The potential and facilitating architecture for futures exchanges in secondary raw materials

Master thesis submitted to Delft University of Technology

in partial fulfilment of the requirements for the degree of

MASTER OF SCIENCE

in Complex Systems Engineering and Management

Faculty of Technology, Policy and Management

by

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June 2022

Anne Schermerhorn: *The potential and facilitating architecture for futures exchanges in secondary raw materials* (2022)
This work is available in the TU Delft Research repository. https://repository.tudelft.nl/.

The work in this thesis was made in the:

Master Complex Systems Engineering and Management
Faculty of Technology, Policy and Management
Delft University of Technology

EXECUTIVE SUMMARY

Introduction. The dominant economic model in the 'Global North' is based on a linear approach. This model is associated with severe environmental damages as well as a dependency upon resource importation. A transition to a Circular Economy (CE) is imperative; entailing economic models in which resources are used in perpetuity. This research is focused upon the CE Techno-Sphere, containing cycles of technical products rather than biological nutrients. CE business models are characterized by complexity and uncertainty of future income caused by price fluctuations of materials. Organized futures markets in Secondary Raw Materials (SRM) are a promising intervention that could decrease the uncertainty of future income, by enabling parts of (future) price risk to be hedged. A futures transaction creates certainty for a seller as well as a buyer that a future transaction on a pre-specified date takes place for a pre-defined price, therefore limiting the risk of price fluctuations in and securing future income. Nevertheless, there lacks research connecting futures markets and the CE. Accordingly, this research aims to address this gap. In doing so, the research aims to **1)** Derive insight into the potential for futures markets to enable a CE and **2)** Derive insight into design practices for interventions to enable futures markets in SRM. The following main research question is addressed: ***To what design principles and requirements should the design of an artefact to enable futures markets in secondary raw materials adhere?***

Approach. In line with the research objectives, the research approach is problem-focused Design Science Research (DSR) entailing three phases: **1)** Problem explication **2)** Requirement elicitation and **3)** Design and Develop.

Problem explication. Based on the results of exploratory interviews, it can be concluded that the direct societal need for futures markets is not present, but that there seems to be a latent (unconscious need) that could become conscious over the coming years. According to the interviewees, futures markets could potentially secure future income streams, but are perceived to have too large an administrative burden as well as no facilitating infrastructure for them being in place. The key facilitating infrastructure needed for futures markets in SRM is an underlying spot market. Therefore, the research focuses upon designing an artefact to support the development of spot markets in SRM, the facilitating infrastructure for futures markets.

Requirement elicitation A. Artefact outline. The requirement elicitation is split into an artefact selection phase and a requirement elicitation phase. Multiple design directions were identified of which *the design of innovative tools to address supply chain visibility and the sharing of the 'right data'* was selected. Circular supply chains are characterized by a high actor complexity and therefore it is difficult to facilitate trust between the actors, a blockchain-based architectures can be deployed to facilitate trust within these complex supply chains and is therefore selected as artefact.

Requirement elicitation B. Eliciting requirements. The requirement elicitation is split into a section on design principles and one on Functional Requirement (FR) and Non-Functional Requirement (NFR). Compared to primary raw materials, for SRM standardized grading schemes are a lot more complex to realize. There these design principles come in play. The design principles provide a high level design direction (Table 0.1). Especially *identification*, to ensure that materials can be recognized as well and their quality and composition be known, *confidentiality* to ensure businesses are willing to share product information, *liquidity* to facilitate real-time transactions and *supply chain visibility* to ensure that information about inventory is up to date for trading to occur, are crucial to facilitate spot markets.

Table 0.1: Design principles summary

Code	Principle	Rationale
DP.A.1	**Accessibility**	All involved actors should have access to the relevant information in the system.
DP.B.1	**Liquidity**	Architecture should facilitate liquidity.
DP.B.2	**Identification**	Architecture has to support identification of products and resources and their respective quality and material composition.
DP.B.3	**Supply chain visibility**	Availability information about demand and inventory across the entire circular supply chain should be increasingly available to increase vertical integration.
DP.C.1	**Confidentiality**	Information should be handled confidentially such that company sensitive information can be shared safely.
DP.C.2	**Traceability**	Architecture has to provide traceability of materials along supply chains such that return flows can be planned.
DP.C.3	**Privacy by design**	Architecture has to provide a sufficient amount of privacy - i.e. respect user privacy - and comply with privacy laws
DP.C.4	**Assurance**	There should be assurance about the immutability and non-repudiation of the information about materials and transactions that the architecture incorporates.
DP.C.5	**Energy efficiency**	The architecture has to be energy efficient, in the sense that the negative effects that it has on the environment are reduced to a minimum.

Based upon the principles, FR and NFR were elicited to provide a more detailed design direction. Important requirements that came forth from this analysis were that the the materials have to be equipped with a type of ID, as well as that architecture has to be equipped with some form of sensing technology to detect materials. Information about the products and materials has to be stored and accessible upon scanning the ID. Also, the architecture has to calculate amounts of materials present in certain locations based on real-time sensing data. Moreover, assurances about confidentiality have to be provided to incentivize actors to share sensitive information.

Design and Develop. A variety of supply chains may require different artefacts. Accordingly, requirements are implemented on a single case study with bio-plastics producer Avantium. The resulting recommended system architecture is illustrated in Figure 0.1. The *user layer* illustrates all the actors involved in the architecture that should have access. The *application layer* illustrates the main functionalities of the blockchain system, with key interfaces being transaction management, and quality and traceability management to enable proactive planning. With regards to the *blockchain layer*,

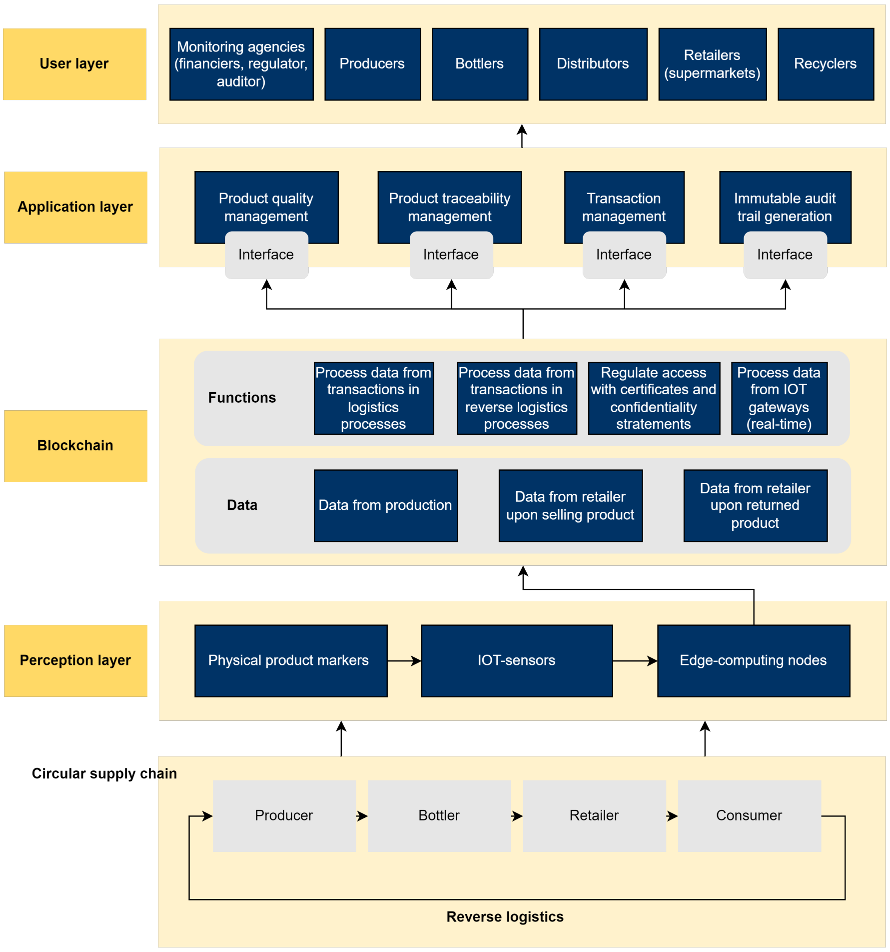

Figure 0.1: System architecture for case study, adapted from Venkatesh et al. [2020]; Wang et al. [2020]

the proposed network is based upon a consortium blockchain, with Proof-of-Authority as consensus mechanism and the traded assets (bottles) being represented by tokens representing ownership. Moreover, to curb energy consumption, data stored in blocks is minimized by only storing essential information. The blocks contain a hash-pointer to off chain data that depicts more detailed information. Furthermore, participating actors can join the network upon providing a confidentiality pledge. Some actors have certificates to view transactions (e.g. regulators), whilst others have the right to add transactions (e.g. producers and recyclers). Through *the perception layer*, the system interacts with the *physical supply chain*. The layer entails the physical product markers that in this case is recommended to be a watermark. Sensors are deployed to detect the physical markers. Sensors can have little storage, so they communicate with edge computing nodes. Overall, the system architecture has the purpose of enabling spot markets in SRM by putting quality controls in place for the materials as well as instruments to verify that a product is composed of a certain material. This certainty of a product being of a material increases the possibility for the trading of homogeneous goods and the development of standard grading schemes, essential to facilitate futures markets.

Contributions. The leading contribution that this research makes is the generation of new knowledge for the blockchain-based architecture design to support the CE knowledge base. For as far is known, this research is the first to link the concepts of futures markets and the CE. Moreover, the set of contributions of this research is threefold, providing insights into the potential for futures markets in SRM, a set of design principles as well as a solution concept in the form of an artefact for a single case study. The results show that futures markets have the potential for circular businesses to hedge some of their price risk, hereby securing their future income stream and being more attractive for investment. The set of design principles can be used by researchers to guide design research to support spot markets in SRM, with an emphasis on identification, confidentiality, liquidity and supply chain visibility in order to ensure spot markets in SRM. These design principles are critical towards achieving standardized grading schemes for SRM to become trade-able on exchanges. Lastly, the designed artefact for the case study can be used to inform future design research. Nevertheless, it is not assumed that the designed artefact can fully achieve the fundamental shift in society that is needed to achieve a CE. Rather, it offers some relief to circular businesses towards securing their future income whilst they still compete with linear models to which society is currently geared.

Limitations and Future Research Based on potentially limited interview information, this research made the assumption that futures markets for the CE would be desirable. It becomes clear futures markets may be desirable from the perspective of individual circular businesses to hedge price risk, but the impact of futures markets on the larger CE ecosystem is very uncertain. With there being signs that futures markets can have destabilizing effects on global commodity prices, the potential effects of futures markets on the larger complex CE ecosystem should be considered by future research. Secondly, due to resource restrictions, this research does not consider the governance aspect of the architecture. Future research may seek to align governance choices with the technical architecture design, especially who is part of the consortium and who issues tokens, are important choices. Moreover, another limitation of the research is that it may be difficult to generalize the designed artefact recommendations, because it is a single case. Future research could consider an artefact design for different cases. Also, the energy footprint of Blockchain Technology (BCT) is disputed. Therefore, future research should quantify the energy consumption of a blockchain-based architecture such that a cost benefit analysis can be made. Lastly, tokenization is very important towards achieving traceability of materials, and is of key importance to the feasibility of this BCT based artefact, whilst as of yet there is no research illustrating how materials can be tokenized. Future research should consider how tokenization of SRM can be achieved.

PREFACE

Albert Einstein was asked once, if he had an hour to solve a problem upon which his life depended, how he would spend this time. Upon which he replied:

"If I had an hour to solve a problem I'd spend 55 minutes thinking about the problem and five minutes thinking about solutions."

Upon the start of my thesis, I thought I had defined the problem I was facing in such a manner that moving forward to requirement analysis was possible; what is required to solve this problem? I couldn't have been more wrong, because upon eliciting requirements, the problem kept becoming more complex and dynamic. I think this is representative of the highly complex nature the circular economy, and how complex the transition to a circular economy is.
After going through this thesis process, which I know usually refer to as "the thesis rollercoaster". At some points you feel like all is going well, while just days later you face an unexpected challenge that brings you back a few steps. After being in the thesis rollercoaster for what feels like a very long time, I walk away with a lot of knowledge on a personal as well as a professional level.

ACKNOWLEDGEMENTS

In February 2021, I embarked on an adventure to write my thesis. It all started with my interest in blockchain technology and it's possibilities, as well as the interest in environmental health. My interest in blockchain technology came forth from a course I had followed that was given by Jolien Ubacht: *Integrated design of I and C architectures*. My interest in environmental health came forth from a 6-month research I had conducted in Ghana, West-Africa, into waste management (although I learned that it is better to not consider it as waste but as a secondary resource with value) and how it can be innovated to prevent damaging flooding of especially the most poorest municipal areas. My interests in environmental health and blockchain technology were brought together after meeting with Jolien Ubacht and being informed of the ongoing research in the area of enabling a circular economy monitoring with blockchain based solutions.

After combining both my interests within the research proposal, I imagined quite a sound project in my horizon. But undoubtedly, conducting design science research was more challenging then expected. Looking back at my research, it has evolved into something very different from what I initially had expected, partially due to being faced with a wicked problem which is very hard to define. The definition of a wicked problem is actually the problem itself. In this complex process, I was fortunate to have been surrounded by many people who guided me. Therefore, I would like to thank everybody who played a role in supporting me throughout the journey of writing this thesis.

Jolien Ubacht, I want to thank you for your continuous support during this journey and in specific for the frequent meetings we had. You helped me to look at the bigger picture and to find the common theme; the 'rode draad'. The design of this artefact, but also the problem explication related to it, made me deal with many details which sometimes made me feel lost in the complexity. Talking with you enabled me to put my focus on the aspects that required focus, rather than getting lost in the small details.

Furthermore, I would like to thank Selinde van Engelenburg for helping me gain a more deeper understanding of blockchain technology. Before this process, I only knew some basics and my main ambition with going into this thesis process was to gain expertise about blockchain technology. As the problem explication at some point had taken up so much time, I was afraid that gaining expertise about - or delving very deep into - blockchain technology would have not been possible anymore. The sessions I had with you made me confident that I was also picking up knowledge about blockchain technology and its inner workings and possibilities, enabling me to integrate this into my design, so thank you for helping in fulfilling that ambition.

Moreover, I would like to thank Yao-Hua Tan, Boriana Rukanova and Gijsbert Korevaar for the feedback that they have provided me during the various meetings that we had. I felt like there was always an open door with regards to asking questions and being able to share thoughts. Also, I would like to thank Marijn Janssen for fulfilling the role of Chairperson in the committee.

On top of this, I am very thankful to Robin Hamerlinck for giving me the opportunity of writing thesis within the context of the Ministry of Infrastructure and Water Management. Being exposed to this environment that was very near to innovations and knowledge related to the circular economy opened the door to many ways to derive knowledge. Also, thank you for showing me how passionate you are about achieving the circular economy and your belief that we can get there, this gives a lot of energy to the people around you.

Anne Schermerhorn

March 30th 2022

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

1 INTRODUCTION

The dominant economic model in the 'Global North' is based on a linear approach, also defined by Blomsma and Brennan [2017] as the 'take-make-waste' economy. Even though this linear model has led to growth in Gross Domestic Product (GDP), it has also led to significant pollution of the natural world [EllenMacArthurFoundation, 2015], emissions related to extraction processes [EllenMacArthurFoundation, 2016] and a loss of biodiversity. The traditional 'take-make-waste' economy is characterized by the mining or extraction of natural resources from the earth and then selling them to consumers to after their end of life, to be disposed as waste. The disposal of natural resources causes severe environmental damages as resources and products often end up in landfills [EllenMacArthurFoundation, 2015]. The extraction of resources also has detrimental effects on the environment, by consuming large amounts of energy and causing carbon dioxide emissions [EllenMacArthurFoundation, 2016].

A landmark new report by hundreds of the world's top climate scientists is a call for direct action to cut down carbon dioxide emissions in the face of unprecedented and quickly advancing climate change [Masson-Delmotte, 2021].
And even though the world has awoken to the ongoing climate crisis and is taking measures to decrease carbon dioxide emissions, the current response to the crisis represents only a partial picture. The methods employed to deal with the climate crisis have put focus on renewable energy production and energy efficiency. These methods are important, but they only account for 55 percent of carbon dioxide emissions [EllenMacArthurFoundation, 2016]. The remaining 45 percent of carbon dioxide emissions originates from production and extraction processes of natural resources from the earth [EllenMacArthurFoundation, 2016] and are therefore directly related to the linear economy. Reducing polluting extraction processes would therefore decrease emissions.
The linear economy has also created a multitude of ecological deficits [Rockström et al., 2009]. Humanity currently uses resources of 1.75 planets per year [GlobalFootPrintNetwork, 2020]. This has led to a decrease in availability of natural raw materials; resource scarcity. Especially in the European Union (EU), resource scarcity is a growing concern [Schanes et al., 2019]. On top of growing resource scarcity, resource dependency is also a risk that manifests in the linear economy. To give an example, The Netherlands imports about 68 percent of its raw materials [Central Bureau for Statistics, 2011], therefore the Netherlands is highly economically dependent upon these imports [Ministry of Infrastructure and Watermanagement, 2016], even though simultaneously, raw materials are becoming scarcer worldwide. Take for example precious minerals and metals used in electronics, these metals are

mostly mined in Asian countries like China. China is the main supplier for 15 out of 25 of the EU's Critical Raw Materials (CRM), accounting for about 65 percent of total imports, hence the EU is heavily dependent on exports from China [Mardegan et al., 2013]. Depletion of some of these resources would vary, but according to Mardegan et al. [2013] Antimony could deplete as soon as 2025. Taking this into account, it can be concluded that China is in control of a large part of the EU's supply of CRM. If these supply controllers such as China decide to stop the export of these commodities, many product supply chains will become nonfunctional.

1.1 USING MATERIALS THAT ARE ALREADY IN THE ECONOMY

Given the problems like increasing environmental pollution, resource scarcity and resource dependency that are caused by the linear economy as described in the previous paragraph, a new economic model should be sought. A economy in which the resources that are already in the economy are reused is becoming more and more attractive. Firstly, to prevent these resources from polluting the natural environment. Secondly, to reduce the risk of these resources depleting and lastly,to reduce dependency on resource imports from other countries. Accordingly, industries have to find ways to efficiently use resources that are already in the economy [Netherlands Environmental Assessment Agency, 2021]; adopting a CE. The EU manufacturing sector alone could create large annual economic gains of up to 600 billion euros if CE type transactions are adopted [European Commission, 2018]. The CE transition calls for new economic models in which resources can be used in perpetuity and emissions related to extraction processes are decreased. The CE provides economic systems with an alternative resource flow model, a cyclical one [EllenMacArthurFoundation, 2015].

1.2 THE NOTION OF THE CIRCULAR ECONOMY

The notion of CE is focused on eliminating waste and reducing overuses of resources. A recent definition of the CE is the following: 'In a circular economy the value of products and materials is maintained for as long as possible; waste and resource use are minimized, and resources are kept within the economy when a product has reached the end of its life, to be used again and again to create further value.' [European Commission, 2018]. The core ideas at the foundation of the CE are cyclical material loops [Mentink, 2014]. CE opens the door to achieving 12 of the 17 Social Development Goals (SDG). The Ellen MacArthur Foundation (EMF) has illustrated the CE as depicted in Figure 1.1. This Figure illustrates the concepts related to a CE and how these relate to the linear economy, that is illustrated on the vertical axis in the middle.

Material loops as illustrated in Figure 1.1 assume in the case of biological nutrients, that they can be cascaded back into their natural ecosystem. In the case of technical nutrients, it is assumed that they should be reused, recycled or refurbished. This requires the collection of products and materials back from the consumer [Govindan et al., 2015]. This research is focused on technical nutrients - the blue cycle in the systems diagram 1.1 - as it focuses on the manufacturing industry in particular. This blue cycle can be defined as the Technosphere. The Biosphere is illustrated by the green cycle and within this cycle, finite materials circulate, materials that can biologically degrade and return to nature. Within the Technosphere, there are varying ways in which circular models can operate, e.g. repair, reuse, refurbish or recycle.

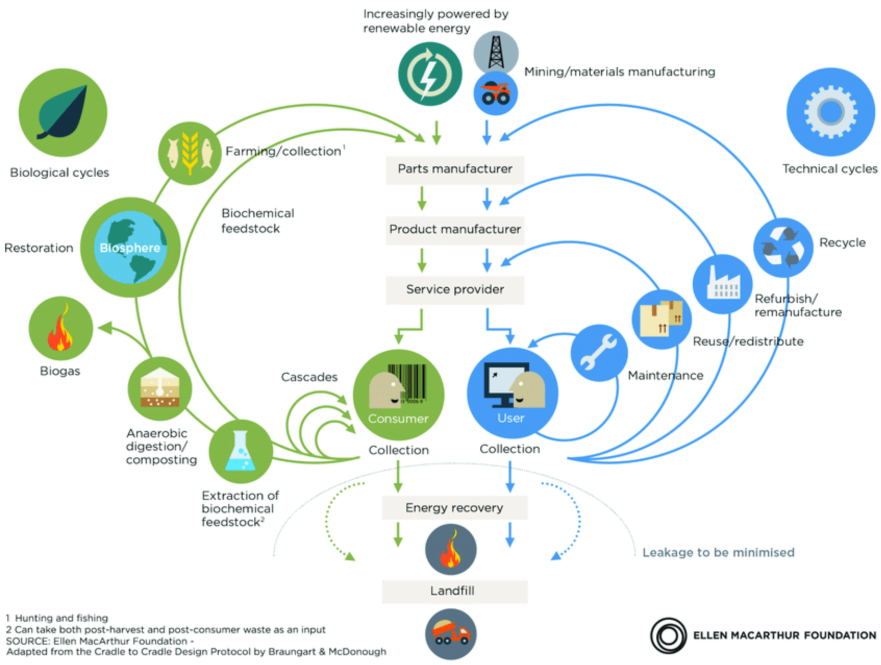

Figure 1.1: Ellen MacArthur Foundation circular economy systems diagram [Ellen MacArthur Foundation, 2019]

These strategies can also be indicated according to an 'R framework'. The most commonly used 'R' framework in the Netherlands is the 7R model developed by Environmental Assessment Agency (EAA) [Lucas et al., 2016]. The 7R framework is illustrated in Figure 1.2.

