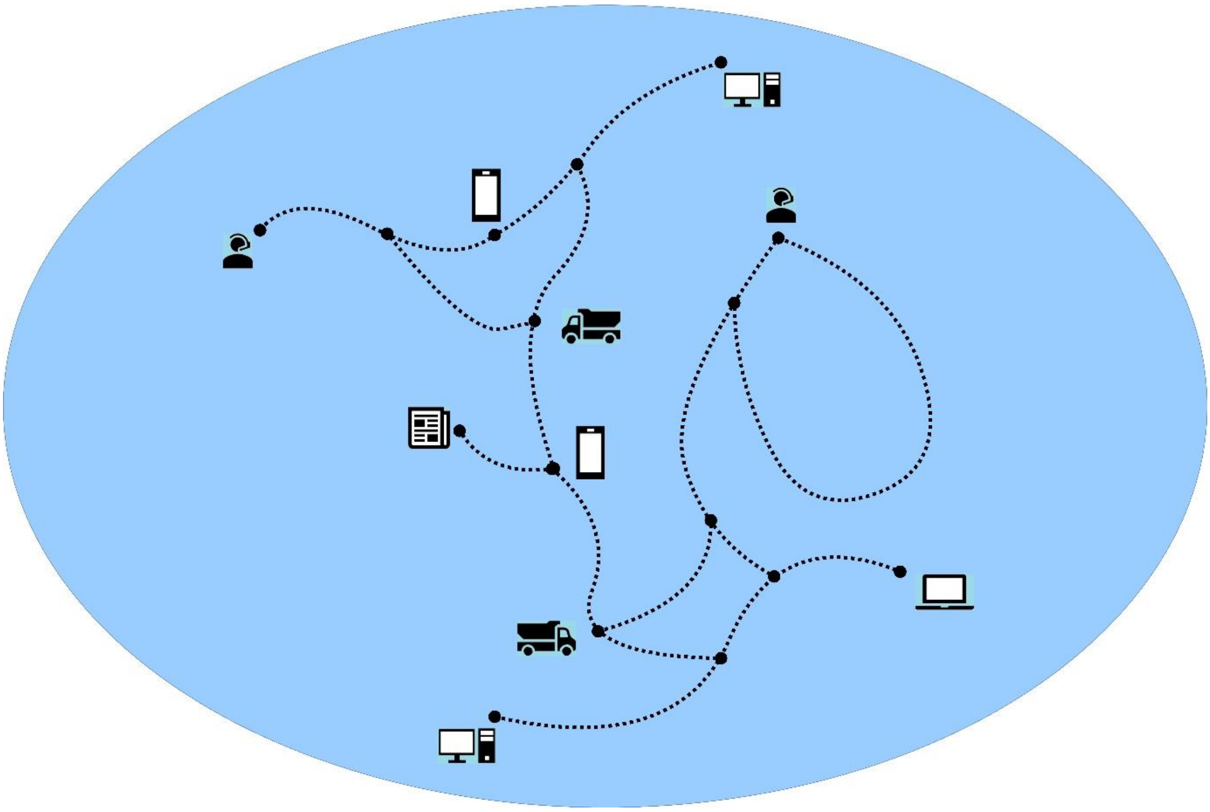
FEASIBILITY STUDY ON THE APPLICATION OF BLOCKCHAIN TECHNOLOGY IN THE RECLAIMING ASPHALT PROCESS

Konstantinos Bachas

Master Thesis Report



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Master Thesis

Feasibility Study on the application of Blockchain Technology in the Reclaiming Asphalt Process

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Master of Science (MSc) in Construction Management and Engineering
Delft University of Technology
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Graduation Committee

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I. Acknowledgement

The report laying in front of you is the final step of my studies in Delft University of Technology. Starting the MSc Construction Management and Engineering in September 2017, from the first moment I realized that I have a high interest in information management and technologies, related to the construction industry and projects. For this reason, I chose to work on this field for my master thesis and there would be no better topic than blockchain technology.

There are many people that I have to thank for this long and entertaining journey in the world of blockchain technology. Starting with my first supervisor, Alexander Koutamanis, our long discussions around (not only) information management arose my interest for further research and investigation in this topic and his expertise helped me to answer crucial questions that came out during the present study. Without a doubt, the experience of Jolien Ubacht in scientific research around blockchain technology helped me to approach the topic and structure this study in the best way possible. Finally, I would like to thank Peter Boelhouwer for guiding the research and for his crucial comments during the execution of this thesis.

The present study would never be competed without the support of Royal BAM Group. Starting with BAM Infraconsult bv, I definitely have to thank Jeroen Nuijten for giving me the opportunity to complete my thesis in this company and for his continuous guidance all these months. Additionally, Sebastiaan Geenen was always on my side for everything I needed in order to complete the present study. Finally, I have to thank all the employees of BAM Infraconsult bv, BAM Infra Asfalt, BAM Infra Regionaal West and all their partners that were always positive on discussing and giving me as much information as I needed.

Last but not least, I have to give special thanks to my family that has always been on my side and all my friends that supported me in this amazing journey in TU Delft.

Enjoy Reading,

Konstantinos Bachas

September 2019

PS: The cover page is inspired by the combination of decentralized networks and some famous constellations. More specifically, the network that is presented is a simplified version of Orion (The Hunter), Hercules (the Strong Man) and Ophiuchus (the Serpent Holder).

II. List of Abbreviations

E&C:	Engineering and Construction
TI:	Trust Issue
IS:	Information Sharing
SCM:	Supply Chain Management
DLT	Distributed Ledger Technology
BT:	Blockchain Technology
SC:	Smart Contracts
PoW	Proof-of-Work
PoS	Proof-of-Stake
PoA	Proof-of-Authority
CC:	Computing Cloud
SE:	Sustainable Development
CE:	Circular Economy
RA:	Reclaiming Asphalt
DSR	Design Science Research
BPMN:	Business Process Model and Notation
RAP:	Reclaimed Asphalt Product
DBFMO:	Design, Build, Finance, Maintain and Operate
AP:	Asphalt Plant
PIM:	Pavement Information Model
UML:	Unified Modelling Language
OO:	Object Oriented
APTN:	Asphalt Process Trading Network

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VI. Executive Summary

The incentive of the present study is the improvement of construction projects in terms of management of information. At first, the circular construction projects are selected as the most interesting to be improved, since the benefits that can be brought will be multiple not only for humanity but for the whole planet.

The starting point of this research is an extended literature review. First of all, the construction projects are analysed in terms of what problems are usually faced, mostly focusing on information sharing and collaboration. On this subject, three main problems related to the present study are determined: i) the trust issue, ii) information sharing and iii) supply chain management. As long as these issues are explained, the available solutions (information systems) are presented, focusing mostly on the method that will be investigated in the present study, blockchain technology.

At first, a short description of traditional databases (methodology and some pros and cons) is presented. Next, the technology that is used in blockchain systems is explained in detail. Blockchain technology and smart contract (as a related applications) are presented in order to make clear all the benefits that these methods could bring in Engineering & Construction Industry. The benefits that are determined and are related to the scientific topic that are discussed in the present research topic could be a) the improvement of integrated information systems and b) a more efficient supply chain management. At the end, the suitability of the selected case study (Reclaiming Asphalt Process) is justified, according to its specific characteristic (large amount of produced information, complicated business network, connection with circularity etc.).

The present research is a feasibility study. The possibilities of implementing blockchain technology in a specific construction project is investigated. The objectives of the research are generated from the aforementioned problems that are faced in most of the construction projects and for this reason, two use cases are selected to be examined: i) an information sharing platform and ii) a transactions recorder that will assist the supply chain management and the total process improvement.

In order to come up with a conclusion on this study, several research subquestions are formed and after determining the respective answers, the main research question is answered in the conclusion. The main research question and the respective subquestions are listed below.

Main Research Question:

"Which parts of the Reclaiming Asphalt Process could be improved through an artifact based on blockchain technology?"

Introductory Questions:

"What is blockchain technology and which are the main advantages it has, in relation to construction industry?"

"How could blockchain technology and smart contracts be used in construction projects?"

Subquestions:

a. "What is the current process for reclaiming asphalt and which parties are involved?"

b. "What is the information that is shared in each step of the process about?"

c. "Which are the problems that the traditional process has in terms of management of information?"

d. "Which parts of the current strategy that the company follows could be improved?"

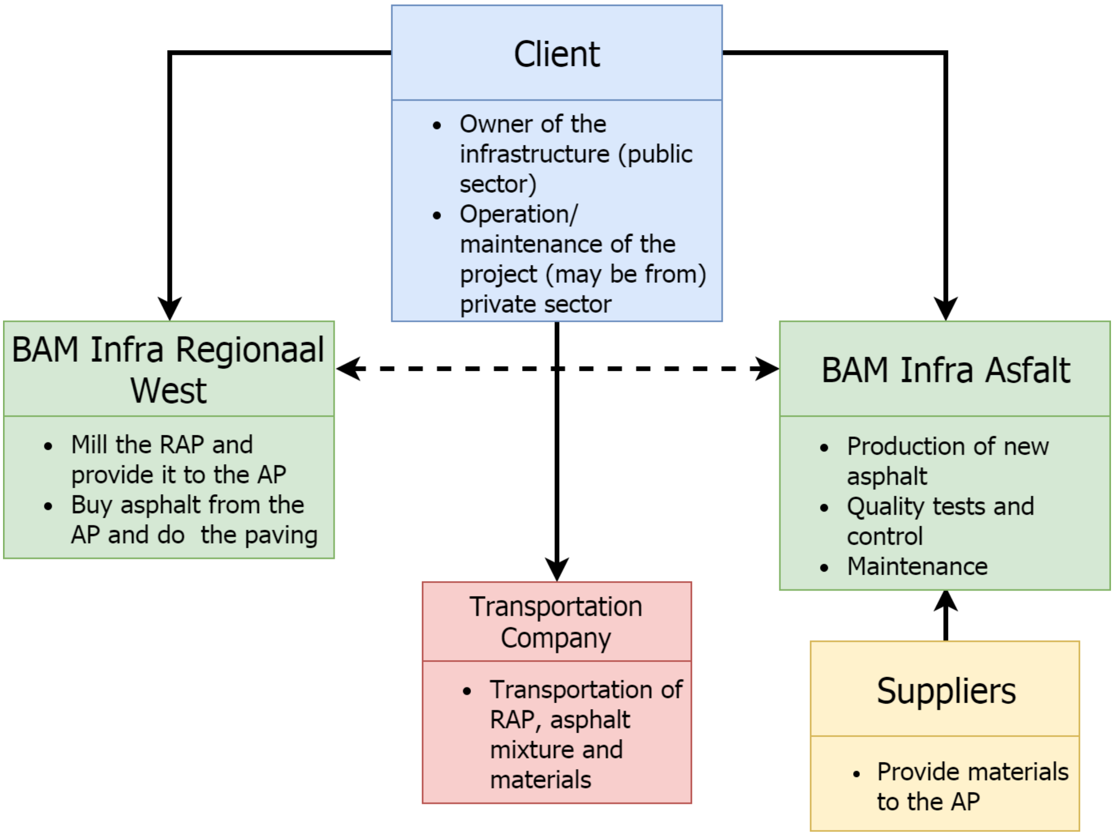
e. "Which are the requirements that an information system should serve in this specific project?"

f. "How should a blockchain artifact be technically organized in order to provide efficient recording and sharing of information?"

For answering the aforementioned questions, the Design Science Research approach is selected. This method is suitable for designing artifacts that will serve specific purposes after considering the complexity of the business networks and the technology that is about to be used. The used approach is consisted of five steps and four of them are executed in the present study. More specifically, i) the Problem Identification, ii) the Requirements Definition, iii) the Design of the Artifact and iv) the Evaluation are executed while the redesign of the artifact according to the validation feedback is not included.

In order to assess the feasibility of a blockchain model in this specific process, the research should be divided into two parts. At first the process that is followed in this specific case study should be analysed in terms of involved activities and stakeholders in order to determine the operational requirements. Next, the involved information that is shared through this model should also be defined in order to determine the technical description of the artifact. The method that is selected for gathering all the useful data is experts' interviews and surveys along with documentation analysis from the involved companies of the process.

The process is analysed in terms of involved stakeholders and their specific roles and responsibilities are identified. In the following figure, the participants of the business network and their responsibilities are presented.



The next step is the analysis of the Reclaiming Asphalt Process, which is consisted of eleven steps. The overview could be summarized in three smaller parts, which are: i) the milling of RAP and transportation to the asphalt plant ii) the production of new asphalt iii) and the laboratory test and infrastructure life period.

At the end, the process is analysed and presented in terms of information sharing in order to have a clear view of what kind of information is exchanged during this process. For this reason, an Input-Process-Output diagram is designed, in which all the activities, the stakeholders and the input and output information is depicted in each one. In this way, it is easier to conclude which stakeholder should have access to which part of information. The most important outcome of this figure is the identification of the problems that the process has in terms of information sharing. In this way, any inefficiencies that may not be easily determined, will be pointed out. At this point, the critical role of the laboratory tests is pointed out which due to their involvement in many different parts of the process and the need of preservation of the results could make it a bottleneck on the process. Additionally, the long and interconnected information flow in the production process can affect the efficiency and productivity.

All this analysis takes place in order to determine the problems that are faced in this case study and assess the added value that could be brought from the implementation of blockchain technology. The management of information is a crucial part of the process that should be carefully treated since it affects several aspects of the process that should be considered.

On the one side, there is the unavailability of information, related either to the quality of the used materials or of the delivered mixture. The main problem concerning the availability of information is not that the required data are not recorded but either the method that is used is not efficient or many different systems are used and consequently the integration is not possible. On the other side, several inefficiencies are faced on the daily process due to problematic coordination of the available personnel and equipment. This has a direct effect on the supply chain management of the asphalt production and is directly depicted in the level of productivity of the project. An important factor that contributes in many cases in this problem is the transactions costs that decrease the efficiency of the process due to the traditional exchange methods that are used (such as paperwork, e-mails etc.).

Starting with the availability of information, this problem is created due to the fact that there is not proper integration and management of the information that is recorded. For this reason, it is not possible to conclude a total overview of each project and use it either for optimizing the process that is already followed or for submitting it to future clients in order to have more possibilities to get new projects. In any case, sharing the data that are already recorded is not practical through the current system that is used, and this has a direct impact on the level of productivity that is determined as the second problem of the process.

The second part that could be connected to the management of information and is noticed in the selected case study is the low productivity. This problem has a direct connection to the information system that is used since in many cases either it is due to insufficient information management that does not allow the optimization of the process or due to the transaction costs that are high in the supply chain transactions and do not allow a faster execution of the project.

In the main part of this research, the blockchain model that could be implemented in the selected case study and improve some of the parts that were previously mentioned is presented. First of all, the requirements of the information system that could be used in this case are analysed. The requirements that are mentioned is this point are divided into two categories: the design principles and the technical requirements of the system.

Starting with the design principles, the main purpose of this part is to mention the requirements that should be served in general from an information system used in this case. The following six requirements are mentioned: i) traceability of material processes, ii) presentation of total process/project overview, iii) include standards and regulations that should be followed, iv) sharing of data in a safe and predetermined way, v) recording and management of information in long terms period and vi) reliability, immutability and trustiness in the stored data.

At the end, the suitability of these principles with a traditional database and a blockchain model is discussed and the blockchain system is considered as more ideal. As a consequence, in the next part the technical characteristics of a blockchain information system are presented.

The technical requirements are discussed in a qualitative way in order to describe as good as possible the proposed model. The following five components are decided to be mentioned in the model description: i) Consensus, ii) Transaction Capabilities, iii) Extensibility, iv) Security and Privacy and v) Identity Management. In order to decide which options for the aforementioned components are more suitable in the selected case, several decision trees from past literature review are used. By combining all the suggested model descriptions from past researches, the following proposed model is decided:

"A Consortium (Private Permissioned Network) Blockchain System, consisting of predetermined members and controlled by preauthorised nodes in which the data will be stored off-chain, in a private and third-party cloud."

In short, this model could be described as a blockchain transactions system that will record every action that take place in the network. The major application of the system will be the monitoring of the supply chain management but as a parallel application, an information platform can be applied. All the documents will be stored off the blockchain system (off-chain) in a private and third-party cloud that will be connected in the blockchain system. In this way, all the changes-actions that will occur in the cloud will be stored as blocks in-chain.

In order to validate the technical feasibility of the proposed model, two methods of its illustration in a high-level architecture are used. First of all, Sequence Diagrams are used for mapping the repetitive process of reclaiming asphalt. In this way, it becomes clear that the process has an automatic character and some parts of it could be simulated by a blockchain-smart contracts system. Additionally, the two aforementioned use cases that are investigated in this research (information and supply chain management platform) are depicted in the diagram and in this way their importance in the process is also illustrated. Consequently, it is worth it investing more on implementing these technologies in this case.

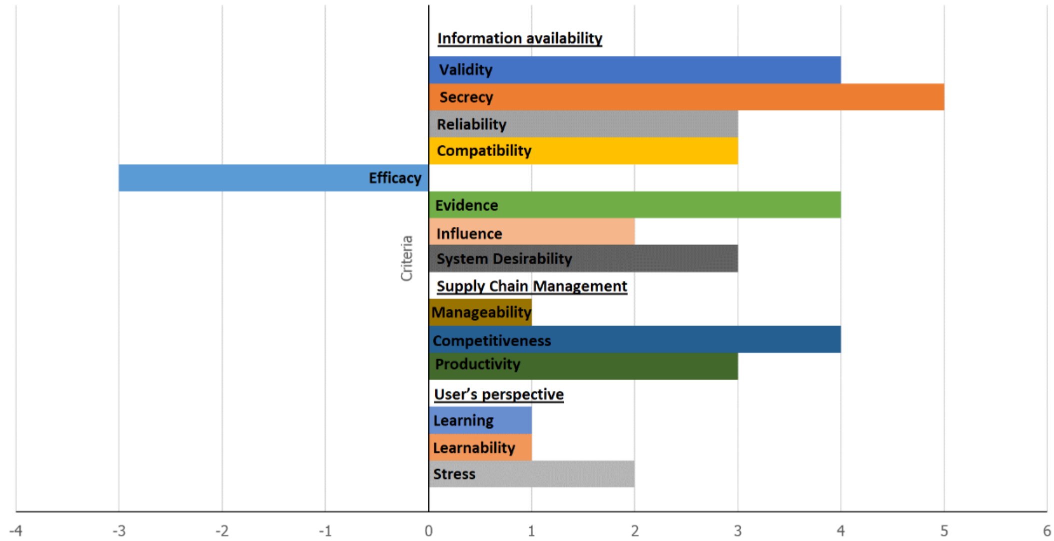
On the other side, Hyperledger Composer online playground is used for actually developing the system in a small scale. In this model, all the core components of the proposed system are carefully implemented and every design requirement such as privacy and security of data and identities are considered. As a conclusion, the development of the suggested system is considered as feasible and the most suitable interface for implementing it in the real case study should be investigated.

In conclusion, after analysing the proposed model and in accordance to the literature review that took place, several benefits that could be brought from each use case are identified. On the one side concerning supply chain management platform, the transactions could be more transparent, and the supply chain could be monitored and optimized in a better way. Additionally, the traceability of all the processes that the used materials are undertaken could be achieved through the proposed system. On the other side, a long terms predetermined sharing of data would be provided and the private character of the system would allow to share specific information with desired external or internal stakeholders. Finally, the system would ensure reliability, immutability and trustiness in the shared data since these are core characteristics of blockchain systems.

At the final part of this research, a validation of the process analysis and model proposal is carried out. A panel consisted of asphalt experts from different companies was set up. First of all, the experts agreed that the design principles that were considered on the design of the model were important for all of them. In addition, the added value that was presented and could be brought in the process was also considered of high importance. More specifically, some of the benefits that are highly related with blockchain technology (such as traceability, reliability and immutability) were considered as the most important. That could be considered as an indirect approval of the selection of blockchain technology.

A positive result that came out from the aforementioned assessment is the high grade on factors that are directly connected to blockchain technology, such as Validity, Secrecy and Reliability. Additionally, Competitiveness and Productivity were also positively assessed and that creates a need for further investigation on how these parts could be improved through an information system.

As it can be presented in the following figure, the experts assessed the Efficacy of the model really low and that can be explained in two ways. On the one side, the benefit that could be brought from the implementation of this model in relation to its cost may be considered as low while on the other side, the high-level architecture that was presented did not allow them to totally understand the usability of the proposed system. Also, factors such as Learning, Learnability and Stress were also negatively assessed. In general, the improvement of the user's perspective comes out as a major recommendation form the experts' panel.



One of the potential benefits that the system could bring to the process was the improvement of motoring and optimizing the process through a better management of information. However, the experts assessed the Manageability that the system provides relatively low. That can be explained due to the small additional options that the system provides concerning the type of data that will be available. In conclusion after the validation part, the final list of possible benefits that the model could bring to the process is summarized in the following table.

Use Case	Added Value
Supply Chain Management Platform	Transparency in transactions
	Materials Traceability
Information platform	Long terms sharing of data in a predetermined way
	Give permission to predetermined actors to view specific data
	Reliability, immutability and trustiness in the stored data

Finally, several recommendations for further research could be stated. First of all, a more developed illustration of the model is needed. In this way, its usability will be better explained, and its levels of efficiency and applicability would be easier identified. Additionally, in order to calculate the possibilities of implementing this proposal, a business case analysis should be conducted in order to assess the actual benefits that the involved stakeholders could have.

Furthermore, some parts that were not addressed on the present study should be investigated in the future. Such examples are the legitimacy of the data that are recorded because in many case there will be problems with the current laws and regulations, concerning sharing private data. In addition, the use of smart contracts in the proposed system could be investigated and the potential benefits that could be brought (such as decrease of the transactions cost) can be discussed. Finally, the improvement of additional parts of the process, such as productivity, competitiveness and circularity, that in some cases were implied in the findings of these research should be further investigated, maybe in a more quantitative analysis.

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Part I

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1. Introduction

In the first chapter of the report, the scientific background of the research is explained. According to existing literature studies, the incentives of this research are analysed and connected to the research objectives that will be introduced in the following chapter. All the information that is related to the main three topics of this research (construction industry, information systems and circular economy), that is presented in this chapter was collected after a long literature review. The main goal of this chapter is to explain what blockchain technology is and the benefits that it could bring in construction projects. In this way, the suitability of the selected case study, that is presented in detail in Chapter 3, is also made clear.

1.1. Research Background

1.1.1. Problems in E&C Industry

Construction sector had never been prompted to new technologies and techniques. It is noticed that a large number of projects in Engineering & Construction (E&C) industry are not successfully completed due to external or internal factors and the denial of the participants to integrate with new technologies is one of them (Esmaeili, Pellicer, & Molenaar, 2016; Williams, 2015). The main problems that describe the construction projects and will be further discussed in the present study are the following three: a) Trust Issue (TI), b) Information Sharing (IS) and c) Supply Chain Management (SCM) (Esmaeili et al., 2016; Turk & Klinc, 2017; J. Wang, Wu, Wang, & Shou, 2017).

Starting with information sharing, the stakeholders of a construction project usually are negative on sharing information with their partners and this is directly connected to the first aforementioned problem, trust issue. There are three main reasons that could be determined and influence the willingness to share information. First of all, there is always a need to keep some of the information confidential since the time horizon of the project is fixed and the collaboration between the partners soon or later will be over. This is related to the main factor which is to avoid liability for actions that took place during the project execution. Finally, sharing information should remain lawful in any case (Engelenburg, Janssen, & Klievink, 2017).

Moving further, supply chain management could be defined as the improvement of materials, information and financial resources between companies that collaborate under long or medium term agreements (Knolmayer, 2009). In the regular supply chains in construction projects, information and services are loosely distributed in the network. For this reason, the collaboration between the partners becomes more risky and in many cases, the availability of supplies becomes a bottleneck for the progress (Cheng, Law, Bjornsson, Jones, & Sriram, 2010). The distortion in information sharing, also known as "bullwhip effect", is one of the major problems that is identified in the current supply chain management systems. More specifically, bullwhip effect could be defined as "the amplification of the demand in the supply chain management when there is no good overview of the expected demand" (Engelenburg, Janssen, & Klievink, 2018). The nodes that participate is a supply chain may have knowledge only on the demand of the following node and not of the total demand that comes also from other participants of the network (Braz, De Mello, de Vasconcelos Gomes, & de Souza Nascimento, 2018; Engelenburg et al., 2018). This can lead to inadequate collaboration and lack of trust between the partners. Consequently, an immutable information flow is of vital importance (Hau Lee, Padmanabhan, & Whang, 2004). In addition, an effective supply chain management can lead to higher profits and better collaboration between the partners (Khan, Hussain, & Saber, 2016).

It can be implied that there is a direct connection between the three aforementioned problems of construction projects. Concerning the connection between information sharing and supply chain management, adequate information sharing is considered as one of the key principles to improve supply chain management. Additionally, the key factors that lead to a proper assessment of a supply chain management, as were identified by an assessment model of Meng in 2010, are 1) trust, 2) collaboration, 3) communications and 4) proper risk allocation (Meng, 2010). These four factors are highly related to the information sharing between the stakeholders of a project. Without efficient and reliable information exchange, proper collaboration and risk allocation will never be achieved.

1.1.2. Information Sharing

As it was defined by Cheng et al. (2010), one of the possible solutions for the information sharing in supply chain management could be the use of integrated supply chain, especially in iterative processes such as the reuse of construction materials. The term of integrated supply chain management is directly connected to information sharing since this is the mean for improving the collaboration between the participants of the chain. The use of an integrated information platform could be a promising solution in order to address this issue. In this way, the information is shared and available between the involved parties, enhancing the supply chain on monitoring and decreasing distortion and delays of useful information (Cheng et al., 2010).

In the present study, the feasibility and effectiveness of a platform that will allow the integration in supply chain management will be tested. In addition, the design of a shared information platform that could be used in storing and exchanging data will be investigated. In order to understand the benefits of an integrated information system, an explanation of the traditional database along with an introduction to more innovative technique for storing data will be introduced in the following paragraphs. Furthermore, several advantages and disadvantages of these systems will be mentioned in order to justify the selected model and techniques that will be proposed in the following chapters of the research.

Nowadays, one of the biggest trends in the scientific society is data management. All previous decades, the traditional method of storing information led to an enormous number of recorded data. As a consequence, the necessity for controlling all this information that was gathered appeared in order to make the process operations more convenient and as efficient as possible. Additionally, the undoubted value of all these data could be used for improving the current processes and maybe produce new business opportunities. Therefore, the management of all this information became an issue and a huge discussion around its exploitation evolved.

At first, along with the development of computer systems and internet, the need for storing and sharing data appeared and thus, traditional ways (databases) for storing information were introduced. These systems are built around a central server on which all the recorded information is stored. Additionally, the database should be built, owned and operated by a single administrator (usually the software company) that created the system. Soon, it became clear that there are important issues in these systems, related to the safety of the stored information and also the transparency on data exchanges which should always be guaranteed (CoinDesk, 2019; Vidhya, Jeyaram, & Ishwarya, 2016).

First of all, there should be a central administrator that will control all the recorded information and will give access and modify the abilities of all the participants according to the agreements that are made. In this model, the danger of hacking or losing information is high since the liability of the server is totally based on the operator that has the control of the system. Additionally, the immutability of stored data is not guaranteed, there is always a possibility of fraud on the recorded information that will lead to conflicts between the participants and maybe terminate the collaboration. Finally, the discrimination of the recorded data between confidential and public information either is not possible, or it should be carefully modified by the administrator of the central system. Consequently, there is always a possibility of leakage of confidential information and difficulties in sharing specific data according to each user's interest (CoinDesk, 2019; Vidhya et al., 2016). In any case, the fact that all the operation of these systems depends on a system administrator makes them vulnerable.

1.1.3. Blockchain Technology & Smart Contracts

From the description of traditional databases, it becomes obvious that their efficiency is highly related to the central administrator. As a solution to all the aforementioned problem, Distributed Ledger Technology (DLT) and Blockchain Technology (BT) appeared. Blockchain technology is a method of controlling data between several parties in a more efficient, verifiable and permanent way without the need of administrators or third parties. This is possible through a distributed ledger that is not controlled by one specific oddity, but data are stored and distributed between different nodes that participate in the network (Mainelli & Smith, 2015). The difference between the governance with a central ledger and a distributed system is depicted in Figure 1, as it was presented by Ølnes et al. (Ølnes, Ubacht, & Janssen, 2017). In this system, the data that are added are directly connected to the existing ones and cannot be altered. In this way, immutability and transparency in the transactions between the participants is achieved (Crosby, Nachiappan, Pattankyak, Verma, & Kalyanaraman, 2015; Ølnes et al., 2017).

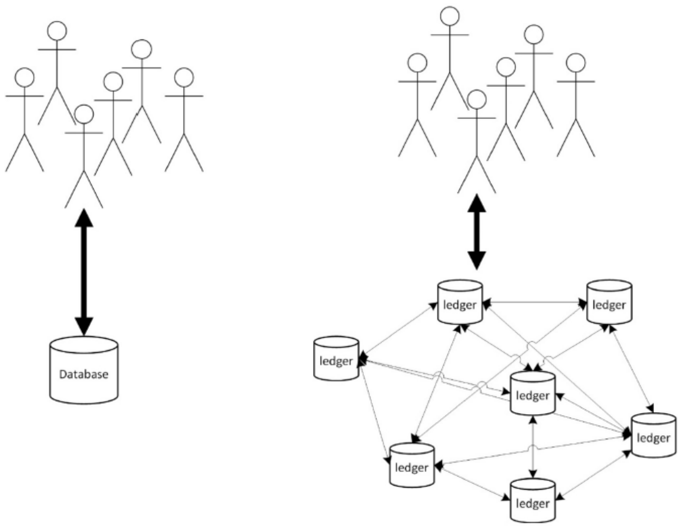

Figure 1: Difference between central and distributed ledger (Ølnes et al., 2017, p. 4).

The possible benefits that distributed ledgers could bring in project management could be summarized in three main topics. First of all, the reduction of financial costs through the reduction of transaction costs. Provided that the necessary exchanged information will be available without delays, the total operational cost of a project can be dramatically improved. Additionally, there will be a higher possibility of predicting and avoiding failures in the project since an overview can be available for everyone and the risk management can become more accurate and trustworthy. Finally, the compliance with standards and regulation that are required of all the activities that take place during the project can be easily proven since they will be stored in an immutable blockchain platform (ENISA, 2016).

There are three different applications of blockchain technology that have been identified in literature. Starting with Blockchain 1.0, it is focused on cryptocurrencies and financial transaction between anonymous nodes. Some of the main examples of these applications is Bitcoin and Ethereum which allow financial transactions between two nodes of the network in a safe and transparent way without the participation of a third part (Ethereum, 2017; Nakamoto, 2008; Swan, 2015; J. Wang et al., 2017).

Moving further, there is Blockchain 2.0 application which is related to smart contracts and assets exchanges. In this case, apart from the financial transactions that can take place, there are also applications for data recording and identification process. Smart contracts play a major role in these application since the monitoring and execution of the terms of a contracts are allowed in an automatic way (Swan, 2015; J. Wang et al., 2017). The most famous examples of a platform based in Blockchain 2.0 industry that the use of smart contracts is feasible are Ethereum and Hyperledger. These platforms are ideal for creating decentralized applications in which every user can create his own system (Ethereum, 2017; hyperledger, 2019a, 2019b).

Finally, Blockchain 3.0 is the most innovative application of blockchain which is related to governance applications, mostly focused in recording public data that can be used in health systems, in elections or in social action such as charities (Swan, 2015; J. Wang et al., 2017).

Speaking more specifically about blockchain applications, there are two variables that characterize a blockchain system. On the one hand, there is the ledger accessibility where the network can be characterized either as public or as private. This variable indicates if the data that are recorded in the network can be accessible by everyone or not.

On the other hand, the maintenance of the ledger is the second variable that determine the consensus mechanism of the network. The consensus mechanism of the system can be either open or closed (Van Valkenburgh, 2016). In the open consensus mechanism, in which the validation is done by everyone (by an action that in many systems is called "mining" (Ethereum, 2017; Nakamoto, 2008)), the system is characterized as permissionless. There are two main types of open consensus, the Proof-of-Work (PoW) and the Proof-of-Stake (PoS).

On the other side, if there is a group of predetermined members (also known as consortium) that validate the transactions that are place in the system, the consensus is called Proof-of-Authority (PoA) and the system called is permissioned (ENISA, 2016; Ølnes et al., 2017; Van Valkenburgh, 2016). In the following table (Table 1), the most prominent consensus mechanisms are explained and in Figure 2 the different variations of blockchain applications are presented.

Table 1: Consensus mechanisms of blockchain systems.

Consensus Mechanisms		
Open	PoW	Users contribute in maintaining the network and receive a reward for their work
	PoS	Users with a recognizable stake (power), sacrifice it to control the network
Closed	PoA	Some nodes are exclusively allowed to create new blocks and secure the blockchain.

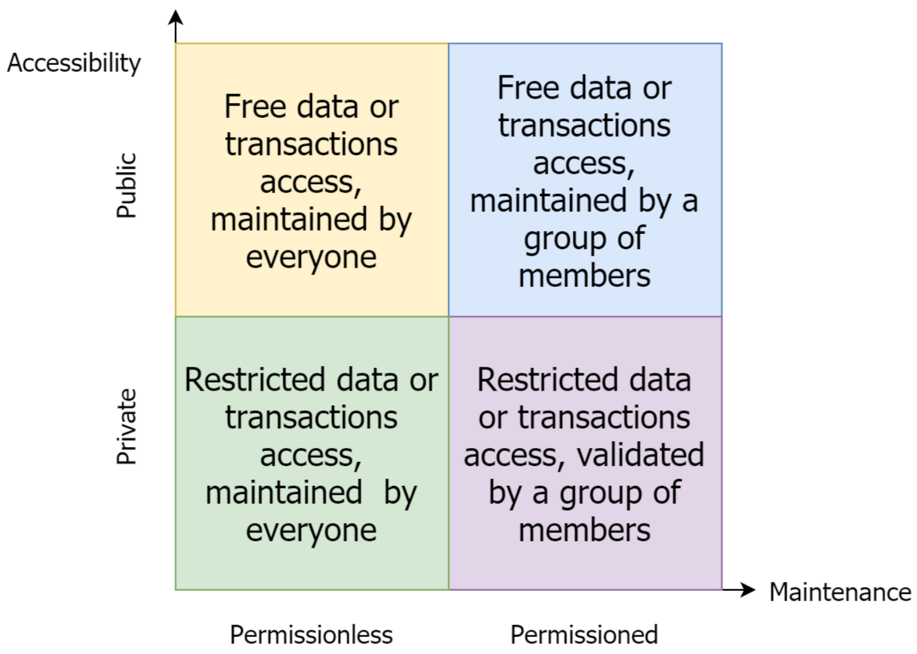

Figure 2: Variations of blockchain applications (own illustration).

One important trade-off that should be considered on designing a blockchain system is cost vs security (Figure 3) (Brennan, 2016). On the one hand, there is the permissionless public system in which authority is fully developed and that means high security. However, the cost for validating transactions can be high due to the large number of participants in the network. On the other hand, permissioned systems are much cheaper since the determined users contribute to validating the transactions. Nonetheless, the less distribution of data due to the closed network decreases the security of the system (Brennan, 2016). This is demonstrated by the fact that less participants can validate the authenticity of the added data in the system and thus, possibilities of fraud are higher.

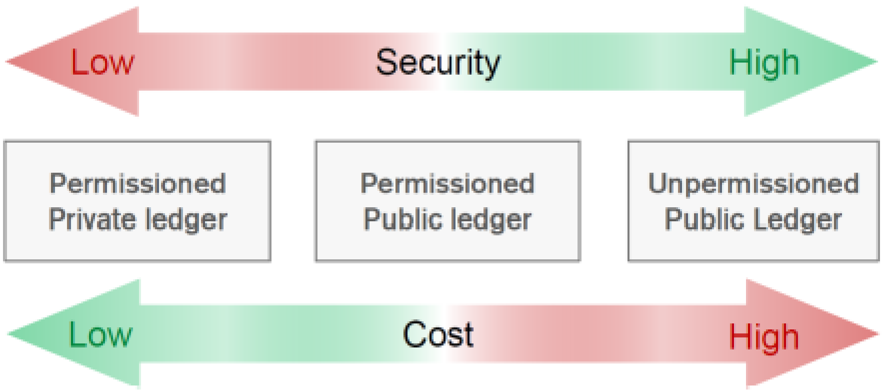

Figure 3: Cost vs Security trade-off in blockchain systems (Brennan, 2016, p. 45).

