakeholders due to the definition of smart contracts and blockchain technologies.

As with the BIM model, the smart contract must be ready to share with contractors at the tendering stage. Thanks to this, they will be enlightened about how the payment processes will proceed with the shared smart contract clauses and BIM model. After the tendering stage, the employer should decide on the contractor with whom the work will be carried out, the employer will request the contractor to open an account in the blockchain where the smart contract is defined. After the employer and contractor digitally sign the smart contract, they will have accepted and

commissioned the BIM model and smart contract conditions presented at the tendering stage. As in traditional contracts, it means that a binding agreement is reached on the terms of the contract after the signing of the contracting parties.

It is possible to define pricing information in the project to BIM objects or smart contracts. If price information is defined to BIM objects, if an update is desired, this can be done by changing the parameter of the relevant object in the BIM model, but this means that there is another issue that needs to be followed and checked for each payment process. On the other hand, if these prices are defined in smart contracts, only quantity and planned time information is captured in the BIM model, and project stakeholders may feel more secure in this system. For this reason, in order to create a transparent and reliable payment system, which is the main reason to transform the contracts to smart contracts, the price information is defined within the smart contract in the proposed workflow.

The contractor will transmit the payment request from his own wallet, together with the export received from the BIM model, to the smart contract, and smart contract will calculate the total amount to be requested from the employer by using the time and quantity information transmitted from the BIM model. In order to make an accurate calculation, it is important that the pricing defined in the smart contract is matched with the correct quantity and time information. The parameters used in the BIM model and defined in the BIM Execution Plan should be used in the codes used in the smart contract and attention should be paid to this before the system is started.

Together with the request sent to the employer, the employer can review the request and decide whether it will be rejected or approved, and if it approves, it can trigger the payment. In this case, the approved amount of money is transferred from the employer's wallet to the contractor's wallet.

The information of the payment transaction will be added to the blockchain by hashing the information received from the BIM model. This information, which is recorded in encrypted form, can be used again when needed.

The selection smart contract platform will play an important role in the payment system to be created with smart contracts, because even the software language in which the smart contract will be written and stable coin that the project stakeholders should acquire will vary depending on the platform to be selected. Previously, the Ethereum platform was the only platform that allowed payment via smart contracts, while in recent years, many blockchain platforms offer a working system suitable for smart contracts, and many stable coins have been created to be used in payments on these platforms (Ante *et al.*, 2021). In addition to that, in order to create the proposed system, it will be sufficient for the selected platform to have an infrastructure suitable for the implementation of smart contracts and to make payment transactions with stable coins. Although the Ethereum platform is considered to be the oldest and most mature platform (Zhao,2022), different platforms can be preferred for the system by comparing the software languages, transaction fees and speeds used on other platforms. Therefore, the smart contract platforms should be compared with their supported languages, TPS (transactions per second), consensus algorithms and average transaction fees to find best combination for the workflow. There are smart contract platforms that use languages that are dominated by many developers in the market, such as C, C++, JavaScript and Python as programming languages. Furthermore, the transaction speed of these platforms (transaction per second) and their average transaction fees are announced on their own websites. In the figure below, the announced features of some smart contract platforms are tabulated.

Name of Platform	Supported Languages	TPS	Consensus Algorithm	Average Transaction Fee
Ethereum	Solidity	15	Proof-of-Work	$12
Solana	Rust, C, and C++	50000	Proof-of-History	$0,00025
Algorand	Java, JavaScript and Python	426	Proof-of-Stake	$0,001
Fantom	Solidity and Vyper	10000	Proof-of-Stake	$0,0001
Polkadot	Rust and JavaScript	2000	Proof-of-Stake	$0,4

Figure 4.4 Some of Smart Contract Platforms with their properties

In the system to be established, the employer can make the selection of the smart contract platform by considering the programming language that the software developers are prone to the speed of the transactions and transaction fees.

In order to explain the smart contract structure in more detail, a sample smart contract model was coded using the Solidity programming language on the Remix IDE Etherium platform. Also, phases, activities and states designed within the sample smart contract are explained.

Remix IDE is a code editor enabling coding, deploying and testing the smart contracts. Solidity is an object-oriented, high-level language for implementing smart contracts influenced by by C++, Python and JavaScript, and is designed to target the Ethereum Virtual Machine (EVM) (GitHub, 2016). Programming languages utilize Integrated Development Environments (IDE) for code editing. An IDE is a software application that provides comprehensive facilities to computer programmers for software development (Busbee, 2021). An IDE normally consists of a source code editor, build automation tools, and a debugger. Remix IDE is an open-source web and desktop application having modules for testing, debugging and deploying of smart contracts (RemixIDE, 2016). The sample smart contract application at this study is coded, deployed and tested at Remix IDE. User interface created at Remix IDE is presented at figure below.