On top of the R framework, there are three strategies for reducing resource flow models as defined by Bocken et al. [2016]; slowing loops; narrowing loops and closing loops. The first steps in the R framework entail the narrowing of loops to use fewer resources, this does not affect the cyclic nature of the product. The next steps in the R framework entail the slowing of resource loops; extending the life cycle of a product by e.g., re-manufacturing or repair. However, these strategies - narrowing and slowing loops - do not address the time dimension nor do they have a cyclical component, therefore they could lead to the optimization of linear flows instead of the creation of circular flows. In essence, pursuing only these strategies could lead to the optimization of sub-optimal systems. Therefore, the concept at the foundation of this research will be the closing of loops by enabling recycling processes

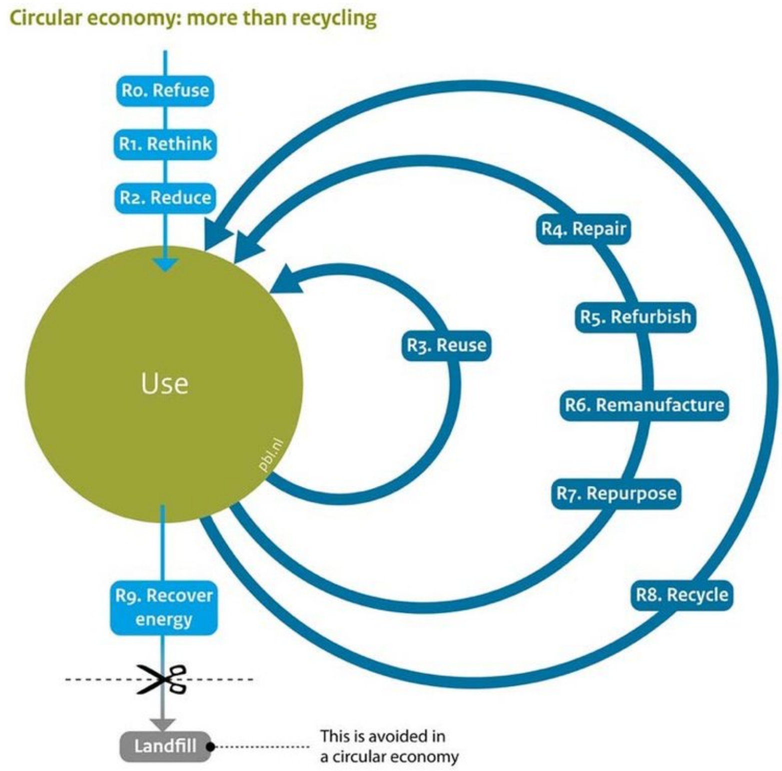

Figure 1.2: 7R Framework for the circular economy [Lucas et al., 2016]

and in specific in the technosphere containing finite materials, as defined by [EllenMacArthurFoundation, 2015].

1.3 SOCIETAL ATTENTION FOR THE CIRCULAR ECONOMY

There has been more attention for the transition to a CE in the past decade by various actors. The EU has been promoting the transition to the CE actively [Korhonen et al., 2018]. In the Netherlands, there is a societal need and momentum for the transition to a CE [Van Buren et al., 2016]. Enterprises are increasingly aware of the potential benefits of circular models and improving their resource efficiency to achieve cost savings for resources, competitive advantages, but also the accessing of new markets. Lastly, financiers want to invest more and more in more circular and green business models [Goovaerts and Verbeek, 2018; Geissdoerfer et al., 2018]. Nevertheless, to achieve a CE, circular models have to be financially feasible and successful business models need to be created. At the same time, it can be concluded that financing is one of the largest issues - or barriers - for the CE [Mellquist et al., 2019].

1.4 THE FINANCIAL BARRIERS FOR A CIRCULAR ECONOMY

It has become clear that the circular economy has a financial component that needs to be taken into account. This section will address some of the key causes underlying the financial issues of circular business models. Transitioning to a circular model may affect the financial performance of a company, which may influence their ability to source financing financing [Goovaerts and Verbeek, 2018]. Mellquist et al. [2019] conclude that financing is a problem for CE. For businesses to transition to a circular model, access to capital is of key importance Rizos et al. [2016]. Currently, the lack of available financing methods is a large barrier for businesses aiming to adopt greener or circular practices [Rizos et al., 2016; Ormazabal et al., 2016]. How these financial barriers manifest to become an issue is also of importance. External financiers perceive circular models or projects as more complex rather than normal investment deals [Goovaerts and Verbeek, 2018]. External financiers need a track record – past data – proving the capacity of the circular model to deal with potential issues. Circular models often have no such track record as their practices are relatively new and groundbreaking. Thus, in the current context, external financiers have insufficient data to infer the (future) stability of cash flows. Therefore, critical reasons that circular businesses are unable to attract external financing are; their lack of stable and short-term cash flows and non-existing track records [Müller and Tunçer, 2013]. Investments in circular models or projects are perceived as being risky endeavors [Aboulamer et al., 2020]. Reinforced by risk assessment strategies from financiers, businesses are currently primarily driven by what can be defined as short-term-ism, only considering the Return On Investment (ROI), and disregarding sustainability in the long term [Böckel et al., 2020]. Hence, there is a need for a way to disrupt this reinforcing cycle that incentivizes short-term-ism, that has been created by financiers and businesses alike. According to Aranda-Usón et al. [2019], there is no doubt that circular businesses and projects will require adapted financial mechanisms. Mellquist et al. [2019] call for more research with regards to financing strategy and about the financiers' role in the transition to CE. It can be concluded that financial innovation is needed to achieve a CE, therefore, this research will consider financial innovation for the CE.

1.5 THE NEED FOR FINANCIAL INNOVATION TO SUPPORT THE CIRCULAR ECONOMY

It has become clear that financial innovation is needed to support the transition to a CE. There are multiple forms in which financial innovation can take shape. Some authors write of tax reforms [Goovaerts and Verbeek, 2018] while others write of new risk modelling methods and stress scenario testing [Goovaerts and Verbeek, 2018], financial incentives like public funding [Aranda-Usón et al., 2019] and creating green banks [Ozili and Opene, 2021]. Although there are a multitude of methods in which financial innovation could be pursued, the Ministry of Infrastructure and Water Management - that this research is conducted for - is especially interested in the prospect of a futures markets to support the financing of circular models (Personal Communication R. Hamerlinck, June 2021). For this reason, this thesis research will focus on exploring this specific financial innovation in the context of the transition to a CE.

1.6 INTRODUCING THE CONCEPT OF FUTURES MARKETS

Before delving in the potential of futures markets for the CE, the concept of futures commodity trading markets will be shortly introduced. Futures commodity trading markets are characterized by the buying and selling of goods for delivery at a future time, usually without the intention to receive or deliver the goods [Gorton and Rouwenhorst, 2006]. The definition of a futures market is the following: 'A futures market is an impersonal market in that actual buyers and sellers are unknown to each other, it is a public and competitive market, since all trades are made by open outcry in the specified trading area, or 'pit,'of the exchange. Floor traders, who must be members of the exchange, sell and buy from a clearinghouse which is usually part of the exchange' [Anderson and Dower, 1978][p.16]. The trading of futures on a futures exchange allows for sellers of underlying commodities to gain certainty with regards to the (future) price they will receive and on the other hand, it allows for consumers or buyers of those underlying commodities a certainty about the price that they will pay on the pre-specified maturity date of the agreement. SRM have many price fluctuations, so sellers could desire more certainty about a future price for their materials for the longevity of their business, hereby securing future income streams of circular businesses.

1.7 LITERATURE ANALYSIS AND KNOWLEDGE GAP

It is first important to derive knowledge on the already available literature about the combination of the two concepts of futures markets and the circular economy. A search including varying keywords was conducted on multiple databases, the keywords are set out in Table 1.1.

First term	Second term
futures markets	circular economy
OR futures contracts	OR secondary raw materials
OR futures exchanges	OR cradle-to-cradle
OR futures trading	OR recycled materials

Table 1.1: Keywords used in literature search for futures markets as financial innovation for the circular economy

A search was conducted on SCOPUS with the various combinations of the designated key words, this delivered no documents and also no secondary documents. A search on Google Scholar delivered some results, but these results mainly considered setting out a vision for the future of the CE [Bauwens et al., 2020; Smith et al., 2017], and were not touching upon the topic of futures markets or futures exchanges for the CE. These irrelevant results make sense as futures market is a concept with a variety of definitions and this may cause search engines to generate results about the future of the CE rather than futures markets for the circular economy.

The search was further executed on Google Scholar and one document was identified, considering futures markets for scrap metals, this dates back to 1978, when the concept of circular economy had not manifested yet, this research identified that futures markets for scrap metal could have potential benefits and called for government involvement in the research and initiation phases of future trading for scrap metals [Anderson and Dower, 1978][p.51]. It becomes clear that at some point, the topic of futures markets for secondary raw materials got attention, but not in the context of achieving a CE, rather in the context of a capitalist perspective, exploring the potential of a potentially valuable business-model due to the relatively high value of scrap metals in particular. Nevertheless, since this publication dating back decades ago, research combining the concepts of futures markets and a circular economy has been scarce and nearly impossible to source.

Because of the scarcity of available scientific research, a search was also conducted on the regular Google Search Engine for grey literature or other publications and reports that may have touched upon the combination of the concepts. This search did deliver one relevant result. In the identified webpage, to be noted, without any scientific grounding or peer reviews, Raes [2021][n.p.], a global sustainability advisor at the Dutch ABN-AMRO bank, states that: 'an accelerated transition to the CE will require financial innovation by creating futures markets for circular commodities'. This recent acknowledgement by an industry expert on financing the circular economy does illustrate that there is a growing awareness of there possibly being a potential for futures markets in the context of the CE. To summarize, from this literature review, it can be concluded that there is a scarcity of available research on the topic of futures markets for the CE, however, there are signs that the topic is indeed getting more attention, but it seems that scientific research has not caught up to the (limited) societal attention yet.

1.8 RESEARCH OBJECTIVE

This study aims to address the main knowledge gap identified by linking the concepts of futures markets and the CE.

It has become clear that the current system is not functioning in a manner that is sustainable for the future, with resource scarcity and resource dependency only set to increase further in the coming years. The current functioning of this socio-technical system will not be sustainable over the coming years, thus, a system intervention is necessary. A transition to the CE can help to solve increasing resource scarcity and dependency, but the facilitation of this transition to a circular economy is highly complex. Futures markets (in SRM) are a financial innovation that could potentially support the transition to the CE.

The Ministry of Infrastructure and Water management, for whom this research is conducted in the form of an internship, is also specifically interested in the potential of futures markets for the CE (Hamerlinck, Personal Communication, September 2021), further validating the choice for this financial innovation to explore in this research. Moreover, according to Jan Raes, a Global Sustainability Advisor for the ABN-AMRO bank, *'An accelerated transition from a linear to a circular economy requires financial innovation including the creation of a futures exchange for circular assets'* [Raes, 2021][n.p.]. However, little research is available that links the concepts of circular economy and futures markets [Raes, 2021]. Therefore, this research therefore aims to link the concepts of circular economy and futures markets. Firstly, it is important to address the potential of futures markets to support the transition to a circular economy. Furthermore, not only should the potential of futures markets be researched, it is also important to address what interventions have to be in place to provide the facilitating infrastructure for futures markets in SRM.

These research objectives have been aligned with the identified knowledge gap as illustrated in Table 1.2.

Table 1.2: Knowledge gap linked to research objectives

Main knowledge gap	**Research Objective**
Lack of theory linking futures markets and the circular economy	Linking futures markets and the circular economy
Underlying knowledge gaps	**Specific Research Objective**
Lack of research on the potential of futures markets to support the circular economy (and address issues of key stakeholders)	Derive insight into the potential for futures markets to enable a circular economy
Lack of research on how futures markets for the circular economy could be facilitated	Derive insight into possible interventions that can be implemented to enable futures markets for the circular economy

Therefore, the lack of scientific literature linking the concepts of futures markets and the circular economy leads to the following two research objectives:

1) considering the potential of futures markets to support the circular economy and

2) what interventions have to be in place to facilitate futures markets in secondary raw materials

1.9 RESEARCH APPROACH

As has become clear in this Chapter, in the context of the CE transition, there are two main research objectives that will be addressed. In essence, going from the why, to the how of this research. The why being is futures markets could potentially support the circular economy and the how being how they could support the circular economy. Capturing both these research objectives in one methodology is possible, namely, DSR studies, consist of a problem explication phase and a design phase. In a DSR study, the objective is to design an artefact (being the how) fit for purpose, by using the existing theories and knowledge as a starting point for a problem explication (being the why) [Johannesson and Perjons, 2014].

1.9.1 DSR structure

The DSR approach considers three cycles; the Relevance Cycle, the Rigor Cycle and the Design Cycle [Hevner et al., 2004]. The Relevance Cycle is where this research will depart and consists of the empirical knowledge collection, this research will implement exploratory interviews to consider the potential of futures markets for the CE. The Rigor Cycle considers the theories and available scientific knowledge about for example financial theory of futures markets. The Design Cycle will combine both the Relevance Cycle and the Rigor Cycle to generate insights and create a design for an intervention to support the development of futures markets.

What characterizes this specific research is the scarcity of available knowledge about the potential of futures markets for the CE in the Rigor Cycle (lack of knowledge base). Therefore, the problem explicating phase is especially important in this research, as it builds upon the knowledge base and sets the foundation for the following phases of the design research in which an intervention can be developed. Figure 1.3 illustrates the three cycle view.

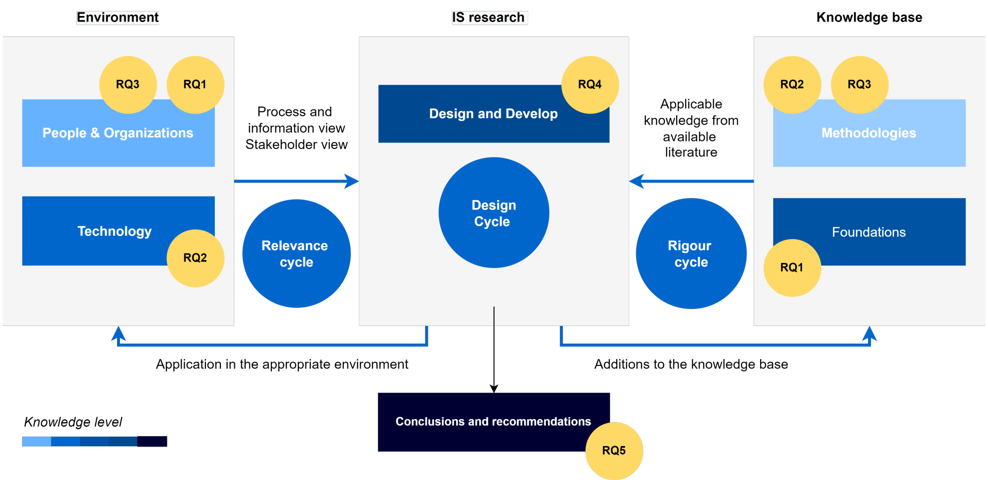

Figure 1.3: Design Science Research Three Cycle View adjusted from Hevner et al. [2004]

1.9.2 DSR focus

[Johannesson and Perjons, 2014][p.76] propose a way in which to structure DSR based research as follows: 1) Explicate Problem, 2) Artefact outline, 3) Define Requirements, 4) Design and Develop Artefact, 5) Demonstrate Artefact and 6) Evaluate Artefact. This nominal structure is used throughout the research report. It is not expected that the researcher always follows the process as described by Johannesson and Perjons [2014] in a sequence from activity one to five [Peffers et al., 2007]. DSR could start at any of the steps and move forward from there [Peffers et al., 2007]. The sequence of activities can depend on the research focus. The focus of DSR can vary across research, some research is more design focused and therefore starts with an already explicated problem. However, DSR research usually doesn't address all phases; DSR can have different focuses, most DSR studies don't undertake all five activities in the framework in depth [Johannesson and Perjons, 2014], rather, the focus is usually one or two of the activities [Johannesson and Perjons, 2014][p.79]. Furthermore, it is possible to make a distinction between five different types of DSR research; Problem-Focused, Requirements-Focused, Requirements- and Development-Focused, Development- and Evaluation-Focused and Evaluation-Focused design [Johannesson and Perjons, 2014].
To determine the type of DSR focus to implement in this research, it is important to consider the characteristics of this research. The most important characteristic of this research is the scarcity of available literature on the subject of futures markets for the CE, a lack of knowledge base. Due to the little available literature, an exploratory phase will first be considered with regards to the potential of futures markets for the CE. Clearly, there is a need to further explore the problem and gain a better understanding of it. Therefore, the DSR focus of this research is Problem-Focused DSR. In Problem-Focused DSR, the design of an artefact is only outlined and neither activities of demonstration nor evaluation are usually conducted [Johannesson and Perjons, 2014]. Research that has a Problem-Focused DSR approach provides additional understanding of a problem, on which more DSR studies can build further with more requirement-focused and development-focused studies. The Problem-focused DSR is at the foundation of the nominal sequence and starts at activity 1: Problem Explication [Peffers et al., 2007]. From this activity on, this research will therefore follow a nominal sequence and address three phases in total, the Problem explication, the Requirement Elicitation and Design and Develop.

1.10 RESEARCH QUESTIONS

The main goal of the research is to strengthen the knowledge domain and gaining insights into how to design artefacts to enable futures markets. Overall, the main research question of this research is the following:

To what design principles and requirements should the design of an artefact to enable futures markets in secondary raw materials adhere?

Because the nature of an artefact is only decided upon after the problem explication phase in DSR, this is purposely not defined yet in the overall research question, but this is addressed in the respective phase. [Johannesson and Perjons, 2014] propose questions that correspond to the phases in the DSR approach. In accordance, the questions for this research have been developed with these proposed questions as a point of departure. The questions are positioned in the three cycle view framework by Hevner et al. [2004] as illustrated in 1.3. Because the DSR methodology is a process with a variety of phases of which the outcome determines the details and specifics of the next sub-question, the sub-questions are developed on a high and abstract level.

- ***Sub-question 1: Problem explication*** *What is the problem as experienced by stakeholders involved in circular processes that is preventing futures markets from emerging?* This first sub-question will consider the problem as experienced by key stakeholders. The main interest of the Ministry lays in exploring futures markets for achieving a CE. To gain further insight, an actor analysis will first be conducted to define what actors are relevant to approach for interviews. Interviews will be implemented to investigate what problems are hindering or preventing the development of futures markets. Also, it will be considered whether there is a societal need for futures markets clearly present, as this is still unknown due to the novelty of the topic. Lastly, desk research will be conducted to further gain insight into why futures markets in the CE haven't emerged yet. The result of this sub-question will be an explicated problem into why futures markets haven't emerged yet.

- ***Sub-question 2: Requirement analysis*** *What artefact can be a solution to stimulate futures markets in secondary raw materials?* This second sub-question will address the outline of an artefact. It will address what type of design should be outlined to support the development of futures markets. For example, defining whether the artefact should be a model, a construct or even a method. This question is purposely very broadly oriented as sub-question one could lead to a variety of explicated problems that may ask for different types of artefacts.

- ***Sub-question 3: Requirement analysis*** *Which design principles and requirements of this artefact are important?* This third sub-question will consider the elicitation of requirements for the artefact, the requirements that will be included depend on many aspects like the characteristics of the explicated problem, relevant scientific research, but also the nature of the artefact to be developed.

- ***Sub-question 4: Design and Develop*** *What artefact can be developed that addresses the explicated problem and fulfils the defined requirements?* This sub-question will occupy the activity of fulfilling the requirements are set in sub-question 3, including a design of the function and structure of an artefact.
- ***Sub-question 5: Conclusion and Discussion*** *Considering the design principles and requirements, what are lessons about how to design artefacts to support futures markets in secondary raw materials?*

Together, these research questions form the answer to the main research question.

1.11 RESEARCH FLOW DIAGRAM

The research flow diagram (Figure 1.4) outlines the different phases of this research together with the respective input and output needed for each phase, as far as those inputs and outputs can be defined for now. Each sub-question considers a different phase of this research. The diagram illustrates the dependency of the various sub-questions on each other, many of the phases use the output generated by a previous phase as an input. Moreover, the output of one phase also determines what type of data is needed as input in the next phase, therefore, these inputs for further phases have not been included yet, but will be addressed in each phase separately. An example is that a set of requirements is needed to design an artefact in phase four.

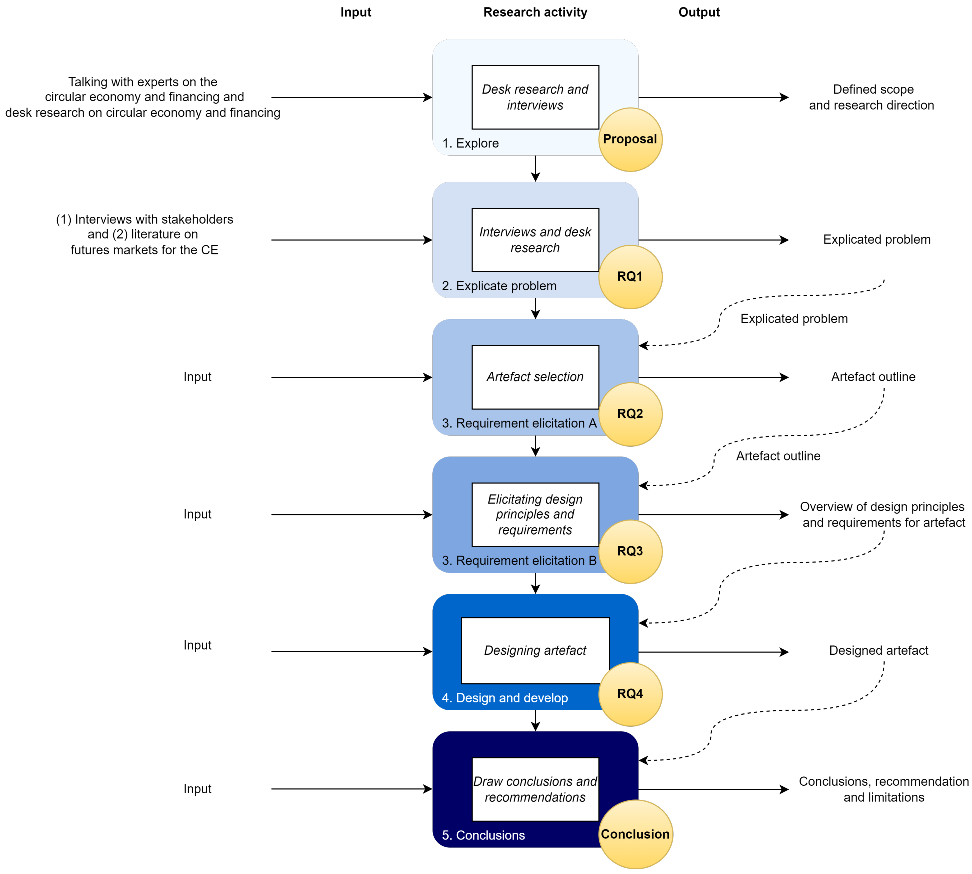

Figure 1.4: Research Flow Diagram

2 PROBLEM EXPLICATION: EXPLORING THE POTENTIAL FOR FUTURES MARKETS IN THE CIRCULAR ECONOMY

This chapter addresses the following research question: ***What is the problem as experienced by stakeholders involved in circular processes that is preventing futures markets from emerging?***

The chapter considers multiple components that play a role in the potential for futures markets for the CE. The Ministry of Infrastructure and Water Management is in particular interested in the potential of futures markets for enabling the circular economy (Hamerlinck, Personal Communication, September 2021).