In order to make clear the benefits of blockchain technology, its operation mechanism should be explained. In general, there should be a network, consisted of nodes that have received the right to participate in the system. At first, the desirable transaction between two nodes of the networks is requested and then it is validated by some (one or more) of the participants, according to the selected consensus mechanism. Next, a block for transactions (one or more according to the computational size of each one) is created, consisted of 1) its own hash which is its personal ID, 2) the hash of the previous block, 3) the timestamp that determines the moment that the transaction took place and 4) the data of the transactions which can be either all the data of the transactions or a link (Engelenburg et al., 2017; Mazonka, 2016; Nakamoto, 2008). Each block that is created is connected to the previous one and then it is added in the chain. In this way, transactions history can be recorded in an immutable and distributed way (Figure 4 and Figure 5).

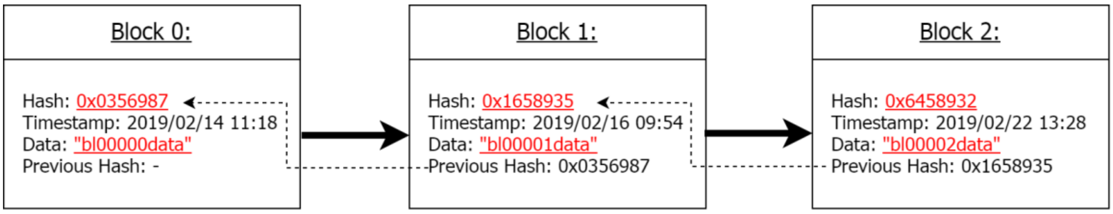

Figure 4: Blocks structure and connection (own illustration).

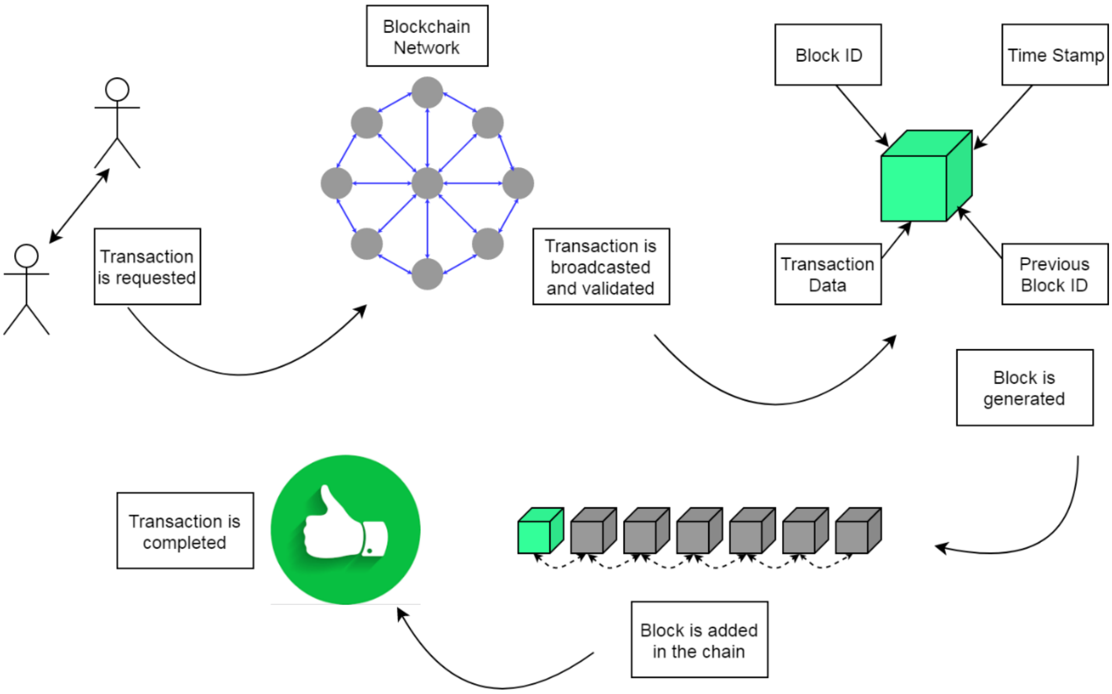

Figure 5: Validation of a transaction in a blockchain environment (own illustration).

An additional component of blockchain systems that is widely used is Smart Contracts (SC). Smart contracts are computer programs (algorithms) that can automatically execute the terms of a contract. Contractual clauses are automatically executed when pre-programmed conditions are satisfied and the performance of credible transactions without third parties are allowed (Crosby et al., 2015; Kakavand, Kost De Sevres, & Chilton, 2017; Swan, 2015).

This technology can have a direct application in systems based on blockchain technology. As it is presented in Figure 6, smart contracts can also be used as an automatic transactions generation system that will lead to blocks creation. In this way, transactions are automatically executed and cannot be altered and consequently sellers and buyers will be protected from fraud. Additionally, the time in case of routine transactions will be minimized since there will be automatically executed without human interface (Nakamoto, 2008). This technology is broadly used in many blockchain applications such as Ethereum, Hyperledger etc. (Ethereum, 2017; hyperledger, 2019a, 2019b). However, it should be mentioned that although smart contracts could assist contractual relationship, the mutual trust is highly related to social functions and this level of cooperation could difficulty be replaced by algorithms (O'Hara, 2017). Additionally, some researchers mention an important security problem that can arise in smart contract systems since they cannot be patched due to their irreversible and immutable character (Luu, Chu, Olickel, Saxena, & Hobor, 2016). Consequently, a careful design plan before the actual implementation is required.

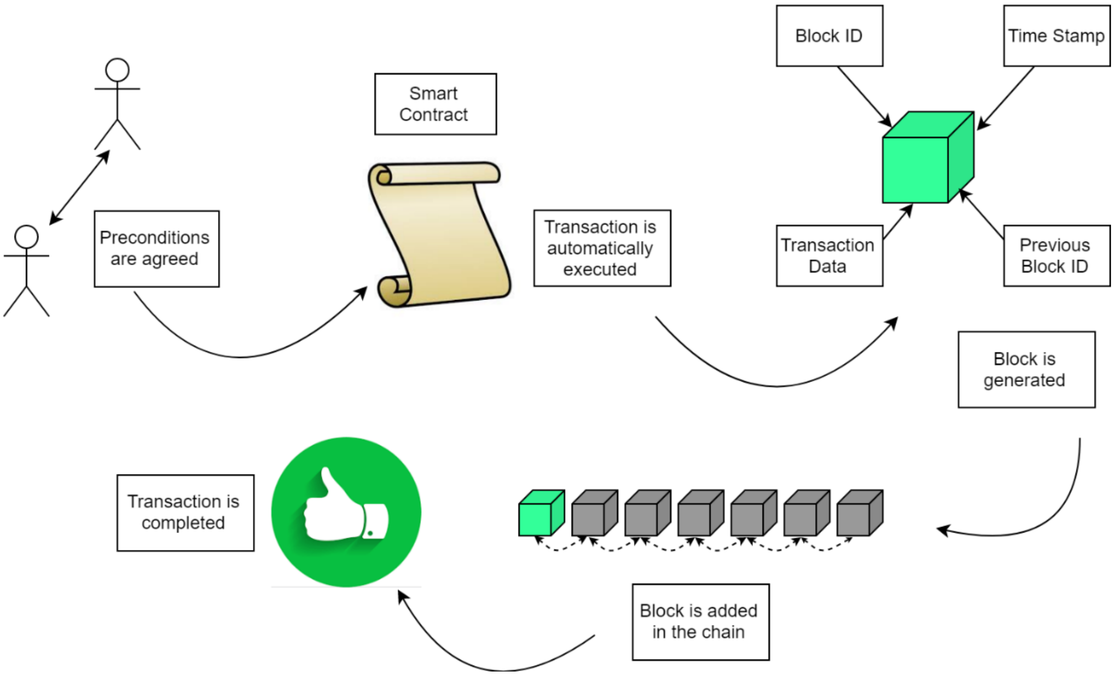

Figure 6: Generation of transactions through smart contracts in blockchain applications (own illustration).

The advantages that have been mentioned in existing literature are not only related to economic or political benefits but there are several parts that could be enhanced through a blockchain application. If the collaboration in a project was monitored by a blockchain platform, an improved coordination, a better data storage and the irrevocability of all the transactions could be achieved (Swan, 2015). According to Tasca et al. the six main driving principles of blockchain technology should be: 1) decentralization of consensus, 2) transparency, 3) security, 4) immutability, 5) automation through smart contracts and 6) storage of information (Tasca & Tessone, 2019).

A blockchain decentralized ledger could be used for recording the history of all the transactions that take place during the process. A blockchain information platform can provide all the advantages of traditional databases plus immutability and transparency, that are crucial characteristics of blockchain technology. In the traditional databases there is a trusted third party that is the central authority and approves all the changes that are done by the users in one single database. In contradiction, in blockchain systems all the participants have a copy of the data and modify the information in parallel. At the end, all the modifications are approved by the participants as long as the agreed consensus rules are met (Figure 7) (CoinDesk, 2019).

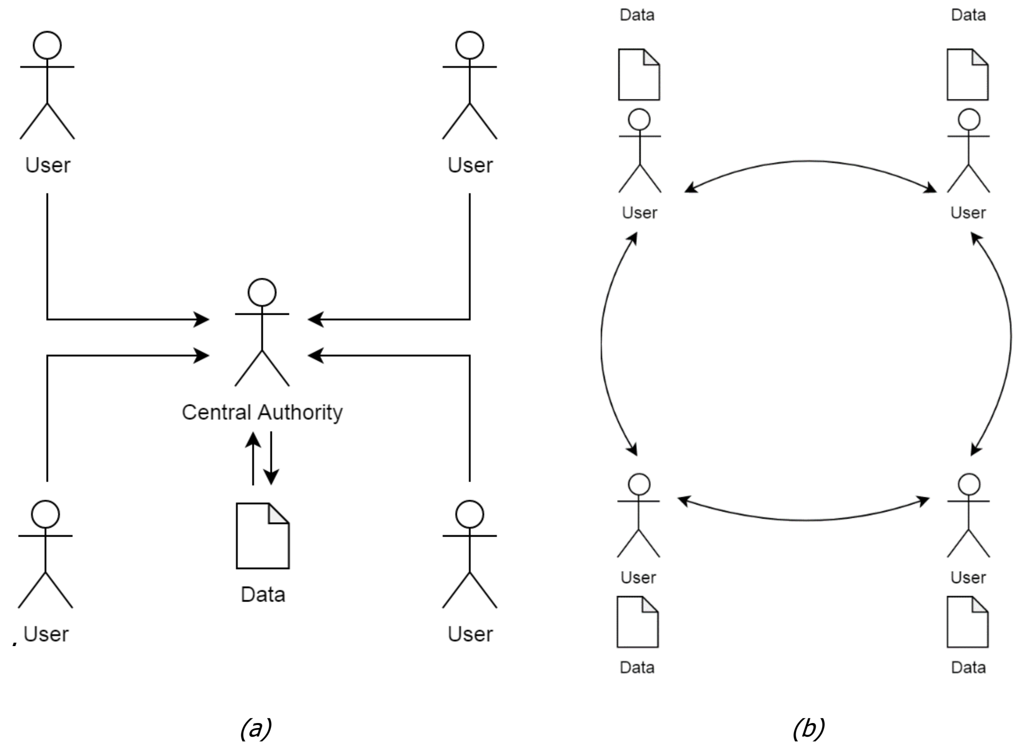

Figure 7: Difference between (a) traditional database and (b) blockchain shared ledger (own illustration).

1.1.4. Applicability

Recently, there has been a huge scientific research around the possible application of blockchain technology and smart contracts. Obviously, the rise of cryptocurrencies generated the interest around other sectors that could benefit from this technology. In the following paragraphs, findings in existing scientific literature concerning the possible connection of blockchain technology with the aforementioned problems of constructions industry will be presented. In this way, the benefits that this technology could possibly bring in construction projects will be clearly illustrated.

The incentives for considering implementing blockchain technology in information sharing and supply chain management of construction project are justified by the applications that were suggested by Wang et al. in 2017. In this research, it is suggested that blockchain could be used in two possible ways. First of all, as a "database" for recording information. In this way, the integrated information sharing between the project participants will be easier. Moving further, a transaction recorder, based on blockchain technology and smart contracts could also be used in construction projects in order to make financial transactions more efficient (J. Wang et al., 2017). In the present research, both applications will be considered.

As it was previously explained, the purpose of the present study is the improvement of information sharing and supply chain management through an integrated system. First of all, it is directly indicated in past literature studies that blockchain platforms could be used for supply chain management in construction projects (Rodrigo, Perera, Senaratne, & Xiaohua, 2018). Generally speaking, it can provide product authenticity and legitimacy as well as manufacturing transparency and traceability (Abeyratne & Monfared, 2016; Y. Wang, Singgih, Wang, & Rit, 2019). Additionally, transparency in financial transaction could be imposed which is directly connected to trust and security. Finally, there could be higher efficiency, through reduction of cost and waste products (Y. Wang et al., 2019). All these factors are crucial on assessing the success and efficiency on a construction project and their improvement is always an important target of their project managers.

More specifically, concerning the improvement of supply chain management, an extensive scientific research of N. Kshetri that took place in 2018 determined the most important parts of supply chain management that could be enhanced through a blockchain application. From all the factors that are included in this research, several are highly related to construction projects, such as: i) the total cost of the project, ii) the speed of execution, iii) the dependability and flexibility of supply chain partners, iv) the risk reduction and v) sustainability (Kshetri, 2018). Talking more specifically about the use of smart contracts on these systems, additional benefits could be mentioned such as faster settlement with higher accuracy, less risks and cost involved and no need for trust (Arup, 2017).

Concerning information sharing, the most important characteristic that a shared information system should guarantee for the users is immutability, and as it has already been mentioned in the previous sections, it is one of the major advantages of blockchain technology. Blockchain technology can be used and once something is stored in a block and added in a blockchain, it cannot be altered or removed. In this way, the collaboration between the users of this networks becomes totally transparent and there are no possibilities of fraud. Additionally, the fact that all the participants can have access to the same information can lead to serious decrease of Bullwhip Effect that is one of the major problems of supply chain management (Engelenburg et al., 2018). Bullwhip effect is related to distortion of information in a supply chain due to miscommunication between the suppliers and this can be solved through a blockchain application that will traceability of materials. Additionally, hiccups in data can be avoided since all the stored data are recorded in a time sequence.

Blockchain platform can be used as "decentralized databases" for storing information online and as it was pointed out by Novais et al., Cloud Computing (CC) could be an effective way of improving integration, system flexibility and collaboration in supply chains (Novais, Maqueira, & Ortiz-Bas, 2019).

Finally, concerning the third mentioned problem of construction projects (trust issue), H. Cardeira concluded in his research that smart contracts could enhance the trust in construction projects (Cardeira, 2015). However, there are also some objections on how feasible this application could be (Apte, 2016) and in the present study its feasibility will be investigated in a critical point of view.

1.1.5. Circular Economy

Undoubtedly, one of the biggest issues that humanity is facing the last decades is climate change. The rise of temperature has brought huge impact on the environment and the consequences not only for people but for the whole planet will be catastrophic (Crowley, 2000; Frigg, Thompson, & Werndl, 2015). It is obvious that in order to mitigate this problem, human intervention is more than imperative.

The carbon footprint of human actions is one of the major reasons for the climate change, since the emissions that are produced from industry and human actions is the main driver on the greenhouse effect (Crowley, 2000; Frigg et al., 2015). The extensive use of raw materials in the industrial sector plays a major role in the production of carbon emissions. According to an extended research of the World Economic Forum that took place in 2016, the industry that contributes the most in the consumption of raw materials is E&C industry (World Economic Forum, 2016). In order to mitigate this problem, some solutions were suggested, and the most promising ones are Sustainable Development (SE) and Circular Economy (CE) (Sauvé, Bernard, & Sloan, 2016). The understanding of these solutions is crucial for the proper implementation of mitigating measures.

First of all, sustainability is the concept that aims to decrease the carbon emissions of an activity as much as possible and in many cases a sustainable development model is proposed as a promising solution. The main target of sustainable development is to satisfy the needs of the present generation without affecting the next ones (Sauvé et al., 2016). This is usually done by decreasing the raw materials consumption that are used since their production highly contributes in the total carbon footprint of a project. However, this is done through an optimization of the design which is not always possible; thus, this solution has serious limitations. Additionally, the mitigation of the environmental impact during the lifetime of the project is another goal of sustainable development, mostly focusing on the energy consumption and carbon emissions that are produced. So far, it has been made clear that the solution of sustainable development has strong limitations and is mostly related to the model of linear economy (Pomponi & Moncaster, 2017; Sauvé et al., 2016). As a result, it makes it a less effective solution and some alternatives should also be considered.

For dealing with these issues, the idea of circular economy emerged. According to the definition that was given by Sauvé et al., the main goal of circular economy is the production of new goods and services by not using virgin materials (Sauvé et al., 2016). This is possible by transforming the production process from a linear one to closed loops and implement techniques such as recycling and reusing materials. In this way, the production process is not dependent on the use of raw materials any more and the production of waste can also be limited as much as possible. More specifically concerning built environment industry, the reduction and reuse of waste material as well as the improvement of supply chain management are key principles of circular economy (Pomponi & Moncaster, 2017). In the following figure (Figure 8), a comparison and some contradictions between Linear and Circular economy is depicted. The Linear Economy model is characterised by a higher production of waste and emissions while in the Circular system the recycling of some of the already used products decreases the total environemental contribution of the system.

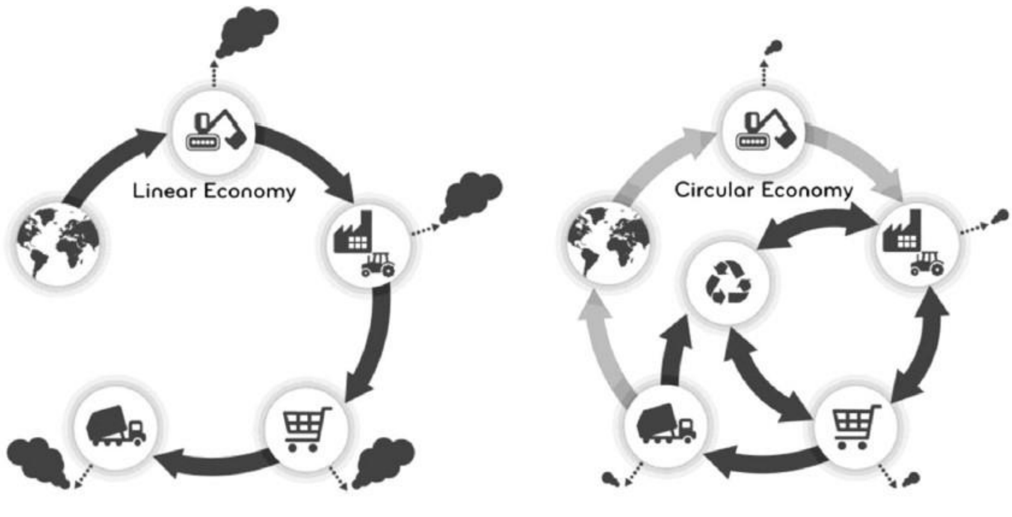

Figure 8: Contradiction between Linear and Circular economy (Sauvé et al., 2016, p. 5).

The present study will be mainly focused on improving circular projects in construction industry. More specifically, the problems of sharing information and supply chain management in these projects in combination with the levels of circularity that are reached will be addressed. The possibilities of improving collaboration and information sharing between the partners through an integrated information system will be addressed. Moreover, any additional benefits in the productivity levels and the improvement of circularity in a specific project will also be investigated.

1.2. Case Study

In the present study, the feasibility of blockchain technology in construction projects will be investigated. The present thesis was conducted in collaboration with BAM Infraconsult bv., which is the consultancy department of Royal BAM Group in the Netherlands. For this reason, one of the projects that this company is running was selected. The project that would be selected to use as a case study should also be related to circular economy. In this way, a possible improvement on the circularity of the project may rise as an additional benefit.

In the previous section, it became clear that blockchain technology has specific advantages and the project that it will be implemented should meet specific requirements. The aforementioned problems of construction projects are met in projects with specific characteristics that should also be found in the selected case study.

First of all, one of the major problems of construction projects is related to the complexity of its business network. Therefore, there should be a network of participants from different sectors that will have different perspectives and interests. This characteristic will directly affect both information sharing and trust issue between the participants and its improvement through blockchain technology can be investigated.

Without doubt, information sharing is a bottleneck in projects that have a huge amount of produced data that have to be exchanged. For this reason, the process that will take place under the selected project should be frequently executed (even daily if possible) with lots of transactions included and with high amount of information generated. In comparison with the different participants of the project, this will create a huge need for integration, immutability and transparency in exchanged data. As it was already mentioned, these are some of the main factors that can be improved through blockchain technology and thus, it is important to face these issues in the selected case study (Abeyratne & Monfared, 2016; Rodrigo et al., 2018).

Finally, the starting incentives of this research is the improvement of the productivity of construction projects that focus in reducing their environmental footprint. In this way, the impact that this project has on the environment will be less and there will be benefits not only for the participants but also for the environment and society. For this reason, the selected project should be related either to sustainable development or circular economy in order to also investigate the possibilities of improving these parts of the project.

After considering all the aforementioned requirements and a lot of discussions with the company experts, the most suitable project that could be used as a case study was the Reclaiming Asphalt (RA) Process. In this project, old pieces of pavement are taken from highways, and after using them for producing new asphalt, they are paved again in new locations. This is a process that has to be executed almost every day and due to the nature of the infrastructure that it is related to (highways), there is a need for huge amounts of asphalt production, especially in the Netherlands. As a consequence, the transactions and information that take place in this process between the stakeholders are also huge.

For this reason, during the first months of the thesis, a long research was conducted in order to understand in depth the process. A more detailed description in terms of activities, stakeholder, information and transactions that are involved etc. along with the problems and requirements that are set by the participants is given in Chapters 3 and 4.

2. Research Analysis

In this chapter, the analysis of the research is presented. Starting with the research scope, the point of view that this topic is approached is explained and it becomes clear that the present thesis is a feasibility study. Moving further, the problem statement that is investigated is further explained and the research objectives are analysed into two use cases that are addressed (Information and Supply Chain Management Platform). The Design Science Research approach is used as the research methodology and at the end the specific research questions concerning the feasibility of blockchain technology that will be answered in this report are also explained. Finally, the deliverables (goals) of the study are given.

2.1. Research Scope

Blockchain is a very promising technology that has created a lot of interest in the scientific community. The benefits that it could bring in project management and collaboration between the partners have made it a big trend for information technology in many different sectors (Y. Wang et al., 2019). However, the feasibility of this application should be investigated in a critical way in order to determine its potentials and the enhancement that could be brought.

In the present study, the feasibility of a blockchain application that will be used in construction projects will be tested. More specifically, the reclaiming asphalt process will be used as a case study and some of the problems of this process will be identified. The applicability and effectiveness of a blockchain platform will be investigated in order to assess how feasible it could be.

The analysis that will take place in this research will be focused on the Reclaiming Asphalt Process that is followed by BAM Infra Group and its partners in the Netherlands. This process will be investigated in terms of efficiency in order to assess how blockchain technology could improve the collaboration between the involved parties. Issues such as trust and efficiency in collaboration and sharing information will be investigated and the effectiveness of an information system based on blockchain technology will be tested. The enhancement of different aspects of the process (such as the level of productivity) and the general strategy of the company through this application will be addressed in the present study.

2.2. Problem Statement

In order to assess the feasibility and effectiveness of blockchain technology in construction projects, the problems that have already been identified in the scientific research will be examined in an actual case study. In this way, the benefits that could be brought will be directly connected to realistic situations and the conclusions and recommendation will be more trustworthy.

More specifically, this research will be focused on the reclaiming asphalt process that BAM Infra follows. According to the traditional asphalt milling process, high amounts of asphalt taken from old highways are processed and reused in new ones. Additionally, due to the business network that is created in this process, the collaboration of the stakeholders is more difficult. Apart from the main contractor, there are several partners from different sectors and in many cases, there is no direct communication between them. As a consequence, many difficulties are faced in the collaboration and the process is not as efficient as possible.

In the previous chapter, a number of problems in construction projects were mentioned. In this part of the report, a brief introduction to these problems and their connection to the case study that will be used is given. More specifically, the problems of sharing information and supply chain management will be addressed (Esmaeili et al., 2016; Turk & Klinc, 2017; J. Wang et al., 2017).

Starting with the information sharing problem, the availability and quality of the exchanged information between the partners in this process as of vital importance. This factor has a huge impact not only on the successful progress of the process, but also on the high quality of the final product. Additionally, apart from BAM Infra there are many involved partners (such as the client, several suppliers and subcontractors etc.) and that makes this process more complicated. Some of the problems that were previously mentioned such as the trust issue and the need for fast and safe transfer of information, are faced on a daily basis. In many cases, coordination between suppliers, contractors and clients is not totally efficient since there is not a direct connection between them in the business network. As a result, the use of materials and equipment such as the trucks for transportation is not totally optimal. Concerning the trust issue, an extended analysis in the business network and the collaboration that is developed between the stakeholders should be conducted in order to validate its existence.

In addition, the inefficient way of exchanging information creates some serious problems on the supply chain management. There is a high need for monitoring all the transactions that take place in the process in order to ensure transparency which is one of the major requirements not only for public sector (which is the major client of construction companies) but also for private sector. Moreover, the lack of information about the quality of the product that will be reclaimed creates problems on the optimizations of the production of new asphalt. The composition and weather or traffic conditions of its lifetime are also useful data that should be included in the system since the production process is affected by these factors. Consequently, the lack of an integrated information system that will combine all these data and give a total overview creates difficulties in the monitoring and optimization of the process.

In Chapter 3, a detailed presentation of the process that is followed in this project will be presented. According to the analysis of all the steps that are included in terms of information sharing and stakeholders involved, a more accurate and justified identification of the problems will be given.

2.3. Research Objectives

As it has already been made clear, the design of a transactions' recorder based on blockchain technology is the central purpose of the present study. This application could be used in two possible ways in the reclaiming asphalt process. On the one side, blockchain could be used as an information sharing platform in order to improve the collaboration between all the stakeholders. On the other side, the transactions that take place on a daily basis in the process, could be monitored and executed in a faster, safer and more transparent way (J. Wang et al., 2017). This could have direct benefits not only for the level of productivity but also for the relationships that are built between the partners.

From the aforementioned possible applications of blockchain, there are two use cases that could be distinguished and will be discussed in this section. The first use case will be related to a blockchain information system while the second one will be a transaction recorder, used in the supply chain management of the process. In several past studies, these two applications have been highlighted as some of the most promising sectors that blockchain could be applied, especially in built environment projects (Arup, 2017; Casino, Dasaklis, & Patsakis, 2019). In the present study, the feasibility and effectiveness of these systems will be investigated.

Starting with the first use case that will be examined in the present study, there are clear financial benefits for the companies that will use this application. For example, the approach of future clients can become more efficient since there will be no doubt for the authenticity of the provided information. Immutability is one of the major characteristics of blockchain technology and consequently, the data that are recorded in a blockchain cannot be altered or removed. This could be a crucial advantage of the company against its competitors since all the quality data for the products that the company produces could be stored in a blockchain system in an immutable and decentralized way. In this way, the high-quality services that the company can provide will be easily shared with future clients that will have no doubt about the reliability of their partners.

In addition, in the case that the client is a governmental actor, the company can ensure that it has provided the required results in a trustworthy and transparent way. Transparency in the financial transactions is major requirement of public sector and through blockchain application, it can be guaranteed in any case. However, since some of the information that will be recorded should remain confidential, a hybrid public-private system, based on blockchain technology could be an effective solution. In this case, "write and read" access on confidential information can be given only to the trustworthy members of the network while the future clients (from public or private sector) can have "read" access to the data that are interesting for them. A discrimination between the "private" and "public" information should be made on the proposed framework. Further details on the requirements of the process and the characteristic of a possible blockchain platform will be given in Chapter 4.

Concerning the second use can that is identified, the collaboration in a supply chain could be rapidly improved. So far, blockchain technology has been applied in many different sector (energy, shipping etc.). However, its effectiveness has not been tested yet in construction industry and this thesis will be a first step on examining these possibilities (Y. Wang et al., 2019). Especially about reclaiming asphalt, this iterative process could be more efficient if the total system was monitored by a blockchain model and the transactions were modified with smart contracts. Through this method, an autonomous distribution of information is achieved, and an optimal process management can be suggested. Additionally, the transactions between the involved parties can automatically be executed and thus the total system could become faster, safer and more effective. The recording of information can be done in a more trustworthy and efficient way and all the participants can benefit. In conclusion, an optimization of the collaboration between client-contractor-suppliers could be achieved through an integrated information system that will provide access to every interested part.

In addition, in terms of environmental and financial advantages, some of the benefits that could be gained from this application have already been mentioned in scientific research. As it was identified in 2016 by the World Economic Forum, some of the mitigation measures for reducing the carbon footprint of construction industry are highly related to the advantages of blockchain systems. For example, from a company's perspective, the enhancement of supply change management and better data exchange between different sectors is required. Additionally, governments should implement anticorruption standards in order to ensure clear transactions (Y. Wang et al., 2019; World Economic Forum, 2016). Moreover, smart contracts can aid blockchain platforms in order to transform them from regular "databases" to "smart" ones in order to make a more efficient and environmentally friendly use of raw materials. Consequently, the implementation of a blockchain platform in supply chain management can also affect the environmental impact of the process.

2.4. Methodology

The present study is focused on the investigation of feasibility on blockchain applications in construction projects. In this objective, the design and proposal of a blockchain application is implied, even if it will be presented in a high-level architecture. Consequently, the methodology that will be used should be focused on the design of software applications.

From the existing literature on this topic, the most suitable for this case is Design Science Research (DSR) approach. According to this approach, the main target of the research is the improvement of an inefficient situation by using an artifact. The definition of design science could be given as a scientific research that has as a target the design of artifact developed and used by people, in order to solve some of their problems (Johannesson & Perjons, 2014).

More specifically, the design problem research question as was described by Wieringa in 2014 is the following:

"Improve a problem context by (re)designing an artifact that satisfies some requirements in order to help stakeholders achieve some goals" (Wieringa, 2014)

In this statement, there are several points that should be identified in a design science research. Starting with the problem context, the reason for proposing the artifact become clear. There should be a not effective process that needs enhancement in order to justify the problem statement that will be mentioned.

The artifact that will be designed or redesigned (if there is an existing one but needs improvement) is also an important part of the research. According to the definition, an artifact is a tool (physical object or not) that is designed by people in order to serve a specific purpose (Johannesson & Perjons, 2014; Wieringa, 2014). It should become clear from the start of the research what kind of tools will be used for the specific artifact that will be proposed.

The proposed artifact should serve the needs of a specific process. In order to make its proposal as trustworthy and realistic as possible, the process should be analysed in detail and define the requirements that should be satisfied. In this way, the design will be targeted on specific needs and the possibilities of proposing something that is not effective will be less.

The final point of this statement that should be defined in a design research approach is the goals of the involved stakeholders that will be achieved through this research. For this reason, it is of vital importance to analyse the business network in terms of involved parties and individual requirements (example of stakeholders that can be involved in an organization is given in Figure 9). In this way, there will be a general overview of the project and the proposal artifact will be accepted by all the participants. Additionally, the research will have the support of more than one stakeholders and consequently the possibilities of adopting the proposed solutions will be higher. In any case, at the end a validation of the proposed system according the needs of the stakeholders should be conducted, and the results should be used for the improvement of its design.

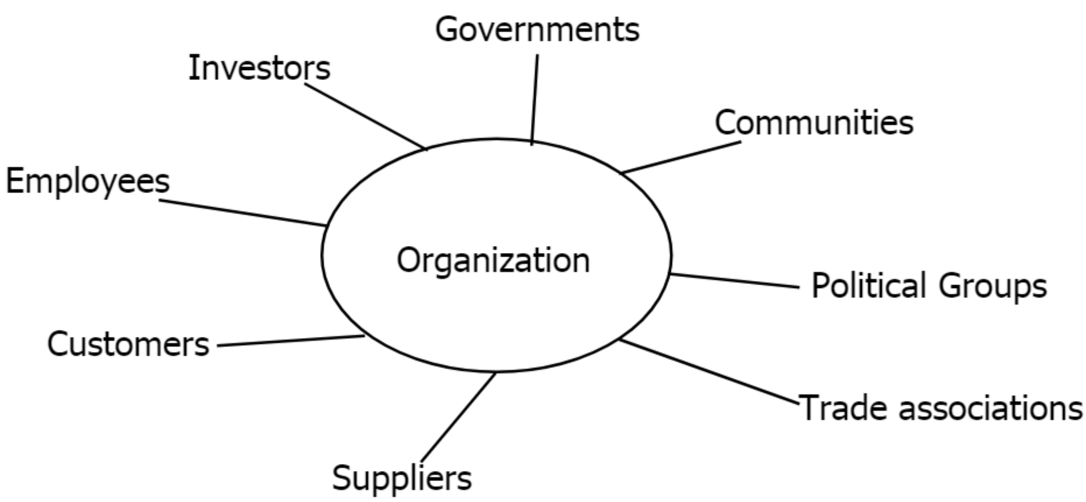

Figure 9: Possible involved stakeholders in an organization (Clements, 2011) (own illustration).

The process that should be followed in this research method has been investigated in many past studies. More of them have come up with common steps that should be taken in order to complete a successful design science research.

According to Wieringa, the design science research approach, is divided into two processes, the design cycle and the engineering cycle. The first process is focused on analysing the process that the artifact will be implemented and propose a possible “treatment”. The second one is the actual implementation of the tool and the evaluation of its effectiveness. It could be deducted that the design cycle is a part of the engineering cycle since the artifact that was designed is actually tested and evaluated (Wieringa, 2014). In Figure 10, an illustration of the engineering cycle is presented, on the right side of the figure the starting steps of the design cycle are mentioned. In each step, the knowledge questions (question marks) and the design problems (exclamation marks) that should be addressed are presented.

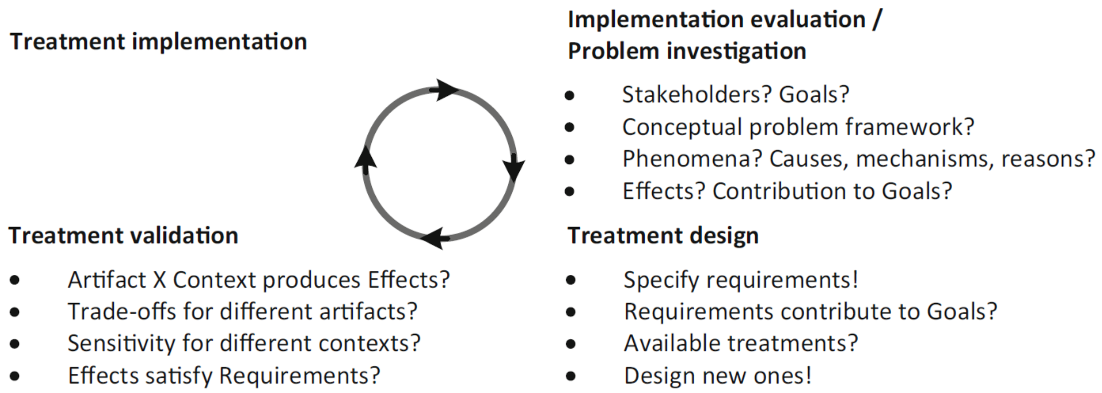

Figure 10: Engineering cycle, including the knowledge and design problems (Wieringa, 2014, p. 28).