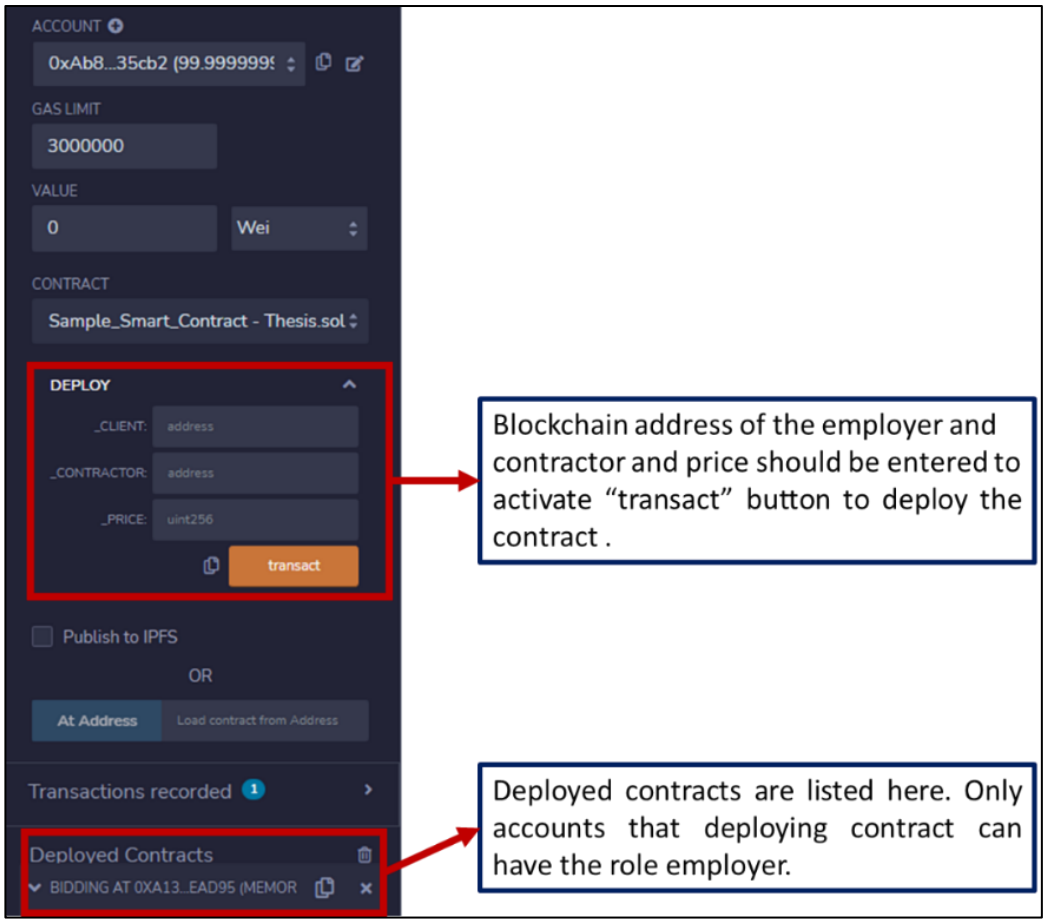

Figure 4.5 User interface for smart contract deployment at Remix IDE

As coded in the smart contract, the employer and contactor should be entered their blockchain addresses with the smart contract to be able to start and activate the contract.

```
constructor(address _Client, address payable _Contractor, uint _price){
    Client = _Client;
    Contractor = _Contractor;
}
```

Figure 4.6 Wallet addresses and roles defined in the smart contract

The buttons represented in the figure below allow users to have ability to enter data or take action within the contract. However, each button could be input regarding the assigned permissions. For example, withdraw or confirm contract buttons presented

can only be executed by the employer while initiate contract button can only be executed by contractor. Furthermore, the fields where the quantity information can be entered for the concrete, formwork and reinforcement that will be requested to be paid are defined within the smart contract, and it is conditional for the contractor to enter the relevant parameters before submitting his request. In this example, while the quantity information is defined manually by the contractor, these parameters shown in the figure below should be obtained from the BIM model in the proposed workflow.