To consider whether futures markets in secondary raw materials have a potential to support the circular economy, it has to be researched whether the problems experienced by actors involved in the technical cycle (manufacturing industry) call for futures markets. The chapter uses two main methodologies to collect data, namely, 1) desk research and 2) interviews.
Desk research is first implemented to analyze the dynamics of futures markets in the form that they are implemented in for primary raw materials. First of all, supply chains in SRM are defined followed by an actor analysis and consecutively, the potential of futures markets is explored through interviews with relevant actors.
An actor analysis is conducted to become familiar with the playing field of actors surrounding typical circular manufacturing supply chains. This provides a detailed overview of the playing field of actors that interact within and outside of circular supply chains. Based on this detailed overview of involved actors, relevant actors are selected for the interviews, to assess the need for futures markets in SRM, as well as what is preventing futures markets from arising. Because there is little scientific literature available on futures markets for the circular economy, knowledge about how futures markets could apply to the circular economy is mainly collected by means of interviews.

The chapter concludes with a discussion on the potential of futures markets for the CE as well as what barriers are in place that are preventing futures markets from arising.

2.1 DESK RESEARCH ON THE DYNAMICS OF FUTURES MARKETS IN PRIMARY RAW MATERIALS

2.1.1 How a futures contract works

Futures commodity trading entails the buying and selling of goods for delivery at a future time, usually without the intention to receive or deliver the goods [Gorton and Rouwenhorst, 2006]. The futures contract is completed by calculating the price difference in the transaction on the previously decided upon future maturity date (Figure 2.1). For instance, a farmer (or any other market player) may sign into a futures contract in late June 2020 specifying wheat delivery in January (the farmer would have a "short position" in late June by agreeing to supply corn in January), according to the jargon of futures markets. For example, futures contracts for wheat for delivery in January were trading at 3.36 per unit, while those for delivery in September were selling at 3.27 and those for delivery in March 2021 were trading at 3.45. A farmer can guarantee a certain price for a crop that has not yet been harvested by engaging into arrangements for the transaction in various months through a futures contract [Nelson, 1985]. In order to minimize price risk and insure against future price variations, farmers can buy and sell futures contracts. Upon the settlement date of the futures contract (In this case in January 2021), the involved parties reach a financial settlement, with typically no delivery of the associated product. Usually, it is recommended for a farmer to sell futures contracts towards a part of his expected harvest, because if his harvest fails and the farmer sold futures contracts as if he would have a fully successful harvest, the farmer may not able to provide all the commodities on the future date. Therefore, futures contracts usually allow farmers to hedge part of their price risk, further securing future income. By securing future income, it is easier for a farmer to receive investments from financial actors. For example, by proving the security of future income streams towards financiers, the farmer can more easily receive an investment to buy seeds to plant new crops.

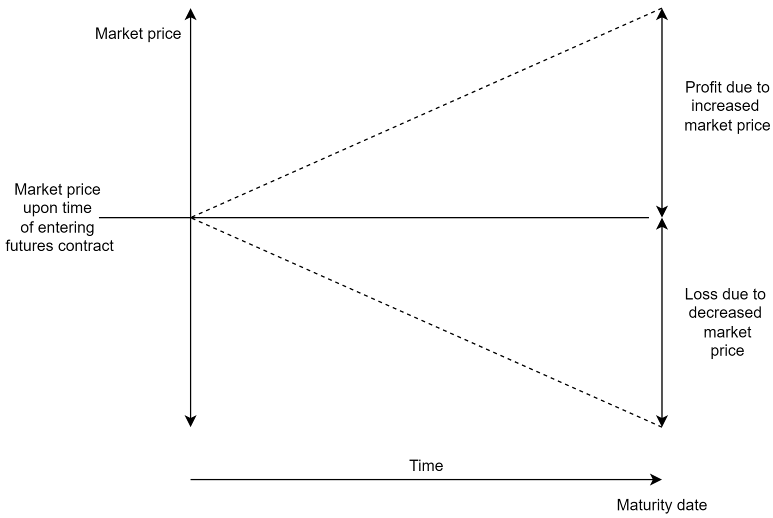

Figure 2.1: Future contract schematic

2.1.2 The emergence of futures markets

The beginnings of futures markets date back to the early 17th century. The first real futures market, with similarities to today's characteristics, arose in the early 17th century at the rice market in Dojima (a sector of Osaka, Japan) [Moss and Kintgen, 2010]. in 1716, it is believed that two merchants were responsible for creating the world's first highly organized futures market. Although this futures market was organized. The structure underlying this market is that the participating people agreed upon a standard grade (quality level) of the traded commodity (rice), which enabled active trading in contracts. The contracts that were traded by the participants were characterized by presenting a pre-specified price and quantity of the previously agreed upon rice standard as well as being executable on a set future date. New information becoming available to market participants could lead to contracts becoming more valuable or losing value, for example, a failed harvest would be expected to increase the future price of rice and therefore the prices of futures contracts would increase similarly. In the 17th century, futures contracts would ordinarily lead to at some point, ownership of the underlying commodity (of rice) being physically transferred to the participant who owned the futures contract.

Since the 17th century, futures markets have been increasingly legalized and are used in various sectors and domains. A variety of the trading rules and practices that were developed in the Doijma Rice Market were carried over to commodity trading, equity trading, and purely financial futures exchanges afterwards. With regards to the futures trading in materials that this research considers, commodity futures trading is the sector of consideration. A commodity is a raw material or agricultural product, such as copper, gold or coffee. The first official organized commodity futures exchanges became reality in the United Kingdom in the 18th century and in the United States, in the nineteenth century [Martin and Clapp, 2015]. Amongst others, driven by technological advances, the amount of futures markets has exploded since 1970 [Carlton, 1984].

Futures markets are now inherently different then at the time that the first futures markets arose. Historically, futures trading was mainly used for trading agricultural products, but more recently, more and more financialisation has saturated the futures markets with speculative instruments [Irwin and Sanders, 2012], rather than only for buyers and sellers seeking to ensure certain future prices. Trading a financial product that carries a high level of risk in the hopes of seeing substantial profits is considered speculating. Futures markets are now dominated by speculative instruments and the actual distribution of ownership of commodities is very rare. In the financial world, a speculative instrument, or speculative trading, entails trading in transactions that have a substantial risk of losing value, but that also have a potential significant gain. Price fluctuations in commodities are very common and they determine the profit that investors make upon completion of the future, causing the substantial risk for loss or gain.

2.1.3 Commodity futures exchanges

Futures exchange markets in primary materials are highly developed. An exchange is an organized and sanctioned trading platform, that mediates transactions. An example of a highly developed primary materials futures exchange market is the London Metal Exchange (LME). The LME is the world's largest futures exchange in the metal industry and provides spot and futures contracts [Park and Lim, 2018]. Spot contracts are contracts that are directly executed, whilst futures contracts have a future maturity date upon which the contract is settled. The spot and futures market affect one another; nonetheless, the nature of the mutual influence is hard to discern [Downes et al., 2005]. Moreover, the futures market extends upon the spot market. On the LME, trading is conducted in mainly an electronic fashion. On such an organized exchange, futures contracts are traded, whilst on Over-the-Counter (OTC) basis (bilateral), forward contracts are traded.

So, how does an organized exchange differ from trading outside of exchanges? On an exchange, futures contracts are traded based on a standard commodity grade, whilst with OTC (bilateral) forward contracts, customized commodities can be traded. Exchanges also allow for high liquidity as a futures contract can be easily resold, whilst OTC contracts may have a lower liquidity as they can only be settled upon the maturity date by the involved parties. Table 2.1 sets apart the difference between futures contracts traded on exchanges and forward contracts that are traded outside of exchanges in bilateral settings. Futures contracts are easily trade-able on a daily basis, also without the maturity date being achieved. Forward contracts are settled upon the previously specified maturity date. In futures markets and spot markets on regulated exchanges, trading can also occur between actors who are unknown to each other.

Table 2.1: Difference between futures and forward contracts

Characteristic	Forward contract	Futures contract
Nature	Over the counter (bilateral)	Traded on organized exchange
Liquidity	Less liquid	More liquid
Contractual terms about commodity	customized	Industry standard

A futures contract typically does not transfer ownership of commodity [Anderson and Dower, 1978][p.17], a futures exchange market is not a delivery market [Anderson and Dower, 1978][p.17]. E.g., on the Chicago Board of Trade, only 2 percent of all (agricultural) contracts are finalized with delivery of a commodity [Downes et al., 2005]. As the buyer of a futures contract need not have an intention to buy or use the commodity upon a future date, it becomes clear that futures contracts are used as speculative instruments that overlay future transaction to hedge price risks. A price risk of a future transaction is defined as the risk of the price of a commodity increasing or decreasing by an unexpected amount, whilst e.g. a seller has already invested a lot to manufacture the commodity and may therefore lose money.

For a farmer, the price risk of a potential oversupply of commodity leading to decreased prices, could be hedged. An investor can speculate that the market price will increase, or decrease [Carlton, 1984]. The relation between the spot market and futures market and correspondingly between suppliers, speculators and buyers (commodity demanders) is illustrated in Figure 2.2.

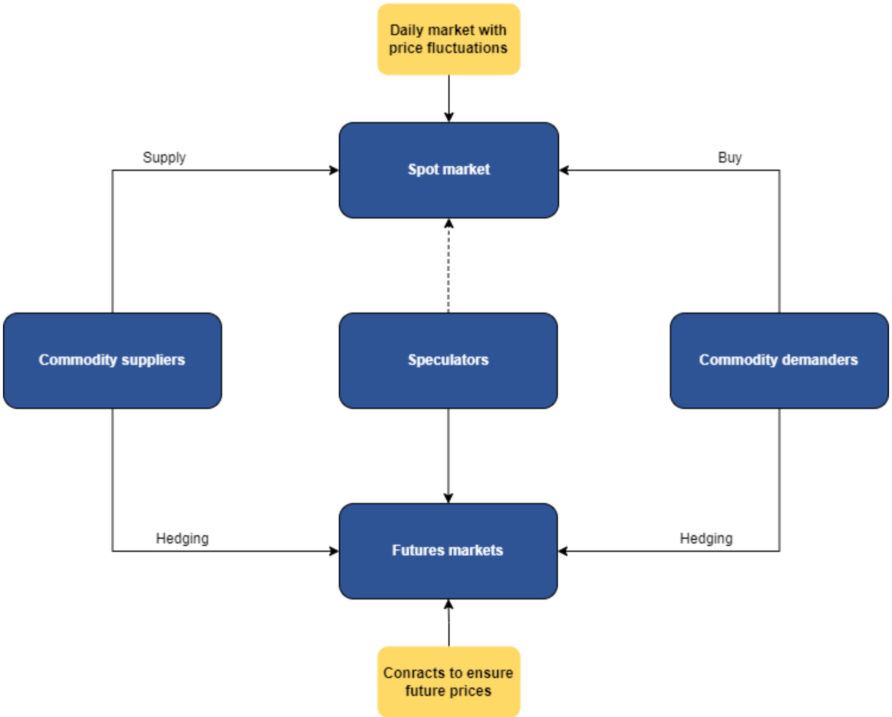

Figure 2.2: Commodity Market Schematic adapted from Ehlen and Scholand [2005]

Additionally, futures market can function as a price discovery mechanism, because many what are likely experts will speculate on the future value of the commodity [Williams, 2001]. To conclude, businesses can reduce price risk by offering their commodities on an organized exchange market that has a futures market extension. As there is typically no delivery of commodities involved, almost all futures contracts are mainly speculative in nature.

2.1.4 Controversy surrounding futures markets

Whilst futures markets have clear advantages for sellers and buyers to hedge price risks, there is also a lot of controversy around them. This controversy dates back to even the rice market in Dogma. Futures markets were widely viewed to be a form of gambling causing prices to rise. The government issued the following statement in response to the futures trading: 'There are people saying that they are just buying and selling rice, but instead they set up a venue, invite multiple people, ask the participants to pay fees, set a due date, as well as speculate on prices in the market. Because this is almost like gambling, we ordered them to stop this immediately. However, we heard that these people are gathering again and are frequently participating in these activities, which is outrageous behavior...' [Moss and Kintgen, 2010]. In essence, it was perceived as a form of gambling that could have destabilizing effects on commodity prices. Nowadays, there is still a lot of controversy surrounding futures markets. Many perceive futures markets as having a destabilizing effect on global commodity prices [de Jong et al., 2022]. The idea that speculation in the futures market is a source of volatility for commodity prices continues to be used as justification for requests for more controls or even outright bans on all commodity future trading [de Jong et al., 2022]. However, there is a lack of empirical evidence showing whether futures markets have a stabilizing or destabilizing effect on global commodity prices [de Jong et al., 2022]. Regardless of the potential negative or positive effects of futures exchanges on global commodities, individual businesses can hedge part of their price risk by selling futures contracts, hereby stabilizing a part of their future income. There may be some validity to both statements (futures markets having a stabilizing versus a destabilizing effect) in the sense that both a stabilizing and a destabilizing influence could exist, as was already acknowledged by Kaldor [1976] and many others after him. It remains to be questioned whether destabilizing effects or stabilizing effects will persevere. These potential stabilizing and destabilizing effects will have to be taken into account in the context of futures markets in SRM as well.

2.1.5 Futures markets in secondary raw materials

Whilst futures markets in primary materials are highly developed, futures markets in secondary materials are not developed. According to O'Neill [1983] secondary raw materials markets are an example of a commodity market for which there is no organized futures exchange present. Transactions in SRM occur on a bilateral basis between parties in the form of OTC transactions. Additionally, centrally organized and regulated spot markets - or cash markets - in secondary materials do not exist. A reason that markets in SRM are very difficult to achieve is that standardized grading schemes and quality assurances are very complex as products go through complex supply chains in which their quality could be affected. Even though there might be a lot of trading in secondary materials between individual industry actors (bilateral in nature) in OTC transactions, central marketplaces are not developed. Unlike in futures markets, current trading in secondary materials is typically conducted by actors who are known to each other in OTC transactions. For circular businesses, futures contracts can be very valuable towards securing future income, because circular businesses face a lot of uncertainty in relation to future income whilst often requiring large initial investments. By selling futures contracts, circular businesses can take steps towards securing future income streams and reducing risk, hereby, become a more likely candidate to receive investments from financiers.

2.1.6 Conclusion desk research on futures exchanges for secondary raw materials

It has become clear that a futures market is an extension of a spot market. A spot market is used for the selling and buying of commodities (raw materials). The futures market is used to hedge the price risks that are associated with this spot market. Commodities futures markets serve a purpose to transfer risks from commercial traders to speculators [Williams, 2001]. The most important take away of analyzing futures markets dynamics in primary raw materials, is that futures markets are not a standalone market, they are an extension of spot markets and are used to hedge price risks on spot markets. It also became clear that organized futures exchanges in SRM do not exist. Therefore, now that the dynamics of futures markets in primary raw materials have been explored by means of desk research, interviews with involved actors can be executed to further explicate the problem. To build towards the interviews, the concept of circular supply chains as well as an actor analysis are first presented in the following sections.

2.2 DEFINING CIRCULAR SUPPLY CHAINS

The concept of a CE has already been explained in the first chapter, but the concept of supply chains for SRM has not been addressed yet. A supply chain is the entirety of goods that are transported and activities that take place between a supplier and an end consumer. Therefore, a supply chain is a chain of links that provides insight into the entire process. A supply chain contains all the links from a raw material or material to a finished product. This includes not only the production or manufacture of the product, but also its transport and storage. A complete supply chain shows which materials have been used to manufacture a certain product and where these materials have come from. The supply chain therefore consists of companies or distributors that are linked to a single other company or distributor. A linear supply chain also involves similar links between involved actors, but when the product is delivered to the end consumer, the materials are disposed of as waste. Ideally, a circular supply chain should not produce any waste, but rather re-use and recycle materials. The structure of actors involved in a circular supply chain is illustrated in Figure 2.3.

Farooque et al. [2019] proposes the following definition for circular supply chain management: '*Circular supply chain management is the integration of circular thinking into the management of the supply chain and its surrounding industrial and natural ecosystems. It systematically restores technical materials and regenerates biological materials toward a zero-waste vision through system-wide innovation in business models and supply chain functions from product/service design to end-of-life and waste management, involving all stakeholders in a product/service life-cycle including parts/product manufacturers, service providers, consumers, and users*.' Furthermore, the type of circular supply chain can be defined as closed loop, or open loop [Weetman, 2016]. In a closed loop supply chain, materials are returned to the producer for reuse purposes, but not all materials in such a chain may be reusable by the same producer. Therefore, closed loop supply chains still tend to lead to some waste being produced. An open loop supply chain goes even further, not only returning materials and products to the producer, but materials are also directed to other channels and supply chains for their reuse purposes. An open-loop supply chain requires more collaboration between a variety of stakeholders.

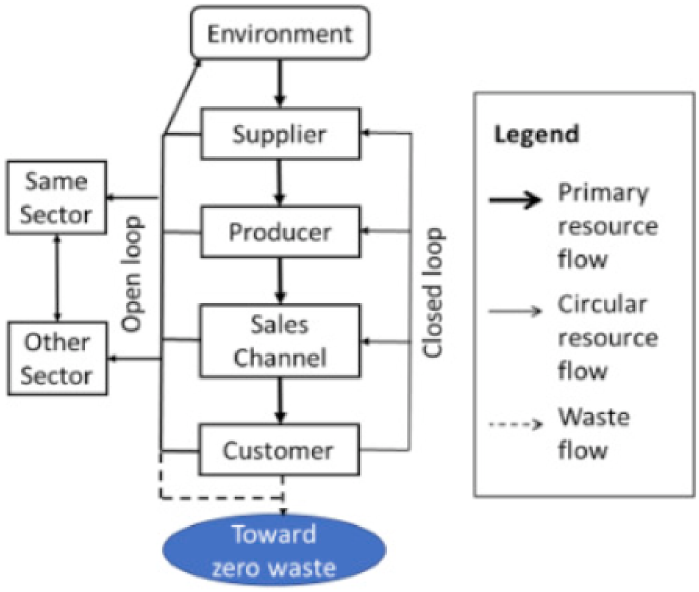

Figure 2.3: Circular supply chain [Farooque et al., 2019]

Although Farooque et al. [2019] provides an informative overview of actors that are involved in circular supply chains, actors directly involved in a supply chain (from now on referred to as internal supply chain actors) are not the only actors that influence the actor playing field of a circular supply chain. The circular supply chain is also influenced by external actors such as regulators and financing bodies. Because it is relevant to gain an overview of the entire actor playing field surrounding circular supply chains, an actor analysis is conducted in the next section.

2.3 THE ACTOR PLAYING FIELD SURROUNDING CIRCULAR SUPPLY CHAINS

Firstly, supported by interviews with expert actors with central roles, an actor playing field analysis will be presented that supports the identification of actors with a central role in the circular economy playing field. A central role in the actor playing field is defined as an actor with a lot of interaction with other actors and also having a clear influence on supply chains, which can be an internal influence, but also an external influence. This actor analysis gives insight into the various parties involved in circular supply chains. How these actors interact might also be of importance to ultimately decide on what type of actors would be relevant to be selected for interviewing. In this section, the actor analysis results will be presented in the form of a formal chart [Enserink et al., 2010].

Based upon conversations with experts in the field of CE and desk research, the following actors were selected to guide the actor analysis based on their expertise and central role:

- **Standardization body** (2021, May, 11th). Program Manager Circular Economy at a standardization body. [Phone interview]
- **National authority policymaker** (2021, May 10th). Policy Officer specialized in circular economy [Phone interview]
- **Auditor** (2021, April 29th). Director international affairs and circular economy at an auditing firm [Phone interview]

The more detailed actor analysis can be found in Appendix A. The appendix provides an explanation of the role of each actor that is discussed. This section provides a summary of the results of the actor analysis.

Because it has been identified that there are actors directly involved in supply chains (internal) and actors with an external influence, these will be addressed separately (external). Firstly, the internal circular supply chain playing field (all the actors that physically own or transport the components for the product) will be discussed.

2.3.1 Internal circular supply chain actors

This internal supply chains consists of suppliers, producers, brandholders, in some occasions retailers, consumers, recyclers, or outside of the scope of a circular supply chain: waste dumps and waste operators. It becomes clear that there can be a multitude of suppliers of raw materials in the beginning of a supply chain. Moreover, these raw materials make their way to possibly also a multitude of producers. How many suppliers and producers are involved in these first phases of a supply chain mainly depends upon mainly the complexity of the final product that will be put together. A producer can also be a supplier. For example, a bottle will need less involved suppliers and producers for the separate parts compared to a mobile phone which has many different components made by different producers with different materials. Moreover, after this initial product development phase is completed, the final producer who puts together the product, provides the product to the end-consumer (it is possible that a retail party is situated in between the producer and consumers, but this differs across supply chains). Following this, consumers dispose the products to waste collectors and from here on out, the product can be delivered to a recycler who can return raw materials to various points in the supply chain. Currently, trading between recyclers and the businesses that they sell the recycled materials to is executed without any third party having a role in this process. In essence, the recyclers take on the role of 'supplier' when selling the secondary materials. Alternatively, 'waste' (which can also be considered a resource and not waste but for the clarity of the explanation referred to as waste) can be disposed to waste dumpsites instead of recyclers, but at the risk of either these resources never being used again, or even worse, them ending up polluting oceans.

2.3.2 External circular supply chain actors

Apart from these within supply chain dynamics, actors outside of the scope of the supply chain also have a big effect on the actors within the supply chain. The most important identified actors in this playing field are auditors, standardization bodies, the European Commission, national government and municipalities. Moreover, financiers play a key role in this playing field as well by providing businesses with the capital to grow and become more dominant. The European Commission sets out high level goals and guidelines that the nations have to adhere to. Nations themselves choose how they impose laws to achieve the before mentioned goals and guidelines. Typically, it is then the municipalities who are actually responsible for the monitoring and executing of the national regulation. Moreover, standardization bodies develop (paid for by government money) metrics and tools that companies can use to report on their circularity behavior. According to the interviewee: *'A standardization body is an instrument that can be applied to set standards about circular performance, on a national level, we have a lot of influence, but on an international level this is smaller'* (Personal Communication, Standardization body, May 2021). Furthermore, companies can use these metrics to report their operations and can provide this to auditors. Auditors make assessments of a companies operations and their compliance with laws to ensure circularity, based on the provided information. According to the interviewee: *'Auditors play a role in the control of circular performance of businesses, currently the focus is mainly on financial reporting, but this should be increased with non-financial reporting'* (Personal communication, Auditor, April 2021).