There are several studies that have analysed the steps that should be taken in a design science research. As a summary of these studies, the following four steps (as presented in Figure 11) could be determined (Johannesson & Perjons, 2014; Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007; Wieringa, 2014):

1. Problem Identification
2. Requirements Definition
3. Design of the Artifact
4. Evaluation

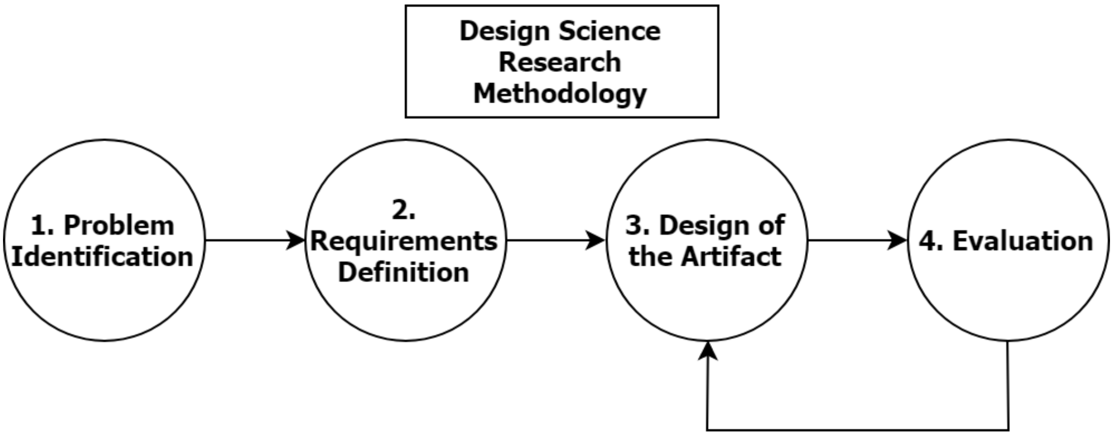

Figure 11: Design science research approach (own illustration).

The present study will be focused on the first three steps of the aforementioned process. Instead of the evaluation of a fully developed model that is proposed as the final step, a validation from experts of its feasibility will take place. A conceptual description of the proposed artifact will be presented and some feedback from experts will be taken in order to redesign it. The identification of the problem in the case study that is selected and the requirements of an artifact that could be used will be first determined. In the end, an artifact in high-level architecture form will be presented and the evaluation of its feasibility will be also included. The verification of the technical feasibility of the proposed model will be discussed in the final part of the research and ways of conducting it will be recommended.

There are several methods that can be used in order to find the answers in the research question. The use of case studies is one of the main methods in the design of artifacts that is suggested in the literature. Either by observing a number of studies or focusing on a single one, an important part of the research can be completed. The investigation of the problem and the identification of the specific requirements that should be considered can be retrieved from a single case study (Stake, 1995; Wieringa, 2014). In the present research, two use cases in the selected case study on a project of BAM Infra will be investigated.

In addition, the specific requirements of the involved stakeholders of the process should be determined. This can be achieved only by long discussions with experts that are involved. An effective way to gather all the information from experts and make their need clearer is through interviews. In addition, the conduction of surveys that will help the research to sort the important parts of the process can also be used (Johannesson & Perjons, 2014; Wieringa, 2014).

The general research statement of design science approach that has already been mentioned has several points that should be defined in order to fulfil the research objectives. This approach has been summarized in four steps as it is depicted in Figure 11.

More specifically, this research will be divided into two parts. On the first part, the process analysis that is followed in the selected case study will be analysed. In this way, the first two steps of the methodology (Problem Investigation and Requirements Definitions) will be conducted. In this part of the research, there will be long discussions and interviews with experts from the project in order to come up with the desired information. After the discussion with experts, if the presented process analysis is not accurate and the extracted conclusions need improvement, there will be a redesign of the analysis according to their feedback. Otherwise, the research will continue to the second and final part.

The second part of the research will be the proposal of the solution. After analysing the process and list the requirements of the involved stakeholder, an investigation of the suitability of blockchain will be conducted. The assessment of the proposed model will be achieved through a discussion with experts from the asphalt process. The main purpose of this discussion will be to assess its effectiveness, how they could use an artifact and the improvement (added value) that it could bring in the process from their perspective (Wieringa, 2014). This discussion with experts will contribute in two parts of the model proposal. On the one side, experts from the reclaiming asphalt process will validate the applicability of a blockchain application in their daily process. On the other side, their feedback will be used for improving the system and make it as effective as possible.

According to Bogner et al., the interviews with experts in order to conduct organizational research is not simple at all. First of all, the expertise of the interviewee should be determined in order to design a better approach. In the present case, the "subject matter know how" experts will be approached in order to extract the required information of the analysis. These experts mostly use their experience on participating in specific activities of the process in order to answer the questions that will be asked (Bogner, Littig, Menz, & Palgrave, 2009).

Additionally, there are two ways of interviewing experts with several advantages for each one. On the one hand, an individual interview with each expert separately will not have the strict question-answer from that is frequently used. This can transform the interview to a discussion and after a while the interviewee will be more open on sharing general information about the topic that is discussed. On the other hand, the group interviews in a panel with more than one participants will provide the opportunity of integration between the experts that will give the opportunity to the interviewer to extract a total overview of the process that is discussed (Bogner et al., 2009).

In the next and final step, a high-level architecture of the platform that could be used will be presented. For this illustration, Business Process Model and Notation (BPMN) method will be used. The main purpose of this method could be summarized in three points. First of all, it can be used for a traditional software development. Alternatively, a restructure of a business process could be suggested through a BPMN presentation. Finally, an extensive analysis of the process will be presented and the reader will have the opportunity to learn it in depth (Aguilar-Saven, 2004). As an additional presentation method of the proposed artifact, an online open-source composer (such as Hyperledger Composer) will be used for the development and illustration of the business network and the operations that could take place in the proposed system.

In this way, the feasibility of this technology in the specific case study will be assessed and the answer to the main research question will be given. At the end, the parts of the process that could be improved through blockchain technology will be presented and the answer in the main research question will be given. In Appendix A, the flow chart of the research plan for the present thesis is presented.

The two steps of the methodology (Case study Analysis and Model Proposal) that have already been described could be connected to the steps of design science research approach that were previously presented (Figure 11). The Case Study Analysis phase will contribute to the first two steps of the approach which is the Problem Identification and the Requirements Definition. For completing the third step of the used approach (Design of the Artifact), the Model Proposal will be conducted and at the end, the Evaluation of the designed artifact will be accomplished through an Experts' Panel.

2.5. Research Questions

In this part of the report, the main research question that will be addressed will be presented. Additionally, a number of subquestions that will lead to the final conclusions and recommendations will be also included. In this way, a more clear view of the topics that will be investigated and a connection to the methodology that was presented in the previous paragraph is explained.

Starting with the main research question, as is it also indicated by the title of the thesis, the assessment of the feasibility of blockchain technology applications in the reclaiming asphalt process will be investigated. More specifically, if the suitability of blockchain technology with the requirements of the selected case study is high enough, any possible benefits will be investigated. The main research question of the present study could be formed as follow:

"Which parts of the Reclaiming Asphalt Process could be improved through an artifact based on blockchain technology?"

Following the main research question, a number of subquestions will be mentioned, along with an explanation of the reason that these questions should be addressed. The first two questions that are mentioned here are set for introduction purposes and have already been answered in the first chapter through literature review. However, it is important to mention them since they contribute in understanding the scientific topic that will be covered in the present study. After that, six subquestions will be stated.

The introductory questions are related to blockchain technology and smart contracts. The background of this technology along with possible applications and benefits should become clear. In this way, the research objectives will be justified, and the final suggestions will be clear. Consequently, the first two subquestions could be formed as follow:

"What is blockchain technology and which are the main advantages it has, in relation to construction industry?"

"How could blockchain technology and smart contracts be used in construction projects?"

The answers to these questions have already been given in paragraphs 1.1.2, 1.1.3 and 1.1.4.

The first four subquestions that will be addressed are related to the case study that will be used. For validation reasons, it is crucial to totally understand and present the reclaiming asphalt process that is followed, in terms of business network, process and exchanged information analysis. In this way, specific problems of the process will be identified and the blockchain platform that will be suggested may lead its enhancement. Additionally, the requirements of the involved stakeholders can be written down and in this way the suitability of the blockchain system can be investigated. Otherwise, a traditional information system will be suggested. As it was explained in the previous paragraph, there are two use cases of blockchain that will be analysed (information and supply chain management platform). Consequently, it is important to analyse the process in terms of actions and parties that are involved but also information input and output. In this way, the suggestions that will be stated in the next parts of the research will be justified. The next four subquestions will be answered in Chapter 3.

a. "What is the current process for reclaiming asphalt and which parties are involved?"

b. "What is the information that is shared in each step of the process about?"

c. "Which are the problems that the traditional process has in terms of management of information?"

d. "Which parts of the current strategy that the company follows could be improved?"

In the end, the applicability and effectiveness of blockchain technology will be investigated. Specific operational and technical requirements should be stated in this point in order to make the design that is proposed clear. The possibilities of solving the problems of the process through a blockchain application will be investigated. Additionally, there should be a clear explanation on which parts of the process will be enhanced from such a platform. The description of the proposed system in a high-level architecture will be given in order to fully explain its operation and the characteristics that the system will have. The answers on the following last two subquestions will be given in Chapter 4, in which the blockchain model will be proposed.

e. "Which are the requirements that an information system should serve in this specific project?"

f. "How should a blockchain artifact be technically organized in order to provide efficient recording and sharing of information?"

It is obvious that there is sequence between the answers of the aforementioned subquestions. Introductory questions will set the scientific background and justification of the present study. In the next four subquestions, the problem statement and research objectives of the specific case study will be mentioned in a clear way. In the final two subquestions, knowledge from the previous ones (blockchain theory and practical information of the project) will be used in order to propose an effective solution based on blockchain technology. In this way, after summarizing everything in the discussion (Chapter 5) a clear answer to the main research question will be given.

For answering the two introductory research questions, a long literature review has been conducted in order to give to the reader a clear view of all the aspects that are discussed in this research. The first four subquestions are related to the case study that was selected and its analysis will lead to the respective answers. Finally, the model proposal will give clear answers on the requirements of an artifact that could be proposed, and its technical details will also be given. In the end, an assessment on how feasible the implementation of blockchain technology in the specific process will be presented. Additionally, the aforementioned research subquestions and the main research question could also be connected to the methodology (DSR) that is used. In Table 2, the methodology for answering each question and their connection with the DSR approach is presented.

Table 2: Research question and subquestions, used methodology and DSR approach steps.

Research Questions	Methodology	DSR step
Introductory Questions: *"What is blockchain technology and which are the main advantages it has, in relation to construction industry?"* *"How could blockchain technology and smart contracts be used in construction projects?"*	Literature Review	-
a. "What is the current process for reclaiming asphalt and which parties are involved?" *b. "What is the information that is shared in each step of the process about?"* *c. "Which are the problems that the traditional process has in terms of management of information?"* *d. "Which parts of the current strategy that the company follows could be improved?"*	Case study Analysis	Problem Identification & Requirements Definition
e. "Which are the requirements that an information system should serve in this specific project?" *f. "How should a blockchain artifact be technically organized in order to provide efficient recording and sharing of information?"*	Model Proposal	Design of the Artifact
Main Research Question: *"Which parts of the Reclaiming Asphalt Process could be improved through an artifact based on blockchain technology?"*	Experts' Panel	Evaluation

2.6. Goals

By answering the aforementioned questions, there are several goals that will be met in the present study. As it is indicated in the title, the main target of the research is to investigate the feasibility of blockchain technology in the reclaiming asphalt process. Consequently, it is crucial to have a detailed view of the process that is followed. Additionally, all the information that is shared in the network should be written down in order to use it for the proposed artifact.

There are two use cases that are identified, and the goals are directly connected to their solutions. First of all, the creation of a blockchain system has to solve the sharing information problem in the supply chain management of the current process. Its feasibility and effectiveness on the current business model should be examined in order to assess if this application is possible or not and the conclusion should be properly justified in order to validate the outcome of this research. Additionally, technical details of the proposed system should be given in order to explain how this kind of platforms can be applied in this specific case. Furthermore, if the answer on the main research question is negative, a clear justification of the reason that led to this result should be given. In the conclusion of the study, an explanation of why blockchain platforms can or cannot be used it this specific case should be given and suggestions and recommendations for future scientific research of this field will be presented.

According to Fowler, the proposal of a model can be done in three different ways. The simplest one is a brief description of the system specification. A more advanced form of a software is blueprints for its design and an extended version of this is the third form which is a system prototype (Fowler, 2004).

In the present study, the main goal is to define the possibilities of implementing blockchain in the specific case study. This will be done from the validation of the proposed blockchain system by experts from the case study. In this way, the improvement of specific parts of the process can be assessed. In addition, the requirements that this model will serve should also be identified. As a result, possible solutions in different techniques and methods could be suggested in future scientific research. Finally, a schematic representation of the functions that could take place in the suggested platforms will also be included.

In conclusion, there are two sub-deliverables that will be introduced in the present study and are the following:

- *"The requirements and specifications of the proposed system."*

- *"An illustration of the artifact in a schematic design (High-level Architecture) and a model in an online composer."*

Finally, the main deliverable of this study will be:

- *"An assessment of which parts of the process could be improved through blockchain technology."*

On the following table, the research goals are connected to the respective sections of the report that are delivered.

Table 3: Research goals and respective sections that are delivered.

Research Goals	Report Section
"The requirements and specifications of the proposed system."	Paragraph 4.1
"An illustration of the artifact in a schematic design (High-level Architecture) and a model in an online composer."	Paragraph 4.2
Main Deliverable: *"An assessment of which parts of the process could be improved through blockchain technology."*	Paragraph 5.2

Part II

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3. Case Study

In this chapter, the Reclaiming Asphalt Process is analysed. At first, the need for reclaiming asphalt is explained through a short literature review. Then, the business network of this process is explained, and the role of each stakeholder is presented. Additionally, the total overview of the process is described, which is consisted of three main parts: i) the milling of RAP and transportation to the asphalt plant ii) the production of new asphalt and iii) the laboratory test and infrastructure life period. The information that is exchanged during the total process is also analysed in order to connect it with one of the main research subject of the present study, information sharing. At the end, the problem in management of information that was identified in this process is explained and its direct or indirect connection with two different aspects (the information availability and the productivity) is mentioned.

3.1. Process Analysis

3.1.1. Introduction

The last decades the environmental crisis has increased the concern around the amount of raw materials that are used in production processes. As it has been stated by the World Economic Forum, the most consuming industry in the 21th is Engineering and Construction industry (World Economic Forum, 2016). The environmental disaster that soon or later will be brought due to the human actions, created the ideas of sustainable development and circular economy. The advantages of circular production against sustainability created the need for decreasing as much as possible the waste production and consequently the ideas of reclaiming and reusing materials. Obviously, construction industry could not be left out of this trend. The increase of reusing construction materials in addition to the decrease of waste production and energy consumption has become a big concern in the scientific society.

The reuse of construction materials aims into two main targets. On the one side, the reclaimed materials that have already been used for producing new infrastructure or products will lead to less consumption of raw materials. On the other side, the extensive use of materials leads to a high production of waste that have to be treated and stored carefully. Otherwise, their environmental impact can be huge, and this is always of high concern in urban design and development. Consequently, the transformation of the production model from a linear to a circular form is one of the main requirements of the present urban development since it can bring multiple benefits not only for the environment but also for humanity.

One of the main infrastructural projects that has gathered a lot of attention concerning its environmental impact is the transportation systems, and more specifically, roads. Nowadays, countries have developed large highways networks since the need of citizens commuting and products transportation is high. This indicates that there is a high need of frequent maintenance in the pavement, especially on the big highways where the traffic volume and loads are respectively high. The short life period of pavements makes the need for periodic maintenance and replacements more than imperative. Therefore, there is a frequent need for replacing the pavement that is not operational and thus, not safe for the drivers.

As a consequence, that creates a respective huge need for new asphalt to be produced and that leads to a higher consumption of raw materials. It is obvious that it comes in contrast to the trend of our era about decreasing the use of raw materials. For this reason, the reclaiming of pavement from existing highways for the production of new asphalt mixture came as a promising solution (Sivakumar Babu, Saride, & Basha, 2016). Several literature studies have shown that the production of new asphalt could be made with more than 50% use of Reclaimed Asphalt Product (RAP) and the most optimistic researchers believe that it could also reach 100% (Zaumanis, Mallick, & Frank, 2014).

However, in the present study the conventional method (with 40-50 % use of RAP) will be investigated. Reusing asphalt and producing new one has specific challenges that have to be faced during the process. Some of them will be mentioned in the following paragraphs but not in much detail since analysing the reclaiming asphalt process itself is not included in the purposes of this research.

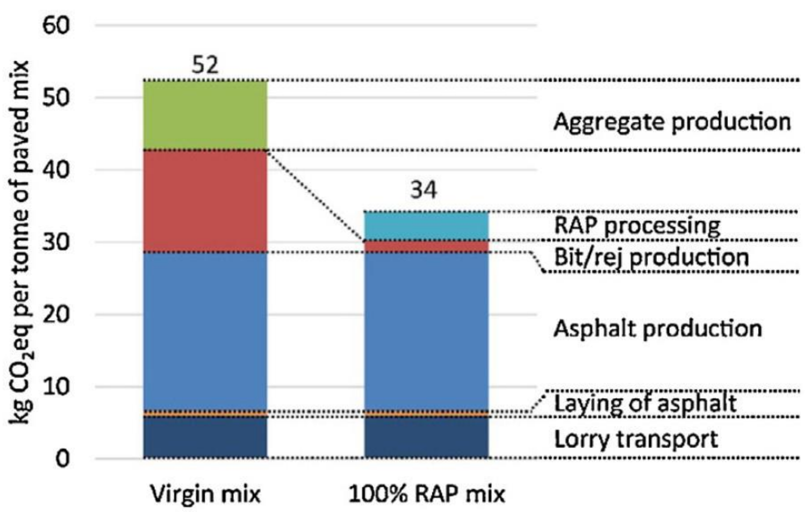
The obvious target of ensuring that the provided quality will be equal to the use of materials has some preconditions. Starting with the processing of RAP, during its heating the required high temperature should be reached without catching fire. There are several techniques that have been developed worldwide in order to prevent this failure. In addition, the aging of binder should be kept at a minimal level as long as the production take place before the final paving. Finally, the obvious control of produced emissions from binder volatilization should be kept as low as possible because otherwise the environmental benefits of using RAP will be lost (Zaumanis et al., 2014).

There are several characteristics of the final product that are affected by the use of RAP. Some of them are the resistance to cracking and rutting, water susceptibility and flushing (Table 4).

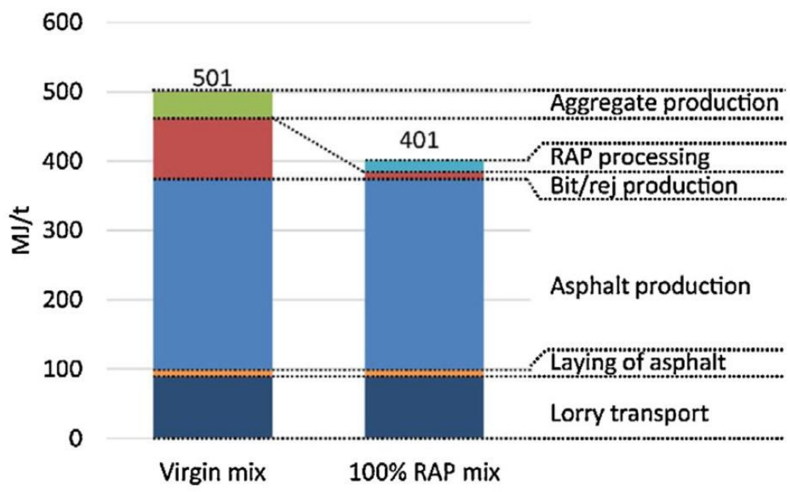
Table 4: Asphalt failure modes (Ishai, Herrin, & Leverenz, 1973; pavement interactive, 2019; Zaumanis et al., 2014).

Asphalt Failure Modes	Description
Cracking	Vertical random cleavage of pavement due to natural causes or traffic action
Rutting	Surface depression in the wheel path
Water Susceptibility	Amount of water penetration in the particles
Flushing	migration of oils toward the pavement surface, resulting in reduction of the friction

There is a strong connection between these characteristics and the percentage of RAP that will be added and its use in higher levels is not always positive lost (Zaumanis et al., 2014). Finally, it is also proven in past scientific studies that the use of RAP has direct environmental benefits against the traditionally produced asphalt. The actual carbon emissions that are produced are seriously decreased and also the energy consumption during the production phase can be limited in an important degree (Zaumanis et al., 2014) (Figure 12).



(a)



(b)

Figure 12: Comparison of (a) carbon emissions and (b) energy consumption for virgin mix and 100% RAP mix (Zaumanis et al., 2014, p. 12).

3.1.2. Analysis

Reclaiming asphalt is not a simple process. Its complexity increases by the steps that should be followed and the business network that is created around it. In the present study, the process that is followed by BAM Infra Group in the Netherlands will be analysed and presented. At first, the business network will be explained and the role of all the participants will also be included. In the next part, the process will be analysed step by step, in terms of actions that should be made and the stakeholders that are involved in each one. At the end, since the main subject that the research is focused is information sharing and collaboration, an analysis of the produced and exchanged information will be given.

The results of this part of the analysis were claimed after long discussions and interviews with five experts that participate in the project, mainly from the different departments of BAM Infra Group. Their roles and responsibilities were discussed, along with some problems and requirements and will be further elaborated in the next part of this report. An analytical description of the experts that were interviewed, a summary of the discussion with them, along with some forms and questionnaires they had to fill in order to extract the desired information is presented in Appendix D.

The business network of this process is not simple at all. In many cases there is no direct connection between critical stakeholders of the process and that creates many problems concerning efficiency and collaboration. In our case, the main contractor is BAM Infra Asfalt which is the department of the company that is mainly involved in the production of the new asphalt. In the case study that will be investigated, there are five stakeholders in the process that can be highlighted. In the following paragraphs, their role will be explained and the connection between them will also be analysed.

These findings came from the interviews and discussions with experts from the process that took place the first months of the research. Summaries of these discussions are presented in Appendix D, in which the discussions are divided into the topic that it was about. The four topics that were mostly discussed are; i) the Business Network, ii) the Process Analysis, iii) the Information Sharing Platform use case and iv) the Supply Chain Management Platform.

Starting with the top of the business network, there always should be a client. The client can either come from the public sector and be the owner of the infrastructure or may be a contractor that has to do the operation and maintenance for several years. On the first case, examples of such clients can be provinces or municipalities that the highway is located in their territory or ministries such as the Ministry of Infrastructure. In this case, the client is ordering either the construction of a new highway or the maintenance of an existing one. On the other side, there are cases that a company from the private sector could act as a client in this project. In this case, there is a Design Build Finance Maintenance and Operation (DBFMO) contract that will be given to a contractor by the owner of the highway. According to this type of agreement, the contractor apart from the obligation to design and build the infrastructure, will also participate in the financing of the project and will have the obligation to do the maintenance and the operation till the contract expires (Walker & Smith, 1995). It is obvious that in this case, the contractor pays a lot of attention to the quality since after the end of the contract, the infrastructure should be given back to the owner meeting some strict quality requirements.

Moving further, one of the most important participant of the process is the asphalt producer and in our case study, this is done by BAM Infra Asfalt. The plants that the new product is produced is owned and operated by this department of the company. Additionally, this department is also responsible for a part of the laboratory tests that take place in order to assess the quality of the used materials and the produced asphalt. These results are used in several steps of the process, as will be explained later. In direct connection to the asphalt producer, there are the suppliers that provide all the necessary raw materials for the production of the asphalt mixture. This is a process that takes place almost on a daily basis and is one of the major parts of the supply chain management use case that will be investigated as a possible blockchain application in the present study.

In addition, there are several subcontractors that also play a vital role in the process. The most important one in our case is also a department of BAM Infra

Group, BAM Infra Regionaal West. The responsibilities of this stakeholder are to receive the new asphalt that is produced from the asphalt plant and to the paving in-site. Additionally, the coring that take place during the lifetime of the highway in order to assess its quality is also done by this departments. Finally, the milling of RAP is also executed by BAM Infra Regionaal West or some of their partners (such as a milling company that will be hired to do it) and the final product is then provided to the asphalt plant for the production of the new mixture. In all these steps, the company conducts inspections and sends reports to the main contractor as well as to the client.

The second subcontractor that is also important for the process is the transportation company. It is obvious that there is a huge need for transportations in all the steps of the process, such as transportation of RAP, materials transportation, transportation of new asphalt in the site etc. There are several problems that are created in the process due to transportation unavailability and this contractor is highly connected to the supply chain management use case that will be mentioned later. At most of these steps, there is no recording of information concerning the transportation conditions (such as traffic and weather condition) which is considered quite important for the assessment of the total process.

A total overview of the business network of the case study that is used is presented in Figure 13, along with the responsibilities of each stakeholder. Additionally, the connection between them is also presented. It can be noticed that there is a two-directions connection between the BAM departments since the roles of seller and buyer between them alternate during the process. Additionally, the transportation company is connected only with the client and that means that their no direct connection between the rest stakeholders and this subcontractor. It is obvious that this can bring inadequate collaboration that will lead to delays to deliveries. The delivery of asphalt mixture is one of the main drivers for assessing the productivity on this project.

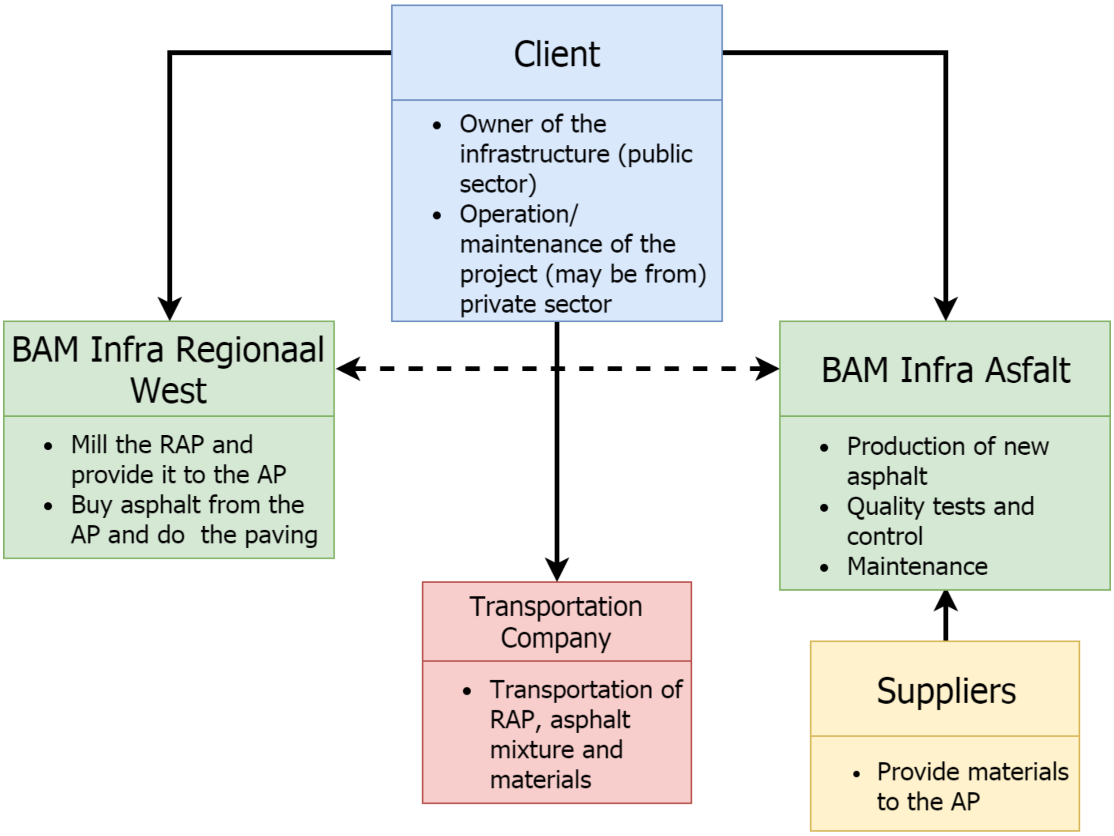


Figure 13: Business network and responsibilities of each stakeholder (own illustration).

At this point of the report, after explaining the roles of all the involved stakeholders, a short description of the process that followed will be presented. The total process is consisted of eleven steps that could be divided into three parts: the milling of RAP and transportation to the asphalt plant (Figure 14), the production of new asphalt (Figure 15) and the laboratory test and infrastructure life period (Figure 16).

These steps came up from the analysis that the company has already done for the process that is followed. More specifically, the documentation of the currently used information system for the asphalt process is investigated. Some of these can be found in the documentation that is presented in Appendix E. In this system, the process is divided into six steps: i) the Materials Approval, ii) the Mixture Design, iii) the Preliminary Production, iv) the In-Plant Production, v) the In-Situ Processing and v) the Laboratory Tests. The additional steps that are required for presenting the total overview of the process came after interviews and meetings with the experts from the asphalt process and the related findings are presented in Appendix D, in the section "Comments in the Process Analysis".

In the first part of the process, the existing pavement is inspected and analysed in order to assess if there is need for replacement. This is done through coring and analysis of the cores of asphalt that are removed. If the quality of asphalt is low and unsafe for the drivers, the milling process takes place in which the pavement is decomposed. The mixture that is produced from the milling process is called Reclaimed Asphalt Product (RAP) and is transported to the Asphalt Plant (AP) where its composition is again analysed. This second analysis is done because may sand or other external materials be added in the mixture during the milling process and affect its quality.

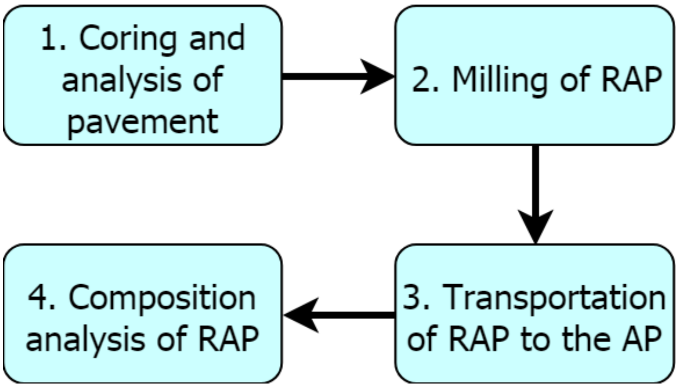


Figure 14: Milling of RAP and transportation to the asphalt plant (own illustration).

In the next phase of the process, the production of new asphalt is executed. At first, the materials that will be used are brought to the asphalt plant and are analysed in order to calculate their properties. The mixture that should be used in this specific case is also calculated, in terms of target composition and density. Then, there is preliminary production investigation in which the asphalt composition and the final production plan is calculated. The production of asphalt mixture is done in two stages: 1) the in-plant and 2) the in-situ production. In the plant, the require mixture is produced according to the calculated characteristics and then is transported in the site where the paving process of the asphalt layers take place.

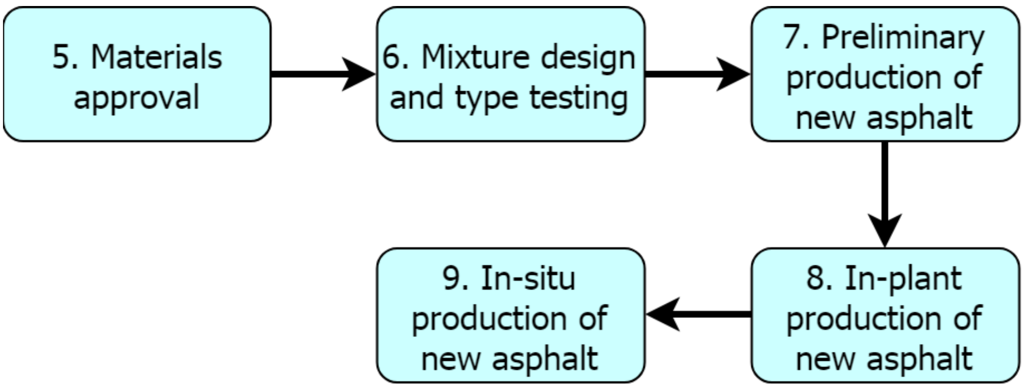


Figure 15: Production of new asphalt (own illustration).

The final part of the process starts during the production process and lasts for the whole infrastructure life period. The main goal of this part is the extraction of the quality measurements of the product. For this reason, laboratory tests are conducted during the total production process from different stakeholders and the results are stored for future use. During the lifetime of the pavement there are two approaches that are followed. Either there is a visual inspection only for the guaranteed period (3-5 years) or there is a long-term inspection of the pavement quality. The second approach is followed in the case of a DBFMO agreement between client and contractor in which the contractor has to deliver the highway in a specific quality level after a long period (more than 10 years).

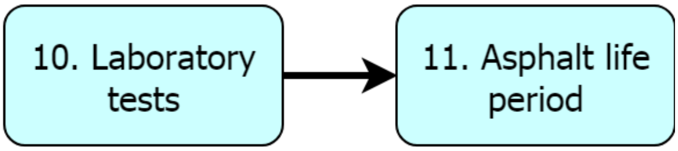


Figure 16: Laboratory test and infrastructure life period (own illustration).

In Appendix B, a total overview of the process that is followed in reclaiming asphalt is presented.

One of the use cases of blockchain that will be investigated in the present study will be the information sharing platform. Consequently, it is crucial to analyse the process not only in terms of business network and actions included but also in terms of information production and sharing. In this way, it will be clear what kind of data are generated and exchanged in each step of the process and the participants that are included. Therefore, the proposal of the artifact that will be presented in the next chapter will be easier and will serve the realistic requirements of the stakeholders. In Appendix C, the information that should be recorded in each step of the process that was previously described is presented. This analysis was conducted after exploring several documents of the companies for designing similar information systems and also for analysing the existing process that is followed (Appendix E).

For presenting the process in terms of information sharing, an Input-Process-Output flowchart will be used. In this way, a combination of data and organisational models will be carried out, as was explained by Albino et al., in this way, a process can be represented and redesigned a) through a data flow chart model and b) a decision model that is included in the organisations representation (Albino, Pontrandolfo, & Scozzi, 2002). In this flow chart, the input information in each action is mentioned and the respective produced information is depicted. Additionally, the stakeholders that participate and each action and as a consequence should have access in these data are also mentioned (Koutamanis, 2019). In Figure 17, a total overview of this flow chart is presented. The importance of this illustration was to determine the problems that are faced in the process in terms of information sharing.