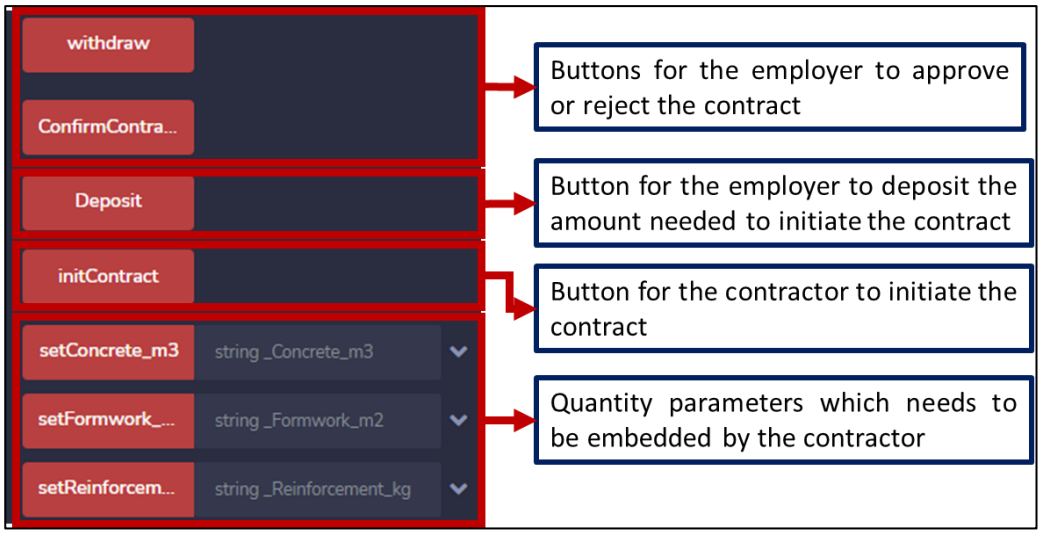

Figure 4.7 Buttons and parameters created within the smart contract

The payment process consists of “status” to ensure and inform parties about the process of the payment. As it is shown in the figure below, five statuses are defined in the smart contract, including contract set, contract started, payment deposited, not approved and completed in case of an approval.

```
enum State {CONTRACT_SET, CONTRACT_STARTED, PAYMENT_DEPOSITED, NOT_APPROVED_BY_CLIENT, COMPLETE}
//Roles
address public Client;
address payable public Contractor;
```

Figure 4.8 Contract Status and Roles

The flow of the created between activities in the sample smart contract is shown in the diagram below.

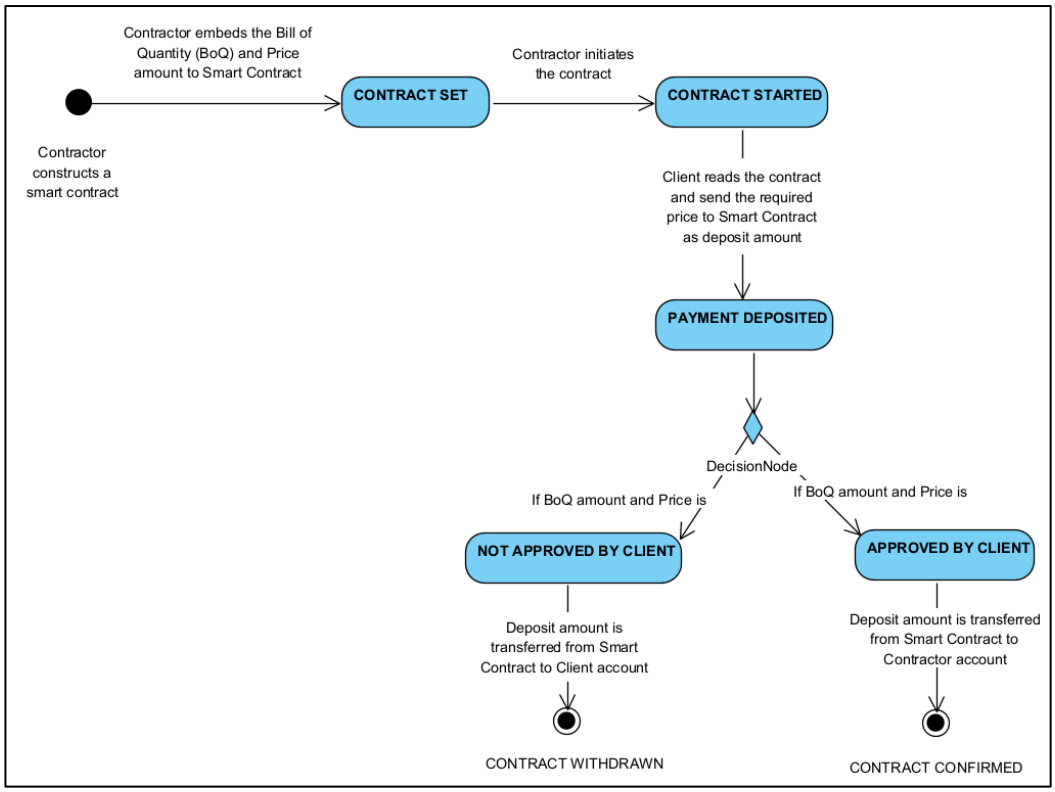

Figure 4.9 Activity Diagram of sample smart contract

As a first step, the contractor describes the Bill of Quantity and the price amount to the smart contract. This will change the status as “Contract set”. Then the contractor will initiate contract and the status will be changed from “Contract set” to “Contract Started”. Later, the employer transfer deposit amount to smart contract. This function will take deposit amount from the employer account and store at blockchain environment. Furthermore, the status will be changed from “Contract Started” to “Payment Deposited”. If the bill of quantity amount and price sent by the contractor are agreed upon then the employer approve the contract. This will cause change of status from “Payment Deposited” to “Complete” and the deposit amount will be transferred from smart contract to the contractor account. If the employer is not approving the quantities and price sent, then the deposit amount would be returned back to the employer account, and this will change the status as “Not Approved”.

The roles and interactions of the transactions made in the sample smart contract are shown in the diagram below.