2.3.3 Formal chart

To map the interactions between actors, a formal chart is developed based upon the actor analysis. A formal chart can be used to illustrate the relations between stakeholders [Enserink et al., 2010]. A formal chart is a useful tool that allows to group certain actors in a similar group by demarcating them with a dotted line. Relations can then be defined between actors, but also between groups of actors. The relations between actors are defined by arrows or lines, arrows in certain directions indicate a hierarchical relationship, the arrow pointing towards the actor that is lower in the specific hierarchical relationship. A line without an arrowhead indicates a non-hierarchical relationship. Figure 2.4 (on the next page) illustrates the identified relationships between the involved actors in a typical manufacturing industry landscape centered around the circular supply chain for one typical product-line supply chain.

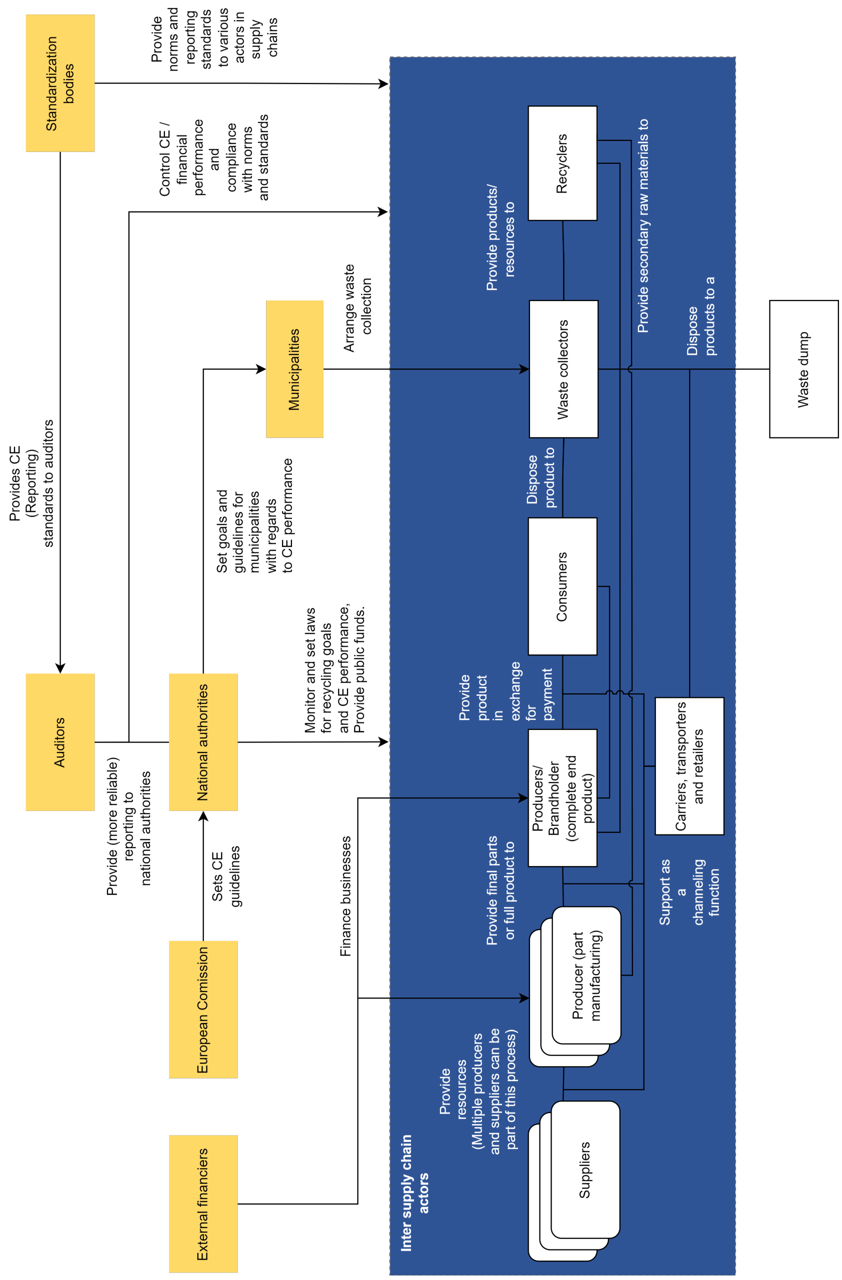

Figure 2.4: Formal chart illustrating the actors involved in the financing of circular processes, methodology by [Enserink et al., 2010]

2.3.4 Conclusion actor analysis

It has been identified that there are actors directly involved in supply chains (internal) and actors with an external influence and these actors have been addressed separately. The formal chart illustrates the before mentioned relationships and shows that there are many complex relationships between the involved actors, not only within supply chains, but also outside of supply chains. Based on this actor analysis, actors can be selected for interviews to analyze their problem perceptions and the need for futures markets.

2.4 INTERVIEW BASED RESEARCH INTO FUTURES MARKETS FOR THE CIRCULAR ECONOMY

Now that the dynamics of futures markets in primary raw materials and the actor playing field surrounding circular supply chains have been explored, the potential of futures markets for enabling the circular economy will be addressed by means of interviews. The analysis of the actor playing field is implemented to select actors to interview.

2.4.1 Actor selection for problem explication interviews

Based on the actor analysis, key actors can be selected for interviews with the purpose of explicating the problem further. The formal chart illustrates the central role that producers have in the supply chain. Producers interact with suppliers, retailers, customers, financiers and with national authorities. Hence, it will be important to conduct interviews with these producers (circular business owners). Financing actors have an important role in providing producers with capital to grow their business and therefore enabling a circular economy. Based on the formal chart, it becomes clear that financiers and producers have very central roles in circular supply chains, these actors are interconnected within and outside of supply chains. Lastly, recyclers have a key role in integrating the entire reverse logistics supply chain, hence they will also be interviewed with regards to their problem perceptions. Therefore, the following interviewees were selected based on the resources of the researcher as well as their central roles in circular supply chains:

- **Industry experts financing the circular economy** (2021, May, 17th) Management functions in circular economy finance at a Dutch Bank. [Phone Interview]
- **Founder of a circular business** (2021, May, 17th). Circular business in electronics sector [Phone interview]
- **Financier sustainable and circular finance** (2021, May, 12th). Sustainable finance account manager at a Dutch Bank. [Phone interview]
- **Founder of a Circular Economy facilitating technology business** (2021, June 7th). [Phone interview]
- **Recyler** (2021, April 30th). CEO at a Dutch recycling firm. [Phone interview]
- **Sustainable Finance for Circular Economy Expert** (2021, June 14th). [Phone interview]

These interviewees include two actors active in financing of the circular economy, two circular producers (founders of circular businesses) and a recycler. Therefore, external supply chain actors as well as internal supply chain actors are considered for interviews. Lastly, one actor not directly involved in the circular supply chain was also interviewed, based on the expertise on the domain of circular economy financing.

2.4.2 Interview protocol

Multiple interviews will be conducted to derive knowledge on the potential of futures markets for the CE. The central theme in these interviews is to research whether the problem perception of actors aligns with the development of futures markets for SRM; i.e. exploring whether there is currently a societal need for futures markets.
Structured interviews gather more information than unstructured interviews [Agarwal and Tanniru, 1990; Browne and Rogich, 2001; Marakas and Elam, 1998]. However, a fully structured interview could also lead to some insights not being discovered. Multiple researchers also claim that an experienced analyst is not a factor during information acquisition with interviews, the main factor is in the preparation of interviews, a well-prepared interview has more impact on the information acquisition than an experienced analyst [Agarwal and Tanniru, 1990; Pitts and Browne, 2004]. Therefore, the interviews were conducted in a semi-structured manner, centering around a few prepared key themes that could differ per actor and that also evolved as insights that were derived from prior interviews could be integrated into the next interview. As in all design science research, the problem is complex and dynamic and evolved over time. Key topics that were typically discussed during the interviews were the following:

- Introduction
- The role of the person within the organisation
- (Dependent upon interviewee) Company business model and supply chain
- (Dependent upon interviewee) Traceability of products in supply chain
- (Dependent upon interviewee) Resource problems
- (Dependent upon interviewee) Problems related to risk management for circular businesses
- (Dependent upon interviewee) External financing problems
- Other unaddressed relevant aspects

Naturally, for founders (circular business owners) it was more relevant to discuss what is preventing them from getting (external) financing for their business and if this is related to price risks, then it is to discuss this with the financier themselves. Moreover, founders were also interviewed based on how much control they have over the traceability of their supply chain. Furthermore, founders were also interviewed about what resource problems they are experiencing (such as dependencies or scarcities). With the financiers, it was discussed more what problems and risks investing in circular businesses brings with it and why this may be problematic in preventing the growth of a circular economy.

2.4.3 Summary of interview results

Based on the results of the exploratory interviews, it can be concluded that currently, the direct societal need for futures markets is not clearly apparent. According to two industry experts in financing the circular economy: *Future markets only arise when there is a clear demand for them* (Personal Communication, Industry experts financing the circular economy, May 2021). The interviews even caused some confusion with some of the interviewees, because it was pointed out that looking into the potential of futures markets may be preemptive, as *futures markets extend on organized spot markets and these aren't in place for SRM* (Personal Communication, Industry experts financing the circular economy, May 2021). (Spot markets being the exchange markets upon which commodities with an agreed standard grade are traded on a day-to-day basis) The interviewees stated that *the demand for futures markets could increase over the coming years, with increased resource scarcity and dependency being indicators of the potential demand, but without the presence of active spot markets, futures markets will not arise* (Personal Communication, Industry experts financing the circular economy, May 2021). Lastly, the interviewees stated that *there is a very clear societal need for organized spot markets in SRM* (Personal Communication, Industry experts financing the circular economy, May 2021).

Furthermore, another interviewee stated that *investments in circular businesses are now usually perceived as risky endeavours and therefore avoided by a risk averse bank* (Personal Communication, Financier sustainable and circular finance at Dutch Bank, May 2021). Future income streams of circular businesses are perceived as uncertain, whilst usually, large investments need to be made in the initial stages of setting up circular business models. Examples of these large investments are the development of recycling facilities, or in the case of leasing out products for multiple years, the products need to be fully financed in advance (think of SwapFiets, consumers pay a monthly rate, but producers have already invested in the full costs for the bike). For this reason, banks usually only want to invest in the parts of a circular business that can be backed by liquid assets. An example of such a part of a circular business that banks would invest was provided by the interviewee, a factory for the purpose of recycling materials, that in the case of bankruptcy of the business, would remain valuable for its machinery and real estate value. To conclude, the interviewee stated that *it would be valuable to have some way that the future income stream could be made more certain, to decrease the investment risk and make an investment in a circular business more attractive* (Personal Communication, Financier sustainable and circular finance at Dutch Bank, May 2021).

Moreover, the interviewed CEO from a recycling firm stated that: *'It would be nice to have some assurances on the price for selling our resources and products, currently we are very dependent upon oil prices and external forces'* as well as that *'We would like some measures to decrease price risk and assure ourselves of an income stream'*. However, the recycler also stated that they have *[we have] no need for more administrative burden that products passports and tags might impose upon us*.

(Personal Communication, CEO Dutch recycling firm, April 2021) Recyclers do have a need to decrease price risk - which futures exchanges can provide -, but would not want all the responsibility for the administrative burden that they perceived it could create.

Conclusion interviews into the need for futures markets

To conclude, as according to industry experts, futures exchanges would arise if there was a clear demand for them, it can be derived that currently there may not be a clear societal demand for organized futures markets, but this could also be caused by the fact that underlying spot markets are not present. However, according to a recycler, there is a need to ensure a steady income stream by decreasing price risk, which is exactly what a futures exchange could achieve. Nevertheless, this same recycler wants to avoid administrative burden that futures markets may bring along, and therefore, does not have a demand for them. Additionally, it became clear that the need for futures markets might arise in the coming years, but only if organized spot markets are created.

This leaves to think that possibly, the need for futures exchanges may not be clearly apparent in society, but be a latent need: a need that actors themselves are not conscious of [Narver et al., 2004]. It is important in design research to not only translate what actors express, but also analyze and discover these latent needs [Narver et al., 2004]. It is understandable that a need for futures markets may indeed be a latent need; because spot markets do not exist yet, it is difficult to imagine the advantages that futures markets may bring for the actors who would be involved in them. Therefore, involved actors may not be conscious of their possibly latent need for futures markets. Latent needs are also sometimes referred to as future needs, and latent needs can be identified by looking at societal patterns that may increase or activate these latent needs increasingly [Narver et al., 2004]. During the interviews, it came forward that potential developments that pointed towards a latent need were *increased resource scarcity* (Personal Communication, Industry experts financing the circular economy, May 2021), *increasing resource dependency* (Personal Communication, Industry experts financing the circular economy, May 2021) and *Increasing price fluctuations* (Personal Communication, CEO Dutch recycling firm, April 2021; Personal Communication, Financier sustainable and circular finance at Dutch Bank, May 2021). Therefore, these developments will be further researched by conducting desk research in the next section.

2.5 DESK RESEARCH INTO DEVELOPMENTS POINTING TOWARDS LATENT DEMAND FOR FUTURES MARKETS IN SECONDARY RAW MATERIALS

The following paragraphs highlight the patterns pointing towards a latent need for futures markets *increased resource scarcity* (Personal Communication, Industry experts financing the circular economy, May 2021), *increasing resource dependency* (Personal Communication, Industry experts financing the circular economy, May 2021) and *Increasing price fluctuations* (Personal Communication, CEO Dutch recycling firm, April 2021; Personal Communication, Financier sustainable and circular finance at Dutch Bank, May 2021).

2.5.1 Increased resource scarcity

Between 1980-2010, primary raw material use doubled from 40 billion to 80 billion t. According to Bertau [2018], in just another 30 years, this will have doubled again to 160 billion. According to Mardegan et al. [2013], an increasing amount of resources will start to deplete over the coming years. Hence, resource scarcity is set to grow. With growing resource scarcity, it will become even more important to transition to a CE. Therefore, already proactively planning for the use of resources that are already in the economy by enabling futures markets could also play a role in decreasing future resource scarcity.

2.5.2 Increasing resource dependency

Resource dependency is only set to grow over the coming years [Mardegan et al., 2013]. China dominates the global primary materials supply [Bertau, 2018], while other countries are reducing extraction processes due to the polluting effects. Growing resource dependency on countries like China will make it more attractive to start implementing resources from the local economy for reuse purposes. Futures markets would also make an interesting intervention in this field as they would allow demanders to already secure access to SRM for a set price during a future period and within the same economy, preventing them from having to outsource to e.g. China.

2.5.3 Increasing price fluctuations in secondary raw materials

Prices of SRM fluctuate constantly and can also differ substantially based upon geographic location [Leverenz and Kreith, 2002]. Dussaux and Glachant [2019] state that there needs to be a strategy developed to control the price fluctuations in SRM, because they are disrupting markets. Hagelüken [2012] also considers that temporary scarcities are now leading to sometimes extreme price volatility in markets and that this price volatility is undesirable and destabilizing. It becomes clear that there is a need to control price volatility (price risk) in these markets, futures markets are said to be an instrument to achieve exactly this [Singh et al., 2005; Dana and Gilbert, 2008].

2.5.4 Conclusion desk research on latent needs

It becomes clear that all these three factors may lead to an increasingly stringent need for futures markets, whilst this need currently takes on a latent form. This latency could be caused by the fact that the underlying foundation for futures markets is not present yet; an organized spot market. Therefore, it is expected that an underlying problem that is preventing futures markets from arising is the fact that there are no active organized spot markets present. Hence, supporting the development of a spot market (on a regulated exchange) could make the need for futures markets conscious to actors.
According to the European Commission [2015] there is a need to support the development of central markets in SRM as they can prevent scarcity issues and reduce dependencies on imported resources. Brorsen and Fofana [2001] also conclude that the most important prerequisite for futures commodity trading is the existence of an active underlying cash market stating that; 'unless an active cash market exists, resources invested in developing futures markets will be wasted'. Cash markets and spot markets imply the same concept, but are different terminologies. This research will use the term 'spot market' from here on to refer to the concept and assume that it is situated on a regulated exchange. Furthermore, according to Brorsen and Fofana [2001], if an active spot markets does not yet exist, the focus should first be on the development of these spot markets, before considering new markets in futures trading.
The before mentioned points further enforce the belief that the development of spot markets should be supported before successful futures markets can be developed as well as before the need for them will arise. Therefore, this research will address the following: the lack of active spot markets in SRM situated on a regulated exchange.

2.6 CONCLUSION PROBLEM EXPLICATION

To summarize this chapter, the dynamics of futures exchanges were outlined, an actor analysis was conducted, interviews with relevant actors were conducted to form an understanding of the need for futures markets followed by desk research on developments that will potentially transition the need for futures markets from a latent to a conscious need.

This chapter centered around sub-question 1: ***What is the problem as experienced by stakeholders involved in circular processes that is preventing futures markets from emerging?***. Recylers experience problems related to price risk of SRM, due to fluctuations in value, and would like to see this risk reduced, but don't see the direct value of futures markets. Moreover, financiers view investments in circular business-models as risky endeavours due to this price risk and would like to see this risk reduced. Nevertheless, it is stated that there is no clear demand for futures markets, because futures markets naturally arise when there is demand for them.

It has become clear from the interview results that the current societal need for futures market may be latent. Although, there are also signs that this need will arise over the coming years and transition from a latent need to a conscious need.
Based on the findings from desk research, it can be concluded that spot markets are a prerequisite for futures markets. As futures market extend upon spot markets and there are no spot markets in secondary materials yet, futures markets will be difficult to design or develop. Therefore, the societal need for supporting the development of futures markets by enabling spot markets has been identified as a key finding. This research will focus on supporting the development of spot markets in secondary raw materials by designing a to be specified artefact. Even though futures markets themselves will not be designed, it is possible to design spot markets for secondary raw materials in such a way that they could accommodate a futures market extension. To conclude, the aim from this point on is to support the development of spot markets that could be extended with a futures market, by means of identifying design principles and designing an artefact.

3 REQUIREMENT ANALYSIS A: OUTLINING THE ARTEFACT

The research question considered by this chapter is sub-question 2: ***What artefact can be a solution to support futures markets in secondary raw materials?***

Now that the initial problem explication has been conducted, insights towards the research direction have been generated. The research is further scoped down towards supporting the development of spot markets in such a manner that they could underlay futures markets. The next phase in the DSR approach is the requirement analysis. In essence, this phase consists of a further problem explication, but in the solution direction that has resulted from earlier problem explication [Johannesson and Perjons, 2014]. The requirement analysis phase is divided into two main sub-activities: outlining the artefact and eliciting requirements [Johannesson and Perjons, 2014]. These sub-activities have been allocated a chapter each in this report, with this chapter commencing the sub-activity of artefact outlining. This Chapter 3 addresses only the first sub-activity; outlining the artefact. The outlining of the artefact consists of choosing what type of artefact should be developed in order to support the development of spot markets in SRM. Hence, this chapter takes a step back from the previous orientation towards futures markets and focuses fully on what artefact should be developed to support spot markets - but taking into account that the spot market should be suitable to be at the foundation of futures markets. This chapter will result in a description of the to be designed artefact on an overview level.

Data that is implemented throughout this chapter is a combination of desk research on spot and futures markets, as well as knowledge derived from the previous problem explication phase (Figure 3.1).

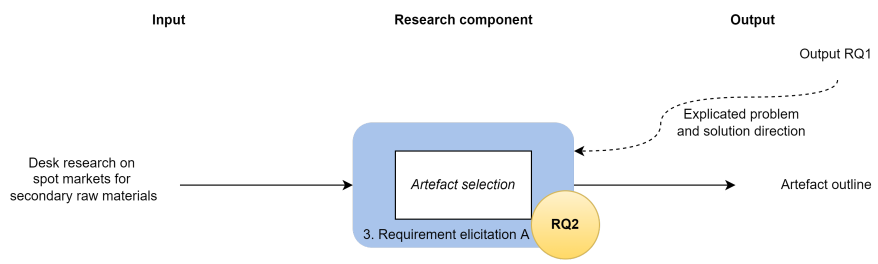

Figure 3.1: Research flow of artefact outline

3.1 SUPPORTING THE DEVELOPMENT OF SPOT MARKETS IN SECONDARY RAW MATERIALS

This section will explore concepts that are important in selecting an artefact outline suited to supporting the development of spot markets in SRM based on desk research. The difference between desk research so far and desk research in this chapter is that in this chapter, the concepts of spot markets and secondary raw materials are linked, rather than that the concepts of futures markets and secondary raw materials are linked. There was relatively little literature that could be sourced on the combination of the concepts of spot markets and secondary raw materials, even when implementing some synonyms for the concepts. Moreover, SCOPUS provided no results on any of the combination of terms or their synonyms. Therefore, Google Scholar was also explored, as it contains more content that is not peer-reviewed [Mikki, 2009]. Google scholar presented with more results, although results could not be retrieved on the topic of organized spot markets in SRM, but on markets in SRM in general. Nevertheless, a spot market is a market, so these publications can also be generalized to spot markets to some capacity. One publication of key relevance was identified on Google Scholar; the results of a workshop conducted by the European Parliament Committees on the Environment, Public Health and Food Safety (ENVI) and Industry, Research and Energy (ITRE) conducted on the topic of supporting markets in SRM [Eliaerts et al., 2017].

One of the key topics in supporting markets in SRM was identified as a lack of supply chain visibility and the need for the 'right data' [Eliaerts et al., 2017]. In accordance with the results of this workshop, it was identified that markets in SRM pose a very real opportunity, but that information gaps are preventing them [Eliaerts et al., 2017]. The workshop stated, that with innovative tools to share (the right) data, markets in SRM could be supported. Supply chain visibility considers how information is shared between actors, and 'the right data' considers what data should be shared.

Another key research topic that came forth of the workshop was that regulatory barriers should be removed to support markets in SRM Eliaerts et al. [2017]. According to Eliaerts et al. [2017] regulatory barriers are caused by conflicting legislation and interests.