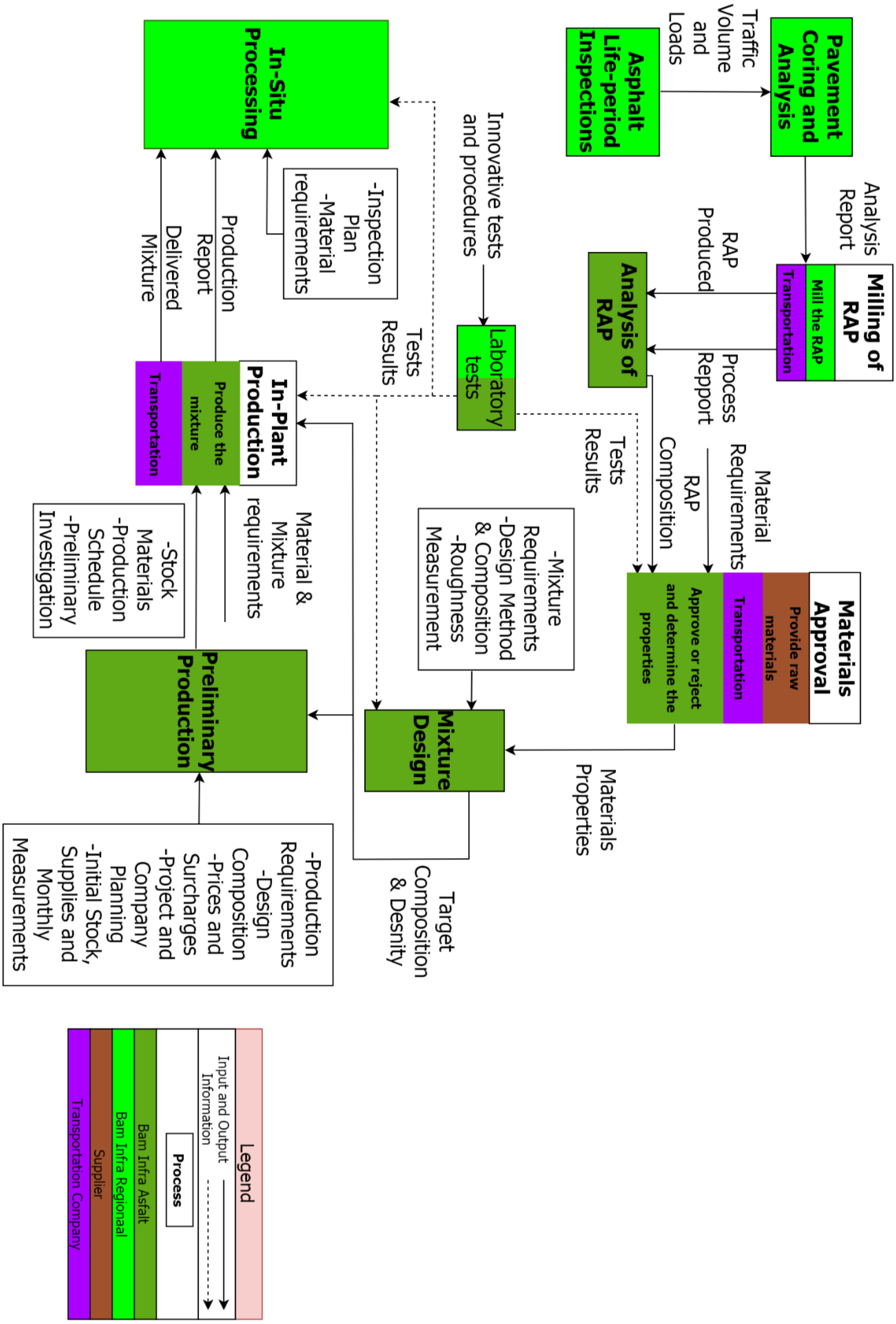


Figure 17: Input–Process-Output Flow Chart (own illustration).

From the information exchanges that are presented on this figure it would be possible to identify some of the critical parts of information flow in the process. First of all, the central role of laboratory tests and results in the process can be easily noticed. The fact that the laboratory tests should be shared with many different stakeholders in many steps of the production process makes the need for a common integrated information system more than imperative.

Additionally, it is noticed that the information flow during the production phase (from mixture design to in-situ pavement) is linear and there is a need of direct and fact exchange of data between the different stakeholders that participate in these steps. Once again, the need of an efficient and real-time information system would be crucial for the successful completion of these steps.

3.2. Problem Identification

3.2.1. Introduction

In this part of the report, the problems that were identified during the process analysis of the selected case study will be presented. In this point, the first step of DSRM approach (Problem Identification) will be executed (Figure 11). In general, there are several problems in construction project that have already been mentioned in the introduction of this study. At this point, a more detailed analysis will take place, specified on the reclaiming asphalt process of this company.

The findings of the present section came after long discussions, meetings and surveys with experts from BAM Infra Asphalt and BAM Infra Regionaal West. Their opinion on the problems or inefficiencies that the current process faces was analysed, and the conclusions are summarized in the following paragraphs. The summary of the discussions with the asphalt experts can be found in Appendix D, in the sections "Comments on the Information Sharing Platform use case" and "Comments on the SCM use case". The problems of the process that they have noticed (such as the insufficient coordination in the SCM, the need for materials traceability, the low productivity that is noticed etc.) were elaborated during the discussion and as a consequence, the requirements for the model that will be proposed in the next chapter will be easily determined. Additionally, the added value of using this technology will be made clear and justified. In the fifth chapter (Paragraph 5.1), the validation of the model from asphalt experts will be presented; consequently, the accurate identification of process problems is crucial.

In general, there is one major inefficiency that has been identified in the current process that is followed. On the one hand, there is the unavailability of information, related either to the quality of the used materials or of the delivered mixture. The main problem concerning the availability of information is not that the required data are not recorded but either the method that is used is not efficient or many different systems are used and consequently the integration is not possible. On the other hand, several inefficiencies are faced on the daily process due to problematic coordination of the available personnel and equipment. This has a direct effect on the supply chain management of the asphalt production and is directly depicted in the level of productivity of the process. An important factor that contributes in many cases to this problem is the transactions costs that decrease the efficiency of the process due to the traditional exchange methods that are used (such as paperwork, e-mails etc.). In the next section, a further elaboration of these problems is carried out.

3.2.2. Management of Information

At first, in many cases there is need for information that either is not available or there is not a proper system to support its use as one piece. Many parts of the project have different ways of storing information for the same project and at the end it is difficult to get a total overview. This is an important requirement that comes not only from the companies' perspective but is also of high importance for clients. The presentation of the total overview of the quality that was provided by the contractor is of vital importance in order to assess the reliability of the selected stakeholders.

Additionally, there are important requirements of the clients concerning the materials that have been used in the production phase. The knowledge of the activities that the materials have been through during the process is an information that the clients want to have in every project in order to know the origin of materials and the process that was followed before the final product was produced. The traceability of a product during a process, especially in case that it has a high environmental impact have been mentioned in past researches. For example, Rijskwaterstaat stated in 2015 that this knowledge can be an effective way to impose circularity in construction project of Dutch industry (Rijkswaterstaat, 2015). However, with the current information system that is used, the traceability of materials is not possible. All this information should be gathered in an integrated system and provide a total overview for the life time of a material that has been used, a document that is called "material passport" (Rijkswaterstaat, 2015).

An additional problem that does not come only from this specific case study but is also met here is the problem of reliable information. As it has been stated in the interviews with experts from this process, there is not a problem of trust right now. However, since the current databases that are used in practice cannot guarantee immutability, stakeholders can always doubt for the information that is or will be provided in the future. There is no doubt that trust in construction projects cannot be and there is always need for immutability and reliability on the transactions that take place in such projects. Additionally, the clients (especially if they come from the public sector) always want open business network in order to involve as many contractors as possible, increase the competition and have a better final result.

As it has been noticed, in many projects the clients (which in our case come either from public or from private sector) gets a huge amount of information from the contractors that has no interest for them. However, the fact that they do not own the recorded information of a specific project (in fact if the client is a public authority, does not even own an information system) creates problems in case of changing some of the stakeholders of the process in the future. For example, if one of the subcontractors that do the maintenance and replacement of pavements changed, the new contractor that would take on the project, would not be able to know what has been done before. This would create inefficiencies in the operational phase and delays on tis executions. There would be need for a lot of new inspections and quality test in order to organize the maintenance plan of a highway.

From the contractor's perspective, there is need for organizing the reclaim and production of new asphalt almost on a daily basis. This is done based on the analysis that take place in the pavement in order to assess the quality of RAP and design the mixture that should be produced. As a consequence, this steps that have to be taken in the reclaim asphalt process create delays in the total execution of the project. Moreover, the optimization of the personnel and equipment management is directly affected by the quality information that is available. Consequently, if this information is not distributed in a fast and reliable way to all the involved participants, this enhancement is not possible.

Finally, the most useful application for the involved companies if they had an overview of the quality that is provided would be to approach future clients. Nowadays, the approach of future clients is done by submitting quality information that may not be trustworthy and reliable. As a consequence, there can always be doubt on how safe is the information that is provided, and, in this way, it is difficult to approach clients, mostly when there is not experience from past projects that had worked together.

A serious consequence that has a direct connection with the insufficient management of information that has already been explained is the low productivity that is noticed in this process. Probably, this is the most important problem that the process faces, and it is obvious that it is not related to the reliability of information but with the availability and assessment of the data that are used during the process. It has been mentioned in many past literature studies that there is a direct connection of the information system that is used by a firm and its business performance (Haewon Lee, Choi, Lee, Min, & Lee, 2016). For example, Gu et al. states that business process performance is highly related the capabilities and quality provided by the used information system (Gu & Jung, 2013).

The production rates that have been measured are considered low in comparison to the desired and feasible ones. As it was mentioned by some experts of the process, during working time, more that 50% is waiting for asphalt mixture. This was observed for the tracing and monitoring system of the trucks. As it can be easily assumed, this problem has direct connection not only with the collaboration with the transportation companies but also with the scheduling of the asphalt production. Consequently, this problem is also related to the supply chain management that is implemented in the process which could be characterized inefficient. Additionally, it can be easily deducted that an improvement of this part of the process will increase the profit of the involved companies and also their reliability concerning execution time.

Finally, the sharing of information in a fast and reliable way along with an optimization of the current process through the use of the available data is a major requirement of the stakeholders. Additionally, the use of traditional methods for the transactions that take place during the process execution create high transaction costs and risks of missing information that is of vital importance and is required by the clients and the governments.

3.3. Conclusion

In the final part of this chapter, the answers on the respective subquestions that were given in the previous sections will be explained. As it has already been mentioned, four subquestions will be answered in this chapter, related to the reclaiming asphalt process that was selected as a case study. In this way, the findings of this chapter will become clear.

The first subquestion that was answered in this chapter was related to the steps that are included in the reclaiming asphalt process and the respective stakeholders:

a. "What is the current process for reclaiming asphalt and which parties are involved?"

In paragraph 3.1 the business network, consisted of five stakeholders was analysed. In short, the participant in the project are:

1. the client,

2. BAM Infra Asfalt which is the main contractor, related to asphalt production,

3. the suppliers of the asphalt plant,

4. BAM Infra Regionaal West which is responsible for the milling process and the paving of the new road, and

5. a transportation company.

The process of reclaiming asphalt is consisted of 11 steps in total that could be divided in:

1. the milling of RAP and transportation to the asphalt plant

2. the production of new asphalt and

3. the laboratory test and infrastructure life period

The total overview of the process can be found in Appendix B.

The next subquestion that was set in the research analysis was about the shared information in each step of the process:

b. "What is the information that is shared in each step of the process about?"

For answering this subquestion, an Input-Process-Output flow chart (Figure 17) for the information flow was designed. In addition to the information and actions that are involved in the process, there is also a depiction of the stakeholders that participate in each step and should have access on the respective information. This analysis mostly aims on defining inefficiencies in information sharing that could be improved through the model that will be proposed.

The information that is included in the process and is exchanged between the involved stakeholders could be divided into two categories. On the one side, all the quality information for the used and produced materials is stored and exchanged during the total process. This done in all the steps of the reclaiming asphalt process, starting with the core analysis of the existing pavement till the final production report that describes the process that was followed during the final part of the production of new pavement. Additionally, there are laboratory test that take place during the total process and some inspection that is done during the highway life-period.

On the other side, information from the supply chain management of the process is also presented in the flow chart. The orders and deliveries of materials and asphalt mixture are depicted mostly in the production part of the process and the transactions that take place between the different participants can also be noticed.

The answers of the last two subquestions that were answered in this chapter are about any problems that faced in the process and the possibilities of improving it. Starting with the problems that can be identified:

c. "Which are the problems that the traditional process has in terms of management of information?"

In paragraph 3.2 the major problem of the current process was analysed. The insufficient management of information that leads to unavailability of information either because of not recording or inadequate used information systems was explained. In short, this problem could be summarized in three parts: i) total overview of the project not available and as a consequence impossible to use it for optimizations or share it with partners to prove the provided quality was what was agreed, ii) traceability of materials that are used is important and is not provided by the current system and ii) although trust issue does not exist now, may the business network change now and sharing of information is not trustworthy any more.

Finally, the possible improvement of the current process has been mentioned:

d. "Which parts of the current strategy that the company follows could be improved?"

In the second section of paragraph 3.2, the inefficient production rates of the reclaiming asphalt process (according to experts' opinion) were mentioned and the respective problems that are connected to the information systems that are used (such as impossible sufficient supply chain management and optimization of the process) were analysed. It is obvious that this situation should be improved, and some ways have been discussed.

At first, a reliable, trustworthy and decentralized information system would be really appreciated and useful for the clients, mostly for the governmental parts. The lack of information that is faced in many parts of this project right now could be easily solved with an integrated platform that will allow efficient share of information. Therefore, the immutability and transparency of the information system that will be used from the company can create a direct advantage against the competitors in future tenderings and a more successful approach of clients. Additionally, the availability of information concerning the materials that have been used could increase the level of circularity that is achieved through this project.

Furthermore, the supply chain management could be better monitored, and the transaction cost of the process could be decreased. As a result, an optimization of the product delivery could be achieved. Thus, an enhancement in the production rates of the company could be brought which will also increase the respective profits.

4. Model Proposal

In the fourth chapter of the report, the proposed model will be explained and presented. At the first part, the requirements of the model that should be used (generally, traditional or blockchain model) are analysed. This analysis is divided into two parts, the design principles and the technical requirements of the model. The design principles came mostly from interviewing experts from the asphalt process while technical requirements derive from the technology that was selected. In the second section, the model is presented in two ways i) a full-scale presentation in BPMN method and ii) a deployment of the user environment in an online composer. In this way, the two subgoals of the research (system requirements and illustration) are delivered.

4.1. Requirements Definition

4.1.1. Introduction

The main incentive of conducting the present study is the investigation of the applicability of blockchain technology in construction projects. The accomplishment of this goal is not possible without exploring in depth the characteristics of this technology. A short description of some critical parts of blockchain technology has already been given in Chapter 1.

Setting the requirements of the proposed model is a crucial part of the present study. More specifically, it is the second step that should be executed, according to the selected research methodology (Figure 11). The description of the requirements that the proposed model should serve will derive from two different parts. On the one side, the reclaiming asphalt process that is selected as a case study has specific requirements from an information system that could be proposed. These requirements will be discussed on the first part, in which the design principles of the proposed model are presented. On the other side, specific technical characteristics should be decided before the actual implementation. This obligation comes from the interest in blockchain technology that is the main topic of the present study. For this reason, the organisation of the blockchain artifact will be discussed in detail in the second part of this section.

4.1.2. Design Principles

Reclaiming asphalt is a highly demanding process, as far as the information sharing needs are concerned. The repetitive process and the complicated business network that is included create the need for information integration in a constant and reliable way. For this reason, there are several requirements that derive from the process itself and are related to the data that will be included but also to the organisation of the information system that will be proposed. These requirements mostly were extracted from long discussions with managers that work on this process (Appendix D) and some documentation of BAM Infra in which the currently used information system is described (Appendix E).

Obviously, the sharing of important data between the involved stakeholder should be possible in a fast, reliable and trustful way. There are several examples of these data that have already been mentioned. The "material passport", as it has already been explained in paragraph 3.2.2, is an important quality information that is useful for many stakeholders of the process, such as the contractors and suppliers but also the client. The knowledge of all the processes that the used materials have been subjected to is of vital importance and should definitely be included in the system. More specifically, the characteristic of all the products that are used and produced should be written down in the system after the type testing that take place during the whole process. The use of these data can bring multiple benefits not only for the improvement of the process but also for the society (such as increase of circularity).

The fact that the overview of the provided quality in a project is not available, creates major problems on the clients and the contractors. The share of this information and the demonstration of the agreement with what was asked to be executed by the client is not possible and this should also be solved through the used information system.

The sharing with the client is of vital importance and is one of the major factors that can create value to the participants. If the contractors can provide information to their current or future clients and prove that the work is carried out in accordance with the requirements, procedures and plan that were agreed, the possibilities of winning more future tenderings are higher.

Additionally, the contractors have to obey to several regulations that are set by the governments. These specification should also be included in the system in order to satisfy the requirements of the governmental parts.

Concerning the organisation of the information system, there are also several design principles that should be considered. First of all, the management of the recorded information should be possible. Several benefits can be brought through this option such as the optimization of the process that is used. Additionally, due to the characteristics of the selected case study, a long-term monitoring of the of the executed works is required. Consequently, the information of a project that was completed should be available for being used in the short or long future. In any case, the fact that reclaiming asphalt is a cyclical process, indicates that the current recorded information will be definitely used in the future. This will have an impact not only on the improvement of the provided product but also in the total process management of the involved companies.

Finally, the reliability, immutability and trustiness on the used information system should be guaranteed. The recorded information should be carefully divided according to the interests of the involved stakeholders and their "read" and "write" options should also be carefully considered. Additionally, the information should be carefully protected from been lost or alerted because documents such as the quality tests are crucial for future use.

In conclusion, the most suitable system that should be used will be decided after matching the aforementioned design principles with the traditional and blockchain information systems. Both have already been briefly described in Chapter 1 and in the following table, their suitability with the requirements of the selected case study is presented. It can be concluded that a traditional database (the system that is currently used) could serve all the crucial requirements that the process has. However, the use of a blockchain system is considered as more effective for some of them 9Real time sharing of data in a safe and predetermined way (Reliability, immutability and trustiness in the stored data & Reliability, immutability and trustiness in the stored data) and it can improve the total way that the information is managed in this case study.

Table 5: Comparing suitability of the design principles with the traditional databases and the blockchain systems.

Design principles	Traditional Databases	Blockchain Systems
Traceability of material processes	✓	✓
Presentation of total project overview	✓	✓

Design principles	Traditional Databases	Blockchain Systems
Include standards and regulations that should be followed	✓	✓
Real time sharing of data in a safe and predetermined way		✓
Recording and Management of information in long terms period	✓	✓
Reliability, immutability and trustiness in the stored data		✓

As a consequence, the implementation of a blockchain system is considered as more suitable proposal for this case. In the following section a more technical description of the proposed model will be introduced. At the end, the model is presented in a High-Level Architecture.

4.1.3. Technical Requirements

In the second part of this section, the technical requirements that directly derive from blockchain technology will be presented. More specifically, the technical organisation of a blockchain platform that would be ideal for the specific case study that was selected will be explained. At first some critical requirements that every blockchain system should have will be mentioned and in the second part, a description of the blockchain system will be given. The technical characteristics will not be presented in a large detailed since this is not included in the scope of the present study. However, some of them will be mentioned in order to explain the decisions that were made.

Generally speaking, a blockchain information platform should be designed with the following characteristics (Moin et al., 2019): i) shared permissioned ledger, ii) standardization, iii) interoperability, iv) object identification and v) identity management.

More specifically talking about data management applications, as it was explained by Casino et al. and is presented in the following figure, four characteristics are crucial of this systems and should definitely be considered (Casino et al., 2019). Scalability, interoperability, audit option and visibility are the mandatory abilities that this system should give to the user while latency should also be considered as optional. On the other hand, securing companies identity privacy is not required in this systems due to the closed business networks that have access on them (Figure 18) (Casino et al., 2019).

	Scalability	Privacy	Interoperability	Audit	Latency	Visibility
Finance	✓	∘	✓	✓	✓	✓
Citizenship Services		✓	✓	✓		
Integrity Verification				✓		✓
Governance	∘	✓	✓	✓		
IoT	✓	✓			✓	
Health	✓	✓	✓	✓		
Privacy & Security		✓		✓		
Business	∘	∘	✓	✓	∘	✓
Education		✓	✓	✓		
Data management	✓		✓	✓	∘	✓

Figure 18: Blockchain networks and characteristics (Casino et al., 2019, p. 15).

The blockchain system that is proposed in this study is designed for being used as a transactions recorder that will have two main uses. On the main operation, the supply chain management will be monitored by a blockchain system while an additional application will be the exchange of data between the participants. Consequently, some of the core components of blockchain systems such as cryptocurrencies are not needed. The components that are obviously needed are related to the network organisation and configuration option and the data storage and exchange.

For determining the core components that will be decided in this study, the blockchain ontology matrix that was introduced by Tasca and Thanabalasingham in 2017 was used. In this analysis, eight main components and several subcomponents are introduced, along with the respective options that can be chosen. In the present study, some of them are considered out of the scope since either they are not related to the case study or are more related to the actual development of the model. For example, having a currency in the model that is about to be proposed is not consider. Additionally, deciding the specific coding language that will be used is not related to the scope that the present research is approached. Consequently, such components will not be discussed. However, a total overview of this matrix is given in Appendix F. In Table 6, the components that will be discussed in the present study and a short description are introduced (Tasca & Thanabalasingham, 2017; Van Valkenburgh, 2016).

Table 6: Blockchain core components (own illustration).

Blockchain Core Component	Description
Consensus	Rules for maintaining, updating and ensure the trustworthiness of the ledger
Transaction Capabilities	Scalability and usability of transactions
Extensibility	Capability of sharing information outside the blockchain system

Blockchain Core Component	Description
Security and Privacy	Preservation of the consistency of the recorded information
Identity Management	Access, Control and Identity management

In order to decided which options are more suitable in each component of blockchain technology, several studies were used. More specifically, a couple of decision trees by Suichies and Seuren about the usability of a blockchain system in our case were used (Seuren, 2018; Suichies, 2015). Additionally, the decision tree that was designed by Seuren also indicates that the use of a blockchain system can lead to the decrease of the transaction costs in a process, which is one of the major goals in this case study (Seuren, 2018).

Then, the flow chart that was introduced by Xu et al in 2017 concerning critical questions that have to be answered before designing a blockchain system was used (Xu et al., 2017). The figures along with an explanation of how these studies were used can be found in Appendix G. At the end, the four scenarios of blockchain architecture, specified for BIM applications that were introduced by Turk and Klink were used (Turk & Klinc, 2017).

After combining all the aforementioned literature studies, the most suitable proposed model for the selected case study could be a transactions recorded that could be described as follow:

"A Consortium (Private Permissioned Network) Blockchain System, consisting of predetermined members and controlled by preauthorised nodes in which the data will be stored off-chain, in a private and third-party cloud."

In short, the proposed model could be described as a blockchain transaction recorder that will be used by all the participants of the network with different options for each one. The central application of the system will be the monitoring of the supply chain management but in addition, an information system can be used. More specifically, all the transactions will be recorded in the blockchain. However, for storing the documents that will be exchanged, an off-chain third party cloud will be used. This cloud will be connected to the blockchain and consequently every change to the stored information will be included in the blockchain as separate transactions.

In the first chapter, all the variables of blockchain applications were explained. Three types of blockchain applications were identified (Blockchain 1.0, 2.0 and 3.0) and four variables according to the selected access and consensus mechanism (Figure 2). The application that is described above and is presented in this research is in Blockchain 2.0 field and the definition of the Private

Permissioned Network that is suggested is presented in the following figure (Figure 19).

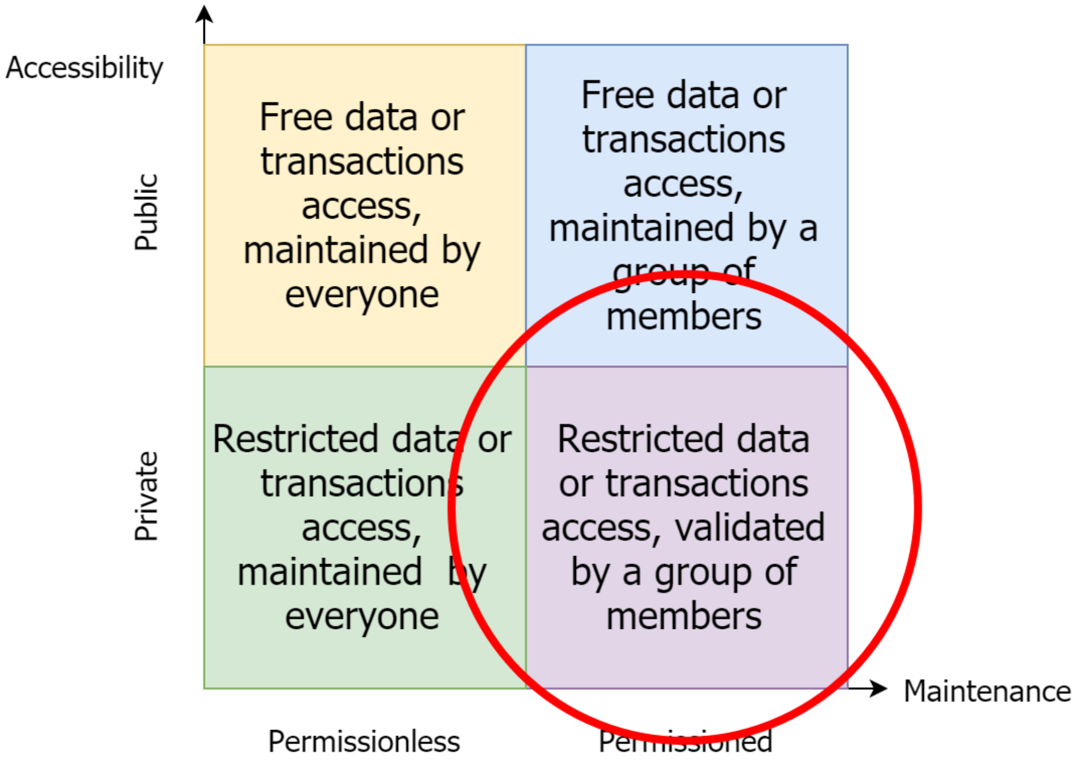


Figure 19: Selected type of blockchain application (own illustration).

Starting with the first core component that is discussed here, the system that is proposed is a consortium with a Proof-of-Authority mechanism. That means that a predetermined group of members will participate in the network and the validation will be done by preauthorised members. Additionally, gossiping indicates how the information will be exchanged and in this case it will be done locally between the users. Finally, the consensus agreement is done without any specific process speed (Asynchronous) and by simply deciding if a transaction will be confirmed or rejected in the blockchain (Deterministic) (Tasca & Thanabalasingham, 2017).

The second component determines the capabilities of the transactions that will take place and, in this proposal, a traditional blockchain ledger will be used and the system will allow high scalability, by discriminating the information in the users according to their interests (Thin Nodes Capabilities). In the next component (Extensibility) the governance of the system is discussed and in the selected case study it would be better if the system operation and technical support is given in a predetermined experienced blockchain company. This will ensure that the system will serve the needs of the users in a guaranteed and trusted way (Tasca & Thanabalasingham, 2017).

Finally, the last two component are Security and Privacy and Identity Management. Concerning the first one, a Built-in data privacy is select in which obfuscation of information is included by default (Tasca & Thanabalasingham, 2017). As far as the identity management is concerned, the Permissioned Private Blockchain System is considered as the best option for the reclaim asphalt process, as it was indicated by many different researchers (Seuren, 2018; Tasca & Thanabalasingham, 2017; Turk & Klinc, 2017). In our case study, this can be demonstrated by the need for restricted "read", "write" and "validate" abilities for the users and this is exactly what Private and Permissioned characteristics provide. Additionally, the need of securing privacy of the IDs of the participating companies is also necessary.

Table 7: Components and subcomponents of the blockchain system that is proposed.

Components	Subcomponents	Decision
Consensus	Consensus Network Topology	Consortium
	Consensus Immutability and Failure Tolerance	PoA
	Gossiping	Local
	Consensus Agreement	Asynchronous – Deterministic
Transaction Capabilities	Transaction Model	Transaction Ledger
	Server Storage	Thin Nodes Capabilities
Extensibility	Governance	Technical Mode
Security and Privacy	Data Privacy	Built-in data privacy
Identity Management	Access Layer and Control Layer	Permissioned Private Blockchain

4.2. Design of the Artifact

4.2.1. Introduction

After explaining the technical characteristics of the proposed model, a simple illustration will be presented. This part is crucial for the completeness of the selected research methodology (DSR approach), and more specifically the third step (Figure 11). Additionally, it contributes to the connection of the construction industry to the software development in order to ensure that the practical implementation of the model is feasible.

At first, the architecture of the system will be presented in a BPMN version, and more specifically, the Sequence Diagrams of Unified Modelling Language (UML) will be used. This illustration will make clear that there are several automatic actions that take place during the reclaiming asphalt process and will impose the feasibility of this system in a blockchain environment.

Next, Hyperledger open-source composer will be used for the deployment of the proposed system. All the aforementioned components will be added in the system in order to serve the initial design requirements. This part of the analysis will be used for the technical feasibility of the model proposal. It is crucial to illustrate it in a blockchain environment in order to ensure that the characteristics that are mentioned on the system description can actually be developed.

4.2.2. UML Diagram

UML diagrams is a method that is generally characterised as Object-Oriented (OO). It was firstly introduced in 1967 and is mostly used for describing systems that are consisted of different types of interacting objects. Alternatively, it could be characterised as a method for modelling and programming a process in terms of participating objects (Aguilar-Saven, 2004). Some important motivating keys that could be mentioned for using OO diagrams, relevant to the present study, are the improvement and problem identification of a process and its representation for analysis, design and programming (Aguilar-Saven, 2004).

More specifically, UML is ideal for specifying, visualizing, constructing and documenting the artifacts in a software system as well as for the presentation of business models and other non-software systems (Aguilar-Saven, 2004). As a consequence, it will be used in the present study. There are several types of UML diagrams that can be used and in the present study, Sequence Diagrams are selected. As the name indicates, sequence diagrams are used for presenting the behavior and decisions of involved objects in sequence activities (Aguilar-Saven, 2004; Fowler, 2004).

The sequence diagram that was designed for the Reclaiming Asphalt Process is presented in Figure 20 and explained in detail in Appendix H. The system that is presented in this diagram can be used for developing a transactions recorder that will serve both the use cases that have already been mentioned (Paragraph 2.3). The interaction of the asphalt plant with the laboratories is about the information platform use case (red lines) while the deliveries from the suppliers and BAM Infra Regionaal West are focused on the transactions platform and SCM system (green lines). The supply chain management application is the central application that can be developed and the exchange of information through the same system (supported by a third-party cloud service) can be included. In any case, from this diagram there are three possible scenarios about the model that could be proposed: i) both use cases included in the system, ii) only the SCM application or iii) only the information platform.

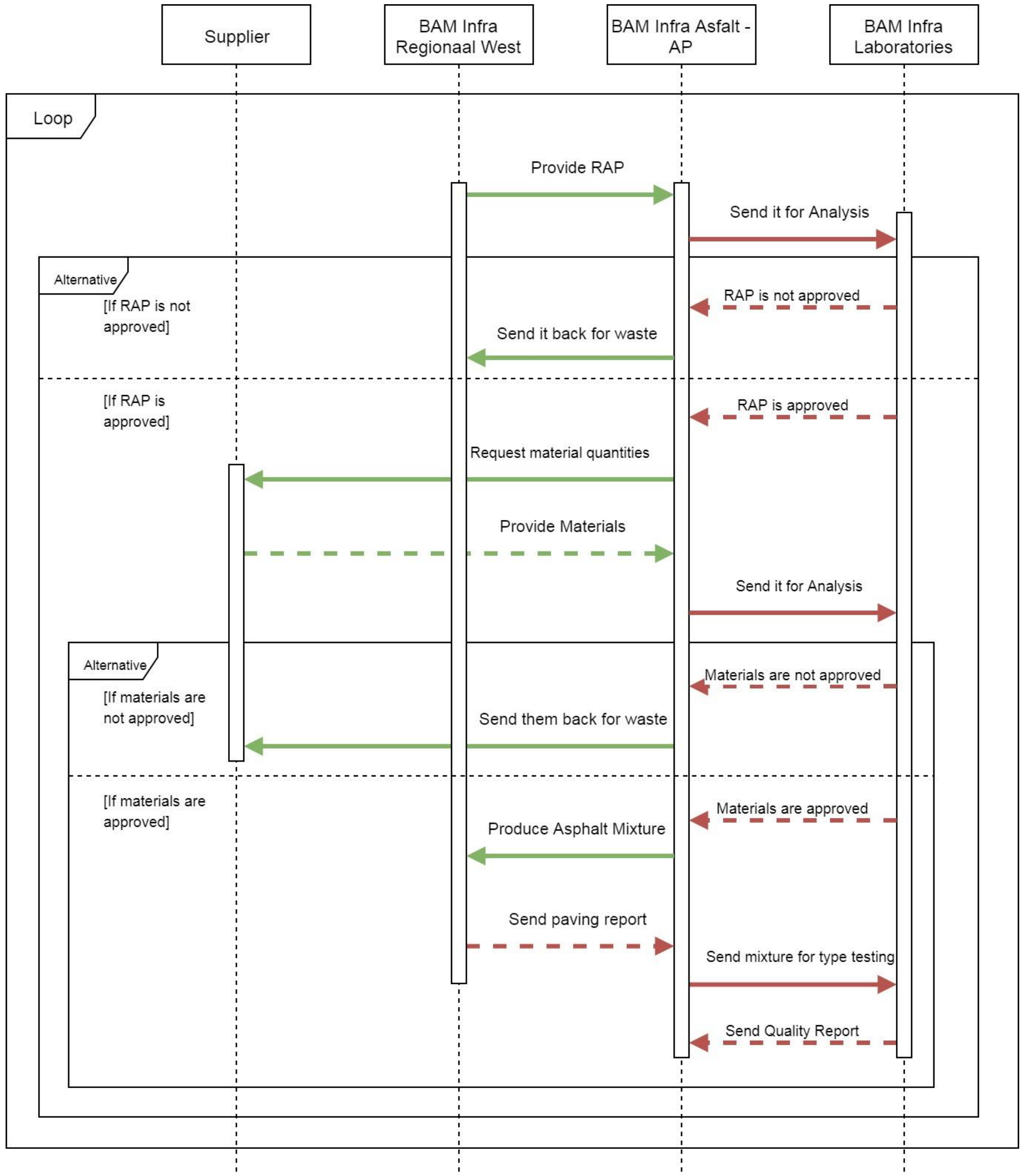


Figure 20: Sequence Diagram for RA process, including the presentation of the two use cases (own illustration).

In the next section, these two "transactions" will be added in the playground of Hyperledger and the deployment of the system for the user will be presented and explained.

4.2.3. Hyperledger System

In this section, the illustration of the proposed model will be carried out. For this purpose, an online open source blockchain tool will be used, the Hyperledger Composer.

Hyperledger is an open source permissioned distributed ledger platform that runs under Linux Foundation. Its enterprise context has developed many different applications such as digital music delivery and it is the first distributed ledger platform that enables smart contract programming in general purposes applications. For the development of an application in this platform several languages such as Java and GO are used (hyperledger, 2019a).

As it is presented in the next figure, there are several frameworks and tools that have been developed under the Hyperledger community (Figure 21). In this research, the Hyperledger Fabric framework which is a permissioned blockchain system that enables private networks and smart contracts support will be used. For the illustration of the business network and the exchange information process of the chosen case study that has already been presented, the Hyperledger Composer tool will be used, since it is considered identical for deploying trading network, supply chain management and traceability (The Linux Foundation, 2018)

Hyperledger Composer is a supportive tool of Hyperledger Fabric that enables pluggable blockchain consensus mechanism and can be used for developing the desired business network. For the development of the selected case study, it is considered as ideal for the deployment of the suggested model.

Figure 21: Hyperledger community structure (The Linux Foundation, 2018).

A more detailed description of Hyperledger Fabric and Composer can be found in Appendix I.

In the first part of this chapter, several requirements that the proposed model should serve were mentioned. It is important to ensure the compatibility of the used tool with these requirements in order to validate the technical feasibility of the proposed system. In short, the crucial components of the proposed model (Table 7) can be summarized in the following four characteristics: i) validation from predetermined authorized participants (PoA), ii) scalability and extensibility available, iii) privacy and security on the recorded data, and iv) safe identity management.

The Hyperledger Fabric is consisted of five modular component at a high level that are relevant to the components that were previously discussed. First of all, the consensus mechanism that is used is related to a pluggable ordering service and a membership service provider is responsible for associating entities in the network. Additionally, an optional peer-to-peer gossiping service disseminates the blocks and a smart contracts system can be also used. Finally, the ledger that can be designed can support several database management application and a third-party cloud system can also be connected to this system to provide the necessary scalability (Hyperledger, 2019b).