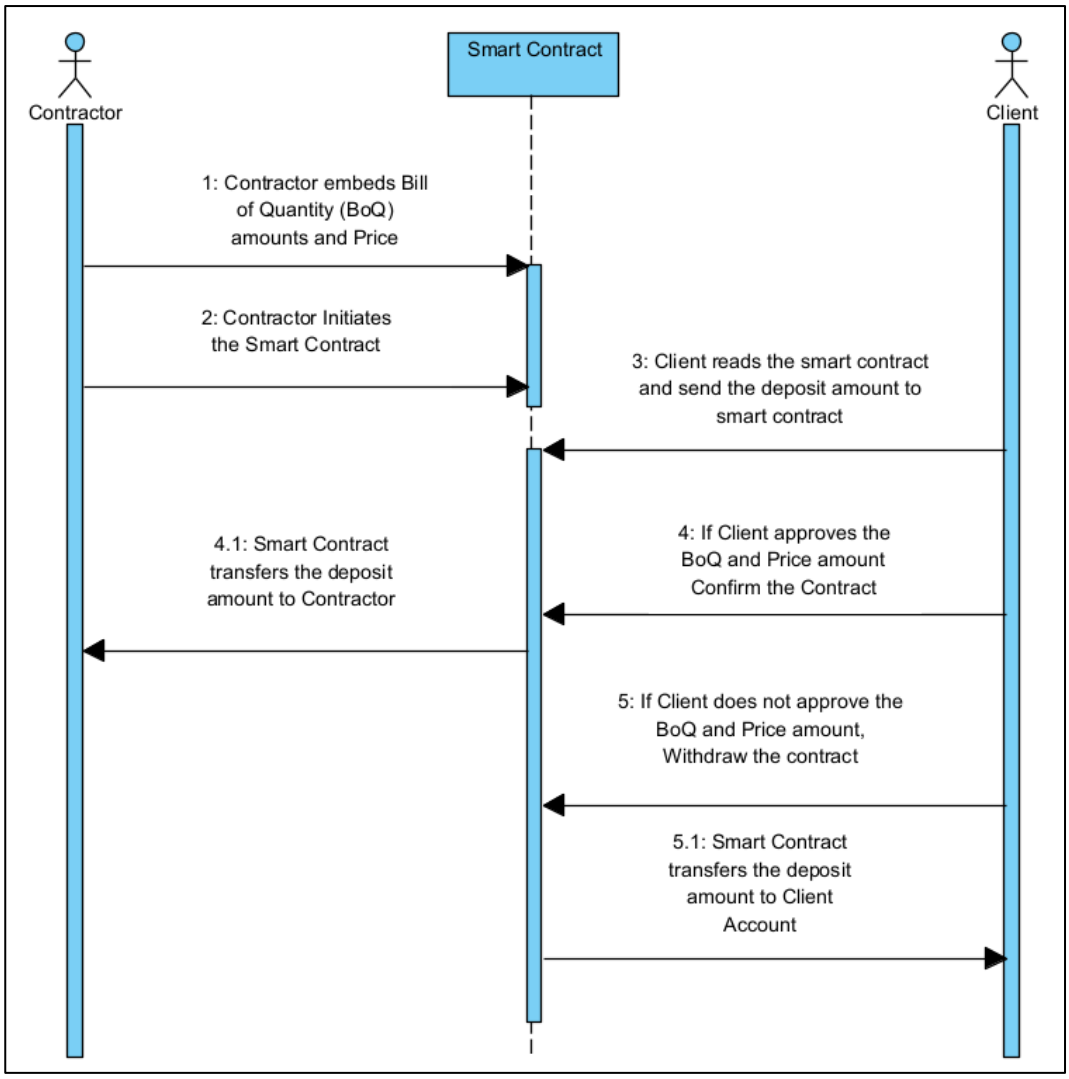

Figure 4.10 Sequence Diagram of sample smart contract

Quantity and time information from the BIM model cannot be directly transferred to the smart contracts, but the exports from the BIM model can be transformed into codes that can be used in the smart contract by using the applications designed by the software developers. With these applications, which are created regardless of whether the wallets of the project stakeholders are web, mobile, desktop and hardware wallets, data conversion, creation of payment request and approval processes can be solved and a connection can be created between BIM models and smart contracts. These applications are not able change the conditions defined in the

smart contract, they can only help to provide data entry to the inputs defined in the smart contract with an external interface.

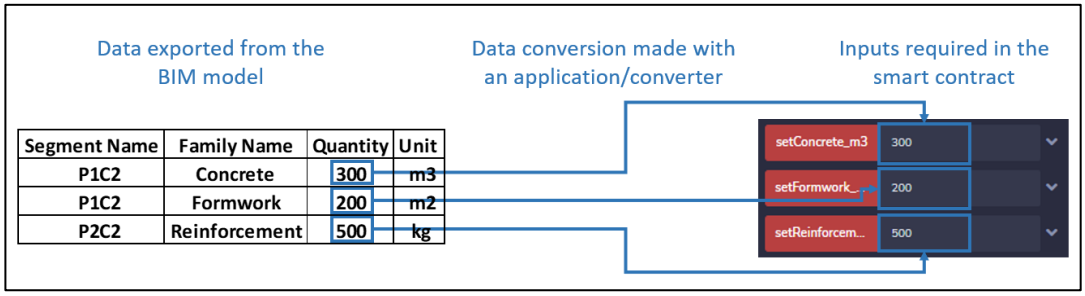

Figure 4.11 Data Conversion from BIM models to Smart Contracts

4.4 Wallets and Coins

The digital asset called "Wallet" in the system are connected to the blockchain accounts of the contractor and the employer defined in the smart contract. Wallets are used for storing and managing users' digital assets in the blockchain environment and can be connected with applications developed for them to manage their transactions. In fact, users can store and manage multiple cryptocurrencies in a single wallet. In most blockchain systems, wallets can be created free of charge. Similar in bank accounts, after the wallet account is created, an ID is generated for each wallet in a unique way. These IDs are defined in the smart contract for both the contractor and the employer.