3.1.1 Increasing supply chain visibility and the need fot the 'right data'

Supply chain visibility

Supply chain invisibility is characterized by there being a lack of information exchange between sellers - the source - and buyers. Many supply-chain related issues arise due to the lack of sharing information between the members of a supply chain [Li et al., 2001]. The increases in outsourcing and multi-modal transport chains of the recent decades have resulted in little supply chain visibility in supply chains; the identity of the manufacturers (the source), as well as the consumers can be clouded and create contractual complexity [Klievink et al., 2012]. Supply chains are characterized by complex processes, with many parties involved, documents, transaction costs, certificates and with inefficiencies across all parts of supply chains [Lakkakula et al., 2020]. For circular business models in particular, it is very problematic for the resource recovery process if there is a lack of supply chain visibility [Rajput and Singh, 2019]. Good information sharing is at the core of supply chain visibility and collaboration [Min et al., 2005]. Circular models need supply chain visibility to arrange reverse logistics processes, enable product traceability, but also to derive knowledge on what components products are made up of to enable efficient recycling to generate SRM. Furthermore, Rukanova et al. [2021a] state a lack of visibility in circular supply chains is one of the key challenges towards achieving the CE. Therefore, to support spot markets in SRM, methods should be sought to increase *supply chain visibility* across circular supply chains with *high actor complexity*.

The right data

The need for the right data was mentioned as a challenge that is paired with the lack of supply chain visibility [Eliaerts et al., 2017]. Not sharing the right data, can lead to a market that cannot exist in some cases [Akerlof, 1978]. For example, Akerlof [1978] gives an example in which quality uncertainty of second hand cars breaks down the market in second hand cars. In this market, low quality as well as high quality cars are sold, but the buyer is not aware of the differences due to insufficient information. Therefore, buyers will want to pay an average price for both low-quality as well as high-quality cars. Simultaneously, the high-quality car seller will want a higher price and will not sell the car and take it out of the market. Accordingly, spot market in SRM can't be created without the right data being shared about the to be traded commodities. How then can the right data be defined. The right data considers data about the quality of materials, but also about how to extract the value from these products. Many products contain a multitude of materials, and it can differ across products how to disassemble them back to raw materials. Data that provides this type of information about materials and products as well as how to disassemble them, is often of a very confidential nature [Licht, 2021]. What resources are used for the development of products can be a company secret and hence not something easily shared. For this reason, it is of the essence that this information is treated as confidential such that the actors sharing information can trust each other. Hence, there is an *information confidentiality complexity* and creating *trust* between actors is of the essence to ensure data sharing.

3.1.2 Removing regulatory barriers

According to Eliaerts et al. [2017] regulatory barriers prevent markets in SRM from being supported. These regulatory barriers are caused by poor implementation as well as conflicting legislation and interests [Eliaerts et al., 2017]. An example is given about the material palladium, of which 115 million euros worth is exported from the European Union on a yearly basis, whilst there is no substantial natural deposit of it situated in the European Union. This amount of palladium exported in scrap vehicles on a yearly basis would be be able to, when extracted, account for 60 per cent of Europe's yearly demand. However, these scrap vehicles are allowed to be exported anyways, whilst imposing legislation could enforce re-use of the material [Eliaerts et al., 2017]. [Grafström and Aasma, 2021] state that regulatory interventions could remove market barriers for a circular economy and propose creating price signals and property rights as well as decreasing subsidies in favour of linear supply chains.

3.1.3 Conclusion and artefact solution direction

To summarize, supporting spot markets in SRM would be a process that is complex, as there are information sharing barriers as well as regulatory barriers that play a role. Information sharing barriers would ask for some type of tool to support information sharing and the right data. Regulatory barriers would ask for the design of new regulatory instruments. Nevertheless, the artefact to be designed in this research can only address one of these barriers in detail due to the time constraints of the thesis research. This research could therefore pursue two directions. Moreover, the thesis research, to fit into the relevance of the MSc. program of the research (Complex Systems Engineering and Management), should contain a technical or engineering component.

Eliaerts et al. [2017] calls for innovative tools to share data in support of markets in SRM. According to Hesketh [2010], digital technologies hold a lot of promise to enable circular supply chain information sharing, but have been explored only in a limited manner. Rukanova et al. [2021a] also state that digital innovations have the potential to increase supply chain visibility.

Moreover, Leverenz and Kreith [2002] also identifies that Information Systems should be further explored to enable information sharing about SRM. Designing a tool to support information sharing from an Information Systems perspective, is of more technical nature than the design of regulatory instruments. Also, DSR is particularly suited for Information Systems research [Peffers et al., 2007].

Therefore, this research will focus on addressing the information sharing gap present in circular supply chains (in the manufacturing sector) by means of an Information Systems perspective. The next section will explore how Information Systems could enable supply chain visibility and information sharing to support spot markets in SRM.

3.2 AN INFORMATION SYSTEMS DESIGN PERSPECTIVE TO SUPPORT OF SPOT MARKETS IN SECONDARY RAW MATERIALS

This section will analyze digitization in the context of supporting spot markets in secondary raw materials. Desk research is implemented to link the theoretical concepts of information sharing about SRM (in the context of a CE) and digitization. This section aims to further scope the design direction within the context of an Information Systems perspective.

According to Pagoropoulos et al. [2017] and Antikainen et al. [2018], digitization will play a prominent role in the transition to a CE. Digitization can provide opportunities for the development of markets in SRM [Eliaerts et al., 2017]. Hesketh [2010] also consider that digital technologies hold a lot of promise to enable circular supply chain information sharing, but have been explored only in a limited manner. Zeiss et al. [2021] conducted an extensive literature review on information systems for the circular economy and identified that existing research has primarily examined isolated intra-organizational processes, whilst not regarding the larger potential for information systems to facilitate the closing of entire material flows for the CE. To close entire material flows, information has to be shared amongst all supply chain actors [Zeiss et al., 2021].

To conclude, innovative digitized tools can be designed to support the development of spot markets in SRM. These innovative digital tools will have to take into account the complexities related to information sharing in circular supply chains, as addressed in the previous section, a high actor complexity, confidentiality issues of the data as well as creating trust to enable data sharing between the involved actors in the supply chain.

One innovative solution particularly suited to handle confidential information and improve transparency comes in the form of BCT (BlockChain Technology) based digital infrastructures [Belotti et al., 2019]. Recently, BCT has been identified as having the potential to disrupt all industry in the world [Ølnes et al., 2017]. BCT has also been identified as a key enabler in overcoming hurdles towards the circular economy and increasing supply chain visibility [Böckel et al., 2020]. Antikainen et al. [2018] conclude their literature review stating that BCT could play a role in overcoming the challenges of data sharing in circular supply chains. Moreover, research by Upadhyay et al. [2021] illustrates that BCT could contribute to the CE by improving communication. Furthermore, Kouhizadeh et al. [2020] states that BCT could be used to increase transparency across supply chains, enabling the possibility to trace products across the entire lifecycle.

In summary, digital architectures based on BCT can provide increased transparency, cooperation and efficiency to facilitate the integration of return flows into the forward flows [Visich et al., 2007]. BCT is also suited for preserving information confidentiality and handling actor complexities. This is summarized in Table 3.1. Lastly, BCT has now reached a maturity that makes it suitable for multiple applications [Tönnissen and Teuteberg, 2020]. This further validates the choice for this artefact design direction.

Complexities	Literature on BCT as enabler
Confidentiality	[Belotti et al., 2019]
Supply chain visibility	[Böckel et al., 2020; Shojaei et al., 2021]
Actor complexity	[Kouhizadeh et al., 2020; Upadhyay et al., 2021]

Table 3.1: BCT-based artefact fit with the needs for supporting spot markets in SRM

3.3 ARTEFACT OUTLINE

Taking into account that DSR is the 'study of artefacts' [Johannesson and Perjons, 2014], an artefact is developed with the intention of it solving a problem. Defining the artefact in the context of DSR methodology is an important point of departure. There are four types of artefacts constructs as defined by Hevner et al. [2004] a construct (vocabulary and symbols), a model (abstractions and representations), a method (algorithms and practices), or an instantiation (implemented and prototype systems). Now that is has become clear that a BCT-based digital infrastructure could potentially support markets in SRM by increasing supply chain visibility, an artefact can be designed based on the solution orientation of a BCT-based digital infrastructure. This research is of a Problem-Focused nature so the artefact will have an objective to gain better understanding of the problem and the system dynamics. For this reason, the artefact to be developed will have a high level of abstraction.

Taking the before mentioned into account, the artefact will consider the design of a BCT-based digital infrastructure, it will be an abstraction of the design for an infrastructure, implying that it falls in the category of a 'model': an abstraction or representation. Now that the artefact selection has been scoped down to a BCT based infrastructure, BCT itself is explained in the following section.

3.4 DEFINING BLOCKCHAIN TECHNOLOGY BASED INFRASTRUCTURES

BCT first entrance into society was in 2008, when an anonymous person launched the system supporting the cryptocurrency known as Bitcoin Nakamoto [2008]. The relatively young technology quickly gained ground and was later deployed in various other sectors. The following definition of BCT will be used throughout this research: "*A blockchain is a distributed database, which is shared among and agreed upon a peer-to-peer network. It consists of a linked sequence of blocks, holding timestamped transactions that are secured by public-key cryptography and verified by the network community. Once an element is appended to the blockchain, it cannot be altered, turning a blockchain into an immutable record of past activity.*" [Seebacher and Schüritz, 2017][p.3].

A system architecture is a conceptual model that defines the structure, behavior, and more views of a system. System architectures for BCT-based networks have been depicted by Venkatesh et al. [2020] and Wang et al. [2020].

A blockchain differs from this traditional digital database. The information in a blockchain is not owned by one party, but by a large number of different parties connected to the blockchain network. Each participant on the network is in possession of the entire ledger, but at the same time no one is the owner. A blockchain is managed by many people together. Each party in the network is not connected to a database, but to each other. This is called peer-to-peer. BCT is of distributed nature, implying that a ledger is distributed across network of actors or entities that are referred to as nodes. Shojaei et al. [2021] explain the main processes of as illustrated in Figure 3.2. This Figure 3.2 shows that when a node or person on the system creates a new transaction, all nodes in the system are made aware and the transaction is then validated based upon agreed upon algorithms. These agreed upon algorithms form the consensus mechanism and consensus mechanisms can vary for different applications of blockchain. If the transaction is indeed validated by the consensus mechanism, the new transaction is added to the chain of blocks and the new chain is distributed across the nodes. This mechanism ensures the immutable nature of transactions that are stored on the blockchain [Zheng et al., 2017]. Moreover, Wang et al. [2020], Dindarian and Chakravarthy [2019] and Rehman Khan et al. [2021] emphasize the potential for BCT to enable traceability of products and value preservation for the CE.

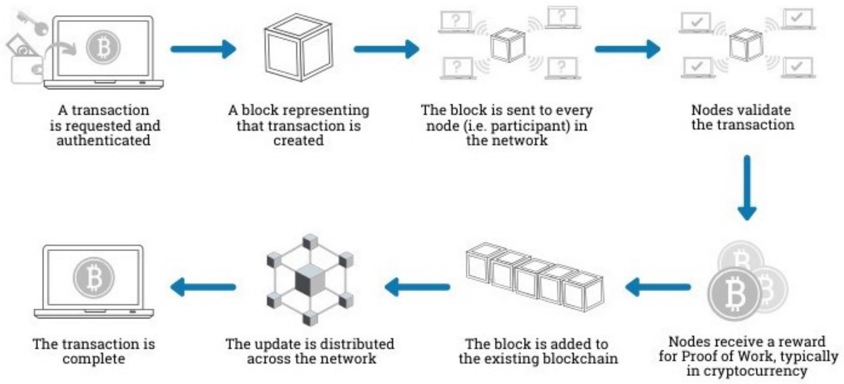

Figure 3.2: Illustration of the major processes of BCT [Chowdhury et al., 2021]

Similar studies designing BCT-based systems architectures have also implemented a DSR approach [Beinke et al., 2019; Notheisen et al., 2017], further validating the choice for this approach in this context.

3.5 RELATION TO EXISTING WORK AND ARTEFACTS

The requirement elicitation phase should consider the relation to existing work and artefacts that have already been developed to illustrate the relevance of the artefact to be designed [Johannesson and Perjons, 2014]. There may be research considering the use of BCT for the CE, not aimed at specifically supporting markets in SRM, but still providing insights that may be useful towards the design phase. According to Johannesson and Perjons [2014], designs of solutions that are similar could be used to derive insights from for the design of the artefact in a new DSR study. Therefore, the existing literature is explored in the following section.

3.5.1 Literature review article selection process, on similar artefacts

An additional literature review was conducted to consider related work with regards to similar artefact designs. Google Scholar as well as SCOPUS were used for the search. Articles were selected based on the process as described in Figure 3.3. Articles were included based upon them **1)** considering BCT as en enabler for the CE, as well as **2)** a BCT-infrastructure design being presented. For example, articles merely discussing the potential of BCT for the CE were disregarded from the search as these do not present an artefact being designed or proposed. Figure 3.3 illustrates the literature review. In the first phase the following search term was used on SCOPUS with 100 results:

(TITLE-ABS-KEY (circular AND economy) AND TITLE-ABS-KEY (blockchain AND technology))

Because the research has an Information Systems perspective, the search was limited to computer science journals, leading to the following search term with 24 results:

(TITLE-ABS-KEY (circular AND economy) AND TITLE-ABS-KEY (blockchain AND technology)) AND (LIMIT-TO (SUBJAREA , "COMP"))

The results were analyzed based on their title and were excluded if it became clear directly that the papers would not present a digital infrastructure design. Moreover, in the next step, the abstracts of the remaining articles were considered for this same criterium, seven articles were selected in total. Table 3.2 summarizes the 24 results and which were selected based on title, and finally, based upon abstract.

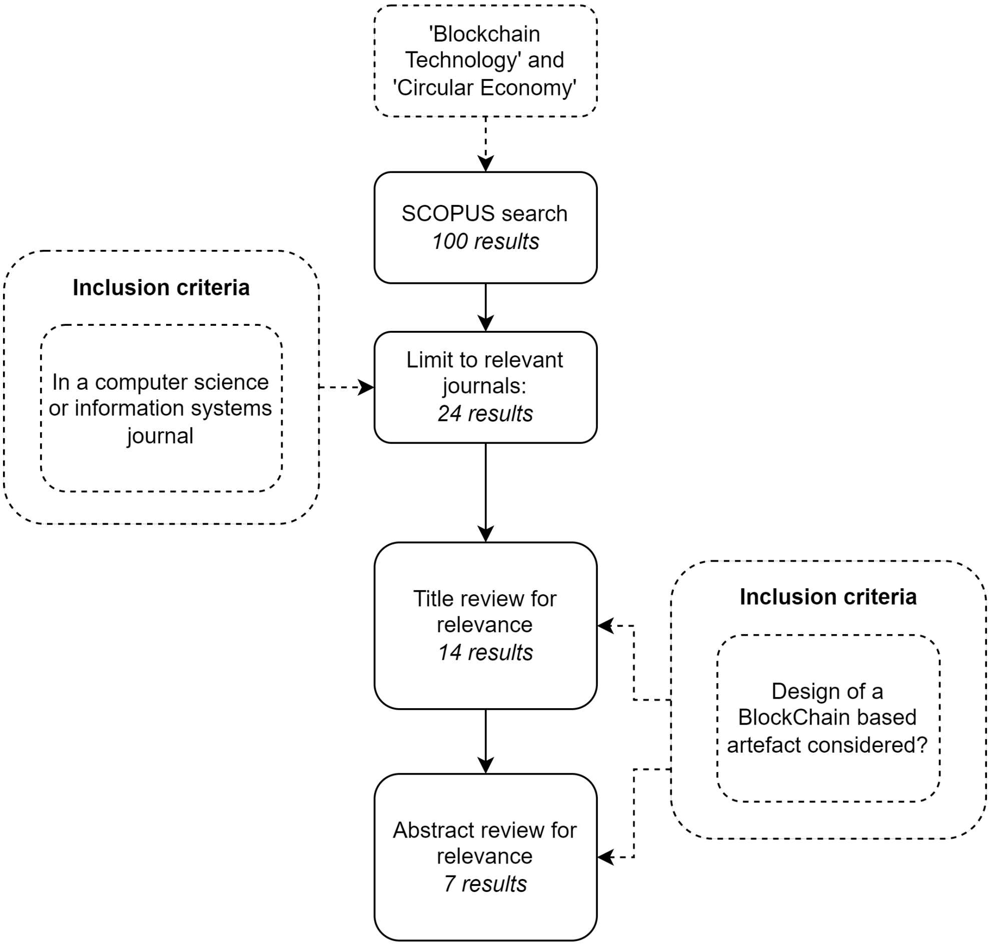

Figure 3.3: Literature review selection process

Table 3.2: Literature sourced on SCOPUS

Title	Year	Author	Title	Abstract
Applications of Industry 4.0 digital technologies towards a construction circular economy: gap analysis and conceptual framework	2022	Elghaish, F., Matarneh, S.T., Edwards, D.J., Pour Rahimian, F., El-Gohary, H., Ejohwomu, O	No	No
Alleviating the Impact of the Barriers to Circular Economy Adoption Through Blockchain: An Investigation Using an Integrated MCDM-based QFD With Hesitant Fuzzy Linguistic Term Sets	2022	Erol, I., Murat Ar, I., Peker, I., Searcy, C.	Yes	No
Open Market for Reusing Auto Parts with Blockchain	2022	Cale, D.	Yes	**Yes**
Exploring the Risks of Blockchain and Circular Economy Initiatives in Food Supply Chains: A Hybrid Model Practice Framework	2022	Okorie, O., Russell, J.D.	No	No
No more flat tires: Overcoming data defects to achieve supply chain resilience	2021	Pehlken, A., Baumann, S.	Yes	No
Do blockchain and circular economy practices improve post COVID-19 supply chains? A resource-based and resource dependence perspective	2021	Nandi, S., Sarkis, J., Hervani, A., Helms, M.	No	No
Regulatory Opportunities and Challenges for Blockchain Adoption for Circular Economies	2021	Steenmans, K., Taylor, P., Steenmans, I.	No	No
Threat Modelling of IoT Systems Using Distributed Ledger Technologies and IOTA	2021	Damianou, A., Khan, M.A., Marios Angelopoulos, C., Katos, V.	Yes	No
Leveraging blockchain technology for circularity in agricultural supply chains: evidence from a fast-growing economy	2021	Sharma, R., Samad, T.A., Chiappetta Jabbour, C.J., de Queiroz, M.J.	No	No
Conceptualising Circular economy performance with non-traditional valuation methods: Lessons for a post-Pandemic recovery	2021	Nandi, S., Hervani, A.A., Helms, M.M., Sarkis, J.	No	No
Blockchain technology for bridging trust, traceability and transparency in circular supply chain	2021	Oropallo, E., Secundo, G., Vecchio, P.D., Centobelli, P., Cerchione, R.	Yes	**Yes**
Fostering Energy Transition in Smart Cities: DLTs for Peer-to-Peer Electricity Trading	2021	Montakhabi, M., Der Graaf, S.V., Madhusudan, A., Sarenche, R., Mustafa, M.A.	No	No
Topology generated non-fungible tokens: Blockchain as infrastructure for a circular economy in architectural design	2021	Dounas, T., Jabi, W., Lombardi, D.	Yes	**Yes**
The role of block chain technology in circular economy practices to improve organisational performance	2021	Rehman Khan, S.A., Yu, Z., Sarwat, S., Godil, D.I., Amin, S., Shujaat, S.	No	No
Blockchain-enabled circular supply chain management: A system architecture for fast fashion	2020	Wang, B., Luo, W., Zhang, A., Tian, Z., Li, Z.	Yes	**Yes**
Blockchain and the circular economy: potential tensions and critical reflections from practice	2020	Kouhizadeh, M., Zhu, Q., Sarkis, J.	No	No
IFIP Advances in Information and Communication Technology	2020	21st IFIP WG 5.5 Working Conference on Virtual Enterprises, PRO-VE 2020	Yes	No
A clicks-and-mortar information exchange mechanism based on blockchain technology	2019	Wu, H.-T., Zhan, J.-W.	Yes	No
An architecture for blockchain over edge-enabled IoT for smart circular cities	2019	Damianou, A., Angelopoulos, C.M., Katos, V.	Yes	**Yes**
At the nexus of blockchain technology, the circular economy, and product deletion	2019	Kouhizadeh, M., Sarkis, J., Zhu, Q.	Yes	No
A study on blockchain-based circular economy credit rating system	2019	Wu, H.-T., Su, Y.-J., Hu, W.-C.	Yes	No
Blockchain-based Electronic Patient Records for Regulated Circular Healthcare Jurisdictions	2018	Alexaki, S., Alexandris, G., Katos, V., Nikolaos Petroulakis, E.	No	No
Blockchains as Enablers for Auditing Cooperative Circular Economy Networks	2018	Alexandris, G., Katos, V., Alexaki, S., Hatzivasilis, G.	Yes	**Yes**
Enabling a circular economy in the built environment sector through blockchain technology	2018	Shojaei A., Ketabi R., Razkenari M., Hakim H., Wang J.	Yes	**Yes**

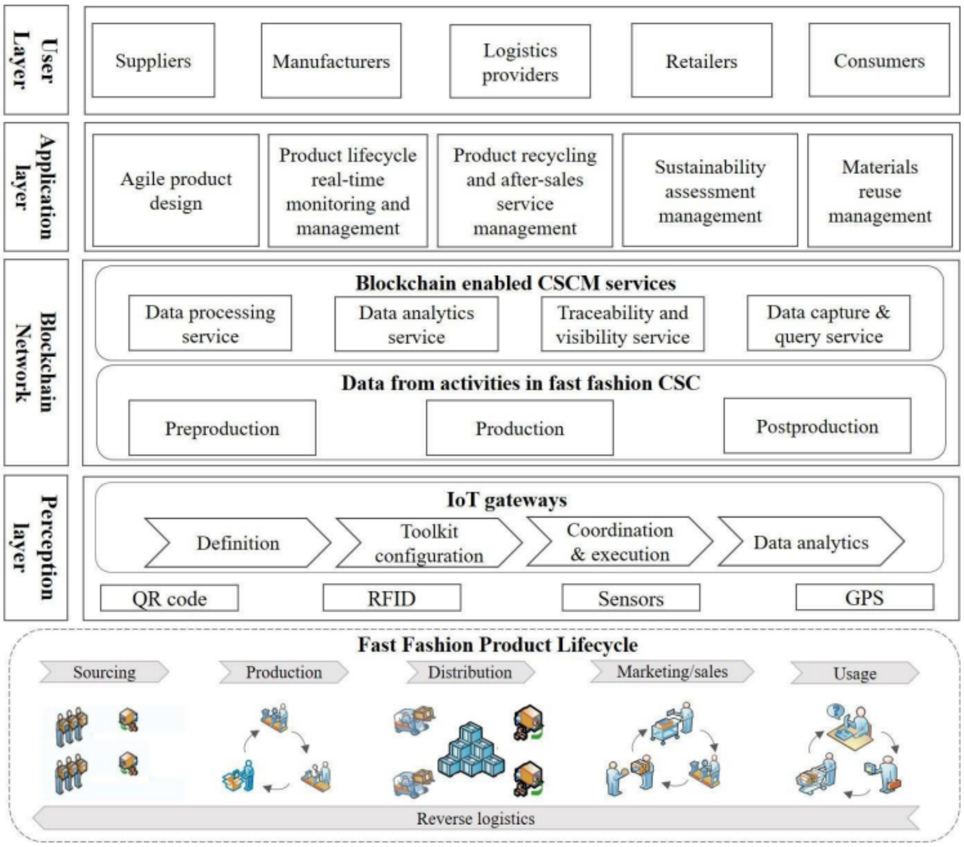

Figure 3.4: System architecture for blockchain in the fashion industry [Wang et al., 2020]

3.5.2 Synthesis results of literature review

Table 3.3 summarizes the selected articles, as well as the proposed blockchain characteristics and the topic of the paper.