Furthermore, the transactions that can be executed in the composer have tree main abilities that are considered highly relevant to the proposed blockchain system. First of all, the execution of a transaction and check of its correctness is possible. Additionally, it is possible to order a transaction via consensus protocol and this provides to the users a more efficient collaboration. Finally, the validation of the transactions before committing them to the ledger is also possible (Hyperledger, 2019b).

Hyperledger can be connected to a cloud system and be used as a blockchain information system. In this way, scalability and extensibility are provided. However, for this option, a third party that will provide this system is required and, in this study, the proposed model will not be supported by third-party cloud. Consequently, in the model that will be presented here, Hyperledger Composer will be used only as a transactions' recorder for documents and materials.

From the description of the model in the previous section, it became clear that there are several parts that should be carefully treated. The consensus mechanism should be trustworthy, and the recorded data should be discriminated according to the interests of the participants. In this way, the participants will have different "read" and "write" abilities and thus, the private permissioned character of the system will be achieved. Additionally, the two use cases (SCM and information platform) that have already been mentioned as critical applications of this research will be explained.

As guideline for designing the prototype system, the sequence diagram that was previously presented was used. In total, seven participants were added, separated in two categories, the contractors and the clients. Additionally, the system provides the option of adding "assets" (physical objects) and in this case, documents and materials will be used (Table 8). Each contractor has the option to create new assets and share them with the respective stakeholder, as it will be explained later. An important restriction that the stakeholders have is that they cannot add any more participants in the network. However, if there is an agreement on that, they can ask from the system administrator to add new members in the network.

The system that is created is called "Asphalt Process Trading Network" (APTN). All this parts of the system designed are firstly added by the system designer. After setting up every part of the model according to the stakeholders' requirements (such as giving the required "read" and "write" permission to each one), the administrator will have only supportive role in the system. In this way, the decision for "Technical Mode" in the subcomponent of "Governance" that was decided in the Technical Requirements (Paragraph 4.1.3) will be achieved (Table 7).

Table 8: Participants and assets that are included in the network.

Participants	
Contractors	BAM Asfalt
	BAM Infra Regionaal West
	BAM Infra Laboratories
	Transportation Company
	Supplier A
	Supplier B
Clients	Municipality of Den Haag
	Municipality of Rotterdam
	Rijkswaterstaat

Assets	
Documents	Raw Materials Properties
	RAP Properties
	Paving Report
Materials	Raw Materials
	RAP
	Asphalt Mixture

The transactions that can take place in the system during the reclaiming asphalt process are shortly presented in Figure 22. The assets that can be added and exchanged in the system will be directly connected to the two use cases that have been described in the research analysis. On the one side, the delivery of asphalt mixture and raw materials will be monitored by the system and the orderings and deliveries (and consequently the respective payments) can be monitored and maybe in the future be executed by an automatic blockchain system. On the other side, the quality information of the used and produced materials of each project will be recorded in the immutable blockchain ledger and can be used in the future in a trustworthy way.

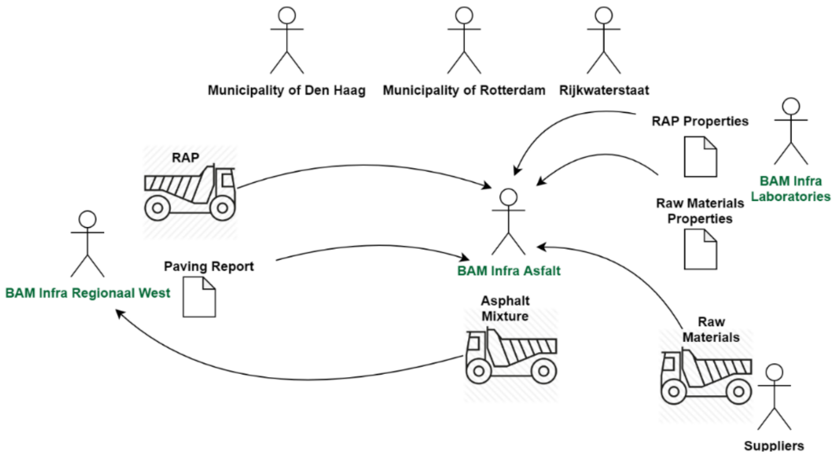


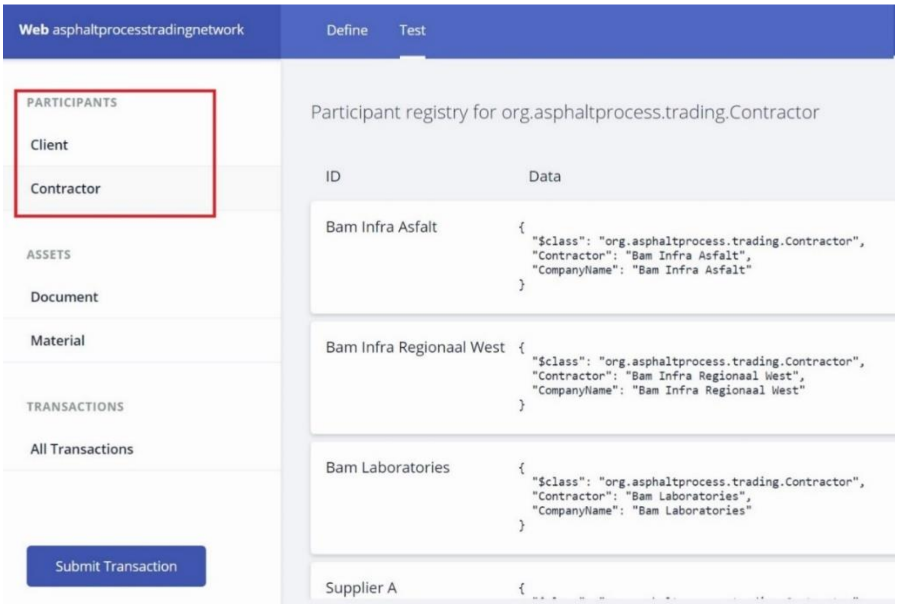
Figure 22: Transactions that will take place in the system (own illustration).

In the following figures, an illustration of the system interface that the users will interact with will be presented. In this way, the feasibility and usability of this system will be demonstrated. An extended description of Hyperledger Composer and how the system was structured is given in Appendix I.

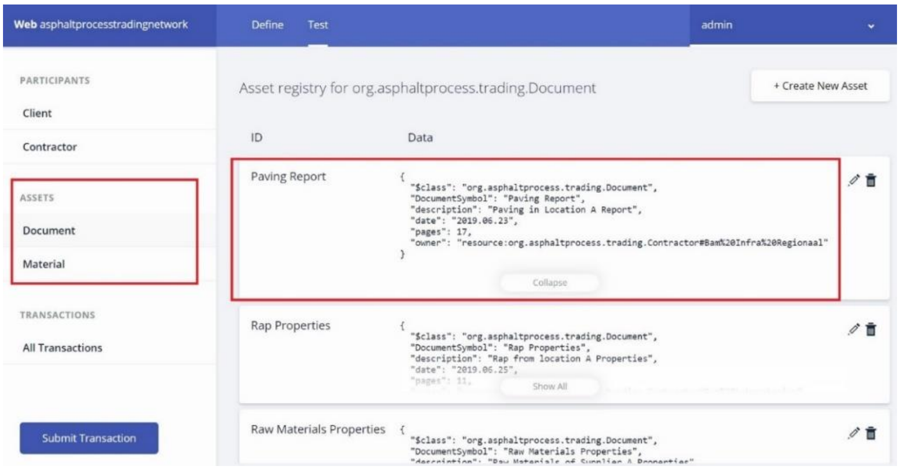
Starting with the total overview of the system, some of the added participants (contractors and clients) and assets (as documents and materials) of the system are presented in the following figures (Figure 23). In the stakeholders' section, only some details are added (company name) while in the assets' description there is much more information, such as a short description, the generation date, the owner of the document, etc. The owner document is a reference on each assets, which means that the owner should be someone from the participants. This is critical for the privacy of the system since as it will be explained later, in this way the discrimination of private data is achieved.

In the case that a third-party cloud was used in the system, an additional link would be included in the assets' details that will connect them to the respective location of the cloud that the document is stored. This is because the system that is presented here is a transactions' recorder and the assets that are exchanged have their own ID that will be used as connection hashes between Hyperledger and the off-chain cloud.

It should also be mentioned that all the actions of the users (such as transactions, updates in the assets or participants details etc.) in this system are considered as transactions and consequently are recorded as separated blocks. In this way, every participant will receive notifications for what is done by the other users, if it is allowed to view the respective transaction. In this way transparency, immutability and reliability of the system will be guaranteed.



(a)

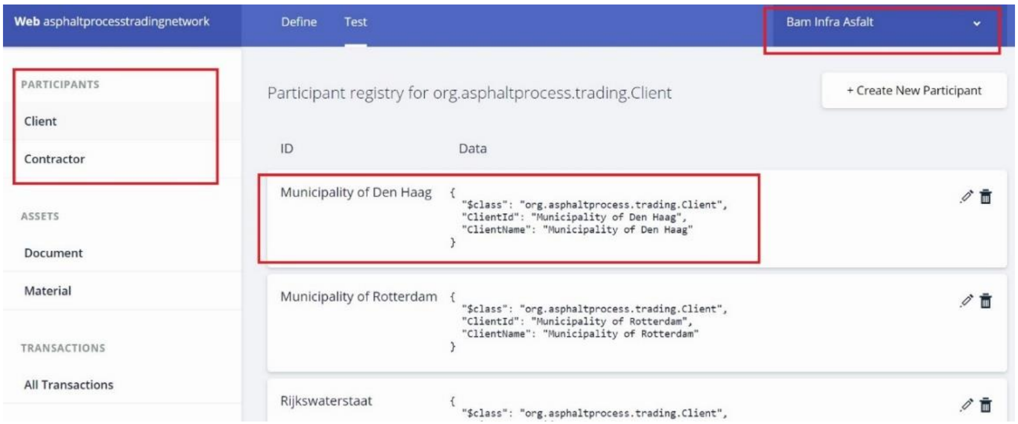


(b)

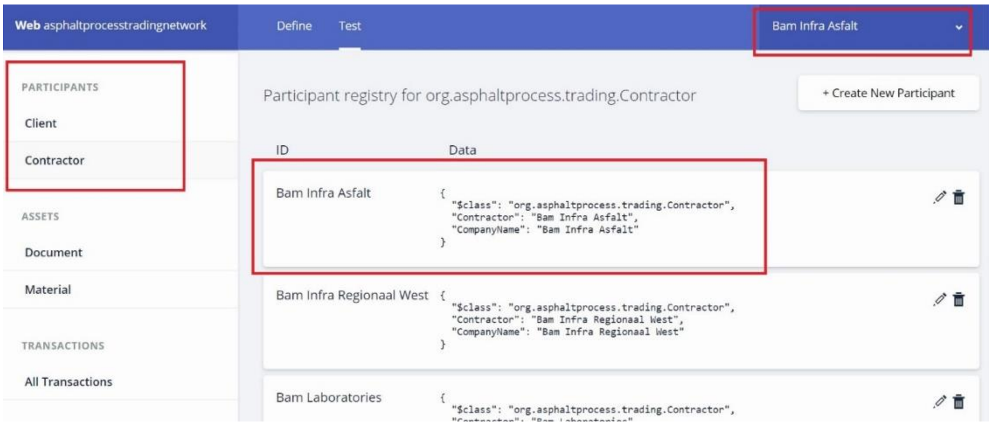
Figure 23: Total overview of the network, a) stakeholders and b) documents.

One of the main key principles that the system should serve and is also indicated by its description (Private Permissioned Network) is the careful discrimination of the recorded data. For this reason, different "read" and "write" ability should be given to each participant in order to eliminate the possibilities of losing private information. The application interface ensures that each participant will have different abilities according to the "read" and "write" restrictions that are applied.

Starting with the permissions in the participants section, concerning "write" ability, in the general case as it has already been explained, the stakeholders cannot modify the participants section (although this option appears as available in the system interface, this action will be blocked by the system). This can only be done by the system administrator after a respective request from the users. However, it is considered crucial to have access to the total list of the participants of the specific network that they participate, either as a contractor or a supervising client (Figure 24, a).



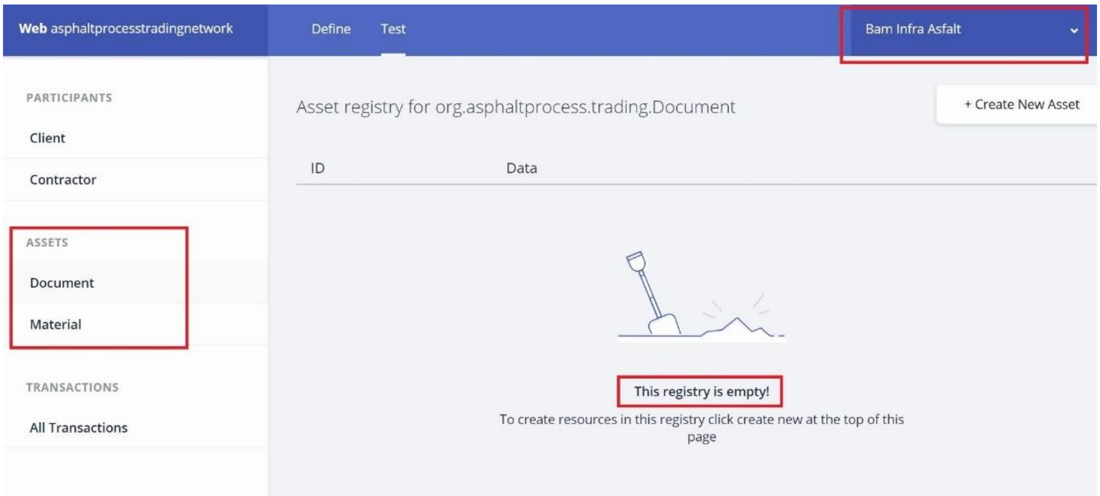
(a)



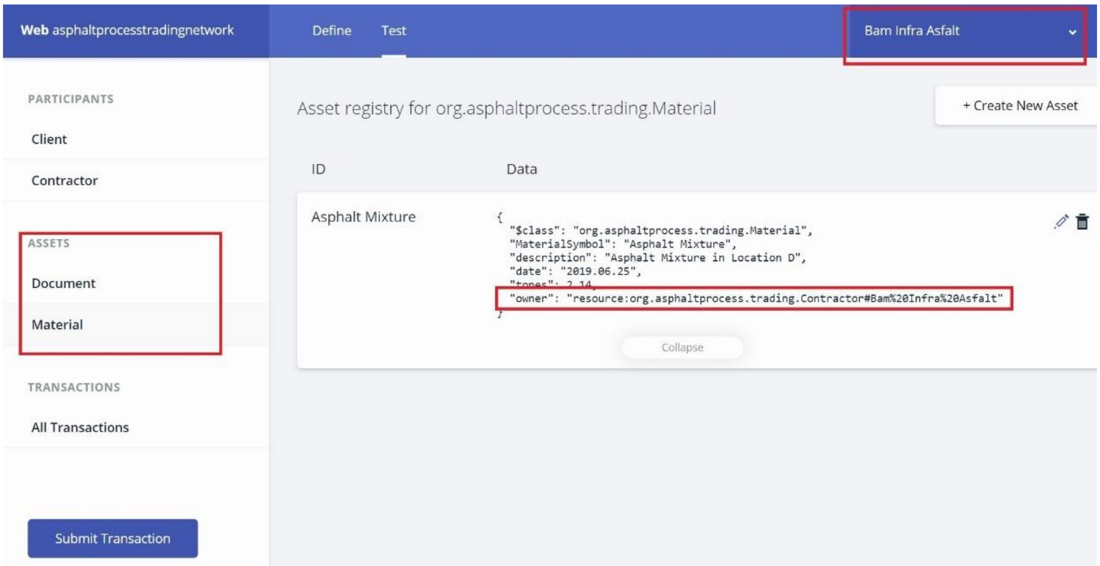
(b)

Figure 24: Network overview that each user can "read", (a) clients and (b) contractors of the system.

On the other hand, there is a crucial discrimination of the abilities of contractors and clients as far as the assets are concerned. Each contractor can create a new asset or update the existing ones. However, each contractor has access only to the assets that owns. For example, in Figure 25, the visible documents and materials for BAM Infra Asfalt are presented. In Figure 25 (a), the documents section appears to be empty since in this current state of the system, no documents were owned by this participant. On the other hand, the details of the Asphalt Mixture are visible, as it is presented in Figure 25 (b). This ensure that each user can only trade and on the same time validate assets that already owns and there is no need of validation from third authorised person. In this way, the suggested consensus mechanism (PoA) is achieved.



(a)



(b)

Figure 25: Documents overview that each user can "read" and also "write", (a) documents and (b) materials owned by the user.

However, every action of the user in the system is recorded as a separate transaction (and a respective block) and consequently every action can be visible to the other participants. In this way, some of the critical blockchain core components such as immutability and reliability are ensured. Additionally, the discrimination for the confidential information that was set as an important design principle the system is achieved.

In the following paragraphs, the transactions execution and validation process will be explained. The careful design of this part is crucial for the system since it is highly related to Consensus, Security and Privacy which are core components of the described system (Table 6). As it has already been explained, since the user has access only in the documents they own, it is impossible to submit transactions for other's assets. In this way, there is a self-validation of transactions since each stakeholder sends the desired documents (or materials) to the interested participant. In this way, the ownership of the participants on the assets they exchange will ensure the "authority" that the selected consensus mechanism (PoA) requires. Additionally, for security and privacy reasons, each stakeholder has access only to its transactions' history (Figure 26).

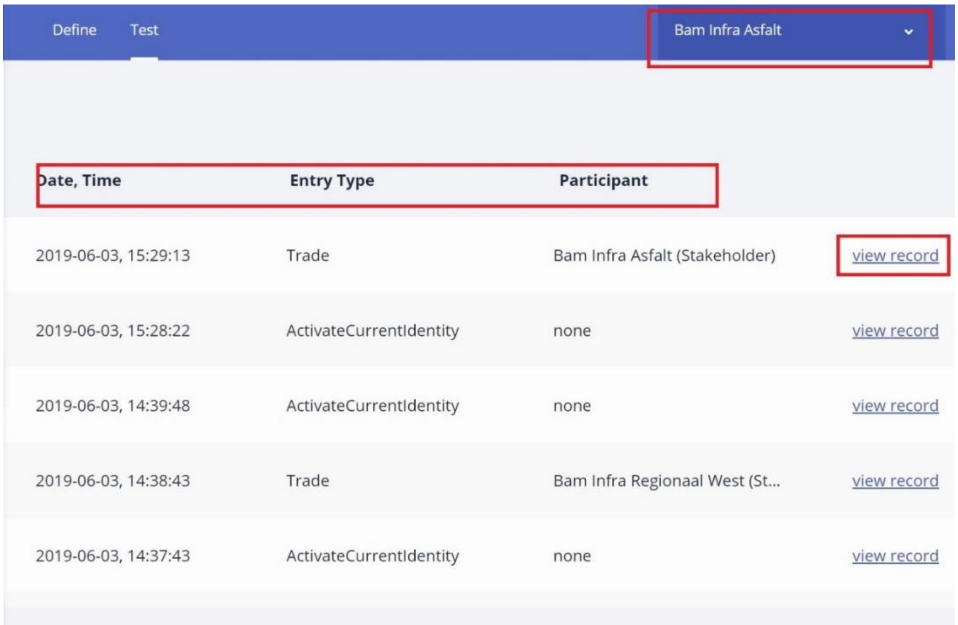


Figure 26: Transaction history of each stakeholder.

In the next figure, the execution of a transaction between BAM Infra Regionaal West and BAM Infra Asfalt is presented (Figure 27). Each transaction is a separate block which has its own unique ID (Transaction ID). In this way, immutability and reliability, which are some of the design principles of the model, are guaranteed.

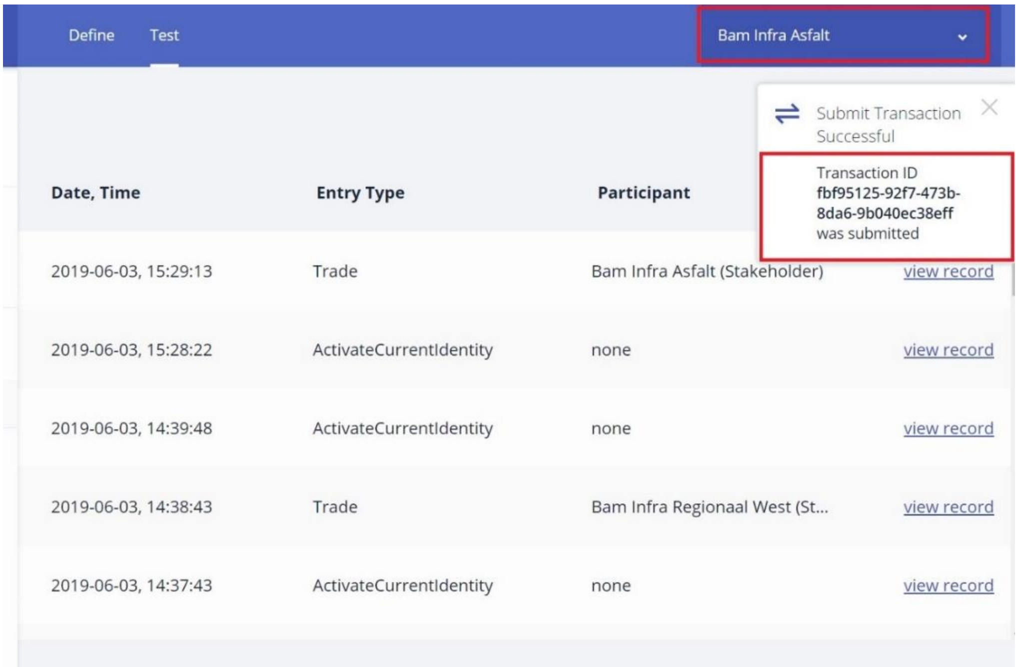


Figure 27: Transaction execution.

However, there is an important difference on the permissions that are given to the internal and external clients that participate in the system. A crucial part of the proposed system and one of the main incentives of implementing blockchain technology in this process was the involvement of clients in the system. The exchange of quality characteristics of the process with current and future clients will provide the opportunity to the contractors to ensure that they can provide the required quality. Consequently, it is important to use an information system that will give the opportunity to share information with clients in an immutable and reliable way. Additionally, it is important to distinguish the information to public and private to ensure that there will be no leakage of sensitive data. For this reason, a blockchain solution was suggested and, in this model, specific benefits for the collaboration of the contractors with possible clients from the public sector is presented.

In the following figures, the overview of the system that a client (such as Rijkswaterstaat) could have is presented. At first, all the data that are included in the system were private; consequently, the client could not have access in this information. However, since the contractors wanted to share some of these details with Rijkswaterstaat, access to the Participants and Assets sections was given. In Figure 28, a total overview of the quality documents that are included in the system that this client could access is presented. In some cases, the total transactions history should be shared with the client in order to ensure that all the transactions (orders, deliveries, payments etc.) took place in the correct moment. This will also increase the transparency in the system which was also one of the key design principles that led in selection a blockchain application for this case study (Figure 29). However, the external client that will get access to view specific data of the system should remain anonymous to the rest contractors for competitive reasons.

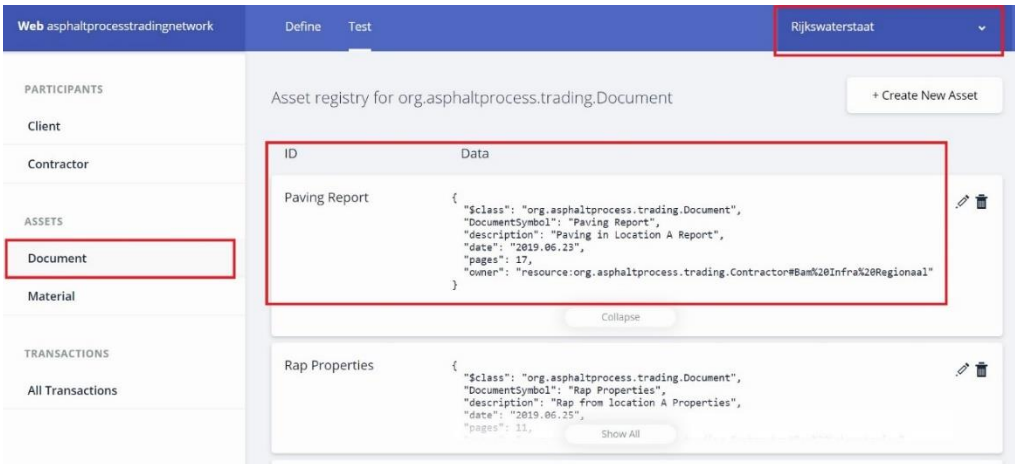


Figure 28: Documents overview that the client can have.

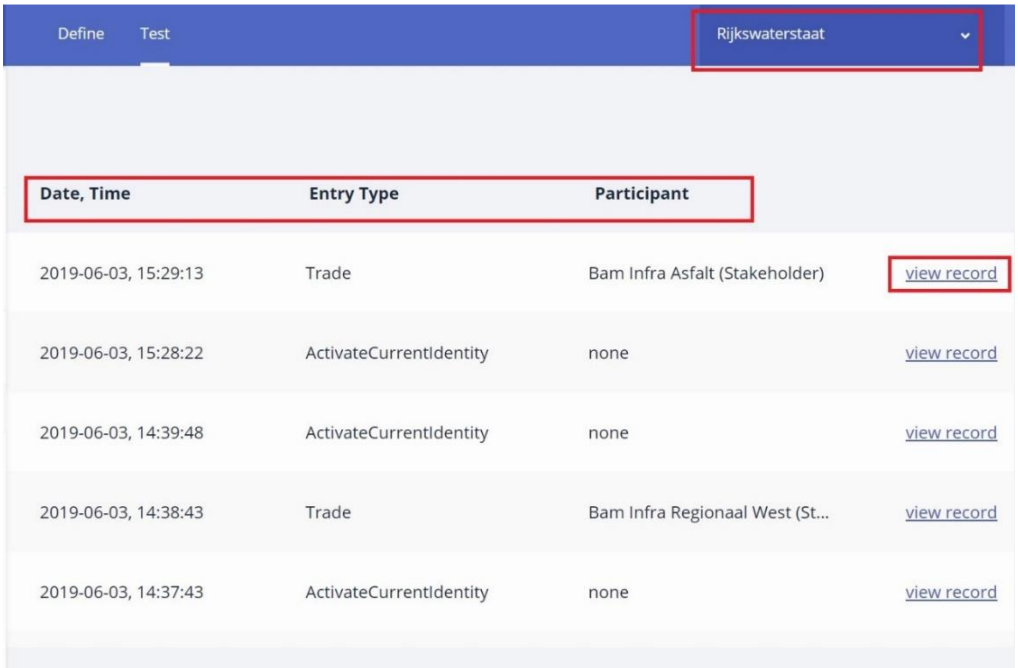


Figure 29: Total transactions history, available for the client.

4.3. Conclusion

In this chapter, the blockchain model that is proposed to be used in the reclaiming asphalt process was presented. At first, an analysis of the requirements that the system should serve were mentioned and in the second part a more technical description was included. All these steps contributed in answering the final two subquestions that were set at the research analysis. At the final part, a clear answer on these questions will be given.

First of all, the fifth subquestions was answered, which is the following:

e. "Which are the requirements that an information system should serve in this specific project?"

In the main report, the system requirements were divided into two part, the design principles and the technical requirements of the model. On the one side, the design principles were extracted from the discussions and interviews with the experts from the asphalt process (Appendix D). Additionally, documentation from the design of the currently used information system was also used in this part (Appendix E). In conclusion, the following six design principles were discussed:

- Traceability of material processes
- Presentation of total project overview
- Include standards and regulations that should be followed
- Real time sharing of data in a safe and predetermined way
- Recording and Management of information in long terms period
- Reliability, immutability and trustiness in the stored data

At this point, it has to be mentioned that during the validation process by asphalt experts, all these design principles were assessed as important. Consequently, using them for designing the proposed artifact can be justified.

On the other side, since a blockchain system was considered as the most suitable for these requirements, an extended technical description for the proposed system was given. This part contributed on answering the final subquestion which was:

f. "How should a blockchain artifact be technically organized in order to provide efficient recording and sharing of information?"

The blockchain model that is proposed in the present research could be described as follow:

"A Consortium (Private Permissioned Network) Blockchain System, consisting of predetermined members and controlled by preauthorised nodes in which the data will be stored off-chain, in a private and third-party cloud."

That means that in the proposed model there will be a discrimination of the involved information according to the individual interests of each stakeholder and the validation will be done by predetermined responsible participants, different in each case (Private). Additionally, only the pre-decided participants will have access in the developed network (Permissioned). All the transactions that will take place will be stored in the blockchain while for the storage of the data, an off-chain third party cloud will be used. Obviously there is a direct connection between these two systems. On this way, every change of the information that will be stored in the cloud will be instantly recorded in the blockchain as a separate transaction.

This characteristics came out after analysing all the core components of a blockchain system and selecting to discuss only about the five that are relevant to the scope of this study. Additionally, several decision trees and guidelines that led to the most suitable blockchain design according to the requirements of the specific case study were used. In the end, specific technical characteristics were decided and are presented in the following table.

Components	Subcomponents	Decision
Consensus	Consensus Network Topology	Consortium
	Consensus Immutability and Failure Tolerance	PoA
	Gossiping	Local
	Consensus Agreement	Asynchronous – Deterministic
Transaction Capabilities	Transaction Model	Transaction Ledger
	Server Storage	Thin Nodes Capabilities
Extensibility	Governance	Technical Mode
Security and Privacy	Data Privacy	Built-in data privacy
Identity Management	Access Layer and Control Layer	Permissioned Private Blockchain

For ensuring the technical verification of the proposed model, two methods for the design of the artifact were used. On the one side, a Sequence Diagram that will depict all the sequence activities that take place between the involved partners was designed. In this way, the automatic characteristic of the case study (and more specifically for the two use cases that are investigated) was highlighted. On the other side, Hyperledger Composer was used for the development of the user's interface and all the characteristics that were previously mentioned were put to the illustrated model.

Part III

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5. Validation & Evaluation

At the final part, the feasibility and usability of this model is validated by experts that would use it. In this way, the possible added value that is mentioned will be assessed by the users of the artifact and important feedback for the model design is extracted. In the fifth chapter of the report, a discussion about the findings of this research will be introduced. At first, a summary of all the findings will be presented and then a clear answer to the main research question that was initially set will be given. Some recommendations about the improvement and suggestions for future research will also be included in the second part of this chapter.

5.1. Model Validation

5.1.1. Introduction

At the final part the report, the validation of the proposed artifact will be presented. At first, the reasoning behind this step and the method that is used will be explained according to the DSRM approach. At the end, the findings of this step are presented, and some important conclusions are extracted.

First of all, a formative or "ex-ante" method will be used for the evaluation of this model. In this process, the artifact that is proposed is evaluated during its design and before the actual development and implementation. In this way, its improvement during subsequent design activities is possible and thus, the design research that is followed is less risky without using large resourcing for the research (Johannesson & Perjons, 2014). In the present study, the redesign activities will be described in the Recommendations part, in paragraph 6.3.

The validation of the proposed artifact mostly focuses on six main goals. First of all, the level of its effectiveness in solving the mentioned problems will be determined. Additionally, the list of requirements that the system should serve will be assessed. The confirmation, disproval or enhancement of the used methodology (in our case this is DSRM approach) could also be resulted from this step. The comparison of the current system that is used with the potential proposed artifact is also one of the main goals of the validation part. The two final goals are the determination of any side effects that the artifact could have and any improvement opportunities of the design. An additional benefit of this method is that the feedback that is provided is of high internal validity and consequently is ideal for assessing the efficiency of an artifact in a quick and inexpensive way (Johannesson & Perjons, 2014; Wieringa, 2014). However, some disadvantages of this method should be also pointed out. The fact that a preliminary version of the proposed artifact is investigated can lead to not reliable conclusions (Johannesson & Perjons, 2014). This can be explained by the fact that the persons that will be asked to assess the designed artifact will not have the fully developed illustration. Consequently, some of its functions or disadvantages will not be made clear.

There are several techniques for conducting validation in a proposed artifact that can be found in the literature. Such examples are surveys, questionnaires or interviews with experts that can be used for collecting their feedback (Johannesson & Perjons, 2014; Wieringa, 2014). These techniques always depend on the interests and knowledge of the experts and are suitable for gathering data and analysing the circumstances in a rigorous way. However, they usually result in shallow responses from the experts, either because of lack of time or because they do not want to insult the designers with extremely negative comments. This increases the risk for false assessment of the proposed artifact and thus, the researcher should carefully treat the positive replies while mostly use the negative feedback for evaluating the proposal (Johannesson & Perjons, 2014).

5.1.2. Validation Protocol

In the present study, the experts' opinion was used for validation purposes. The goal of experts' panels is to assess the applicability of the proposed model by using the reactions of the experts. This is done not only by observing the opinion of each participant separately but also by using the interaction between them. In general, the positive opinions should be carefully treated, and a clear explanation should be asked before coming up with the final conclusions. As it has already been explained, the negative opinions are usually more useful since they are more accurately justified and can lead to improvement of the proposed artifact (Wieringa, 2014).

A group of project managers with different roles in the reclaiming asphalt process was gathered to discuss the possibilities of implementing blockchain technology. Their companies along with their roles in the process are presented in Table 9. At first as an introduction, blockchain technology was explained in order to make clear the methodology and the possible benefits that it could bring to the users. Then, a connection to the asphalt process was carried out and in this way the direct benefits of this technology were highlighted. In this way, the assessment of the experts would be more accurate and realistic.

Table 9: Participants in the validation workshop.

No.	Position	Company
1.	Project Manager	BAM Infra Asfalt
2.	Project Manager	BAM Infra
3.	Director	Transportation company
4.	Manager	Milling company
5.	Director	BAM Infra Regionaal West

Following the introduction part, the proposed blockchain model was presented and explained. In this way, its characteristics and all the possible added value that could be added was made clear. The level of importance was graded, according to the scale that is presented in the Table 10.

Table 10: Grading scale of the levels of important.

Level of Importance	Grade
Very Low	1
Low	2
Medium	3
High	4
Very High	5

The final part of the assessment that was conducted by the experts' panel was the information system itself, based on several evaluation methods that are mentioned on literature. Several criteria that are relevant to this research were identified and were used for the assessment of the model that is proposed. This method of assessing an information system based on a list of criteria is called "Criteria-based evaluation of IT-system as such" (Cronholm & Goldkuhl, 2003). In this method, a list of criteria relevant to the system that is about to be evaluated were used. In the following table, the characteristics of this evaluation methods are presented (Cronholm & Goldkuhl, 2003).

Table 11: Characterization of criteria-based evaluation of IT-systems as such (Cronholm & Goldkuhl, 2003, p. 8).

Main perspective	Depending on the character of the criteria
What to achieve knowl-edge about	The quality of the IT-system according to the perspective that is underpinning the criteria
Data sources	The IT-system, descriptions of the IT-system, descriptions of the criteria.
Deductive or inductive	Deductive
Who will participate	Evaluator expert
When to chose this type	When a focused evaluation is wanted, when there are less re-sources at hand, when there are no users available

More specifically, a list of requirements from Palmius was used for assessing the proposed model (Palmius, 2007) (Table 12). In the following table all the criteria that are suggested are presented, divided into the categories they are related to. Some of the suggested criteria were not included in this evaluation since are made for already developed systems. Examples of these could be the criteria related to the used Hardware, Cybernetics, Organisation and System Performance etc. Additionally, some of the criteria could not be answered by the experts either because are relevant to the end user of the system or because the proposed model is not presented in much detail and consequently a clear answer could not be given (such examples are Communication, etc.).

On the other hand, the selected criteria were related to the presented model either because they are core components of blockchain technology (such has Reliability and Secrecy) or because can affect the total assessment of the implementation of the system (Manageability, Productivity and Learnability are such examples).