There are several types of wallets such as web, mobile, desktop and hardware wallets. As can be seen from the names of the types, the names vary according to the location of server where the information of wallet is stored. Each of these types offers different advantages to users in different subjects, so in the system to be installed, users can choose wallets according to the subjects they give importance.

Web wallets are wallets in which users can store and manage their digital assets using a web browser or internet connected app. In this type of wallet, the private keys are protected by an encrypted system of the selected web database. Unlike other wallets,

private keys belonging to web wallets are processed on a server that does not belong to the user. For this reason, if users want to keep their keys only on their own servers in the system, it would be better to choose mobile, desktop or hardware wallets. On the other hand, web wallets are easily integrated with various decentralized applications in which payment process can be designed both for contractor and employer. Therefore, Web 3.0 wallets offered in the last period created a system that allows users to keep their private keys on the user's server instead of keeping them on their own servers in order to solve this reliability problem. Also, there are many Web 3.0 wallet options such as Trust Wallet, Argent, MetaMask and Trezor. By making an evaluation among these options, the employer can set up the system on the most suitable option. Moreover, the employer and the contractor can create their own application and shape the interfaces and set up the system as their needs.

In the proposed system, a system is described where the contractor can send the payment request to the smart contract together with the output from the BIM model, regardless of the selected smart contract platform and wallet type, and the request can be evaluated as approval or rejection by the employer.

As mentioned before, it is stated that it would be more appropriate to use stable coins in order to protect and guarantee the rights of both the employer and the contractor, due to the variability in the use of cryptocurrencies against fiat currencies. There are several stable coins which can be used in the blockchain systems and smart contract transactions such as Tether Dollar, USD coin and DAI. All of these are available to be used in Ethereum blockchain and smart contracts created in the Ethereum blockchain. In other words, in order to use these stable coins for smart contract payments, these coins must be available in the blockchain where the smart contract is located. After the smart contract platform, wallet and stable coin types to be used are determined, the system can be established by training the relevant personnel. A document containing the technical details and rules regarding the created system can be shared with the contractors who will bid, and the contractors can be informed about this procedure.

4.5 Summary of the Proposed Workflow

BIM models are used to provide accurate quantity and time information. Therefore, it is stated that the models should be updated constantly with the progress in the field so that the contractor will not lose time while preparing the progress payment reports and directly use the exported reports from the models. In order to ensure that the BIM model can be viewed and accessed by any stakeholder from anywhere, it is suggested to store BIM models in the cloud servers. According to the detail levels specified in the BIMFORUM standards, the detail level of BIM models should be at the minimum LOD350 level in order to provide the accurate information. It is also stated that the BIM model elements should be divided in such a way that each steps of the construction progress can be represented with them.

In the proposed workflow, the contractor exports the quantity and time information obtained from the BIM model. The data exported from the BIM model is transferred to the fields defined as input in the smart contract with the help of an application or data converter. After entering information into the input fields created within the scope of the sample smart contract, the payment request created is forwarded to the Employer by the Contractor. The employer starts the evaluation process by depositing the amount that needs to be paid. This amount can be deposited in the system at the beginning of the process or after the request. Then, the employer evaluates the request. During the evaluation phase, the employer can use the features of the BIM software to examine the request.

If the employer approves the amount to be paid after evaluating, the approved amount is credited to the contractor's account and the transaction information and export file of BIM can be recorded in the blockchain. If the request is denied, the deposited amount will be transferred back to the Employer's account. Thus, both the need for banks will be eliminated, and the need for trust will be eliminated by depositing money that cannot be transacted without fulfilling the predefined conditions in the system.The summarized outline of the proposed workflow is shown at the scheme below.