It becomes clear that there is quite a variety of different types of infrastructures present in literature. Some articles choose for an Ethereum based infrastructure [Dounas et al., 2021; Cale, 2021], with smart contracts written in Solidify, whilst others choose for Hyperledger Fabric-based infrastructures [Shojaei et al., 2021; Centobelli et al., 2021]. Therefore, both Ethereum and Hyperledger Fabric can be considered for the design of the infrastructure. Alexandris et al. [2018] proposes to use Quorum, the permissioned sibling of Ethereum that also allows for smart contracts to be written in Solidify.

The level of detail of the presented infrastructures also varies, for example, Shojaei et al. [2021] present an elaborate infrastructure of which a prototype has already been made, whilst Wang et al. [2020] proposes to implement BCT on a more fundamental level and proposes a more holistic architecture of interrelated components (Figure 3.4). Wang et al. [2020] considers different layers of architecture, a user layer, application layer, blockchain network, perception layer and the fast fashion product life-cycle. As a perception layer, Wang et al. [2020] considers IoT gateways as an important component of the architecture.

Table 3.3: Literature results blockchain characteristics and main functionality of infrastructure.

Title	Author	Blockchain type	Topic
Open Market for Reusing Auto Parts with Blockchain	Cale, D.	Ethereum with smart contracts in Solidify language.	Used car parts are added to a network that is associated with the original car of the parts and therefore providing access to the original information about the used car part.
Blockchain technology for bridging trust, traceability and transparency in circular supply chain	Oropallo, E., Secundo, G., Vecchio, P.D., Centobelli, P., Cerchione, R.	Hyperledger Fabric (Allowing private recording or transactions, that are viewable by participating nodes, a fundamental prerequisite for the creation of a supply blockchain).	A reverse logistics management provider has full permission to visualize as well as approve transactions by e.g. manufacturer and recycling centers
Topology generated non-fungible tokens: Blockchain as infrastructure for a circular economy in architectural design	Dounas, T., Jabi, W., Lombardi, D.	Ethereum blockchain with smart contracts and tokens.	Infrastructure provides an immutable overview of all building components and their topological relations. Unique EC721 tokens are generated to present components.
Blockchain-enabled circular supply chain management: A system architecture for fast fashion	Wang, B., Luo, W., Zhang, A., Tian, Z., Li, Z.	No specific blockchain characteristics are discussed, but smart contracts are proposed.	The paper presents a blockchain-based system for the certification of suppliers of fashion, as well as a transparant way of monitoring suppliers. It is proposed that post-production, sub-systems should be realized for reselling and recycling purposes.
An architecture for blockchain over edge-enabled IoT for smart circular cities	Damianou, A., Angelopoulos, C.M., Katos, V.	No specific characteristics specified, only fundamental that each user has a private and public key to authorize transactions.	The paper hypothesizes that IOT-devices are of key essence for circular economy information sharing (real-time) and transparancy. But IOT-devices have little storage, so Edge-Computing nodes are proposed linked to the IOT-devices.
Blockchains as Enablers for Auditing Cooperative Circular Economy Networks	Alexandris, G., Katos, V., Alexaki, S., Hatzivasilis, G.	Permissioned Quorum (sibling of Ethereum) with smart contracts in Solidify language.	The state of assets and the transition between different operators is monitored by regulators and auditors to provide insight into asset integrity as well as compliance with environmental targets
Enabling a circular economy in the built environment sector through blockchain technology	Shojaei A., Ketabi R., Razkenari M., Hakim H., Wang J.	Hyperledger fabric: the participants are regulated through certificates and transactions are traceable to participants themselves	System so that materials and products can be traced to their sources and tracing the current state of each material.

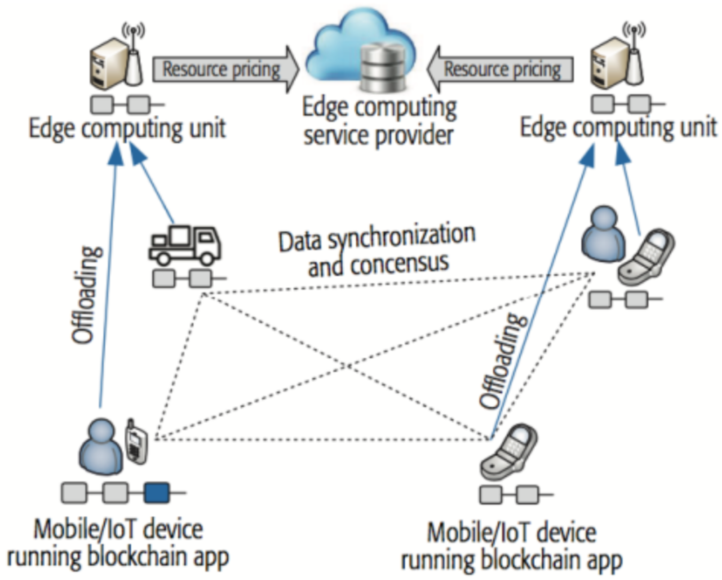

Figure 3.5: Edge-Computing for alleviating resource capacity of IoT devices in a CE [Damianou et al., 2019]

Damianou et al. [2019] also considers IoT devices as a key enabler of the CE and proposes, that for IoT devices to be integrated into BCT-based infrastructures, the devices have to be linked to Edge-Computing nodes that store the ledger, as IoT devices themselves usually have very limited storaga capacity. The IoT device interacts with the Edge-Computing node and the ledger is stored on the Edge-Computing node as illustrated in Figure 3.5.

Furthermore, Shojaei et al. [2021] proposes BCT-based on Hyperledger fabric to achieve CE, illustrating that it could provide material traceability and enable proactive planning for reuse. The research by Shojaei et al. [2021] focuses on the building sector and takes into account the role of regulators, builders and manufacturers. Various roles are assigned certificates on the network, as illustrated in Figure 3.6. Shojaei et al. [2021] propose a that a Hyperledger Fabric should be implemented, as it is stated that for circular supply chains, it is necessary to have transactions be traceable to actual persons, rather than anonymous entities. Shojaei et al. [2021] considers that producers, traders, builders and regulators should be nodes in the presented system.

Alexandris et al. [2018] considers that auditors should be a node on the system, to ensure that the infrastructure can be implemented to audit the circular behavior of involved entities (Figure 3.7).

Moreover, Dounas et al. [2021] propose unique (tradeable) tokens that correspond to different building component, as illustrated in Figure 3.8. This system is suited for mapping complex products such as buildings with many components. It becomes clear that assets can be presented by means of tokens.

Even though not all of the articles may be directly applicable to the design of the artefact in this research, the articles also provide insight into how to illustrate the artefact in such a way that it is understandable to the reader. The insights derived from this literature review will be applied throughout

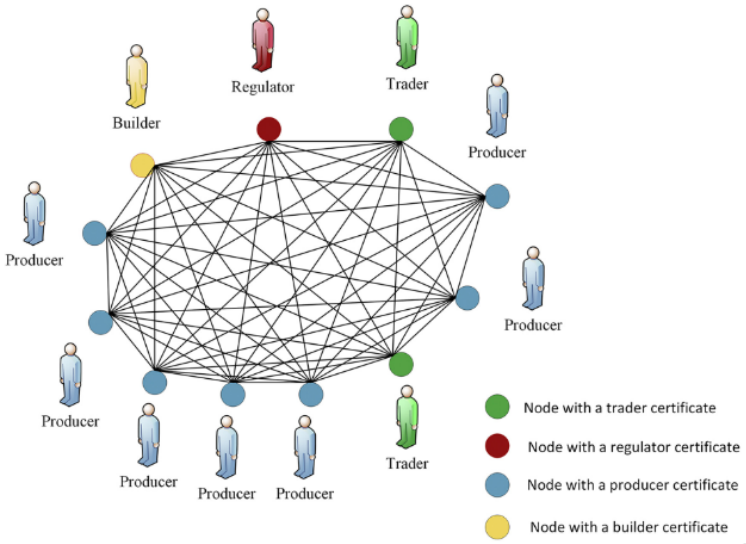

Figure 3.6: Certificates in system [Shojaei et al., 2021]

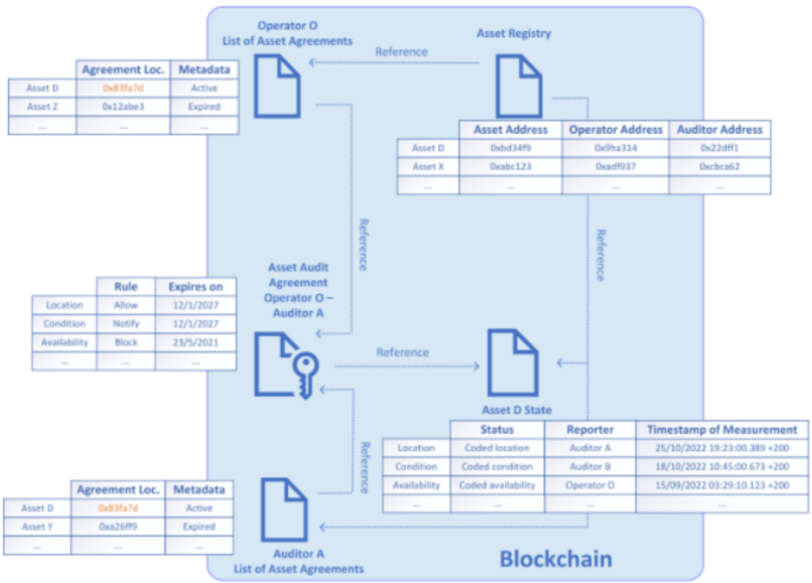

Figure 3.7: System with auditor [Alexandris et al., 2018]

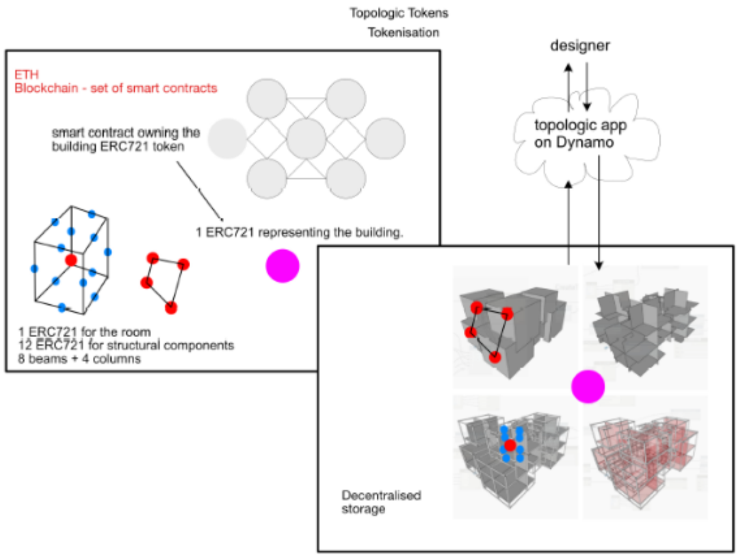

Figure 3.8: Presentation of topological token [Dounas et al., 2021]

the design phases. Moreover, the artefact that will be designed in this research doesn't consider improving supply chain visibility for the CE as an isolated topic, but considers it in the scope of supporting the development of spot markets extensible with futures markets.

3.6 CONCLUSION ARTEFACT OUTLINE

To conclude, this chapter describes the process of artefact outline selection. The research question considered by this chapter was sub-question 2: ***What artefact can be a solution to support futures markets in secondary raw materials?***. The selected artefact for design is a blockchain based digital infrastructure to enhance supply chain visibility and provide the right data in support of spot markets in SRM that can underlay futures markets (on a regulated exchange). Each section in the Chapter further scoped down the nature of the artefact by means of desk research, and the Chapter was concluded with a literature review on the existing literature regarding digital blockchain based infrastructures for the circular economy. Related literature can be used to guide the design phase.
Based on the artefact outline as presented in this chapter, the second-sub activity of the requirement analysis can be conducted in the next chapter; requirement elicitation for the outlined artefact.

4 REQUIREMENTS ANALYSIS B: REQUIREMENT ELICITATION FOR OUTLINED ARTEFACT

This Chapter will center around the following sub-question 3: ***Which design principles and requirements of this artefact are important?***

Now that the artefact outline has been presented, the requirements for the artefact can be elicited. According to Johannesson and Perjons [2014], this phase is in essence an extension of the problem explication phase, but it is conducted using the proposed artefact outline as a pair of glasses guiding the elicitation.
The requirement elicitation phase can be based on - amongst others - characteristics of the chosen artefact, characteristics of the problem, stakeholder interviews and available documentation [Johannesson and Perjons, 2014]. The main methodology implemented in this Chapter is desk research, some insights are also derived from the results of the interviews that were already conducted, but no new interviews are conducted. Four main perspectives are used to guide the identification of design principles: **1)** the functioning of spot markets, **2)** the success factors of spot markets to underlay futures markets and **3)** A circular economy perspective.

Lastly, the requirement elicitation will be split into a section on design principles and a section on FR and NFR. Design principles provide a guiding high level design direction, whilst the FR and NFR provide a more detailed design direction for the manufacturing sector in particular. Figure 4.1 illustrates the research flow of this Chapter.

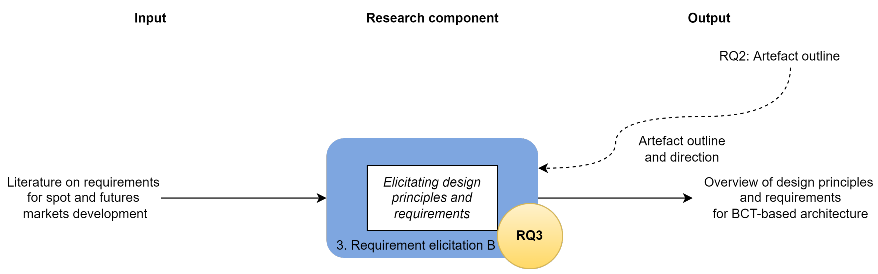

Figure 4.1: Research flow of requirement elicitation

4.1 DESIGN PRINCIPLE IDENTIFICATION DESCRIPTION

As outlined in the Introduction 1, the research environment is very broad. Requirements elicited in this phase will have to be applicable to all stakeholders and sectors within this research environment. Therefore, the requirement elicitation phase can only be conducted based on on what can be seen as quite a high level of abstraction. This is contradictory to the usual implementation of DSR, in which requirements for an artefact are usually based on a very specific situation [Johannesson and Perjons, 2014] - experiencing a specific problem - with specific actors involved whose needs and requirements can be elicited. Nevertheless, this is also one of the pitfalls of DSR, the lack of addressing a class of problems but only a single problem with an artefact. Therefore, this broader scope might lead to a more generalizable requirement elicitation, applicable to a larger class of problems for future research.

The requirement elicitation will be split into two parts. Firstly, developing high-level design principles and secondly, developing a set of FR and NFR.

The first phase in this requirement elicitation phase will consist of the identification of design principles. These design principles are a set of values that can act as a compass for an artefact design. Furthermore, design principles can support researchers in designing appropriate solutions [Fu et al., 2015]. From an academic viewpoint, design principles are at the foundation of design theory for Information Systems (IS) [Gregor et al., 2002]. Design principles address a generalization or class of problems [Sein et al., 2011], rather than being focused on a specific organizational setting [Peffers et al., 2018]. The objective is that these design principles can be generalized towards multiple classes of problems. These design principles consider the important elements for designing an architecture for the facilitation of markets in SRM underlying to futures markets.

4.2 DESIGN PRINCIPLE IDENTIFICATION

The main information used to identify the design principles is derived from desk research. Firstly, the design of spot markets considers how spot markets function and therefore how this functioning should be supported. Secondly, the success factors of spot markets to accommodate futures markets are also important in understanding what additional design features will be important in the facilitation of a digital solution. Both of these elements will be researched by means of desk research. Furthermore, a circular economy perspective will be implemented.

4.2.1 Section 1: Design principles based on the functioning of spot markets

Design principles will be developed firstly, by considering how the BCT-based architecture should facilitate spot markets in SRM.

There are many exchanges that support trading in various commodities. Commodity exchanges (organized spot markets) exist in over twenty countries including Canada, England, France, Japan and Australia [Downes et al., 2005]. The working of a a centrally organized commodity market is illustrated in Figure 4.2.

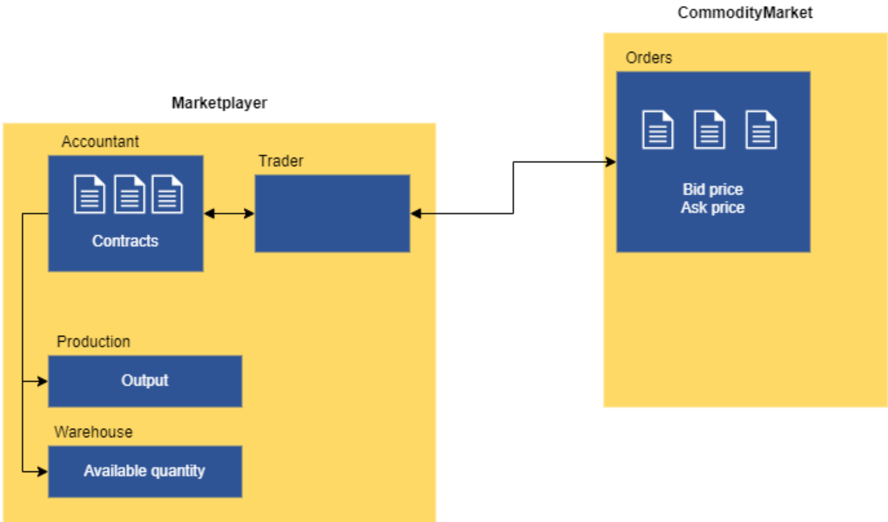

Figure 4.2: Overview of financial commodity market adapted from [Downes et al., 2005]

The information provided by warehouses and by production facilities is an important input for commodity spot markets and is used for the development of contracts such that trading can be conducted. In a primary materials market, the production output and warehouse quantity are more simple than for secondary materials, because there are no return logistics or recycling processes involved. For primary materials, there are also more assurances about the quality of the materials, because the materials have not been used in products before and the chances of contamination with other materials are therefore smaller.

The part of the commodity market that the BCT-based architecture addresses is situated on the left side of this illustration (Figure 4.3), by providing information about the available quantities of resources that can be traded. Hence, it supports the information sharinig processes underlying *Production* and *Warehouse*. The architecture provides information about the production and warehouse quantities to the market, such that contracts can be developed and trading can be conducted. Figure 4.3 illustrates where in the market schematic the research is situated.

For this market to be facilitated, multiple market players should have access to the system and the information generated by it, such that contracts can be developed. To have access to the information on the architecture, actors need to be included as nodes on the system. Hence, it is important for the system to give access to the relevant actors for it to function properly. Moreover, Nuryakin et al. [2021] find a positive relation between market information accessibility and financial performance. Furthermore, Lakkakula et al. [2022] also perceive information accessibility as one of the traditional

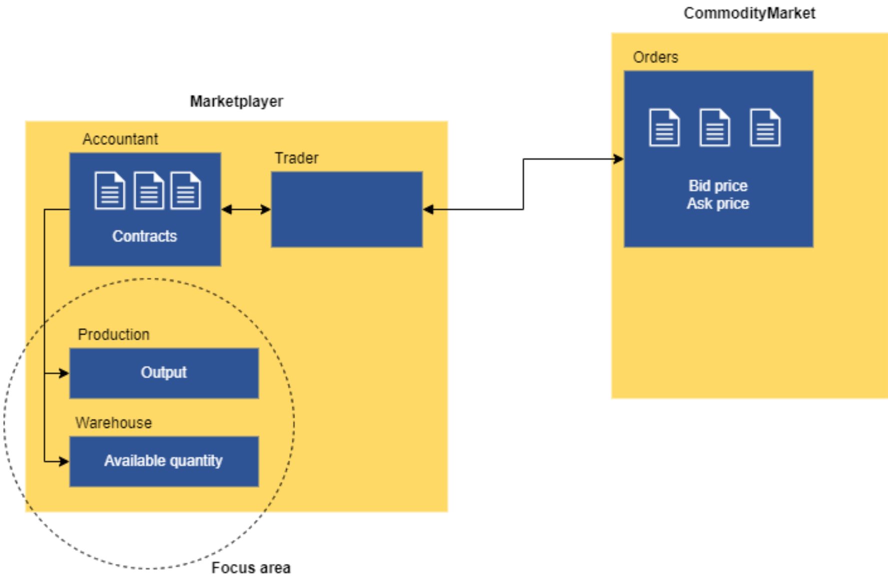

Figure 4.3: Overview of financial commodity market adapted from [Downes et al., 2005] with research focus elaborated

sources of advantage that commodity trading firms have. On the other hand, a lack of information accessibility to market players can lead to information asymmetry and financial under-performance in the form of underselling resources and fragmented commodity value chains Katengeza et al. [2011]. Therefore, the first design principle that can be identified for the to be designed artefact is (information) accessibility.

DP.A.1: Accessibility
Rationale: All relevant actors should have access to the information in the system for financial transactions to be accommodated properly as well as to prevent information asymmetry.

Conclusion section 1

It has become clear that for financial commodity markets to function, accessibility to information is one of the crucial requirements. Therefore, the design principle of accessibility was identified in this section.

4.2.2 Section 2: Design principles based on success factors for spot markets to accommodate futures markets

Now that it has become clear what the basic market schematic is shaped like, the next step is to consider what characteristics the market should have to accommodate a futures market. For this reason, an evaluation has been conducted regarding the drivers and factors that contribute to the success of futures commodities markets in a spot market. In essence, what characteristics a market should have to facilitate successful futures markets. It should be taken into account that not all drivers for successful futures markets can be influenced with the proposed BCT-based architecture artefact due to the complex nature of the socio-technical system that is considered here.