Table 12: Information systems assessment criteria (Palmius, 2007) (own illustration).

Control	**Quality**	**Durability**	**Software**
Knowledge	Accuracy	Achievability	**Compatibility**
Overview	Relevance	Movability	Saliency
Flexibility	Importance	Portability	Availability
Manageability	**Reliability**	Traceability	Replaceability
Decisions Speed	Uniqueness	Original look	Licensing
Decisions accuracy	Free from bias	**Evidence**	Administration
Communication	**Access**	**Security**	**Hardware**
Informedness	Accessibility	Stability	Scalability
Social interaction	Searchability	**Validity**	Administration
Social belonging	Format	**Secrecy**	Performance
Organisation Performance	**Economy**	**Emancipation**	**Ergonomy**

Transmission	Return on investment	Satisfaction	**Stress**
Fail rate	**Competitiveness**	Democracy	Overload
Congestion	Customer satisfaction	**Influence**	Underfeed
Underfeed	**Productivity**	**Learning**	Control
Usability	**Cybernetics**	**System Performance**	**Systems properties**
Learnability	Filters	Viable System Model	**Efficacy**
Memorability	Sensors	Living systems	Cult. Feasibility
Efficiency	Amplifiers	Soft Systems Meth.	**System Desirability**
Effectiveness	Feedback	Info. Tech. Infra. Library	
Error proneness	Viability		

A more extended description of the suggested assessment criteria by Palmius is given in Appendix J.

In the end, all the selected criteria were categorized into three parts, according to the aspect of the system that are related to. The list of the selected criteria is presented in Table 13.

Table 13: Selected assessment criteria.

Assessment Criteria		
Information management	**Supply Chain Management**	**User's Perspective**
Validity	Manageability	Learning
Secrecy		
Reliability	Competitiveness	Learnability
Compatibility		
Efficacy		
Evidence	Productivity	Stress
Influence		
System Desirability		

The selected criteria were decided to have the same weight and be graded by the experts according to their existence in the proposed model. In the assessment part, it is important to write down not only the positive opinion of the experts, but also the negative contribution. Additionally, in some cases the neutral reaction of the expert (either because the model presentation was not clear or not enough) should be depicted in the results. For this reason, the experts were asked to grade the criteria according to the method that is presented in the next table (Table 14). In this way, the positive, negative or neutral contribution of each criterion will be depicted in the final results. At the end, the total points for each criterion were calculated and are presented in the Experts' Panel Protocol (Appendix K)

Table 14: Grading method for assessing the evaluation criteria of the IS.

Expert opinion	Grade
The IS supports this criterion (positive contribution)	1
The IS does not support the criterion (negative contribution)	-1
This criterion was not defined in the model presentation (neutral contribution)	0

This part was analyzed in two different ways. On the one side, the final grade of each criterion was calculated (Figure 33). In this way, the criteria that are successfully included in the proposed model could be determined while some parts of the model that need improvement were also identified. The second way that the system assessment was used was the calculation of the total score of each expert. In this way, the "Level of Satisfaction" of each company from the presented system can be calculated and assess which participants have to be better approached in the redesign phase.

5.1.3. Results

Three parts of the research were asked to be assessed by the experts. It has to be mentioned that the opinion of the experts was not weighted since they are considered equal (in terms of level of contribution and importance) in the process execution. Starting with the design principles, the level of importance of the aforementioned design requirements should be assessed. Undoubtedly, it should be ensured that the proposed model is built based on realistic and important requirements.

The initial list of design principles that were mentioned in this chapter came out from specific interviews and documentation of BAM Infra. However, it is crucial to gather as much opinion as possible from participants of the process. In Figure 30, the level of importance of each design principle, as it was assessed by the experts' panel, is presented. In this graph, it is depicted that the stakeholders agreed that all the considered design principles were important for the design of the model. It is also crucial to mention that the core design principles that led to the selection of blockchain technology as the most suitable model (Table 5), such as materials traceability, predetermined sharing and reliability, are also considered as important by the experts. As a consequence, it could be assumed that they understood the additional benefits this technology could have and indirectly approve the selected technology.

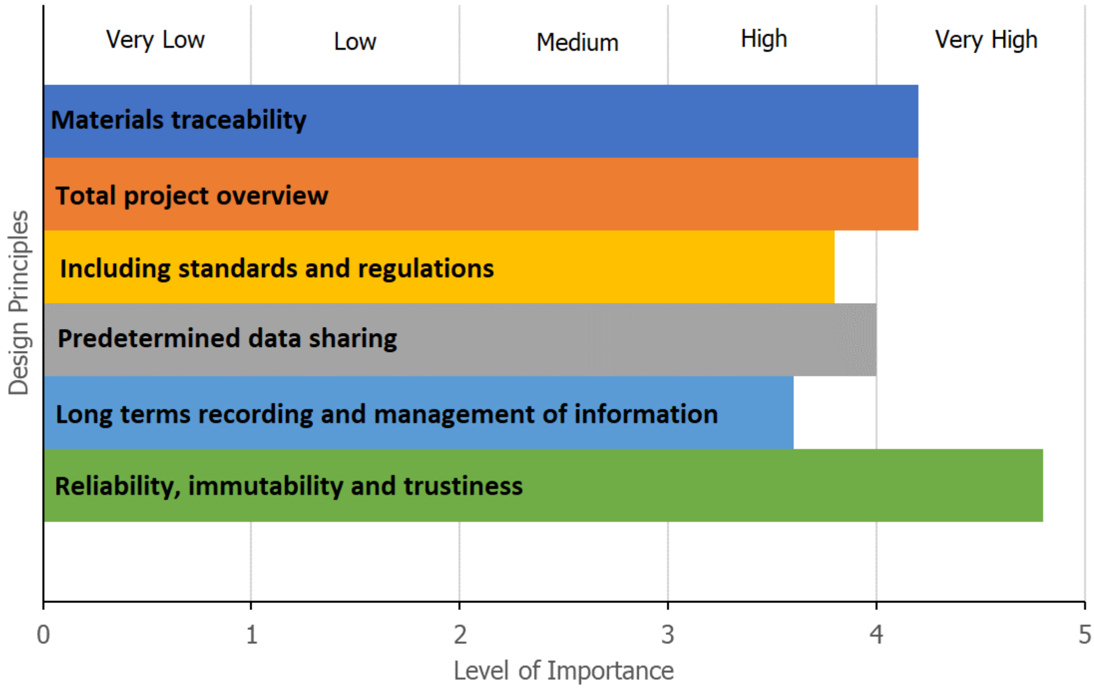

Figure 30: Assessment of design principles from the experts' panel (own illustration).

The next part that was asked to be assessed by the panel was the added value that has been identified for each use case of blockchain technology, according to their level of importance (from very low to very high). In this way, some of the benefits that are considered to be brought in this process by implementing blockchain technology will be confirmed and the importance of implementing this model in reclaiming asphalt process will be validated by a more trustworthy side. From the graph of Figure 31, it can be concluded that, similarly to the design principles assessment, the factors that are highly related to blockchain technology as considered as the most important. In general, all the benefits that were described were highly graded but more specifically, the importance of transparency and reliability was highlighted. Additionally, some of the functions that the system supports were approved by the experts, such as the ability of tracing the materials and the opportunity to give specific permissioned to predetermined actors were also appreciated.

In the next graph (Figure 32), the opinion of the experts was also calculated according to companies' perspective and their level of satisfaction with the possible added value was calculated. For this reason, the opinion of the three experts for BAM was summarized in one and also the opinion of transportation and milling company is presented. It can be concluded that all the participants are satisfied with the presented benefits they could have.

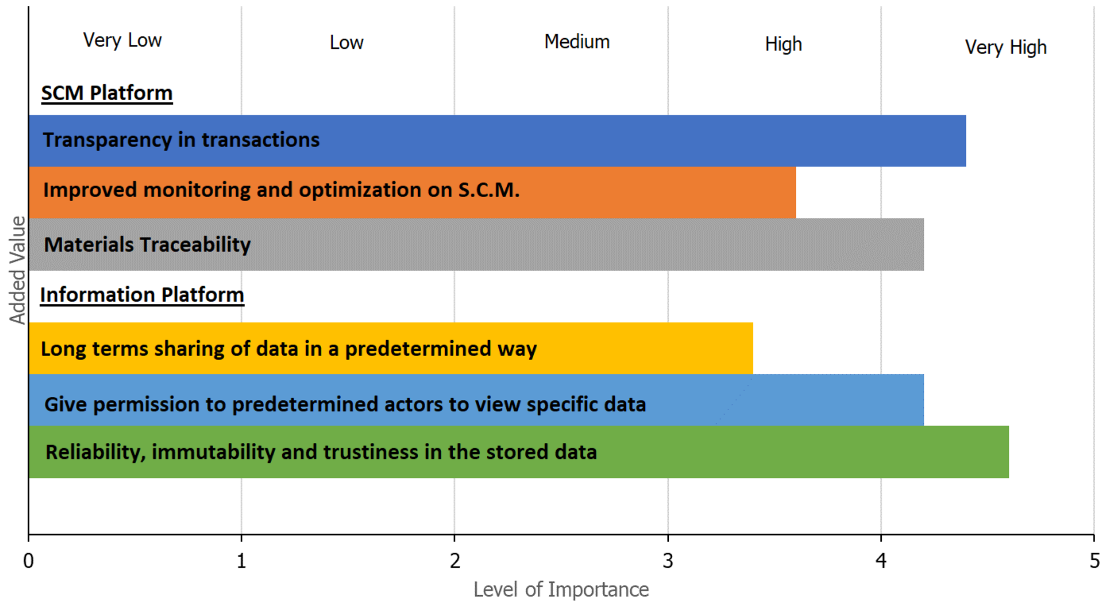

Figure 31: Assessment of added value by the experts' panel (own illustration).

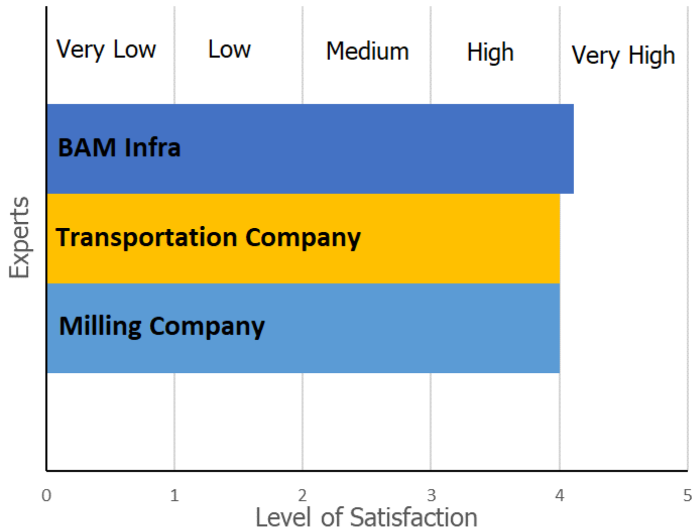

Figure 32: Level of satisfaction of each company from the potential added value (own illsutration).

At the end, several assessment criteria for information systems were presented to the experts and they were asked to mention which one are supported by the proposed model. There are many interesting results that could be discussed from this analysis. Starting with the positive results of this assessment, the high grade on Validity and Secrecy could be mentioned. However, these results are considered normal since these characteristic of blockchain technology were mentioned in the presentation several times and the experts realised that are some of the core components of blockchain technology. The most important positive result of this assessment is the high results in Competitiveness and the relatively high Productivity that the system could bring. According to the experts' opinion, the proposed model could improve the competitiveness of the companies and lead to a higher productivity in the process. These were some of the potential additional benefits that the system could bring, and these results create interest around further instigation of this part.

As it was previously explained, the negative answers on this kind of assessments are usually more interesting and helpful and thus, the discussion will be mostly focused on these. The really low grade on Efficacy that the experts' panel gave to the proposed model should be explained. More specifically, three out of five participants gave a negative grade to this factors while the rest considered that this part of the model was not defined. There are two possible reasons that could explain this result. At first, the presentation of the model was not detailed enough in order to present the level of efficiency of the proposed system. The fact that it is not fully developed, and the users cannot understand totally how it works may increase their concern for its usability. Additionally, the experts maybe considered that the added value that the system provides in comparison with the effort (cost) that it requires for its development is not worth it.

At this point, there is one more negative result from this assessment that should be discussed. The management of information for process optimization purposes was one of the core design principles and one of the expected added value that the system could bring. However, the experts assessed the Manageability of the recorded data really low. That means that they question the contribution of the proposed model on this part of the process. Their main concern on how to use the recorded data in order to improve the process was not solved by the suggested system. The reason behind this low grading can come from the fact that the system cannot solve the availability of information since it focuses on the storage and sharing of information and not on how and what kind of data are recorded. As a consequence, more data or options will not be provided to the users. Consequently, there will be no difference with the currently used systems..

The low level of Learning and Learnability could be expected since these advantages were not included in the benefits that the proposed information system could bring. Furthermore, a conceptual presentation of the model could not explain these possibilities since a fully developed system is needed in order to explain how the users could benefit from that. Similar to these factor, the high Stress that would be brought to the user is also considered as negative. The high stress level can be explained by the general denial of the people in construction industry to use new technologies. In general, the total User's perspective on the proposed system is questionable and should be discussed and improved.

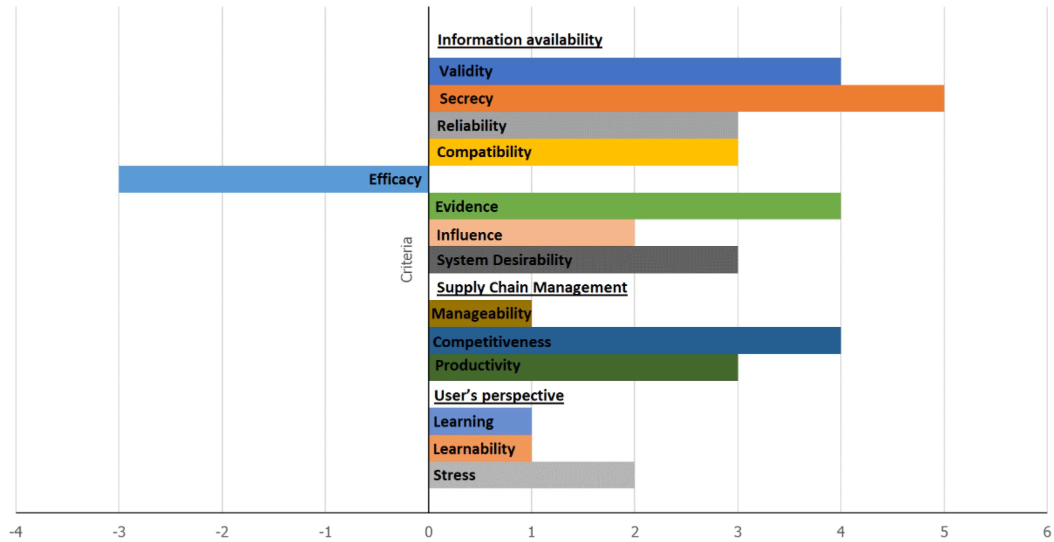

Figure 33: Level of existence of each criterion in the proposed model (own illustration).

Again, an interesting result that could be extracted from this assessment would be the level of satisfaction of each participant in the experts' panel. In this way, on the next part of improving the proposed model, it would be known which stakeholders to approach better in order to also fulfil their requirements. This analysis is presented in Figure 34 and the negative result of the milling company should be considered. It can be explained from the fact that their role was not separately included in the process analysis and as a result their perspective was not considered during the model design.

Figure 34: Level of satisfaction of each company from the proposed model (own illsutration).

In the end, during the discussion with the experts, several additional parts that should be considered came out. First of all, legitimacy issues that have not been addressed in the present study concerning the recording of private data were mentioned. In this daily process, there are several personal information that should be recorded (such as the personal details and actual location of the drivers of the trucks) but the current laws do not allow it. Additionally, inefficiencies concerning the sharing information came out. In many cases, the total overview is recorded in one single document (even on paperwork) and later, the discrimination and sharing to all the relevant participant either is impossible or it increases the transaction costs. Finally, the additional storage space that would be needed for transforming the current shared information system with local decentralised clouds was one of the objections of the participants due to the additional need of storage and the consequent cost.

All the aforementioned aspects should be considered on the improvement of the model proposal and will be discussed in the following chapter.

5.2. Discussion

This is the final part of the present research. In the following section, the findings of this analysis will be presented and discussed. At the end, an answer to the main research question will be given and the final conclusions will be extracted.

Starting with the findings of this research, this thesis is a feasibility study. The possibilities of applying blockchain technology in the reclaiming asphalt process were investigated. After analysing the process, two main use cases were identified for blockchain technology and all the possible added value is related to them. On the one hand, this system could be used for improving the supply chain management in order to monitor all the transactions that take place. As an additional application, blockchain technology could be used in management of information and through an information platform, allow the participants to exchange data during the process.

The transactions recorder will be the central application in the proposed model. The participants will mostly use the blockchain system for recording and monitoring all the transactions that take place in the process. For this reason, both transactions of materials and documents were included in the system. The exchange of materials will have an impact in many aspects of the process such as the supply chain management while the information exchange will provide several advantages in the information management of the process. After the model proposal and its validation, several benefits could be determined in each case.

Starting with the supply chain management use case, three important aspects can be mentioned. The obvious benefit that blockchain will provide in the system is transparency. All the transactions will be immutably recorded in a shared ledger system and in this way, all the interested participants will have access on the respective information. Additionally, since the platform will provide integration between all the participants of the process, monitoring and optimizing every part of it will be easier. Sharing information on time is a crucial factor that leads to a faster and better optimization process and a blockchain system will provide these abilities. The monitoring of supplies and deliveries will be easier if all the data are gathered on time in one single platform that will be used by all the participants.

Finally, an important requirement that a blockchain system can satisfy through the proposed system is materials traceability. The "material passport" as it is also known, is one of the crucial requirements of the governmental parts that participate in the process since transparency on the supply chain can have multiple benefits, such as decrease of corruption and environmental impact. Additionally, less distortion of information in the supply chain can be achieved through the tracing system of the materials. This requirement could also be fulfilled by traditional databases but the blockchain solution is considered as more trustworthy since reliability and immutability can be guaranteed by default. There are also some indications in the literature review that materials traceability could improve circularity. In addition, after the discussions with experts during the process analysis and the validation of the model, some indications for a possible improvement of the levels of circularity were mentioned. However, there is still need for further investigation on the possible improvement that could come out.

As far as the second use case is concerned, the exchange of information in this process could be improved through the proposed blockchain model. First of all, it is obvious that by using a blockchain system, all the data will be stored in a transparent, immutable and consequently, reliable way. This will ensure to all the participants that they can keep safe all the useful information of long terms projects (such as the maintenance of highways pavement). Additionally, the contractors that participate in the project can guarantee the authenticity of the data they provide to their current or future clients and in this way increase the possibilities of winning more tenders.

The system that is proposed provides several advantages that could improve the process and make the collaboration between the participants better. First of all, the exchange of information will be done in a predetermined way and in this way there will be no possibility of leakage of information. This is guaranteed through the different and specific "read" and "write" abilities the users will have (through the "private" blockchain system). Finally, the fact that the participants can have and also (if there is agreement on that) give "read" access option to external stakeholders provides them the opportunity to prove their reliability in many different ways. For example, it is always possible to prove that the executed actions in the process agree with all the standards and regulations that are imposed by the governments. An additional benefit from this opportunity is that the contractors that participate in the project can present the quality of the services they provide to their future clients in a transparent and reliable way since all these data will be stored in a blockchain environment.

All the added value that has been mentioned and could be brought in each use case from the implementation of a blockchain system are presented in the following table.

Table 15: Added value in each use case of the process.

Use Case	Added Value
Supply Chain Management Platform	Transparency in transactions
	Improved monitoring and optimization on S.C.M.
	Materials Traceability
Information platform	Long terms sharing of data in a predetermined way
	Give permission to predetermined actors to view specific data
	Reliability, immutability and trustiness in the stored data

As a result, after discussing all the possible benefits that blockchain technology could bring in this process, an answer to the main research question can be given. The main research question that was stated in Chapter 2 is:

"Which parts of the Reclaiming Asphalt Process could be improved through an artifact based on blockchain technology?"

The answer to this question could be derived from two different parts of the analysis. On the one side, the undoubted benefits that blockchain could bring in this process were extracted from literature review and have already been explained as added value. On the other side, there are several objections that were stated in the validation experts' panel and should also be considered.

Starting with the findings from the literature review, blockchain technology could be applied in the daily process of reclaiming asphalt mostly as a transaction' recorder. In this way, the supply chain management could be directly improved and several benefits to the total execution of the process could also be brought. In addition, its combination with an information platform could provide several advantages for the participants. Transparency, immutability and reliability are core characteristics of a blockchain system and could be used not only for improving the collaboration in the process but also for increasing the profits of the participating companies. The approach of future clients can become better and in this way the possibilities of executing more similar projects in the future will be higher. These benefits were also supported by the experts since they realised the importance of reliability and security that the system provides. Additionally, the improvement of competitiveness and productivity on the selected case study was one of their remarks.

On the other side, the efficiency of the presented system was questioned by the experts' panel. It could be assumed that the amount of work that is required for developing the proposed model will not be rewarded from the potential benefits that have been identified. Additionally, the better optimization of the process (one of the major improvements that was determined) was questioned since there are no new options provided concerning the information availability. In any case, the user environment of the system was one of the major concerns and that creates a difficulty for the conceptual propose to the actual implementation of the model. It is known that construction industry is not the easiest in adopting new technologies and as a consequence any proposed new technology will create concern to the users.

Furthermore, the use of decentralised information system instead of one common shared cloud was mentioned as a problem by the experts' panel since there will be need for more data storage. The centralised system that is used now provides a shared cloud with a specific storage ability that is used by all the participants. However, in the blockchain environment, the distributed ledger will demand local storage from each participant, and this is translated to higher cost. In addition, one of the major concerns that was highlighted in the validation is related to the legitimacy of the recorded data. Due to laws and regulations that do not allow the recording of personal information, a careful design and discrimination of the information should be proposed. The current system proposal, as it was presented in Chapter 4, has to be developed in further detail in order to ensure that there will be no violations.

As a consequence, the list of possible added value that the system could bring in the reclaiming asphalt process should be different, according to the findings of the validation part. In the following table, the benefits for each use case are presented.

Table 16: Possible benefits in the process, after the validation part.

Use Case	Added Value
Supply Chain Management Platform	Transparency in transactions
	Materials Traceability
Information platform	Long terms sharing of data in a predetermined way
	Give permission to predetermined actors to view specific data
	Reliability, immutability and trustiness in the stored data

6. Conclusion

On the final chapter of this report, a short summary of the analysis and that was conducted, and the respective results will be presented. The findings of this thesis along with some suggestions of improvement in the future are mentioned.

6.1. Research Summary

In the present study, the possibilities of implementing blockchain technology in reclaiming asphalt process were investigated. The main research question that was answered in this study was related to the parts of the process that could be improved. More specifically:

"Which parts of the Reclaiming Asphalt Process could be improved through an artifact based on blockchain technology?"

The answer to this question is also the main deliverable that was initially set. Two kind of use cases were proposed for the implementation of blockchain in RA process. On the one hand, blockchain could be used as a supply chain management platform while it could also support the process as an information platform. Both cases could contribute on the improvement of the process, by adding specific benefits that are presented in the following table.

Use Case	Added Value
Supply Chain Management Platform	Transparency in transactions
	Improved monitoring and optimization on S.C.M.
	Materials Traceability

Use Case	Added Value
Information platform	Long terms sharing of data in a predetermined way
	Give permission to predetermined actors to view specific data
	Reliability, immutability and trustiness in the stored data

However, a validation of these findings was conducted by some experts from the asphalt process. In this way, the possible benefits that the proposed model could bring would be assessed and a clear conclusion on its applicability came out. Starting with the supply chain management platform use case, the experts agreed on the added transparency in the transactions that could be brought. Additionally, the traceability of materials is an undoubted benefits that the system will bring, and it is of high importance for the participants. However, the possibilities of improvement and optimization of the process through the presented artifact were questioned by the panel. The manageability of information that the system provides was assessed as low and consequently the third benefit cannot be mentioned as a possible improvement. Concerning the second use case, all the benefits that are mentioned were assessed as highly important and the system that was presented will be improve this aspect of the process.

In the following table, the final list of the added value that the system can bring to the reclaiming asphalt process is presented.

Use Case	Added Value
Supply Chain Management Platform	Transparency in transactions
	Materials Traceability
Information platform	Long terms sharing of data in a predetermined way
	Give permission to predetermined actors to view specific data
	Reliability, immutability and trustiness in the stored data

After a long research on the possibilities of implementing blockchain technology in construction projects, several useful results came out and will be concluded in the following paragraphs. In order to answer the main research question that is addressed, several steps had to be taken in order to have all the necessary information. These steps were described as subquestions and their answers will be in short presented in the following paragraphs.

a. "What is the current process for reclaiming asphalt and which parties are involved?"

The answer in this subquestion came after long discussions and interviews with experts from the asphalt process, along with an extended study in the documentation of the companies that are involved. The reclaiming asphalt process is consisted of eleven steps and could be divided into three parts: i) the milling of RAP and transportation to the asphalt plant ii) the production of new asphalt iii) and the laboratory test and infrastructure life period.

The business network that was analysed in the selected case study of the present thesis is consisted of five stakeholders, that are: i) the client, ii) the asphalt producer that is the main contractor (BAM Infra Asfalt), iii) a subcontractor that is responsible for the milling and paving of asphalt (BAM Infra Regionaal West), iv) the suppliers and v) the transportation company.

b. "What is the information that is shared in each step of the process about?"

In short, the information that has to be exchanged during the process is related to three main topics: i) information about the production conditions (production report, paving report, etc), ii) results from the quality tests and iii) documents related to the supply chain, such as orders, deliveries, payments etc. The data that are exchanged during the reclaiming asphalt process were written down after analysing the currently used information system.

c. "Which are the problems that the traditional process has in terms of management of information?"

The main problem of the selected case study is related to the management of information and came out after interviews with experts from the involved companies. The data that are recorded are not distributed properly and as a consequence that creates difficulties on the opportunities for optimizing the process. Additionally, since the integration in some cases is not possible, high transaction costs are created with a direct effect on the efficiency of the process. This problem affects the supply chain management of the asphalt plant since it is difficult to coordinate the deliveries from the suppliers. Additionally, the coordination of the trucks that deliver the asphalt mixture in the construction site is not always perfectly executed and this has a direct impact in the levels of productivity of the asphalt plants.

d. "Which parts of the current strategy that the company follows could be improved?"

Both the use cases of blockchain technology that are investigated on the present study could be improved in the reclaiming asphalt process. This result came after combining the possible benefits of blockchain technology that are mentioned in the literature and the analysis of the case study that took place. On the one hand, the supply chain management could be better executed and lead to a more efficiency production process. On the other hand, a better information management could be achieved if an integrated information system is needed. There is a high need of real-time sharing of information and that could be achieved by a different information platform.

e. "Which are the requirements that an information system should serve in this specific project?"

After analysing the process, a list of design principles came out. In this way, the first sub-goal (System Requirements) of the research was delivered. In any case, the information system that will be used should serve the following requirements:

- Traceability of material processes
- Presentation of total project overview
- Include standards and regulations that should be followed
- Real time sharing of data in a safe and predetermined way
- Recording and Management of information in long terms period
- Reliability, immutability and trustiness in the stored data

f. "How should a blockchain artifact be technically organized in order to provide efficient recording and sharing of information?"

According to the suitability of traditional and blockchain information system with the aforementioned design principles, the following definition for the proposed model came out:

"A Consortium (Private Permissioned Network) Blockchain System, consisting of predetermined members and controlled by preauthorised nodes in which the data will be stored off-chain, in a private and third-party cloud."

The illustration of this model in two ways (a UML diagram and an online blockchain composer) was also carried out and in this way, the second sub— goal of the research was delivered at the end.

6.2. Reflection

The reflection of the present study could be divided into two parts. On the one side, there are the findings that are related to the scientific contribution of the research and derive mostly from the literature review and the conceptual design of the model. On the other side, the interaction with the construction industry reveled the societal relevance and the results are more related to the actual implementation of blockchain technology.

6.2.1. Scientific Relevance

The incentives of exploring the feasibility of a blockchain application in the construction industry came after identifying several benefits it could bring. More specifically, construction projects could be improved by blockchain technology in three aspects: i) supply chain management, ii) information sharing and iii) trust. Starting with the first problem, a possible improvement for the supply chain management of the selected case study came out after the present analysis. Benefits such as transparency and materials traceability that the proposed model provided could improve the supply chain management in the process. Information sharing is a major application of blockchain since the reliability and transparency in transactions that is provides can enhance the current information system. Finally, a trust issue was not noticed in the present business network. However, a high level of trust could be ensured in any case through the implementation of the suggested model, especially if also smart contracts were included in the system.

The contribution of the present study in the scientific community could be connected to the existing literature studies that have been carried out for the specific sector and process. More specifically, the potentials of blockchain technology in construction projects were previously discussed by several researchers (Turk & Klinc, 2017; Visser, 2018; J. Wang et al., 2017). However, this was the first time that an actual case study was used for designing a blockchain model. Additionally, the application of blockchain technology in the supply chain management of the selected process was investigated and the research resulted in some possible validated improvement, supporting existing scientific research that stated similar findings (Abeyratne & Monfared, 2016; Cheng et al., 2010; Engelenburg et al., 2018). Furthermore, the feasibility and effectiveness of the proposed model was validated by experts of the process and in this way, solid results about the potentials of implementing blockchain technology in construction sector came out. Speaking more specifically about the selected case study, the improvement of its supply chain management of the reclaiming asphalt process through a different information system was tried out and the connection of several parts of this process (information sharing, supply chain management, levels of circularity and productivity) was investigated in the present research. This is an investigation that has not been discussed in the existing literature study and the findings of the present research will rise further concerns for the possible ways of improving the selected process.

6.2.2. Societal Relevance

The societal benefits of the proposed model could mostly be focused on the involved companies. In the findings of the present study, an improvement of their policy on approaching future clients could be achieved. The immutability of information that a blockchain information system provides will increase their reliability and as a consequence, the trust in the data that they provide to their client will also increase. This is also demonstrated by the opinion of the experts that assessed the proposed model. Mode specifically, they left some indications that the competitiveness of their companies could be improved by implementing this information system.

Since the selected case study is related to circularity any possible improvement in this part of the process could benefit not only the involved companies but the whole society. The environmental impact of the production of new asphalt can be decreased if the percentage of RAP that is used is increased. During the analysis of the process and the evaluation of the proposed model, there were some indications that the level of circularity in the process could be improved. Additionally, the experts implied that the productivity of their companies could be improved. That can also be translated as a more efficient use of human resources and materials which will also bring environmental benefits. Consequently, a positive reflection in the society could be also brought by the implementation of the proposed model. However, a more extended (quantitative, if possible) analysis is required in order to define its benefits in comparison to the cost of the implementation.

6.3. Recommendations

In the present research, the Design Science Research approach was used, consisted of four steps and a redesign loop, after the "Validation and Evaluation" step (Figure 11). However, the four steps were apart from the last part, which is the redesign of the proposed artifact, based on the findings of the evaluation part. As a result, there are several recommendations that should be considered in the future for this step and some of them will be mentioned in the following paragraphs.

Starting with the technical feasibility of the proposed model, the use of a blockchain environment (Hyperledger Composer) to illustrate it, definitely contributed to it. However, the high level that this design was developed left some questions concerning its technical verification. For this reason, it is important to discuss this topic with some blockchain experts that will verify that this suggestion can for sure be developed. This discussion will also contribute in the assessment of the selected model description (Private Permissioned Network) and at the end, an improvement of the proposal may arise.

This was also depicted on the low assessment of the model concerning its efficacy that took place in the validation. The fact that the experts could not have a clear illustration of the user's interface and the abilities it could give them, forced them to question its efficiency and usability. On the next step of the research, it would be crucial to ask the support of a software development company in order to present a more detailed and user-friendly version.

An additional way to define the level of efficiency of the proposed model would be to conduct a cost-benefit analysis. The development of an actual business case around this proposal and the identification of all the benefits that could be brought for the participating companies would make its efficiency higher and would increase the possibilities of implementing it.

Additionally, there are some omissions on the presented research that should be mentioned. First of all, in the introduction part an extended discussion was carried out concerning the benefits that smart contracts could bring in construction project. However, in the proposed model all the actions that are allowed seem to be executed manually. The investigation of a further implementation of smart contracts in the process in order to improve the transaction costs (especially in the supply chain management use case) would be very interesting for future research.

There is a critical part that was mentioned in the validation part and was not investigated at all in this research. The legitimacy of the proposed model should be investigated in order to ensure that everything is in accordance with the existing laws. Such an example of this is the recording of personal information that is currently not allowed. It should be carefully treated in the proposed model since in some cases it is necessary to record real time data and that will violate some of the regulations.

An important issue concerning the sharing of private data derive from the General Data Protection Regulation (GDPR). A solution concerning the implementation of blockchain technology concerning the limitations of this regulation is the use of private and permissioned networks (the type that is proposed in the present study) since all the nodes are known and thus, the sharing of private data can easier be controlled. However, this only minimize the problem since there is always the need for recording private data of the end users. As a result, it can be conclude that blockchain applications can be comply with the directions of GDPR, but there are still some parts that need to be reconsidered (Van Baren, 2019).

Furthermore, one of the primary goals of the present study was the improvement of circularity. The main reason for selecting this process as a case study was its direct connection with additional environmental benefits. However, during the process analysis part, a clear answer on the connection of the information system with the increase of RAP never came. There are some indications that the improvement of the data management could lead in an optimization of the process and consequently in an increase of the circularity. However, it cannot be declared from the existing findings, there was not specific data that were found during the process analysis that there is a clear connection between the information system that is used and the respective percentage of RAP. An extended research (even quantitative if it is possible) that will depict the connection of information system and levels of circularity should be carried out in the future. In addition, some indications in the validation part related to the increase of competitiveness and productivity create the need of investigating these possibilities. It is crucial to define if other parts of the companies' policy could be improved through the proposed information system.

At this point, it is important to mention that there are several challenges that have to be solved before the actual implementation. It is crucial to understand that the design of this model should be focused on the daily activities of the selected process. In the present study, the model was described in a High-Level Architecture and the concept seems to be feasible. Blockchain technology can be an effective solution for the process that was described. However, an extended analysis on the reclaiming asphalt process, the people that participate and the actions that are executed in a further detail is required. In this way, a clear implementation plan can be designed that will leave no doubt on its applicability in this process.