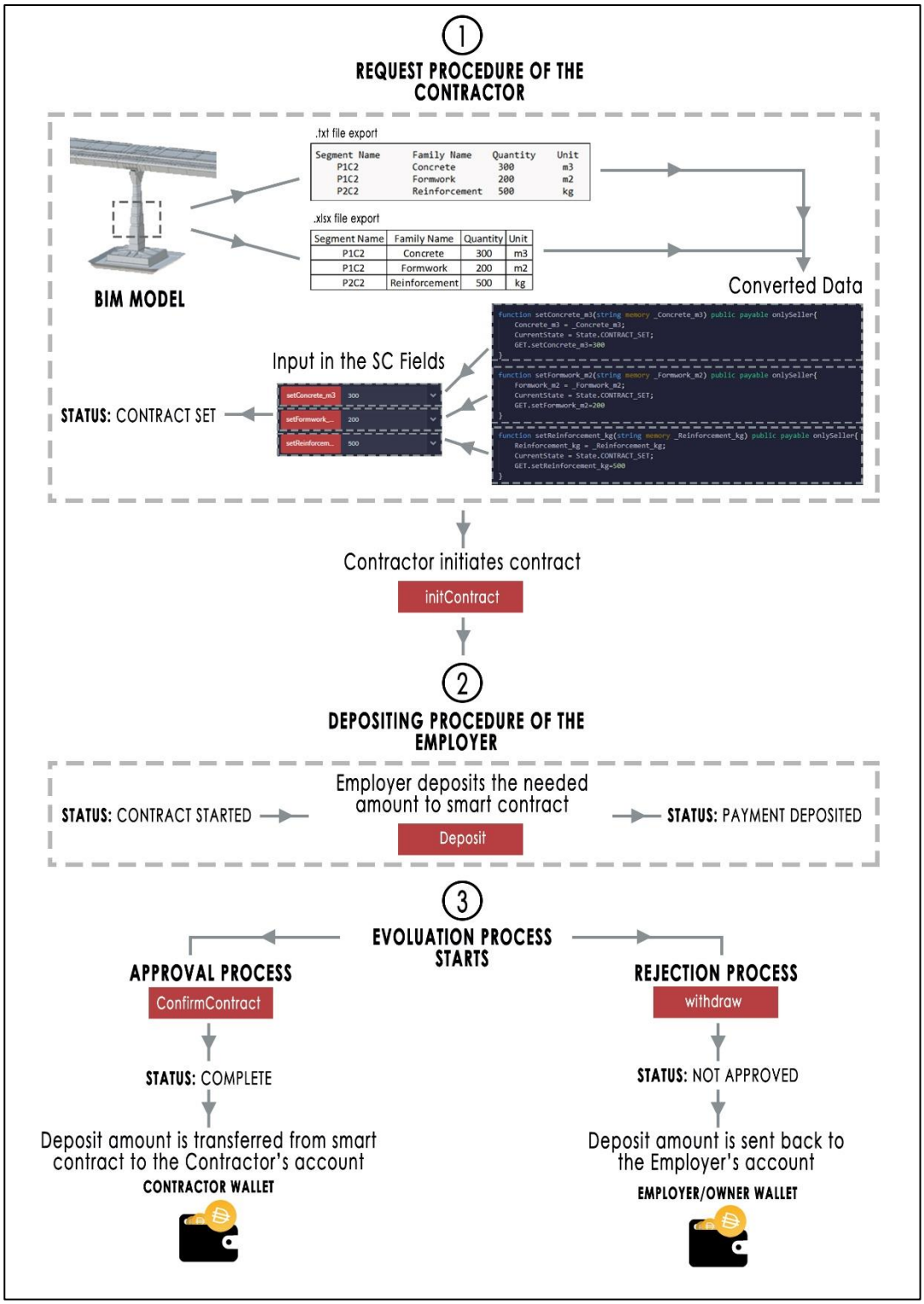

Figure 4.12 Summary of the Proposed Workflow

CHAPTER 5

DISCUSSION

It can take a long time to detect and solve a problem in systems where different technologies are integrated. In this proposed system, if there is a problem in the information from the BIM model, the items encoded in the smart contract, or the applications that connect the contract to the wallet, it may take more time to detect, find the cause and solve the problem than in traditional contracts.

In order to revise the payment system of smart contracts, the code written in the smart contract and the BIM model may need to be updated. This may require the availability of technical personnel to be committed to the process. Since construction projects generally face many decision changes and revision needs during the process, the difficulty of revision in smart contracts can be more challenging in traditional contracts, especially when there are not enough technical personnel at the adaptation stage. Therefore, while taking the first steps in the transition phase, the employer should start creating the system with items that are less likely to be revised such as rough construction, concrete, reinforcement, formwork.

Another issue to be careful about is security, due to the lack of experience in these new technologies that are expected to be adapted, the wrong platform or wallet application selections may cause the project stakeholders to lose their money in the process. Therefore, all technical decisions to be taken in the establishment of the system should be taken with experienced personnel or third parties by considering safety factors.

While the working system with BIM models was integrated into construction projects, it was used in the first process in a way that only quantity could be taken and ensured interdisciplinary 3D coordination, but it was seen that the BIM models created over time started to be used in processes such as operation and maintenance.

The same process can be valid for smart contracts, while adapting the system to the construction sector. First, the system can be set up in a semi-automatic way and in a way that can only be used for certain work items. In time, the system can be fully automated by solving the deficiencies of the system and making the fully automatic.

Although it is foreseen that there will be a challenging transition period, with the new technologies that are planned to be adapted to the system, documentation period for the progress payment in traditional contracts can be shortened and the mistakes made in these processes can be prevented. In the process of trying to adapt these technologies, the main target is to automatically receive the progress information required for the smart contract using other technologies such as reality capture technologies and fully automate the payments. While preparing progress payments in the system, time is not lost as in traditional contracts, but preparing BIM models in the establishment of the system and updating it in the process can take a longer time depending on the technical capacity and experience of the project team. Therefore, it is very important that the team that will set up and update the system is technically competent.

In the proposed system, since the elements to be paid and the smart contract matches of these elements are determined in advance, it will not be possible to partially pay for an element that is not sufficiently fragmented in the BIM model. For the elements modeled as a single piece in the BIM model, the contractor cannot request the payment partially, therefore it would be more accurate to model BIM model elements in small parts as much as possible and match them with smart contract clauses. In this way, the contractor shall be in a position to demand payment for any partially work performed. If the BIM model elements are modeled larger than the part to be requested, the contractor will have to demand the money of the relevant work in the next payment request.