Research by Brorsen and Fofana [2001] and Bekkerman and Tejeda [2017] identified factors that contribute significantly to the success of futures commodities exchanges. These articles will be at the foundation of this section. The following paragraphs will analyze the factors that they identified. Some of these factors may already be present, because the factors represent characteristics of markets. Therefore, this section will first derive if the factor is already present or fulfilled in the current system and if it is not, analyze if the artefact can be used to fulfill the factor and increase the potential for a successful futures market. Based on there being a factor unfulfilled which the artefact could fulfill, design principles for the BCT-based architecture artefact will be set apart. Only the factors that could be fulfilled by the artefact have been included in detail, the others are only discussed in a more simple manner. Table 4.1 summarizes the findings of this section.

Success factor	Source	Fulfilled by system already?	Can be influenced by artefact?	Design principle
The liquidity costs associated with the future commodities markets shouldn't be a lot higher compared to the current hedging contracts	Brorsen and Fofana (2001)	No	Yes	**Liquidity**
There should be a large enough price volatility to create a need for hedging the price risk	Brorsen and Fofana (2001), Bekkerman and Tejeda (2017)	Yes	-	
The commodities that are traded on the futures exchange must be homogenous, or at least have a standardized grading scheme associated with it. If the commodity has high fluctuations in quality and the quality may be subjective, e.g. in the case of tobacco, the risk will be very high and delivery standards may not be met.	Brorsen and Fofana (2001), Bekkerman and Tejeda (2017)	No	Yes	**Identification**
The (cash) markets of the commodity must be large enough to attract a substantial amount of investors	Brorsen and Fofana (2001), Bekkerman and Tejeda (2017)	No	No, not directly at least	
The market channel shouldn't be very buyer concentrated	Brorsen and Fofana (2001), Bekkerman and Tejeda (2017)	No	No	
The market channel should vertically integrated	Brorsen and Fofana (2001), Bekkerman and Tejeda (2017)	No	Yes	**Supply Chain Visibility**
The current (cash) market has to boast frequent transactions	Brorsen and Fofana (2001), Bekkerman and Tejeda (2017)	No	No	

Table 4.1: Overview of success factors for futures markets and design principles for the artefact based on Brorsen and Fofana [2001] and Bekkerman and Tejeda [2017]

The liquidity costs associated with the future commodities markets shouldn't be a lot higher compared to the current hedging contracts [Brorsen and Fofana, 2001]

Current situation: Liquidity cost are the costs associated with converting assets (SRM in this case) to cash. Liquidity itself is measured by how easy it is to convert assets to cash. In the current landscape, transactions in SRM are mainly OTC and bilateral (CEO of Recyling firm, Personal Communication, April 2021), and there is no centrally organized exchange that standardizes transactions. Hence, currently the liquidity costs associated with the SRM are relatively high as for each transaction a contract has to be drafted and this can be a time consuming process. Moreover, a bilateral contract between two parties cannot be easily sold to another party, so the liquidity of such a contract is low.
Need for system intervention: There is a need for increased liquidity and therefore transactions need to be easily facilitated and fast. It should be possible to sell a contract to another party, who will then partake in the transaction. Also, transaction costs should not be too high, so cost efficiency will play a role in achieving this. It can be concluded that transactions have to be facilitated in a manner that provides sufficient liquidity to actors that are trading on the exchange.

DP.B.1: Liquidity
Rationale: BCT-based architecture should facilitate liquidity of contracts. System should provide transactions with high liquidity such that it is cost-efficient and fast and therefore an attractive alternative to other trading.

There should be a large enough price volatility to create a need for hedging the price risk [Brorsen and Fofana, 2001; Bekkerman and Tejeda, 2017]

Current situation: Current prices of SRM fluctuate a lot [Stromberg, 2004], this is one of the main reasons that futures markets are desirable, such that circular businesses have a way to cope with price fluctuations. To explain the reasons behind the already existing price fluctuations, temporary scarcities are one of the main reasons for the sometimes extreme price volatility in the price for SRM [Hagelüken, 2012]. The price of most SRM is dependent on the price of virgin materials [Coda Canati, 2000]. To give an example, the price of recycled plastic is dependent on the price of virgin plastic. The price of virgin plastic is determined by the price of the oil that is used to produce it, prices for oil are highly volatile, whilst the price of recycled plastic is relatively stable due to the stable nature of production costs. This creates volatility for selling recycled plastic, as the price of recycled plastic is relatively stable compared to virgin plastic and these prices compete. Therefore, the price that buyers are willing to pay for recycled plastic fluctuates a lot due to external factors.
Need for system intervention: It can be concluded that there is already quite a high price volatility in the current situation, which is one of the reasons that futures markets are so desirable in this situation. There is no need for a system intervention here, and it is not expected that an artefact could even affect price fluctuations, as these fluctuations are inherent to the complex system.

Therefore, no design principles for the BCT-based digital infrastructure can be derived as the complex socio-technical system boasts high volatility.

The commodities that are traded on the futures exchange must be homogeneous [Bekkerman and Tejeda, 2017], or at least have a standardized grading scheme associated with it [Brorsen and Fofana, 2001]. If the commodity has high fluctuations in quality and the quality may be subjective, e.g. in the case of tobacco, the risk will be very high and delivery standards may not be met.

Current situation: There is a lack of standardized grading schemes for SRM. On top of this, there is also a lack of certainty on the quality of commodities because there is little transparency about what happens with them in the supply chain. Hence, it is difficult to develop an objective quality standard for SRM. This might differ a bit across varying types of SRM, but it will be assumed that in most cases of SRM, standardized grading schemes and assurances on homogeneity of resources are missing. The lack of standardized grading schemes is one of the key reasons that markets in SRM are so hard to realize.

Need for system intervention: System should enable homogeneity of resources and improve grading schemes. To achieve homogeneity of resources, an intervention should ensure that the resources have a certain composition and can be categorized according to a grading scheme. Hence, it needs to be possible to identify products or resources in such a manner that standardized grading schemes can be applied for transactions in these commodities. For the implementation of standardized grading schemes, the identification process should also enable the identification of the quality or composition of the product or resource. Nevertheless, identifying the quality of products and materials can be very complex, as industrial advances have led to increasingly complex products with more materials. Compared to traditional models, the quality and composition of secondary materials is a lot harder to discern, as the original source and original materials are often unknown. Identifying the materials and their quality is therefore especially important for circular models.

DP.B.2: Identification
Rationale: BCT-based architecture has to support identification of products and resources and their respective quality or composition.

The (cash) markets of the commodity must be large enough to attract a substantial amount of investors [Brorsen and Fofana, 2001; Bekkerman and Tejeda, 2017].

Current situation: It has already become clear that centrally organized cash markets in SRM don't exist. That doesn't imply that there is no active trading in SRM, it has become clear that there is an underlying active OTC market. Whilst OTC transactions may take place a lot, these should take place on centrally organized exchanges rather than being bilateral in nature for futures markets to be accommodated.
Need for system intervention: Centrally organized cash markets need to be facilitated to attract investors and create a large enough network of investors

to ensure that one investor can't affect the exchange too much - to ensure that the exchange can absorb risky transactions. Whilst these system interventions are needed to support the development of spot markets as well as the development of futures markets as an extension to them, a BCT-based architecture can't be used to directly affect it. The BCT-based architecture might by itself - just by being developed - influence traders and create a more active organized cash market, but it can't directly influence how active cash markets are.

The market channel should not have a high buyer concentration [Brorsen and Fofana, 2001; Bekkerman and Tejeda, 2017]

Current situation: Buyer concentration consists of the relative size of commodities that are handled by the biggest companies. For some SRM, the buyer concentration can be very high, meaning that there are only a few large companies that buy the SRM. Because transactions in SRM are mostly OTC, is becomes clear the market is dominated by some key large buyers and sellers, hence, a high buyer concentration is present. In the plastics sector, buyer concentration is e.g. quite high, there are only a few recyclers and recycled material buyers (P. Hurks, Personal Communication, April 2021). However, this can still be different across different types of SRM. This research will assume that buyer concentration for most SRM is quite high.
Need for system intervention: There is definitely a need for a system intervention to decrease the relatively high buyer concentration that characterizes markets in SRM. Nevertheless, the BCT-based architecture can't directly affect the buyer concentration. The artefact may indirectly affect the buyer concentration, because it opens up access to the market for more buyers, this may lead to a decrease in buyer concentration by itself. Nevertheless, because there can be no direct influence on the buyer concentration with a functionality of the artefact, no design principles come forth from this driver.

The market channel should be vertically integrated [Brorsen and Fofana, 2001; Bekkerman and Tejeda, 2017]

Current situation: Vertical integration considers the amount of price points that a commodity has throughout the supply chain, more price points is better for facilitating spot markets. A price point is a point in a supply chain where a commodity is valued and priced accordingly. Vertical integration can differ a lot between different types of SRM. For most SRM, vertical integration is quite low, because the materials usually only have one price point (or very few price points) throughout supply chains. E.g., one of the only price points can be the moment that materials are sold from a recycling facility to a buyer.
Need for system intervention: It becomes clear that there is a need for more vertical integration in the current system to facilitate spot markets. Because vertical integration is defined as the amount of price points throughout a supply chain, increased supply chain visibility can enable the development of more price points. Supply chain visibility is characterized as the availability of information about demand and inventory across the supply chain

[Somapa et al., 2018]. Materials could be valued not only on their end-of-life point when they are sold to a new manufacturer, but may be valued at several points in the supply chain if there is more supply chain visibility. If there is also information about inventory when materials are at a producer, manufacturer, consumers or in retail stores, inventory assessments can be made and it is possible to value the inventory at more price points. Therefore, a design principle forthcoming of this driver is supply chain visibility.

DP.B.3: Supply chain visibility
Rationale: Availability information about demand and inventory across the entire circular supply chain should be increasingly available to increase vertical integration.

The current (cash) market has to boast frequent transactions [Brorsen and Fofana, 2001; Bekkerman and Tejeda, 2017].

Current situation: The current cash market already boasts quite frequent transactions as there are already some SRM that are frequently traded such as scrap metal. Other SRM may not boast frequent transactions, so there may be differences across a variety of SRM. For example, trade in low-grade plastics is not very active, compared to the higher valued scrap metal. Even though there may already be frequent transactions, trading takes places on unregulated cash markets rather than regulated exchanges. The transactions that occur are frequent, but on a bilateral basis and can therefore be defined as an unregulated market. These unregulated cash markets are unsuited for futures markets extensions and may cause inefficiencies in the market due to information asymmetry.
Need for system intervention: Transactions should be facilitated on a regulated exchange and frequent transactions should be incentivized more. Although transactions are already quite frequent, it seems that more frequent transactions might still be desirable to increase the success of futures markets. Nevertheless, a BCT-based artefact can't directly affect the frequency of transactions, but it can support the necessary data needed for transactions themselves. The artefact can therefore not play a role in influencing this factor through its functionality.

Conclusion Section 2

To conclude, multiple success factors for spot markets to accommodate futures markets have been discussed. It becomes clear that the proposed artefact can play a role in fulfilling some of these factors by enabling the design principles supply chain visibility, identification and liquidity. Furthermore, one of the factors is already met by the current market structure, this is the factor of there being a high enough price volatility to create a need for hedging price risk. It became clear that the price volatility of SRM is already significantly high.

Moreover, one of the factors is partially fulfilled by the current market structure, namely, the occurrence of frequent transactions. However, more frequent transactions may still be desirable to further support the development of futures markets, nevertheless, this is not a factor that the architecture could play a role in influencing directly through its functionality. Lastly, there are also some factors that are not fulfilled by the current market structure and can also not be influenced directly by including functionality into the artefact. Simultaneously, these factors can also be crucial towards the development of spot markets, for example, decreasing buyer concentration, increasing the cash market size and increasing the frequency of transactions in SRM. These factors may for example be influenced by regulatory instruments or governance schemes, but these methods are outside of the scope of this research, hence they may be relevant for future research practices to consider.

4.2.3 Section 3: A circular economy perspective

It has already become clear from Chapter 3, that confidential handling of information is an important aspect that the artefact should be characterized with. One of the reasons that BCT in specific was selected is it's suitability for providing confidentiality. Information about product composition - that is needed for reselling the materials they contain - is often of sensitive nature and companies might only be willing to share such data if they know that there is a confidential handling of it. Hurks (P. Hurks, Personal Communication, April 2021) also states that confidentiality of information is crucial to achieve information sharing for circular purposes. Furthermore, confidentiality is also related to the identification of resources, because without companies sharing information about the product composition and quality, standardizes grading schemes are difficult to realize. Moreover, Tseng et al. [2018] see confidentiality issues as one of the issues preventing circular systems from arising.

Therefore, information has to be handled in a confidential manner, this leads to the design principle of confidentiality.

DP.C.1: Confidentiality
Rationale: Information should be handled confidentially such that company sensitive information can be shared safely.

Whilst interviewing business owners of businesses with a circular ambition, it also became clear that traceability of materials is an important aspect towards achieving circularity. There is a need for traceability to enable proactive planning of return flows from supply chains [Kouhizadeh et al., 2020]. Because return flows provide the resource output, they need to be facilitated to ensure that SRM can be sold on the spot market. Shojaei et al. [2021] also emphasizes on the importance of traceability for enabling markets in SRM. There needs to be a solution that provides reliable traceability, not only to the source of the materials, but more so also traceability about the materials and their current state [Shojaei et al., 2021]. Traceability is also related to preserving the homogeneity of resources in accordance with Brorsen and Fofana [2001], as for the homogeneity of resources, it is important to know what has happened to the products during the supply chain lifecycle. This leads to the following design principle:

DP.C.2: Traceability
Rationale: BCT-based architecture has to provide traceability of materials along supply chains such that return flows can be planned.

The interviews also made clear that traceability is sometimes hard to achieve as there can be tensions with privacy laws that are in place. Askoxylakis [2018] emphasizes that privacy properties of systems for the circular economy should be insured.

The tension between the principles of privacy and traceability illustrates that the tracing of products along supply chains such that a circular flow is facilitated has to be conducted in such a way that compliance with privacy laws such as General Data Protection Regulation (GDPR) is maintained. Especially while tracing products when the product is in ownership of a consumer who bought it can privacy issues be relevant. An example about washing machines can be provided. Ideally, the organization leasing washing machines, wants to trace a washing machine to the consumer and also be aware of how the user is using it (i.e. if the washing machine is maintaining its value and not being damaged). However, collecting this data is very privacy sensitive, because personal consumer data may also be collected at the same time. This is an example of how privacy and traceability can cause tensions and shows that they will both need to be taken into account for the design of the artefact. This tension may pose limitations on the artefact. Furthermore, according to Cavoukian et al. [2009], privacy should be embedded into every process and has to be incorporated to the design of systems in a preventive rather than reactive manner. It is proposed that the principle 'privacy by design' should be incorporated to the artefact design when the design should insure privacy properties. To conclude, the forthcoming design principle is the following:

DP.C.3: Privacy by design
Rationale: BCT-based architecture has to provide a sufficient amount of privacy - i.e. respect user privacy - and comply with privacy laws.

There is another aspect of the architecture that will be important for a successful implementation. The architecture may have to be used to provide assurances to regulatory bodies or other external stakeholders about the circular nature of the material flows, as became clear from the interviews. If the information is used for administrative institutional processes, there needs to be a certainty that the information is correct and unaltered such that there is assurance about the quality of materials (Hamerlinck, Personal Communication, 15th September 2021). Furthermore, Zerbino et al. [2021] also considers that quality assurances are essential for enabling markets in SRM, also stating that there is a stringent need for improved quality assurances of SRM.

DP.C.4: Assurance
Rationale: There should be assurance about the immutability and non-repudiation

of the information about materials and transactions that the architecture incorporates.

The architecture should be designed with the aim to be a sustainable solution for stimulating the CE transition. To achieve a circular economy, resource loops should be closed and energy leakage should be minimized [Geissdoerfer et al., 2017]. A loop - or supply chain - in which resources are recycled, but in the process of doing so, a tremendous amount of energy used, may sometimes be even more damaging for the environment than linear supply chains without a return logistics process. In that context, it is important to consider the energy leakage that the artefact itself may create. Blockchain technology as implemented for the Bitcoin network is well known to have a significant energy consumption. To give an example, the energy usage of Bitcoin mining was between 15,47 and 50,25 Twh per year in 2018 [Küfeoğlu and Özkuran, 2019]. In comparison, Denmark in it's entirety consumes about 32 Twh per year. This doesn't immediately mean that blockchain technology can't be considered as a way to design an artefact, but an important takeaway is that the energy consumption of different design choices should be taken into account. Because Bitcoin operating a proof of work consensus mechanism, the energy consumption is very high. There are other consensus mechanisms that are said to consume less energy which can be explored for the artefact. It becomes clear that the energy consumption of the artefact is an important consideration for the design, as energy leakage should be prevented. Therefore, the next identified design principle is energy efficiency.

DP.C.5: Energy efficiency
Rationale: This design principle implies that the architecture has to be energy efficient, in the sense that the negative effects that it has on the environment are reduced to a minimum.

Conclusion section 3

To conclude, section three highlights multiple design principles that have come forth from additional desk research and interviews. Although the list of design principles may not be exhaustive. The broad perspective taken during the interviews and the widespread desk research into a variety of topics, support the belief that the most important design principles have been identified in this section, where they not yet identified in section one or two. Confidentiality, traceability, privacy-by-design, traceability, assurance and energy-efficiency are the five design principles forthcoming of this section three.

4.2.4 Summary of design principles

The identified design principles in this section are summarized in table 4.2.

These design principles are intentionally set up in a manner that increases their applicability to a variety of different cases. For example, the design principles do not limit future design researchers to limit themselves to a

ID	Design principle	Source
Spot market perspective spot markets		
DP.A.1	Accessibility	Downes (2005), Nuryakin et al. (2021), Lakkakula et al. (2022), Katengeza et al. (2011)
Success factors for spot markets		
DP.B.1	Liquidity	Brorsen and Fofana (2001)
DP.B.2	Identification	Brorsen and Fofana (2001), Bekkerman and Tejeda (2017)
DP.B.3	Supply chain visibility	Somapa et al. (2018), Brorsen and Fofana (2001), Bekkerman and Tejeda (2017)
Circular economy perspective		
DP.C.1	Confidentiality	Licht (2021), Tseng et al. (2018)
DP.C.2	Traceability	Kouhizadeh (2020), Shojaei et al. (2022)
DP.C.3	Privacy by design	Cavoukian (2009), Askoxylakis et al. (2018)
DP.C.4	Assurance	Hamerlinck (Personal communication, September 2021), Zerbino et al. (2021)
DP.C.5	Energy-efficiency	Hamerlinck (Personal communication, September 2021), Geissdoerfer et al. (2017)

Table 4.2: Design principles identified in this chapter

design featuring blockchain technology, but may also consider other technologies at the foundation of an information architecture. Furthermore, the design principles can be used in the process of defining FR and NFR in the next section.

4.3 REQUIREMENT ELICITATION

Following these design principles, it is considered valuable to also define more specific requirements so that an artefact can be designed in more detail in the next chapter. These requirements don't focus on values, but more so on functionality of the artefact. The distinction between FR and NFR will be described and respectively, requirements will be elicited further based on the guiding design principles and additional research. The FR and NFR can't be generalized as much as the design principles, because they are more so focused on the specific scope and functioning of the the manufacturing sector that deals with finite materials and the geopolitical demarcation being the Netherlands, rather than on values.

4.3.1 The distinction between Functional and Non-Functional requirements

Requirements are broadly classified as FR and NFR; however, a special concern is required for FR as the information system for an organization is expected to meet the functional behavior of that organization [Sharma and Biswas, 2015]. The difference between FR and NFR is that FR define the performance requirements, while NFR define the restrictions on this functionality [Ullah et al., 2011]. Cysneiros and Yu [2004][p. 115] states that; 'NFR constrains how the system must accomplish the FR'. The following are examples of FR and NFR:

- *Examples of Functional Requirements* Berg and Wilts [2019] define functional requirement categories for CE as preserving identifiable and traceability of materials, providing detailed information sharing on material composition and lastly, ensuring data quality and reliability with e.g. standards and procedures.
- *Examples of Non-Functional Requirements* Kirner and Davis [1996] gives examples of some NFR; performance, reliability, safety, security, maintainability and usability. Other examples of are defined by do Prado Leite and Doorn [2012] as costs and performance. Boehm [1984] proposes that NFR should be dealt with at a high level of abstraction.

The following sections will elicit requirements of the artefact and distinguish them as being FR or NFR. The main focus will be on the FR, as special attention should be given to them, because the system should meet the functional behavior at least [Sharma and Biswas, 2015]. The design principles are used as a guiding mechanism to derive the relevant requirements in the following sections.

4.3.2 DP.A.1 Accessibility

The design principle of access implies that access is important to facilitate spot markets. Therefore, all relevant actors should have access to the system for financial transactions to be supported properly. For the BCT-architecture functionality, this means that actors should be incorporated as nodes on the system, such that data can be shared with them. In specific, each actor that plays a key role in the supply chain should be a node on the BCT-based architecture. Hence, if a supply chain consists of a supplier, producer and distributor, each actor should represent a node on the architecture.

FR.A.1 The architecture shall include involved stakeholders as a node on the network

To further enable information accessibility, the BCT-based architecture should be able to provide the necessary information for financial transactions to be conducted. To achieve this, the correct actors should have access to the correct information. Because it has become clear that this information has to be shared with the collaborating accountants for the facilitation of a spot market, the relevant information should be shared with these accountants.

FR.A.2 The architecture should provide the information for financial transactions to be executed to the accountants to enable them to set up contracts

4.3.3 DP.B.1 Supply chain visibility

Supply chain visibility considers that there should be more visibility about the demand and inventory of materials across supply chains [Somapa et al., 2018]. Functionally, for the architecture to achieve supply chain visibility, information about materials streams as well as about demand, should be accessible to multiple actors along the supply chain. Therefore, transaction information (information exchanged when materials change owner at a point in the supply chain) should be stored in blocks in such a way that there is available information about the inventory. E.g., data should inform actors about the inventory in a manner that not only a quantity of products is known, but also information about the weight of these products and the materials that these products contain (the trade-able inventory).

FR.V.1 The architecture shall provide information about the inventory of products and materials as well as their quantity in weight to all involved stakeholders in a circular supply chain

Also, when a transaction has occurred, the inventory of the actor that sold the materials should be updated and the sold inventory should be added to the inventory of the buyer. By continuously updating inventories and documenting the prices for which trading occurs, there is information about the demand for materials and the selling prices for a variety of quantities. The increased information about inventory, enhances the amount of price points of a material along the supply chain and therefore increasing vertical integration.