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Part IV

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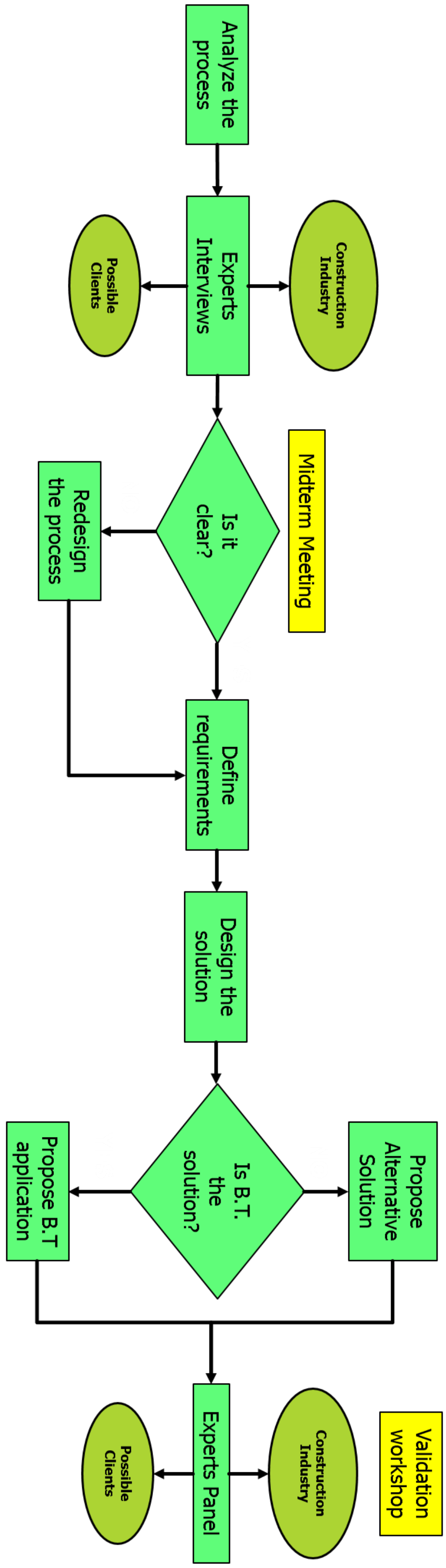
Appendices

Appendix A: Research Plan Flow Chart

The present research is a feasibility study of blockchain applications in reclaiming asphalt process and the research plan is consisted of two parts. First of all, the asphalt process was analysed after long meetings and interviews with experts that work on the process. Then, after assessing if the findings of the process analysis were enough, the second part of the research started. At the starting point, the requirements that the system should serve were defined and the answer in the question if blockchain is the solution was given. At the final part, the proposed model was decided and presented and a validation workshop with experts from the asphalt process was conducted in order to extract some conclusions about the applicability, effectiveness and feasibility of the proposed system.

Figure 35: Research Plan Flow Chart (own Illustration).



Appendix B: Reclaiming Asphalt Total Process

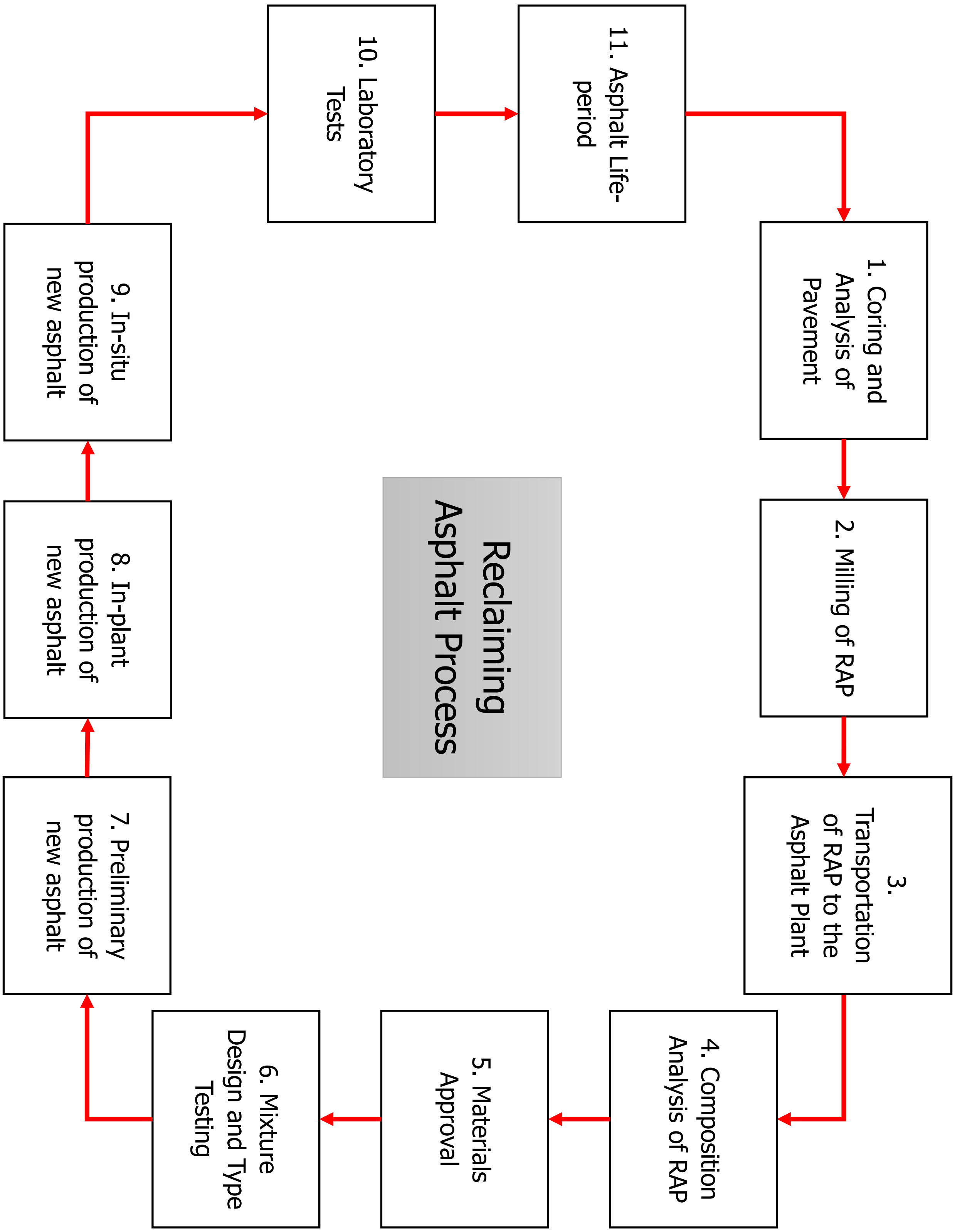


Figure 36: RAP (own Illustration).

Appendix C: Information table

During the process analysis, an overview of what information is included in the process should be defined. In this way, the role of the participants in each steps will also be defined, and it will be easier to identify specific problems or inefficiencies in the information management that take place. The data that are presented in the following table were extracted from documentation that was used for designing the previous information system of BAM Infra and are presented in a following appendix (Appendix E).

Table 17: Information included in the process.

Steps	Information Recorded
Coring and Analysis of Pavement	Quality and Composition of Asphalt Layers
Milling of RAP	Amount of Rap produced
	Milling Process Report (Conditions, Equipment used, etc.)
	Transportation Report (Weather and Traffic Conditions)
Composition Analysis of RAP	RAP materials analysis & composition
Materials Approval	Material Requirements
	Approved Materials Properties
Mixture Design	Mixture Requirements, Design Method, Composition and Roughness Measurements
	Target Composition & Density
Preliminary Production	Production Requirements, Design and Target Composition, Material Quantities, Prices and Surcharges, Project and Company Planning, Initial Stock of Supplies
	Composition
	Stock Materials
	Production Schedule
	Preliminary Investigation
In-Plant Production of new asphalt	Material & Mixture requirements
	Production Report (Conditions, Equipment used, etc.)

Steps	Information Recorded
	Delivered Mixture
In-Situ Production of new asphalt	Inspection Plan and Materials Requirements
	Approved Materials
	Process & Inspection Report (Conditions, Equipment and Assessment of Process)
Laboratory Tests	Innovative Tests and Procedures
	Tests Results
Asphalt Life-period	Traffic Volume and Loads

Appendix D: Interviews with five Asphalt Experts

Expert 1:

Introduction:

- The meeting was arranged during the first weeks of the literature study, during the research for a suitable case study for blockchain technology. Alternative processes that BAM follows on producing asphalt were discussed. Some innovative alternative processes that the company has (aiming in using almost 100% RAP) were rejected due low frequency of execution. In conclusion, the traditional process of producing asphalt with some use of RAP was selected since it is a daily process with a huge amount of transactions and information included.
- The main topics that were briefly discussed was the general process for reclaiming asphalt, who is involved and what actions are accomplished during this process.
- Additionally, more contacts were given for discussing the idea of using blockchain technology in the reclaiming asphalt process with experts from this project.

Summary:

<u>Comments on the Business Network:</u>

- The participation of BAM Infra Regionaal West and BAM Infra Asfalt was mentioned and their role in the process that is followed was briefly introduced.
- For more information on the role of the stakeholders in the process, several contact details of people from different departments were given.

<u>Comments on the Process Analysis:</u>

- In this meeting, the five main steps of the process were mentioned, and the role of the respective stakeholders was also briefly explained. In short, there are 1) Road life period, 2) Milling of RAP, 3) Analysis of RAP, 4) Production of new asphalt, 5) Transportation to the site and 6) Paving.

Expert 2:

Introduction:

- Head of Technology, mostly focusing on the quality of materials.
- This meeting took place in 28th of February 2019, in the office of BAM Infra Asfalt, in Culemborg.

Summary:

Comments on the Business Network:

- There are BAM venture companies that also participate in the process (such as BAM Infra Regionaal West).
- The transportation companies are not in BAM Group.

Comments on the Process Analysis:

- During the process, there are tests that analyse the product development in order to improve the process.

Comments on the Information Sharing Platform use case:

- Every step of the process should be involved in the database, in this way the existing information database has been structured.
- The percentage of RAP used in the mixture is directly connected to the quality, consequently it is important to know as much as possible.

Comments on the SCM use case:

- It is important to know the "material passport", clients want to know what is included in a piece of asphalt. Consequently, traceability of materials and asphalt mixture is important.
- A combination of the percentage of equipment used (such as trucks) with the productivity rates of a project could be connected and help assess and optimize the process.

Expert 3:

Introduction:

- Advisor in BAM Infra Asfalt, mostly in consulting for paving technologies not only in the Netherlands.
- The main incentive for meeting him was that there is a need for analysing huge
- The meeting took place in the office of BAM Infra Asfalt in Culemborg, in 19th of Marth, 2019.

Summary:

Comments on the Business Network:

- Usually clients doubt about the use of all the recorded data that they receive. However, Rijkswaterstaat recently realized that there is a huge amount of information for specific projects that are stored in contractor's databases and they cannot access them. So, in came of changing the contractor in the future, all the information will be also lost.
- The willingness that BAM shows on sharing information is not also noticed in most of the competitors. However, governments put pressure on that.

Comments on the Process Analysis:

- The first step in the process is the coring on existing roads, in which composition analysis of the removed asphalt takes place. This is an action that should happen very usually.
- The main target is to investigate the quality of pressured pavement and composition of asphalt. Moving further, it is tested in the asphalt plant for the tar composition, but it is also tested for the quality of the RAP that will be delivered in the asphalt plant.
- Due to lack of storage space in the asphalt plant, the RAP reclaimed from different project is mixed in piles according to the quality categories. Consequently, it is difficult to track which product came from which project. However, it is useful to now the total quality of the RAP in the pile and share it with clients and the production department.
- There is investigation of the RAP also in the pile to know if it agrees with the previous findings and the mixture from different projects did not affect the total quality. The goal is to achieve homogeneity and get a quality with good standards deviation. Roughness measurement is also important in long terms.
- Concerning the measurements that take place during the project lifecycle, there is no standard answers. For the 80% of the projects, only visual inspection during the guarantee period (3-5 years) to ensure that the pavement is still in high quality.
- For longer contracts projects (DBFMO contracts, that BAM takes mostly outside of the Netherlands), there is a need to track the traffic volumes and

loads, using weighing system. This is done due to the fact that a specific quality must be delivered. The DBFMO Contracts give high for better maintenance and need for using public data. Also, in this case, there is trust on the provided data even if the measuring systems face some problems. This is not a trust problem.

Comments on the Information Sharing Platform use case:

- The validation of information that cannot be changed can be an advantage.
- On the other hand, the availability of information is a biggest issue than trust, usually stakeholders trust each other for the shared data.
- The immutability of information for the future is also an important aspect that could be used since no one should be able to change the data. That would be considered as a fraud.

Comments on the SCM use case:

- Indeed, SCM is the part that needs improvement because when you see the data from trucks tracing and monitoring, the productivity is 47% working, 53% waiting for asphalt. Obviously, it cannot be 100%, but 47% is too low and a huge part of delays is due to unavailability of trucks to transport the asphalt in the construction site.
- An improvement of this part could obviously lead to higher profit and better quality on the final provided product.
- The problem in this case is not a matter of trust but of using the available data in an efficient way. Blockchain could help through smart contracts on decreasing the transaction costs between contractor and suppliers and at the end make the process automatic, safer, faster and more efficient.

Expert 4:

Introduction:

- Director of Production in the West Region of The Netherlands for the roads.
- The meeting took place in the office of BAM Infra Regionaal West, in Den Haag in 10th of April 2019.

Summary:

Comments on the Business Network:

- BAM Infra Regionaal West mostly participate in the milling process and provide RAP to the Asphalt Plants. Then, also do the in-situ pavement and is also indirectly connected to the client. It could be considered as a supplier and a client of BAM Infra Asfalt on the same time.

Comments on the Process Analysis:

- There are no missing parts on the process, as you can see there are so many steps, but the quality of the final product is decided into two or three sub-steps.

Comments on the Information Sharing Platform use case:

- This department would be interested in knowing the quality of asphalt they buy, also for sharing with the clients. This would help on competing in tendering with the advantage of trustworthy provided quality.
- If the information of how asphalt was produced and paved is available, then will know which parts of the road should milled and treated.
- The planning of the process could also be optimized if all the information about what had been done is available.
- It would be also helpful if through an information platform can know what all the contractors do.
- In terms of information availability, the most useful part would be to have a total overview of the quality that was provided in an infrastructure and not small parts in order to share it with clients and proof that the provided quality was what was agreed.

In this asphalt expert, the information table of Appendix C was given, in order to characterize it as:

-not important (red)

-useful to be shared (green)

-confidential, not for sharing (yellow)

This assessment was used for designing the information platform in Chapter 4, according to the requirements of the involved stakeholders.

Table 18: Information table, including assessment from an asphalt expert.

Steps	Information Recorded
Coring and Analysis of Pavement	Quality and Composition of Asphalt Layers
Milling of RAP	Amount of Rap produced
	Milling Process Report (Conditions, Equipment used, etc.)
	Transportation Report (Weather and Traffic Conditions)
Composition Analysis of RAP	RAP materials analysis & composition
Materials Approval	Material Requirements
	Approved Materials Properties
Mixture Design	Mixture Requirements, Design Method, Composition and Roughness Measurements
	Target Composition & Density
Preliminary Production	Production Requirements, Design and Target Composition, Material Quantities
	Prices and Surcharges, Project and Company Planning, Initial Stock of Supplies
	Composition
	Stock Materials
	Production Schedule
	Preliminary Investigation
In-Plant Production	Material & Mixture requirements
	Production Report (Conditions, Equipment used, etc.)
	Delivered Mixture
In-Situ Production of new asphalt	Inspection Plan and Materials Requirements
	Approved Materials
	Process & Inspection Report (Conditions, Equipment and Assessment of Process)

Steps	Information Recorded
Laboratory Tests	Innovative Tests and Procedures
	Tests Results
Asphalt Life-period	Traffic Volume and Loads

Comments on the SCM use case:

- The application on SCM for coordinating and monitoring orders, payments and all kind of transaction could also be very beneficial.

Expert 5:

Introduction:

- Responsible for the personnel, maintenance of materials and equipment and optimization of the process.
- This discussion was a phone call that took place in 11^{th} of April 2019.

Summary:

Comments on the Information Sharing Platform use case:

- In order to improve the current process and the productivity not only of equipment but also the personnel, it is important to know as much information as possible. For example, the quality information is important to be distributed in a fast and reliable way to all the interested participants.
- The problem that all information systems faces nowadays is that the information can change, there no immutability. This creates trust and reliability problems.

Appendix E: Asphalt process documentation

The following figures were deducted by the documents that BAM Infra Asfalt used for designing its existing information system for asphalt production, which is called Pavement Information Model (PIM).

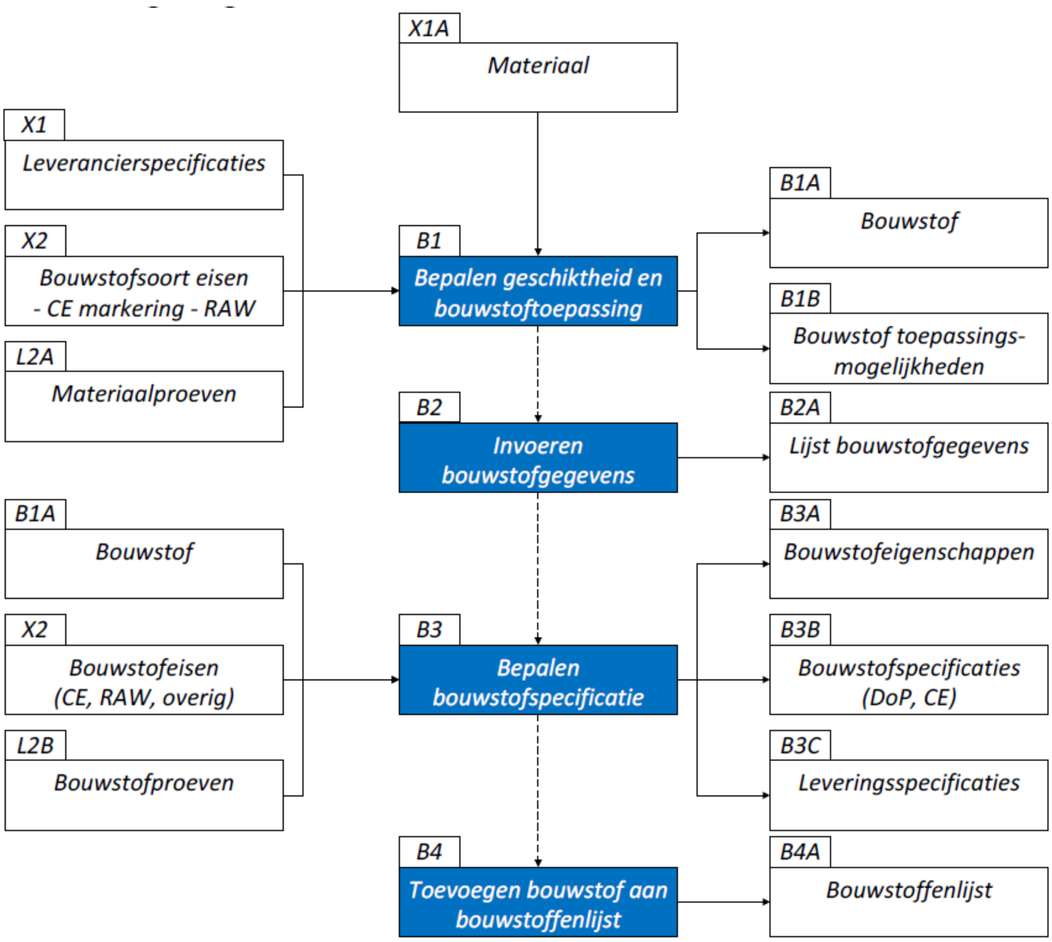


Figure 37: Materials Approval.

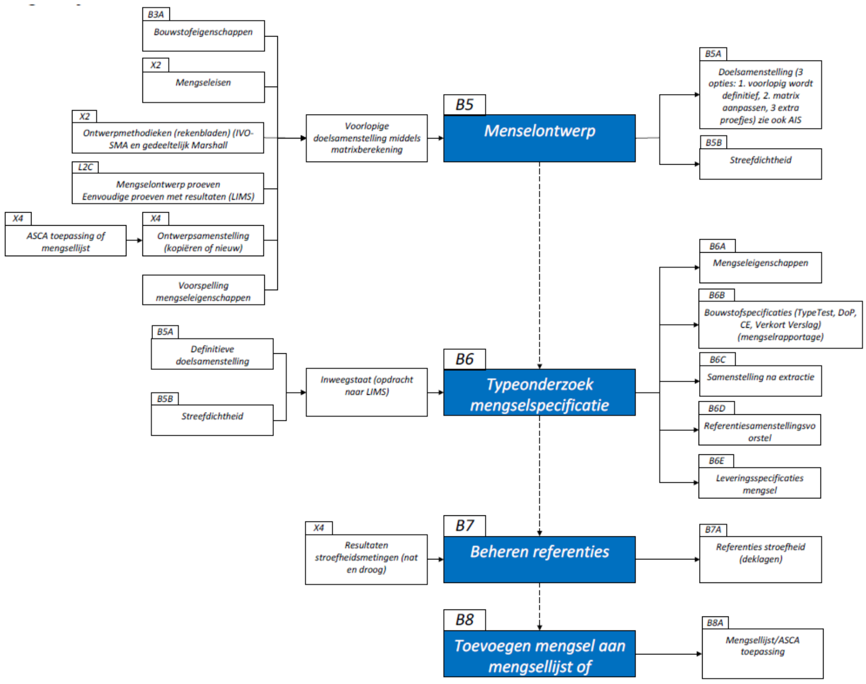


Figure 38: Mixture Design and Type Testing.

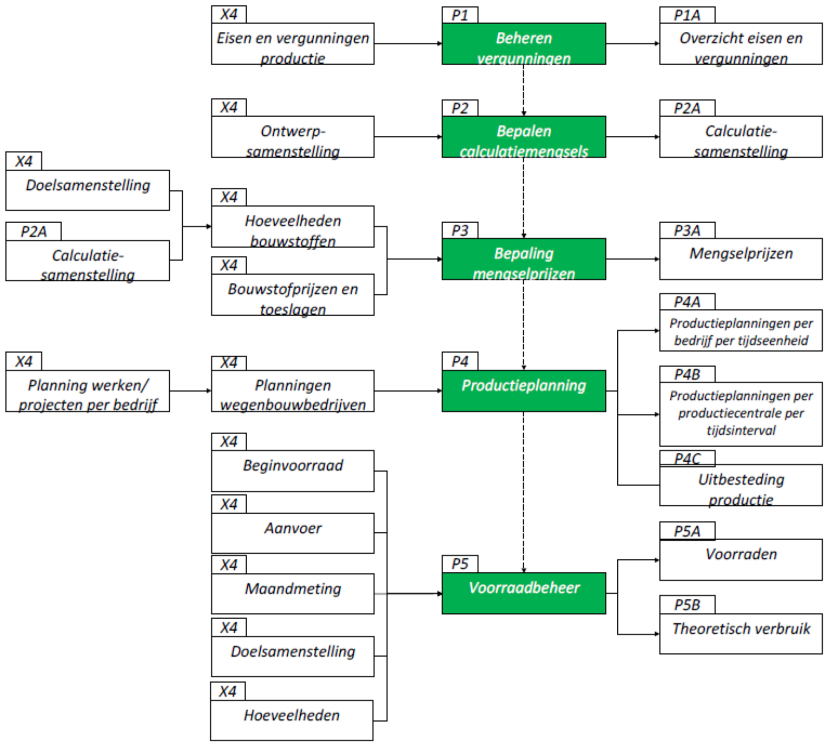


Figure 39: Preliminary production of new asphalt.

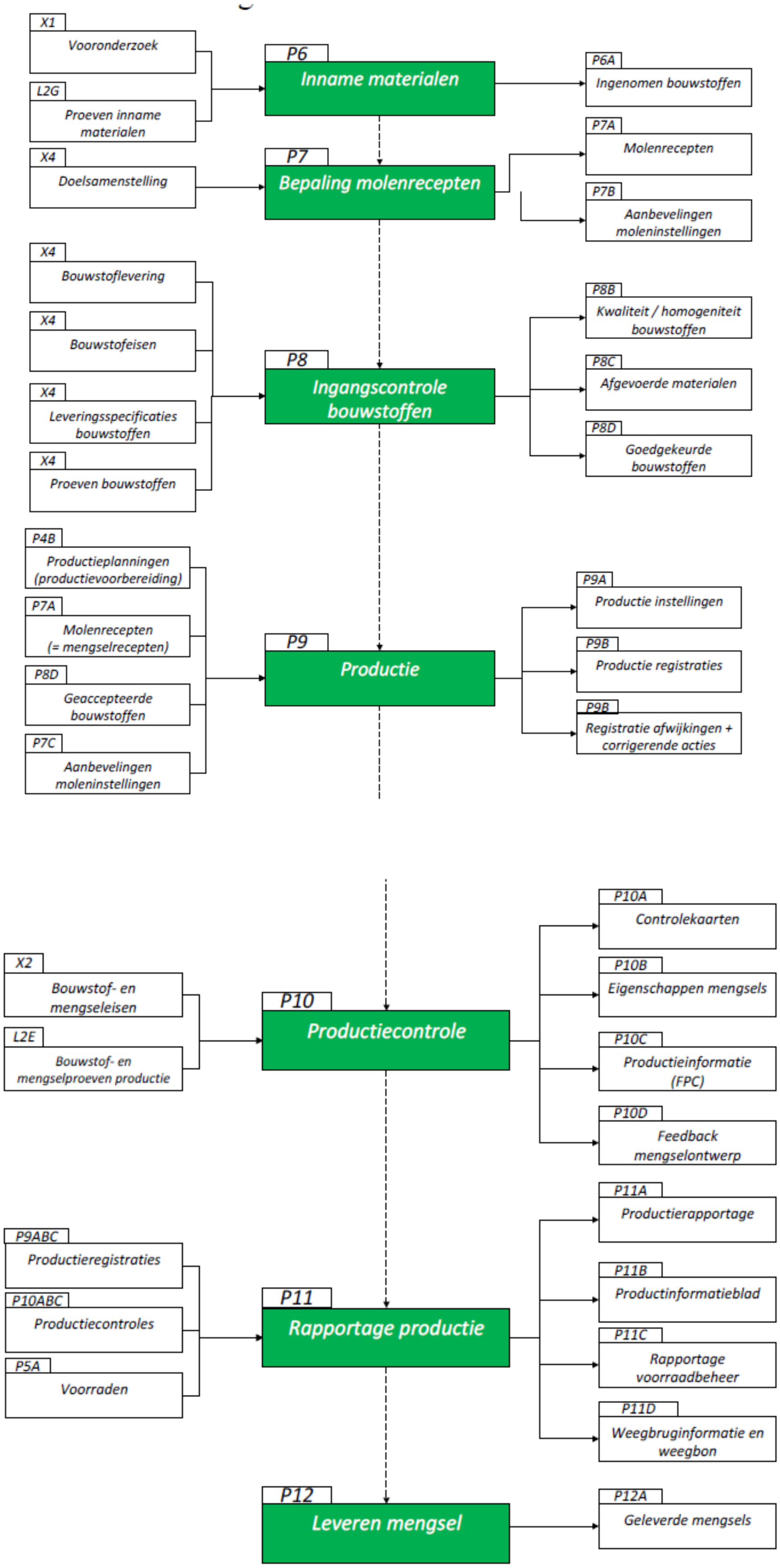


Figure 40: In-plant production of new asphalt

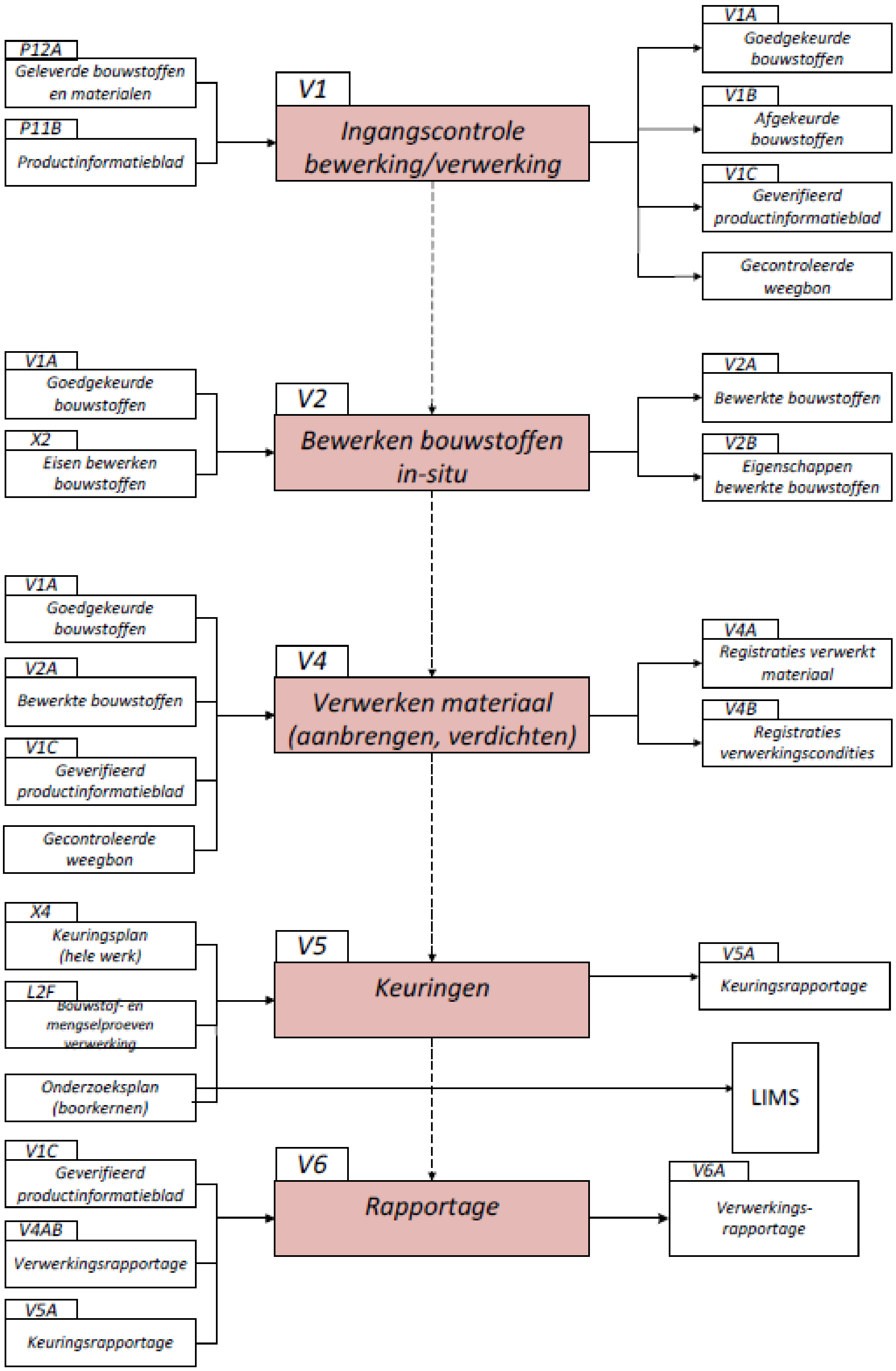


Figure 41: In-Situ Production of new asphalt.

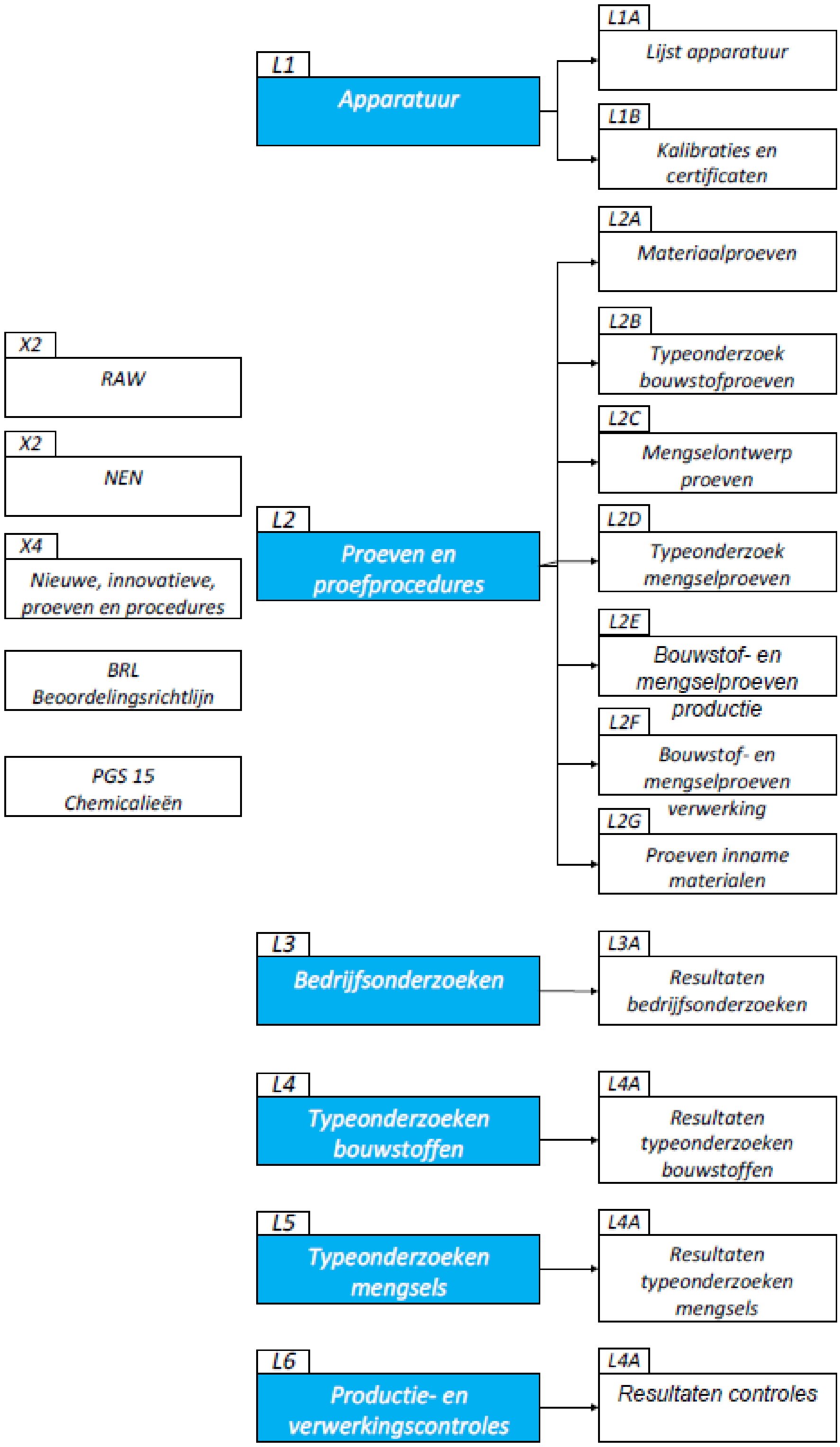


Figure 42: Laboratory Tests.

The following figure is the asphalt production as it is described by BAM Infra Regionaal West:

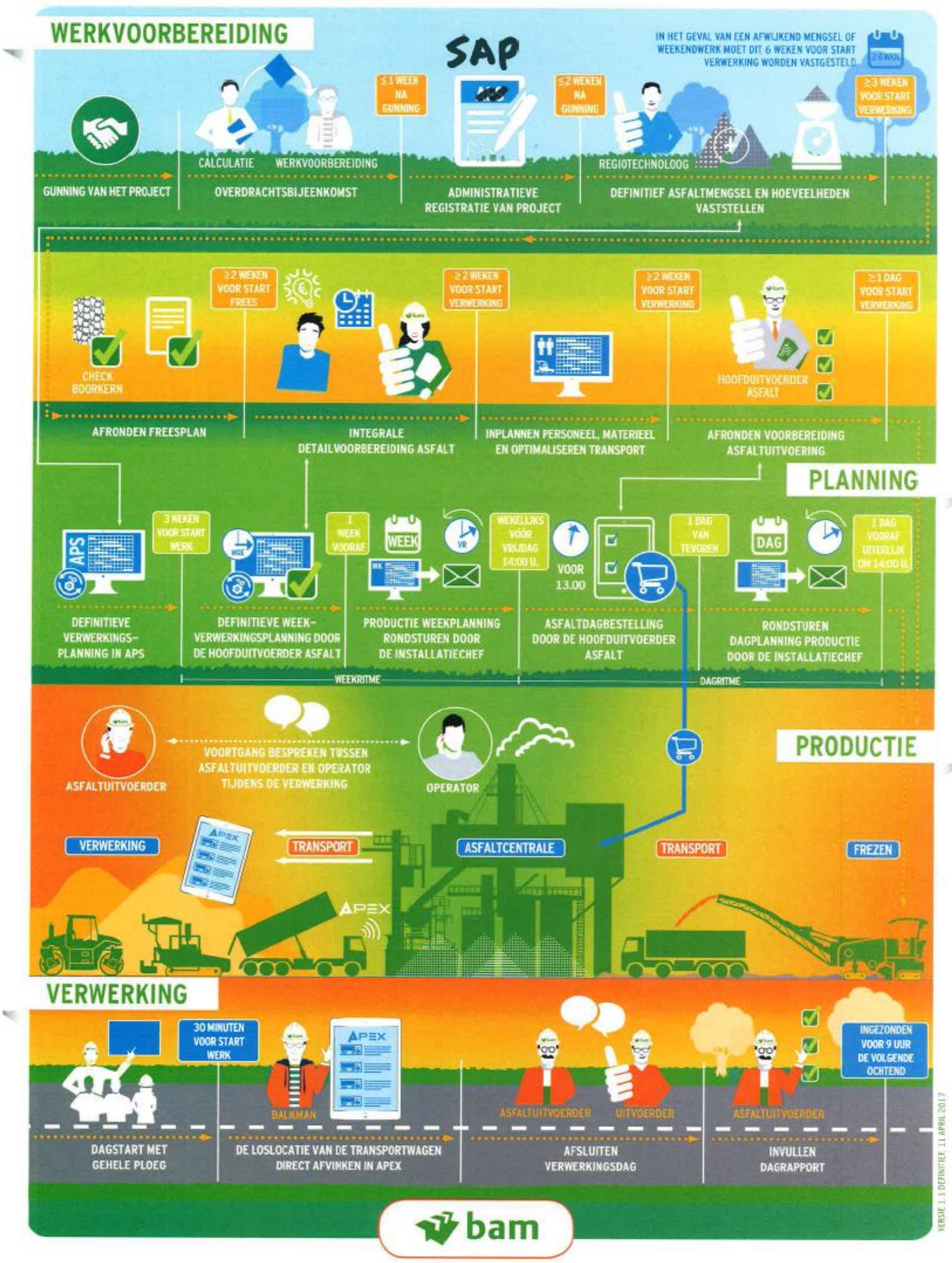


Figure 43: The asphalt production process from BAM Infra Regionaal West perspective.