In the blockchain environment, each transaction requires a cost. Gas in Ethereum blockchain refers to the cost necessary to perform a transaction on the network (Jabbar & Dani, 2020; Zarir *et al.*, 2021). Gas fees are payments made by users to

compensate for the computing energy required to process and validate transactions on the blockchain (Jabbar & Dani, 2020; Zarir *et al.*, 2021). The gas usage depends on the number and type of instructions that are executed during runtime, as well as the pieces of information that need to be stored in the blockchain (Zarir *et al.*, 2021). Although the transactions and the cost of these transactions are thought to be economical compared to the scenario where they are made with banks, when making payment transactions and storing information, attention should be paid to the optimum amount as much as possible.

The transparent system that is intended to be created using these technologies may cause difficulties in hiding information that is not desired to be shared with all of the project stakeholders. For example, subcontractors may see the price agreed between the contractor and the employer for a payment item, which may be undesirable for some contractors. This situation may cause the subcontractor to bid higher considering the price agreed between the contractor and the employer. Therefore, in the future, if subcontractors and manufacturers are included in the payment system by smart contract, it will be very important to include the amount to be paid to the contractor in the system in a way that will remain confidential between the contractor and the employer.

With the inclusion of these technologies in the payment system, it is aimed that the project stakeholders save time and spend less on payment transactions, but in order to prove the advantages of this evaluation, payment processes created with these technologies should be tested in a few large-scale projects. Thus, the usability of the system can be proven with more solid data for the companies in the sector.

Considering that the payment costs made with traditional methods in small-scale projects are not very high, it should be taken into account that using this proposed system in large-scale projects may become useful for project stakeholders. It is expected that the installation costs of the system will be high due to the need for technical support in the early stages, and it is anticipated that these costs will become

insignificant with the savings to be made in the numerous payment transactions to be made by eliminating banks in large projects.

Since smart contracts and blockchain technologies are new technologies for most countries, there is no legal infrastructure yet. In case the benefits of the use of these technologies are proven by the trials, it will be necessary to establish the relevant legal infrastructure so that the technologies can be fully used within several sectors.

CHAPTER 6

CONCLUSION

The causes of the problems arising from the late payments in the construction sector are examined, it can be seen that the companies make the payments late or incompletely in line with their own initiatives. In the industry, the “Project Bank Accounts” system is proposed by the banks as a solution to eliminate the initiative of companies or individuals. This proposal has not become widespread yet because of high installation cost and low demand. In the literature, it is stated that blockchain and smart contract technologies can bring a solution to these problems by automating the payment system that is currently used in the construction industry and requires human intervention.

Smart contracts are the written form of the contract clauses in computer code and since they work in the blockchain, every transaction made in them is recorded in an encrypted manner, creating an infrastructure that can be followed transparently by every user in the network. On the other hand, it has been stated that the projects produced by using BIM methodology can be used as a source for the information needed in the payments that are aimed to be created together with smart contracts, by considering data intensive structure of the BIM models.

As a result of the research conducted with the expert, it can be seen that if the BIM model is created in a proper which the experts find useful for the project process, the model will also include the quantity and time information required by the smart contract. According to the results of the survey conducted with the experts, it is feasible to create a workflow where the bill of quantities and reports that need to be prepared in the payment processes can actually be prepared automatically using the BIM model and then transferred to smart contracts.

In line with the results of the research and expert opinions, a workflow was proposed in this study in which smart contracts and BIM models are used together as a recommendation to improve the payment process. Proposed workflow which was executed within the blockchain environment consists of three main components such as BIM model of the project, smart contract and wallets of the contractor and employer.

Each component of the proposed workflow were explained in detail with their requirements and alternatives. Within the proposed workflow, it is recommended to store BIM models on cloud servers to make the model accessible from anywhere. At the same time, it is important that the changes made on the BIM model in these cloud servers can be tracked, in terms of execution the entire process on trackable systems. It has been stated that the model elements should be modeled at least at LOD350 level in line with the LOD levels defined by BIMFORUM in order to obtain the correct quantity information from the created BIM model elements. In the created BIM model elements, besides the quantity information, the actual and planned time information that will affect the calculations in payments can also be defined. In addition to these requirements, the modeled BIM elements should be modeled in a way that they can be separated in line with the planned payment items. Regarding the BIM model used in the workflow, it is also mentioned that the quantity and time information obtained from the model can be recorded in a block as hash in the blockchain so that the exports taken from the BIM model can be recorded in an encrypted way.

In smart contract, which is another component of the proposed workflow, the contract items that are planned to be paid using smart contract should be created by coding in the programming language of the preferred smart contract platform. The unit prices of the items to be matched with the quantity parameters obtained from the BIM model will be defined and the amount requested by the contractor will be calculated and shared with the employer. Depending on the decision of the employer, the requested amount will either be transferred to the contractor or the request or the contractor will be rejected. In the blockchains where smart contracts are created,

every transaction made is already recorded in an encrypted way. In addition, it is stated that the exports from the BIM model can be transferred into the smart contract using an application/data converter. These applications are not able to change the conditions defined in the smart contract, they can only transform and transmit data to the fields defined as input in the smart contract.