Appendix F: Blockchain Ontology Matric

(next page)

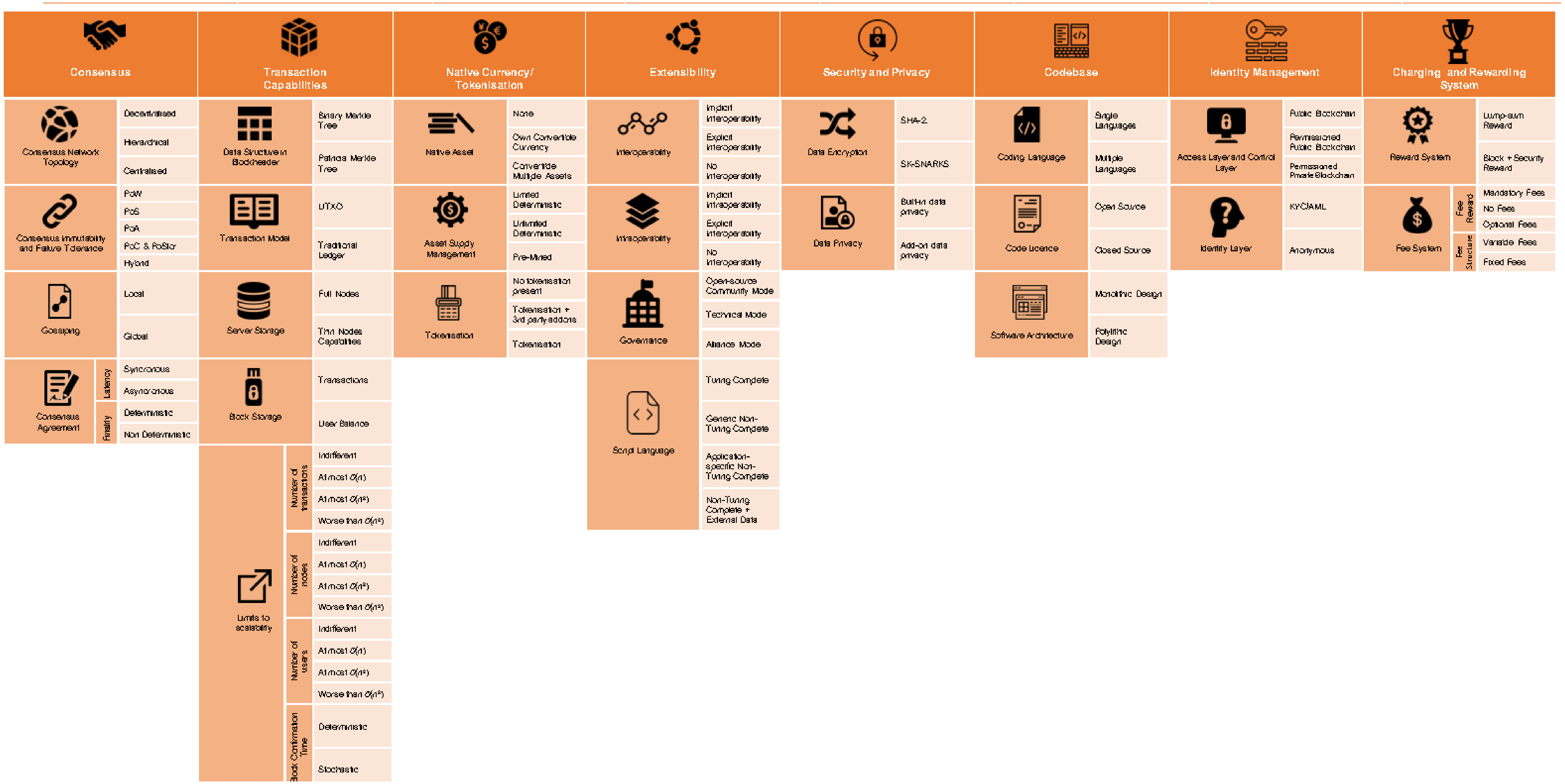


Figure 44: Blockchain ontology matrix (Tasca & Tessone, 2019, p. 55).

Appendix G: Applicability of Blockchain Technology

The following decision tree was used for assessing which type of blockchain is needed in the selected case study. The path that was followed according to the decisions that had to be taken in this study are coloured in purple. The final suggestion from this research according to the characteristics of the selected case study is **Private Permissioned Blockchain**.

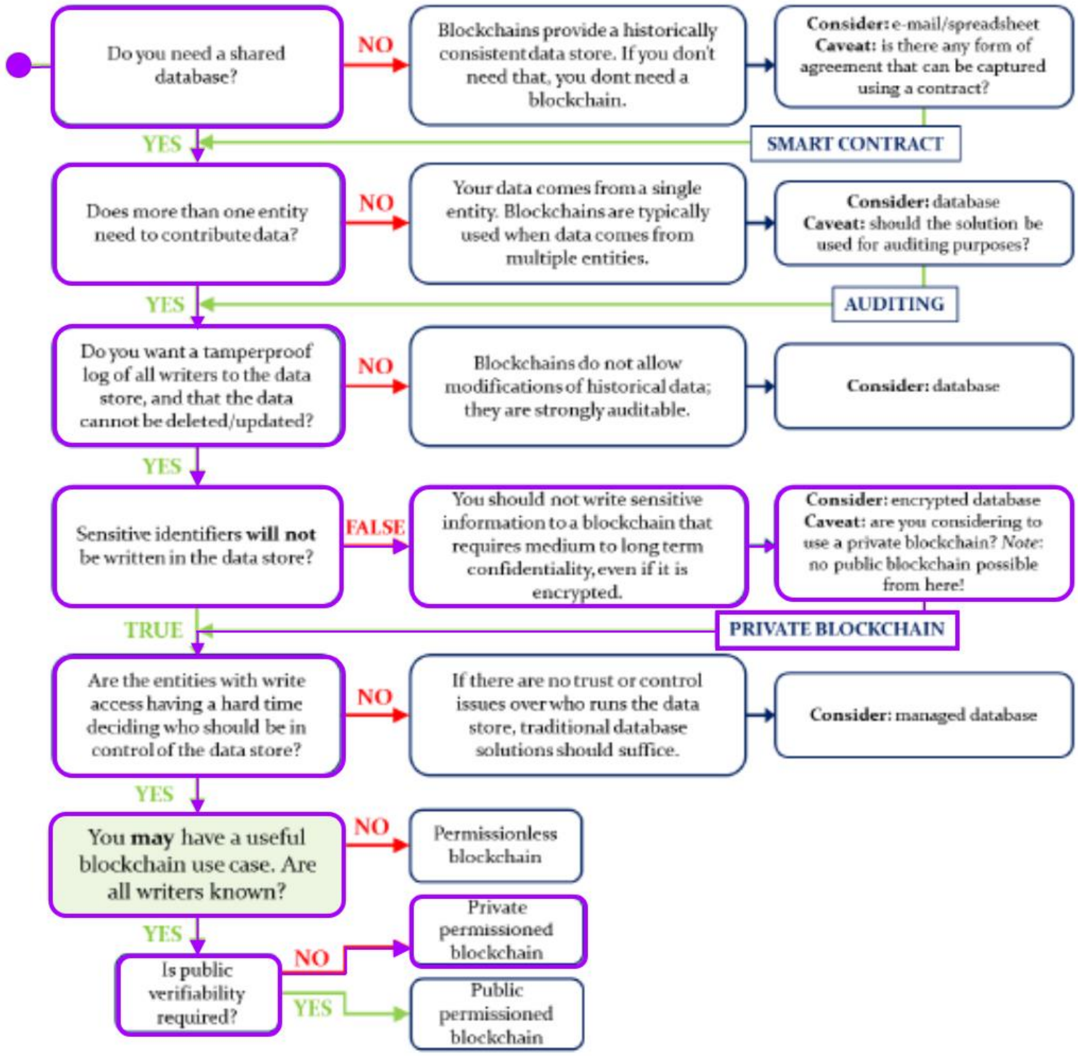


Figure 45: Path for assessing applicability of Blockchain Technology (Seuren, 2018, p. 35).

Similar to the previous decision tree, the following that was designed by Suichies demonstrated that a **Hybrid (Public-Private) Blockchain System** is required. The path that should be followed in deciding which type will be selected is also presented.

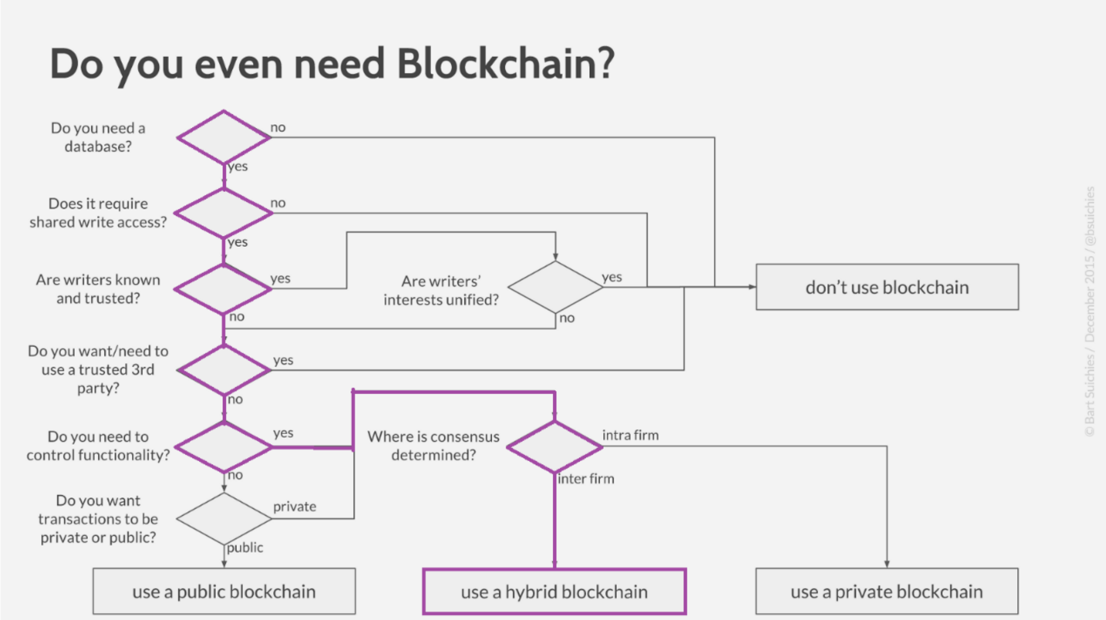


Figure 46: Decision tree on what blockchain to use (Suichies, 2015).

The final study that was used in this thesis for choosing the structure of the proposed blockchain system was introduced by Xu et al. in 2017 (Figure 47). In this study, the first part could be considered as a decision tree while the second part is consisted of several questions that should be addressed in the design of the system.

For answering the first part of this model (Trust Decentralisation), the characteristics of the reclaim asphalt process is selected. In the next two, technical characteristics should directly be decided and for answering these parts, the blockchain ontology components that were presented in the previous appendix were used.

Finally, especially for the implementation of blockchain in BIM application, the study of Turk and Klink was used, in which four options are given. More specifically, the four options are: 1) chained and very decentralised system, 2) chained and slightly decentralised system, 3) unchained and 4) blockchain of BIM transactions (Turk & Klinc, 2017). In this research, the third option (**Unchained Blockchain System**) is selected, in which the fingerprints and maybe the metadata of each block are stored in the blockchain system and the original files are stored in a cloud.

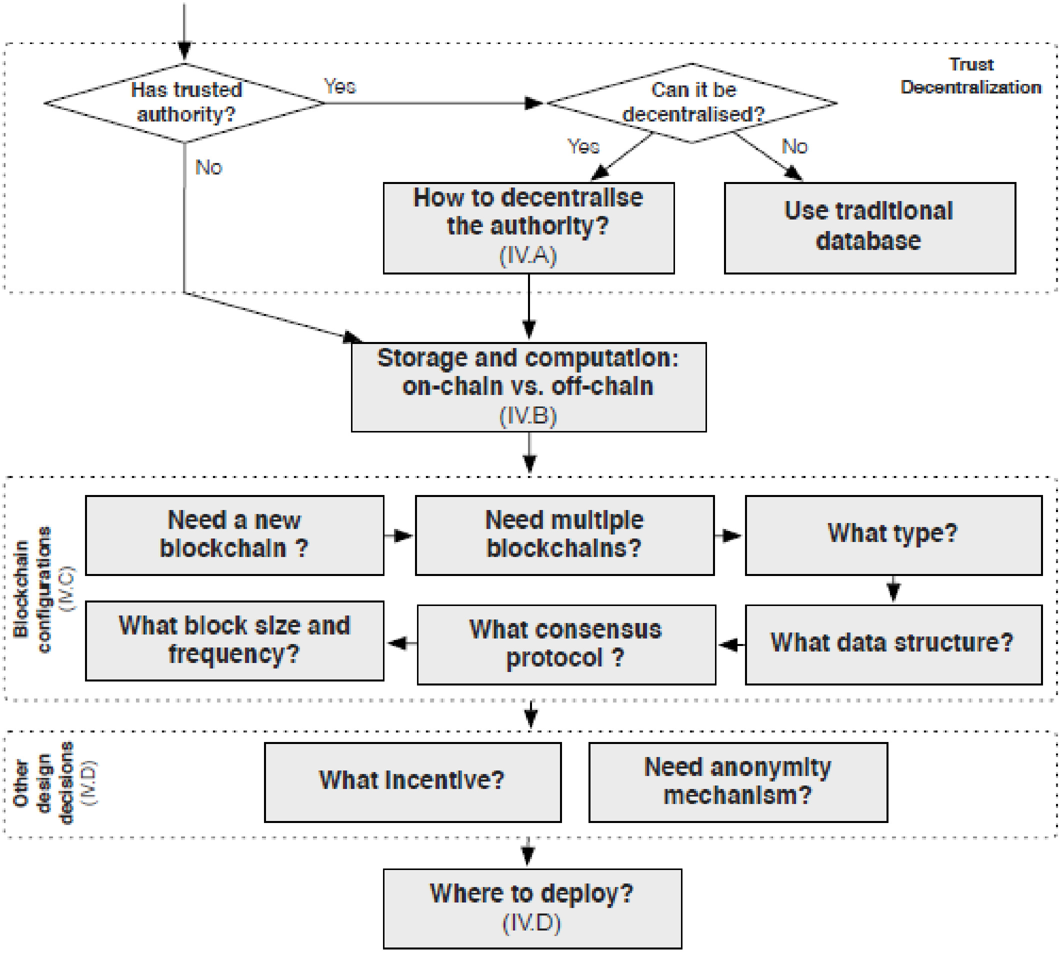


Figure 47: Blockchain design decision tree (Xu et al., 2017, p. 10).

Appendix H: Sequence Diagram

The sequence diagram is a type of UML diagrams that is used for presenting and analysing business processes. In general, there are many components and functions that can be used in this type of diagrams. However, on the present study only a small number of them was used. In the following paragraphs, a short explanation will be presented in order to make the information that is included clearer.

Starting with the top part of the figure, the objects-participants that are included in the process are presented in the boxes. In our case there four main participants (Supplier, BAM Infra Regionaal West, BAM Infra Asfalt -Asphalt Plant and Bam Infra Laboratories). Each box has a dotted line bellow it that indicates its lifetime on the process. The interactions between them are presented as lines (either solid or dotted) that indicate the messages-actions that occur (Fowler, 2004).

In order to present the cyclical characteristic of the process, a Loop frame is used. That frame indicates that all the activities that take place in it are repeated. Additionally, the Alternative frame is used that could be compared to the logical conditions that are used in software development. In this frame, there are two alternative ways that are mentioned in the brackets and are separated by a dotted line. Finally, each lifeline is covered with a box in the parts that the respective object is active. In this way, it is easily to understand which part is more critical for the process (Fowler, 2004).

In the following part, the sequence diagram that was designed will be presented in order to make clear the information that is provided to the reader. The participants of the network are presented in bold. The transactions that contribute in the information platform use case are coloured in red while the supply chain management transactions are green.

Loop:

- **BAM Infra Regionaal West** **provides the RAP** to the **Asphalt Plant**.

- The **Asphalt Plant** sends it to **BAM Infra Laboratories** for **analysis**.

1st Alternative:

- If the RAP is not good for use, it is sent back to **BAM Infra Regionaal West** for waste.

Otherwise:

- The **Asphalt Plan**t **requests the needed amounts of raw materials** from the **Supplier**.

- The **Supplier** **provides the raw materials** and the **Asphalt Plant** sends them in the **Laboratories** for **analysis**.

2nd Alternative:

- If the materials are not approved, the **Asphalt Plant** sends them back for waste.

Otherwise:

- The materials are approved and are used in the **Asphalt Plant** for producing the required asphalt mixture. **The mixture is delivered** to **BAM Infra Regionaal West** that does the paving.
- After the paving, **BAM Infra Regionaal West** sends the **production report** to the **Asphalt Plant**.
- The **Asphalt Plant** sends the mixture to **BAM Infra Laboratories** for type testing and receives back the **quality report**.
  [end of 2nd Alternative]

[end of 1st Alternative]

[end of Loop]

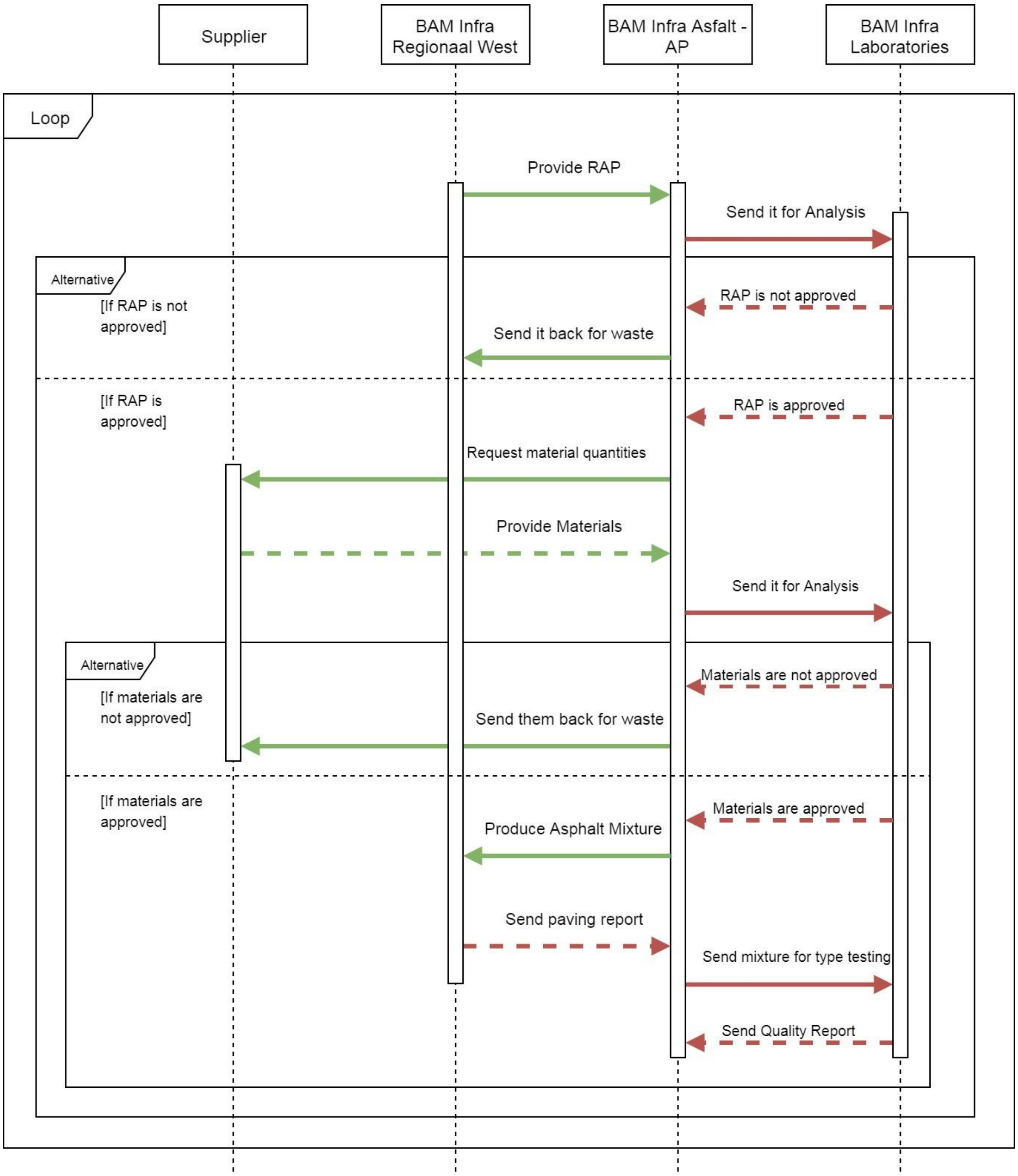


Figure 48: Sequence diagram for the Reclaiming Asphalt Process (own illustration).

Appendix I: Hyperledger Platform

At the fourth chapter of the report, Hyperledger was used for the illustration of the transactions that could be included in the proposed model. In this part, this technology will be explained in order to make it clear for the reader in case of personal interest or further research. All this information was extracted from the documentation report that was released by Hyperledger in 2019 (hyperledger, 2019a). Additionally, the configuration of the model that is introduced in the main report along with all the steps that were done will be explained in further details.

Hyperledger is an open- source permissioned distributed ledger platform that runs under Linux Foundation. Its enterprise context has developed many different applications such as digital music delivery and it the first distributed ledger platform that enables smart contract programming in general purposes applications. For the development of an application in this platform several languages such as Java and GO are used (hyperledger, 2019a).

This platform is permissioned and that means that is ideal for designing blockchain applications around a business network that the participants know each other and there is already a level of trust between them. However, the consensus protocol can be pluggable and enable the platform to be more effectively customized to fit particular use cases and trust models Finally, the use of a native cryptocurrency is not required and this make the feasibility of this platform more broad in different use cases such as documents trading (hyperledger, 2019a).

For designing a simple business network and execute some transactions in a blockchain environment, the Hyperledger Composes Online Playground can be used. In order to set up this system, several main documents should be modified (Figure 49). At first, the model should be described in detail in the Model File (.cto). The Hyperledger environment is mostly consisted of three parts, the assets, the participants and the transactions (there are also events that can be used). In the model file, the characteristics of these properties are set and described.

The second file that should be modified in the Hyperledger Composer is the Script File (.js). In this file, the transaction functions that will be executed in the system (such as trading, deleting or adding assets, etc.) are included. This file is also called Smart Contract since the automatic execution of transactions is also possible. However, this is not the general case, also manual execution can be modified.

The rules of the system that have direct impact on the consensus, the security and privacy of the blockchain application are described in the Access Control (.acl) file. The discrimination in "read" and "write" ability that the participants will have should be set in this document. By default, in the composer the access is denied to the participant and consequently the required abilities should be mentioned in detail. Finally, the Query File (.qry) is used for extracting specific data from the system.

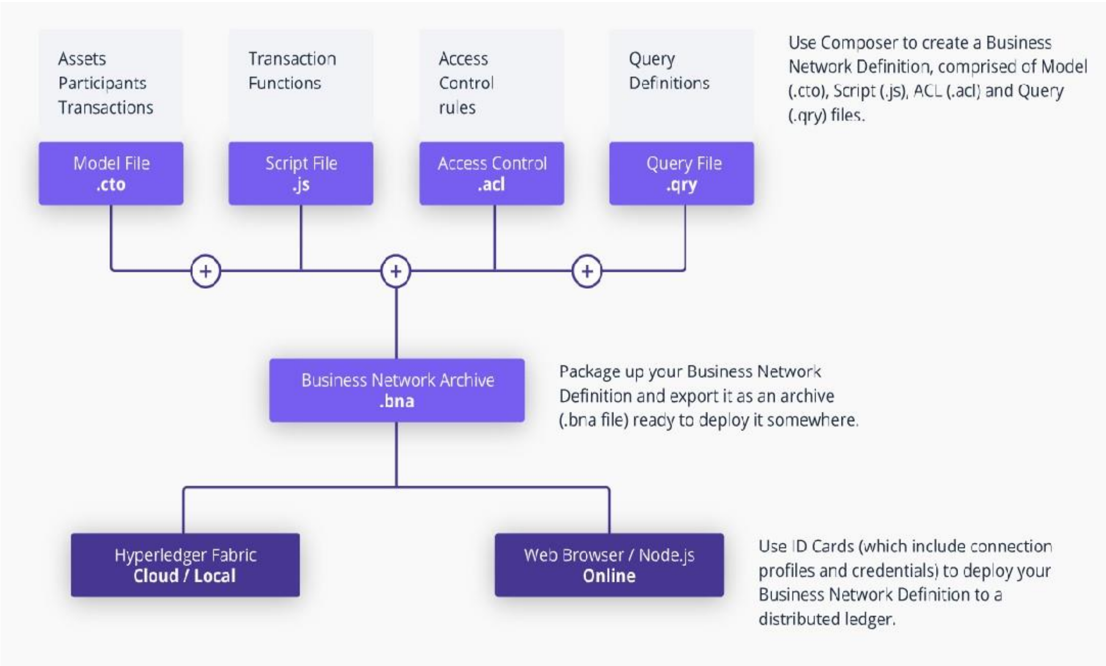


Figure 49: Hyperledger Composer components (Hyperledger, 2019b).

In order to run the system, all this files should be merged in the Business Network Archive (.bna) file in order to include all the desired characteristics in one and run it. Finally, ID Cards for the users of the system should be created and shared in order to make the ledger distributed and then use the local cloud and browsers to run the system individually.

At the next paragraphs, the development of the system that is presented and proposed in the main part of this report will be explained. Starting with the Model File, the main three parts of the network are determined. The assets that will be exchanged are divided into documents and materials while and the participants of the network will be the contractors and the clients. Additionally, the trade functions that will be used are written down along with the respective notifications that are descripted as events in the system.

Table 19: Model file description of the proposed Hyperledger system.

Model Parts		Details
Asset	Document	Document Symbol
		Description
		Date
		Pages
		Owner
	Material	Material Symbol
		Description
		Date
		Tones
		Owner
Participant	Client	Client ID
		Client Name
	Contractor	Contractor ID
		Company Name
Transaction	Trade Documents	Document traded
		Document new owner
	Trade Materials	Material traded
		Material new owner
Event	Trade Document Notification	Document traded
	Trade Material Notification	Material traded

The Script file is the next crucial component of the system that should be determined. In this file, the transactions that have been mentioned in the model file are written down in a function form in order to execute it automatically. For this reason, some developers also call this file "smart contract" In the proposed case, there are only trade functions, the trade documents and trade materials.

A crucial part of a blockchain system is the rules that will determine the permissions that each user will have in the system resources. In Hyperledger, this is done through the Access File, and in the developed system the following five rules were added:

i) rules for administrator's access in network and documents modification (as long as the participants are not activated).

ii) contractors can see all the participants of the network.

iii) contractors can see and update only their own details, assets and transactions history,

iv) client can see all the participants, the assets and the whole transactions history and

v) enable contractors to submit transactions

Finally, the Query File is designed for extracting specific data from the system and in this system, this is done for the assets (documents and materials) that are owned by each participant.

Appendix J: Palmius Assessment Criteria

Table 20: Assessment criteria for information systems (Palmius, 2007).

Criterion	Description
Organisation Performance	
Transmission	Efficient information distribution within the organization
Fail rate	Failure frequency
Congestion	Information overflow or overfeed
Underfeed	Frequency of idle segments of the organisation
Control	
Knowledge	Information storage in the organization
Overview	Salient information channels
Flexibility	Easiness in modifications
Manageability	Ability of managing the organisation
Decisions Speed	Taken decisions speed
Decisions accuracy	Taken decisions accuracy
Economy	
Return on investment (ROI)	Return on investment
Competitiveness	Improvement in competitiveness of organisation
Customer satisfaction	External customer satisfaction
Productivity	Supported productivity
Emancipation	
Satisfaction	Individuals satisfaction
Democracy	Individuals freedom
Influence	Individuals influence on the system
Learning	Opportunities to develop skills
Ergonomy	
Stress	Stress on individuals from the system
Overload	Too much information from the system
Underfeed	Too less information from the system
Control	Configurations in the system according to individual needs
Communication	
Informedness	Provided information to the individual

Criterion	Description
Social interaction	Ability to interact
Social belonging	Sense of belonging to the individual
Access	
Accessibility	Reachable information
Searchability	Easiness in finding specific information
Format	Appropriate form of the information included
Quality	
Accuracy	Accuracy of information
Relevance	Relevance of information
Importance	Importance of information
Reliability	Reliability of information
Uniqueness	Redundancy of information flow
Free from bias	Objectiveness of information
Durability	
Archivability	Information fit to be stored in the archive
Movability	Easiness in moving archived information
Portability	Easiness in transferring information to other system
Traceability	Traceability of archived information
Original look	Authenticity of archived information
Evidence	How well does the archived information support proving that something has happened
Usability	
Learnability	Easiness for new users to understand the system
Memorability	Easiness to remember how the system works
Efficiency	Energy needed to produce desired result
Effectiveness	Energy needed to solve a problem
Error proneness	Frequency or errors
Security	
Stability	Frequency of inaccessibility and loss of data
Validity	Correctness of information
Secrecy	Protection of information

Criterion	Description
Software	
Compatibility	Easiness in moving information within the system
Saliency	Easiness in understanding the software structure
Availability	Easiness in acquiring the software
Replaceability	Easiness in replacing parts of the system
Licensing	Easiness in licensing the system
Administration	Manageability
Hardware	
Scalability	Support of future needs
Administration	Manageability
Performance	Support of current needs
Cybernetics	
Filters	Divisions between parts of the system
Sensors	Easiness in collecting information from the environment
Amplifiers	Easiness in highlighting specific data
Feedback	Easiness in getting feedback
Viability	Survival of the host system
Requisite variety	Manageability of input from the host system
Performance	
Viable System Model (VSM)	Compatibility with VSM
Living systems	Compatibility with Living Systems
Soft Systems Methodology (SSM)	Compatibility with SSM
Information Technology Infrastructure Library (ITIL)	Compatibility with ITIL
Systems properties	
Efficacy	Level of efficiency
Cult. Feasibility	Compatibility with what users need
System Desirability	Desirability of the system

Appendix K: Experts' Panel Protocol

Agenda

1. Introduction
2. What is blockchain
3. Model presentation
4. Added value
5. Discussion
6. Assessment

1. Introduction

No.	Position	Company
1.	Project Manager	BAM Infra Asfalt
2.	Project Manager	BAM Infra
3.	Director	Transportation company
4.	Manager	Milling company
5.	Director	BAM Infra Regionaal West

Date: June 28th, 2019.

Location: BAM Infraconsult bv Office in Gouda.

2. What is blockchain

Explain how blockchain works and the difference between traditional and blockchain information systems.

3. Model presentation

Present in short the connection of the asphalt process and the proposed model and explain in an interactive way (video presentation) how it works. Also, some screenshots from Hyperledger environment were presented.

4. Possible added value

Present the two use cases that are proposed and the respective benefits in each one.

5. Discussion

Open discussion for the connection of blockchain with the asphalt process.

6. Assessment

Level of Importance	Grade
Very Low	1
Low	2
Medium	3
High	4
Very High	5

Table 21: Assess the design principles.

Design Principles	Experts' opinion on level of importance					
	1.	2.	3.	4.	5.	Average
Materials traceability	5	5	5	2	4	4.2
Total project overview	4	5	4	4	4	4.2
Including standards and regulations	5	4	3	4	3	3.8
Predetermined data sharing	4	3	5	4	4	4.0
Long terms recording and management of information	3	3	3	4	5	3.6
Reliability, immutability and trustiness	5	5	5	5	4	4.8

Table 22: Assess the added values that are mentioned for each use case.

Use Case	Added Value	Experts' opinion on level of importance					
		1.	2.	3.	4.	5.	Average
SCM Platform	Transparency in transactions	4	4	4	5	5	4.4
	Improved monitoring and optimization on S.C.M.	4	3	4	3	4	3.6
	Materials Traceability	5	5	5	2	4	4.2
Information platform	Long terms sharing of data in a predetermined way	3	2	3	5	4	3.4
	Give permission to predetermined actors to view specific data	4	4	4	4	5	4.2

Use Case	Added Value	Experts' opinion on level of importance					
		1.	2.	3.	4.	5.	Average
	Reliability, immutability and trustiness in the stored data	5	5	4	5	4	4.6
Level of Satisfaction		4.2	3.8	4.0	4.0	4.3	4.1

Table 23: Assessment criteria (1 for yes, 0 for not defined, -1 for no) (Palmius, 2007).

Criteria	Explanation	Support it?					
		1.	2.	3.	4.	5.	Total
Information management							
Validity	To what extend does the system ensure that information within it is correct (for example not tampered with)?	1	1	1	1	0	4
Secrecy	How well does the system protect information from being seen by outsiders?	1	1	1	1	1	5
Reliability	How reliable (repeatable, stable) is the information within the IS?	1	-1	1	1	1	3
Compatibility	How easy it is to move information between different parts of the system?	1	1	1	0	0	3
Efficacy	Does the IS actually solve the problem it was intended to solve?	0	0	-1	-1	-1	-3
Evidence	How well does the archived information support proving that something has happened?	1	0	1	1	1	4
Influence	Can the individual influence his/her own situation through the system?	0	1	1	-1	1	2
System Desirability	From an expert point of view, is the system constructed in what is usually thought a good manner?	1	1	0	0	1	3
Supply Chain Management							
Manageability	How well the system supports management?	-1	-1	1	1	1	1

Criteria	Explanation	Support it?					
		1.	2.	3.	4.	5.	Total
Competitiveness	Does the information system make the organization more able to compete with the environment?	1	1	1	1	0	4
Productivity	Does the system support production in a satisfactory fashion?	1	1	1	1	-1	3
User's perspective							
Learning	Is the individual given the opportunity to develop skills and understanding through the system?	0	1	0	-1	1	1
Learnability	How easy is it for a new user to understand how to act in the system?	-1	1	1	1	-1	1
Stress	Does the IS contribute to stressing the individual (for example through being difficult to manage)?	0	1	1	1	-1	2
Total		6	8	10	-1	3	33

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