Wallets and coins used in the blockchain environment are mentioned as a last component of proposed workflow. It has been stated that the types of wallets that can be defined for smart contracts vary according to the location where the wallet information is stored. The relevant project stakeholder can select the desired type and perform the payment transactions. Regarding coins, it has been mentioned that payments can be made with stable coins, whose value is pegged to a fiat currency, or with popular cryptocurrencies.

In the discussion section it is mentioned that in systems created with integrated technologies, it may take some time to understand and solve the problem. At the same time, it is foreseen that technical personnel who are familiar with BIM models and smart contract codes will be constantly needed, as construction projects may require too many decision changes and revisions. Technical personnel should not only be involved in the installation amd updating of the process, but also in the selection phase of the smart contract platform to be selected and inform the decision makers about security issues.

In order to start the adaptation to the system, instead of automating the whole process in the first stages, automating the items that are less revised can provide an easier transition process for the companies. With the inclusion of technologies such as reality capture, it can be aimed to create a fully automatic payment system that covers all payment items.

The correct division of the BIM model elements, the optimum decision of the transactions to be made within the smart contracts and the information to be recorded in an encrypted manner in the blockchain play a very important role in the workflow. Correctly separated model elements will help the contractor to show every work he

has done with the outputs from the BIM model, while the optimized payment transactions in the smart contract will result the use of the blockchain platform at less cost.

The problems that the transparent structure offered to the users by the blockchain environment can cause to several problems for the contractors such as high bids. It has been mentioned that if the price information agreed between the parties is included in the system, it will be necessary to establish a smart contract infrastructure in such a way that this price information can be kept confidential in order not to cause a problem.

It has been stated that the time and cost savings targeted by smart contracts may not be achieved in small projects due to the cost of installation of the proposed system. It has also been mentioned that there is a need for solid data that has been used and tried in several projects in order to convince the companies in the sector about its use in large projects.

Experts participating in the research and studies in the literature state smart contract and blockchain technologies as a serious potential to solve the problems experienced in payments. Studies in the literature also underlined the need to establish an adequate legal infrastructure in order for the process to become truly usable.

In this study, the aim was to make a contribution to the literature by proposing a workflow that can be a pioneer, although not fully automatic, in the payment processes.

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APPENDICES

A. Sample Smart Contract Code

```
pragma solidity >=0.7.0 <0.9.0;

contract Sample Smart Contract {

   enum State {CONTRACT_SET, CONTRACT_STARTED,
PAYMENT_DEPOSITED, NOT_APPROVED_BY_CLIENT, COMPLETE}

   //Parameters

   address public Client;

   address payable public Contractor;

   uint public price;

   bool public isClientIn;

   bool public isContractorIn;

   //CONTRACTOR INPUTS

   string public Concrete_m3;

   string public Formwork_m2;

   string public Reinforcement_kg;

   State public CurrentState;

         modifier onlyBuyer() {

          require(msg.sender == Client, "Only Client can call this function");

      _;

      }
```

```
        modifier onlySeller() {
            require(msg.sender == Contractor, "Only Contractor can call this function");
            _;
        }
    constructor(address _Client, address payable _Contractor, uint _price){
        Client = _Client;
        Contractor = _Contractor;
        price = _price * (1 ether);
    }
    function setConcrete_m3(string memory _Concrete_m3) public payable onlySeller{
        Concrete_m3 = _Concrete_m3;
        CurrentState = State.CONTRACT_SET;
    }
    function setFormwork_m2(string memory _Formwork_m2) public payable onlySeller{
        Formwork_m2 = _Formwork_m2;
        CurrentState = State.CONTRACT_SET;
    }
    function setReinforcement_kg(string memory _Reinforcement_kg) public payable onlySeller{
        Reinforcement_kg = _Reinforcement_kg;
```

```
    CurrentState = State.CONTRACT_SET;
}
function initContract() onlySeller public payable {
    if(msg.sender == Contractor){
        isClientIn = true;
        require(CurrentState == State.CONTRACT_SET);
        CurrentState = State.CONTRACT_STARTED;
    }
}
function Deposit() onlyBuyer public payable {
    require(msg.value == price, "Wrong deposit amount");
    require(CurrentState == State.CONTRACT_STARTED);
    CurrentState = State.PAYMENT_DEPOSITED;
}
function ConfirmContract () onlyBuyer payable public {
    Contractor.transfer(price);
    require(CurrentState == State.PAYMENT_DEPOSITED);
    CurrentState = State.COMPLETE;
}
    function withdraw() onlyBuyer payable public {
    require(CurrentState == State.PAYMENT_DEPOSITED);
    payable(msg.sender).transfer(price);
```

```
        CurrentState = State.NOT_APPROVED_BY_CLIENT;
    }
}
```

B. Interview Questions

1. Do you think that the use of BIM is beneficial in the construction projects?
2. At which project phases do you think the use of BIM is beneficial?
3. Which BIM uses are beneficial in your opinion?
4. Do you think that automating payment processes by using smart contracts will solve the problems experienced in payments?
5. Which payment items do you think can be paid with smart contracts?
6. Which way should be used to get the quantity and time information to be entered into smart contracts?
7. What do you think should be considered when choosing a smart contract platform?
8. Which coin type should be used in the payments with smart contract?
9. Would it be a problem for you if the wallet information is saved on another server?