FR.V.2 The architecture shall update total product quantity inventories of nodes after a transaction of products has occurred.

Moreover, an NFR can also be identified in the form of availability. The relevant information has to available for supply chain visibility to be enabled.

NFR.V.3 Availability

4.3.4 DP.B.2 Liquidity

From the design principle: 'Liquidity', It becomes clear that the transactions have to be cost-efficient such that transaction costs shouldn't be too high. On the other hand, transactions should take place in a speedy manner. This implies that transactions should take place even before the materials or products have been shipped from a seller to a buyer. Additionally, to achieve speedy transactions, real-time data is needed about the materials that are available to be traded and the outstanding buy and sell orders of speculators. This real-time data ensures that a resource is always marketable at any point in time. Therefore, the functional requirement forthcoming of this is:

FR.L.1 The architecture should provide real-time data on the availability of materials and the buy and sell orders.

4.3.5 DP.B.3 Identification

The identification design principle implies that the BCT-based architecture has to support identification of products and resources. By embedding a product type identifier as a unique identifier on products, product life cycle information can be managed [Främling et al., 2007].

FR.I.1 The architecture shall embed each product with an unique identifier

On top of embedding products with a unique identifier, product information should be stored somewhere and there needs to be a linking mechanism that links the unique identifier to the product information [Främling et al., 2007]. The product information should be traceable and that is only possible if the information is stored somewhere and also accessible through linking mechanisms, therefore, the following functional requirement is devised.

FR.I.2 The architecture should link product unique identifier to an information source where the relevant data about the product is stored

Also, something to consider would be the impact of the unique identifier on the product and how well it can maintain its quality. Some identifiers may be quite intrusive for recycling processes, if they contain a variety of different materials that can contain the recyclable value. Therefore, a non-functional requirement of the architecture is the following.

FR.I.3 Sensors should store information about the location of the product upon the Unique Identifier being 'scanned' and update a record of the total volume of product for that location.

NFR.I.4 The unique identifier should impact the quality preservation of the product and the materials it contains as little as possible

4.3.6 DP.C.1 Confidentiality

The design principle of confidentiality implies that company sensitive information has to be handled in a confidential manner. Efforts to achieve mutual trust and information transparency are often hampered by confidentiality issues [Tseng et al., 2018]. Functionally, this implies that information can only be shared with those actors that have been given permission to access it by the information owner. The actor receiving the information should not be allowed to share this any further than was given permission for, provisions should also be made for this. This can be achieved by some type of 'pledge' of confidentiality by involved actors [Plewes, 1985][p.219]. A pledge of confidentiality could be e.g. a signed certificate that is stored on the blockchain.

FR.C.1 The architecture should only allow actors access to the blockchain if they provide a signed certificate containing a pledge of confidentiality

Moreover, this pledge of confidentiality should of course also have some monitoring entity to preserve the confidentiality and there should also be sanctions upon a breach of this pledge. However, these aspects reside more in the governance domain of the architecture and are therefore left outside of the design scope, but could be taken into consideration when researching the governance of the architecture.

4.3.7 DP.C.2 Traceability

The principle of traceability implies that products and materials need to be traced at some point in the supply chain to ensure the return flow planning. The manner of traceability may vary accross supply chains (One supply chain may allow tracking it the entire time, others may only allow tracking at the selling point and return point). Functionally, this means that items should be traceable with some type of sensor whose data is shared with the BCT-based architecture. The sensors as are referred to in this requirement are digital sensors that are able to share real-time data with the architecture.

FR.T.1: Each to be traced item by the architecture should be traceable with a sensor that links the unique identifier to an information source where product data is stored

To clarify, the difference between traceability and identifiability is that traceability is about the sensors detecting the unique identifiers, whilst identifiability is about the unique identifiers situated on products and them being linked to databases. The sensors provide a linking mechanism for linking the unique identifier to a database with the stored product information.

4.3.8 DP.C.3 Privacy by design

The principle of privacy by design considers that user privacy should be respected and the BCT-based architecture should comply with privacy laws. The most important pillar of privacy by design is that privacy should be considered in the design process of any artefact, rather than trying to mend 'patches' after the artefact has already been developed [Schaar, 2010]. Mending patches is less effective and it can be very costly. This is more of a requirement imposed on the design process rather than a requirement for the artefact itself, but it is very important to take into account to fulfill the privacy by design principles in a successful manner. One of the main privacy laws that companies come in touch with is the GDPR. The GDPR implies that personally identifiable information can only be accessed if permission has been provided by the designated user. It is also important that users are clearly informed about what data is stored on the platform, be it personally identifiable information. Below, one functional requirement is provided that sums all components of the GDPR with sub-requirements.

FR.P.2 *Personal information will only be processed by the system if:*

FR.P.2.1 the person it belongs to has unambiguously given permission
FR.P.2.2 the data processing is necessary for the performance of a contract to which the data subject is a party
FR.P.2.3 the data processing is necessary in order to comply with a legal obligation
FR.P.2.4 the data processing is necessary in order to protect the vital interests of the data subject
FR.P.2.5 data processing is necessary for the proper performance of a public law task
FR.P.2.6 data processing is necessary in order to safeguard the legitimate interests of the interest of the responsible party or of a third party to whom the data are disclosed

Whilst it is important to note these privacy related functional requirements in light of the GDPR, in some specific cases privacy law issues may not occur as much as in others. This is the case when exchanged data is not traceable to real persons. In some cases, only companies need to exchange data, and this data is not traceable to a single person anyways, but only to a company entity itself. Company entities themselves are not included in the GDPR regulation. The discussed requirements so far, relate mostly to the GDPR and what it requires of companies in their processing of data from individuals. Therefore, it can be assessed whether for each specific case if these requirements are relevant to incorporate in a design. For example, if there is a product for which it is necessary to collect data from individuals that may be personally identifiable (this can be desirable for e.g. washing machines to track their usage), these requirements become very important to carefully consider. In the case of processing personally identifiable data, these requirements can be implemented as a checklist to consider whether compliance is achieved.

Moreover, privacy by design may also be considered for company related data rather than only for data of individuals. For this, a more holistic approach can be taken. In a part, confidentiality also covers privacy by design, as it advocates for pledges of companies to handle information confidentially, therefore, this requirement is not repeated, but is also relevant for privacy by design. Apart from this, an advocate of privacy by design is Gürses et al. [2011], stating that privacy by design can be achieved by one core approach of taking data minimization into account during the entire design process. Data minimization considers that only relevant information should be shared and reduced to the bare minimum. This manifests into a non-functional requirement for the artefact.

NFR.P.3 Data minimization

4.3.9 DP.C.4 Assurance

Assurance implies that there should be assurance about the immutability and non-repudiation of the information the architecture incorporates. Also, assurances should be shareable with monitoring organizations such as government. An audit trail should be derivable from the transaction on the information architecture, such that 1) organizations can prove that they comply with laws and regulations and may get exemptions from regulations that impose higher taxes on resource usage and 2) they prove that the materials are really SRM and they have not handled in a fraudulent manner.

FR.A.1: The transactions on the architecture must be immutably stored and not be repudiated.

Whilst this is one of the key characteristics of blockchain technology, it is still included as a requirement of the system. If a part of the transactional data is stored off the chain (something that is common when there is too much data to store in a block), there may still be a possibility that these records could be repudiated. Therefore, there should be caution when storing certain transactional data off chain, such that the most relevant and important transactional data remains immutable.

Moreover, audit trails will become more and more important to enable effective CE monitoring [Rukanova et al., 2021b]. Audit trails are not only useful in the monitoring of the CE from a regulators point of view, but can also be valuable from a financing point of view. From a regulators point of view, assurances about performance and circular behavior of companies may enable them to reward the truly circular businesses better, whilst also being better informed about companies that may state to be circular, but in essence, aren't. Therefore, for businesses that do behave in a circular manner, providing an audit trail can be very beneficial under the right regulatory circumstances. If financing actors can become more informed about a reliable audit trail connected to a circular business, there is more assurance on the performance and therefore investing in the business may be viewed as an affair carrying less risk. A decrease in the perceived risk may lead to more investments under better conditions.

FR.A.2: The architecture shall enable an audit trail to be exported which can be verified by an auditing body.

4.3.10 DP.C.5 Energy efficiency

The main requirement that comes forth from the principle of sustainability is that of energy-efficiency. There can be multiple forms in which a BCT-based architecture is designed, these forms can have different degrees of energy usage. For example, the Bitcoin architecture consumes vast amounts of energy, equaling a total energy use equal to that of Denmark. Nevertheless, there are also forms of blockchain architecture that consume less energy. Therefore, the architecture must process transactions and data in an energy efficient manner. How this can be functionally achieved is firstly, by choosing a consensus mechanism that doesn't require a lot of computing power. Whilst it has become widely known that the consensus mechanism powering Bitcoin consumes a tremendous amount of energy [De Vries, 2018], smarter solutions should be designed for this architecture. Some researchers even consider that all blockchain usage could be inhibited due to the negative impact on the environment [Beck et al., 2018], but still little is known about how different blockchain designs affect the environmental impact of an architecture. Nevertheless, it has become clear that other consensus mechanisms then the traditional Proof-Of-Work significantly reduce the energy consumption of a blockchain solution [Sedlmeir et al., 2020]. Therefore, the architecture should be made as energy efficient as possible and take into account the most energy efficient consensus mechanism. Nonetheless, researching the actual energy footprint of a variety of blockchain designs may be a topic of future research, to assess whether blockchain technology could have a net positive impact.

FR.S.1: The architecture shall implement a consensus mechanism that processes transactions in an energy-efficient manner

Another method in which blockchain technology can be applied in such a manner that the energy consumption is reduced is by minimizing the amount of data stored on blocks. Minimizing the amount of data stored on blocks is possible by storing the data on the blocks in a manner as efficient as possible (e.g. merging data that is similar). Moreover, minimizing the amount of data stored on blocks is also possible by storing a part of the data off the chain with only a hash to the off chain data on the chain. As you may notice, this could cause some tensions with the immutability of records,

Priority level	Description
Low	The requirements may not be crucial for the user experience or critical functionalities of the system
Medium	The requirement has an impact on the user experience but is not crucial for functionality
High	It is essential that the requirement is met for the system to properly function

Table 4.3: Priority levels and their definitions

because off chain storage can be tempered with, whilst on chain storage is non reputable. Namely, the off chain data could be tampered with, if records are changed off chain, indeed the hash will not match anymore, so it is still noticeable that the data has been tempered, however, what exactly has been altered is not traceable (so the original data may be lost). The architecture should therefore achieve some type of balance between minimization of data on blocks and preserving the immutability of transactions records, leading to the following requirement:

FR.S.2 The architecture shall balance off chain storage and on chain storage in such a way that the most important transaction data remains immutable

4.3.11 Conclusion requirement elicitation

A summary of the before mentioned functional requirements is illustrated in Table 4.4. These requirements can be used to guide a design phase for a BCT based architecture that supports markets in SRM. The priority levels for each requirement are also specified in this table. Priority levels for requirements are defined according to table 4.3. Levels range from low to medium to high, the table also illustrates the definitions of the levels. The priority levels can be used to provide focus to the design phase, in a trade-off situation, a requirement with a higher priority would be given preference. The NFR specify quality characteristics of the system and are not given priority levels. The NFR are illustrated in Table 4.5

ID	Design principle		P
		Functioning of markets	
DP.A.1	Accessibility	**FR.A.1** The architecture shall include involved stakeholders as a node on the network	H
		FR.A.2 The architecture should provide the information for financial transactions to be executed to the accountants to enable them to set up contracts	H
		Success factors for spot markets	
DP.B.1	Supply Chain Visibility	**FR.V.1** The architecture shall provide information about the inventory of products and materials as well as their quantity in weight to all involved stakeholders in a circular supply chain	M
		FR.V.2 The architecture shall update total product quantity inventories of nodes after a transaction of products has occurred.	H
DP.B.2	Liquidity	**FR.L.1** The architecture should provide real-time data on the availability of materials and the buy and sell orders.	M
DP.B.3	Identification	**FR.I.1** The architecture shall embed each product with an unique identifier	H
		FR.I.2 The system shall link each unique ID to an information source where the relevant data about the product or material is stored	H
		FR.I.3 Sensors should store information about the location of the product upon the Unique Identifier being 'scanned' and update a record of the total volume of product for that location.	H
		Circular economy perspective	
DP.C.1	Confidentiality	**FR.C.1** The architecture should only allow actors access to the blockchain if they provide a signed certificate containing a pledge of confidentiality	M
DP.C.2	Traceability	**FR.T.1** Each to be traced item by the architecture should be traceable with a sensor that links the unique identifier to an information source where product data is stored	H
DP.C.3	Privacy by design	**FR.P.1** Personal information will only be processed by the system if: **FR.P.1.1** the person it belongs to has unambiguously given permission **FR.P.1.2** the data processing is necessary for the performance of a contract to which the data subject is a party **FR.P.1.3** the data processing is necessary in order to comply with a legal obligation **FR.P.1.4** the data processing is necessary in order to protect the vital interests of the data subject **FR.P.1.5** data processing is necessary for the proper performance of a public law task **FR.P.1.6** data processing is necessary in order to safeguard the legitimate interests of the interest of the responsible party or of a third party to whom the data are disclosed	M
DP.C.4	Assurance	**FR.A.1** The transactions on the architecture must be immutably stored and not be repudiated.	M
		FR.A.2 The architecture shall enable an audit trail to be exported which can be verified by an auditing body.	M
DP.C.5	Energy-efficiency	**FR.S.1** The architecture shall implement a consensus mechanism that processes transactions in an energy-efficient manner	L
		FR.S.2 The architecture shall balance off chain storage and on chain storage in such a way that the most important transaction data remains immutable	M

Table 4.4: Functional requirements overview with priority levels

ID	Design principle	
		Success factors for spot markets
DP.B.1	Supply Chain Visibility	**NFR.V.3** Availability
DP.B.3	Identification	**NFR.I.4** The unique identifier should impact the quality preservation of the product and the materials it contains as little as possible
		Circular economy perspective
DP.C.3	Privacy by design	**NFR.P.3** Data minimization

Table 4.5: Non functional requirements overview

4.4 CHAPTER CONCLUSION

This chapter centered around sub-question 3: ***Which design principles and requirements of this artefact are important?***

This chapter has illustrated design principles and requirements for the to be designed artefact: a BCT-based information architecture. The design principles and requirements were identified by means of combination of desk research and stakeholder interviews. Design principles are set up at a high level of abstraction and are not specific to a BCT based architecture, but may also be applied to architectures underlying other technologies. Furthermore, the forthcoming requirements are more specific and centered around a BCT based architecture being the artefact to be designed in the next phase. The requirements will be implemented in the next chapter to make design choices for the artefact.

5 DESIGN AND DEVELOP

The sub-question that is addressed in this chapter is : ***What artefact can be developed that addresses the explicated problem and fulfils the defined requirements?***

This chapter will consider the design phase of the DSR method. According to Johannesson and Perjons [2014], this activity creates an artefact that fulfills the requirements from the prior phase. The design phase considers the functionality as well as the structure of the artefact. The output of this phase is knowledge that can be incorporated in future artefact development [Johannesson and Perjons, 2014].

The approach implemented throughout this chapter is a case study. The methodologies implemented for the case study are a combination of interviews with stakeholders as well as desk research for the structuring of the design. First of all, the case study will be presented, as well as how the case study is defined in accordance with different circular supply chain business models that occur. Thereafter, a design of a BCT-based architecture will be presented for the specific case study setting. For the design phase, desk research into alternative design choices for BCT-based architectures will be implemented. Findings from the artefact outline chapter with regards to similar artefact designs will also be incorporated. Lastly, it will be illustrated how the design fulfills the requirements identified in the previous section. Figure 5.1 illustrates the research flow of this chapter.

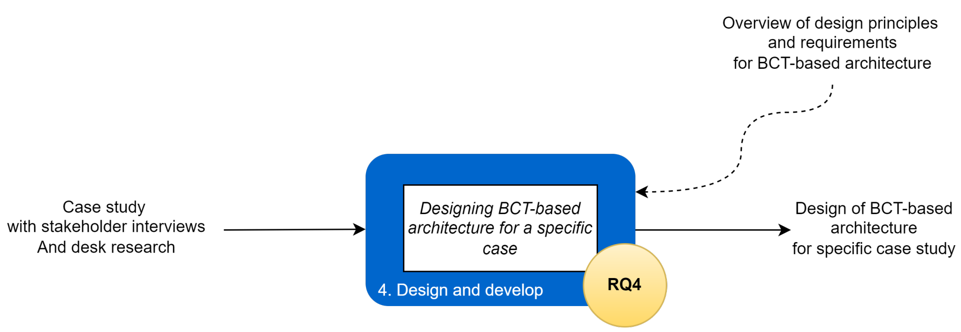

Figure 5.1: Research flow of design phase

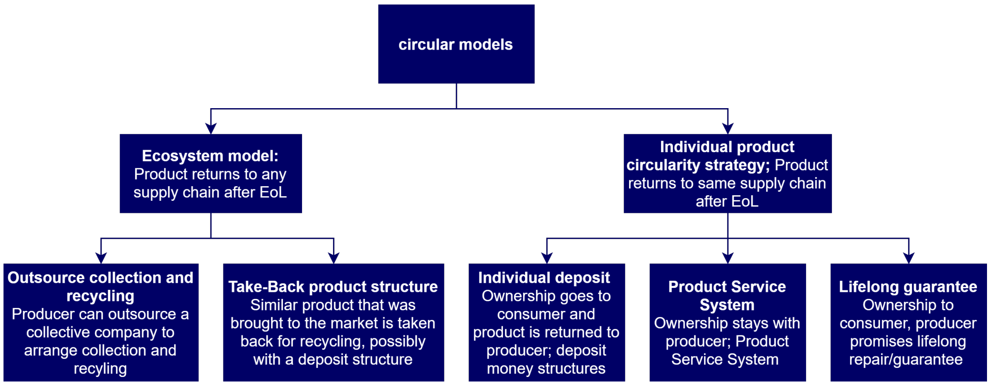

Figure 5.2: Overview of different circular business models

5.1 DESIGN APPROACH

It has been illustrated that it is not possible to design a one-size-fits all BCT-based solution for circularity [Dindarian and Chakravarthy, 2019]. Research by Lewandowski [2016] even identifies 26 different business models in the circular economy. This abundance of different business models requires a variety of solutions. Therefore, with the goal of designing an artefact with more detail, a more narrow scope will have to be chosen for the design phase. Therefore, the decision is made to develop a design translating the design principles and requirements for a single case. Such case studies offer a methodology in which issues or phenomenon can be investigated in a real-life setting. A case study is an 'in-depth, multifaceted investigation, using qualitative research methods, of one single phenomenon' [Feagin et al., 1991]. There are multiple approaches for case studies, such as intrinsic or instrumental [Crowe et al., 2011]. This chapter will implement an instrumental approach, in which a case study is chosen because it is a case that allows the researcher to investigate a certain phenomenon rather than the case being chosen specifically for the uniqueness of studying that specific case. An instrumental case allows to choose a simple case to illustrate how the requirements lead to an infrastructure design. Such an instrumental case increases the ability to generalize the design, compared to a less easy to generalize intrinsic case.

5.2 CASE STUDY SELECTION PROCESS

5.2.1 Varying circular models that can be analyzed in a case study setting

An observation that was made throughout the various research phases is that BCT can take on many forms as well as that circular business models may operate differently from each other. An overview of the relevant variations in circular models as have been identified during this research is illustrated in Figure 5.2.

Figure 5.2 illustrates that there can be variations in the structure of circular business models. Circular models can aim to create an ecosystem model or take on an individual product circularity strategy. In an ecosystem model, a product may return to any supply chain, whilst in an individual circularity strategy, products return to the same supply chain and are usually reused in the same product.

Circular models can either operate in an *ecosystem model* or in an *individual product circularity model*. Firstly, an ecosystem model considers that products are returned after usage, but not necessarily to the same producer or towards the same supply chain. An example is the separation of household waste into glass, paper and other. Ecosystem models are very complex to study as there is a multitude of actors and different products involved. Secondly, individual circularity models operate on more of a product level.

An example of an individual product circularity model is a Product Service System (PSS). A PSS is a model in which the maker or seller, instead of relinquishing ownership, remains the owner of a product. The user therefore gets the product on loan and pays a fee for it. Usually on the basis of use, but a subscription is also possible. This business model is most applicable for companies that own a product. An example of such a PSS is bundles, a circular washing machine leasing company, consumers pay a fixed amount per month and an extra price per wash. By attaching a smart meter to the washing machines, Bundles can monitor their usage. In the application, customers can see their usage and the company gives tips on how to reduce the total cost of washing, including the consumption of energy, water and detergent. The life-cycle of washing machines can be increased and Bundles stays in ownership of the washing machines, hereby enabling their recycling and reuse.

Another individual circularity model is the deposit model, a deposit model is a model in which a specific product from a specific producer or set of producers is collected. It is expected that this individual deposit model is one of the less complex models to analyze in a case study setting, because there can be a well defined set of involved actors in such a setting. An example of a deposit model is that of brand specific beer crates. For example, Heineken crates can be returned in the supermarket and will be returned to Heineken in specific to clean and refill.

Moreover, another example of an individual circularity model is that of lifelong guarantees, this type of businessmodel is implemented by Gerard Street, a circular headphone producer. They offer a pair of headphones paired with lifelong guarantee on their modular headphones (for the exchange of parts when this is needed).

With regards to ecosystem models, a take-back product structure can be implemented, or collection and recycling can be fully outsourced.
An example of a take-back product model is Blackbear Carbon. Blackbear Carbon converts discarded car tyres into carbon black, an industrial product. Carbon black can be used in rubber (70-80 percent) or as pigment for plastics, mascara, paint and ink. The collected tyres can originate to any type of car or supplier.

In a fully outsourced model, producers may also pay extended producer responsibility entities for the recycling of the generated waste. The waste that is generated can be recycled and can end up in a very different type of product. An example is that of black street-poles made out of recycled plastic waste that was discarded in the standard consumer waste streams.

Based upon this variety of different models, a case study can be selected and defined in accordance to the presented framework in the next section.

5.2.2 Selecting the case

During this research, it has become clear that supply chains can be very complex to study. Supply chains are frequently of cross-border nature and characterized by a lack of visibility. For this chapter, this implies that a case should be chosen that offers enough simplicity to make a complete design for the BCT-based architecture. By choosing a case that has a minimum level of simplicity, it can be made more concrete how the BCT-based architecture can be designed to enable markets in SRM. One way to determine simplicity is the amount of materials present in the product or product group that is taken into consideration. A more complex product consists of a multitude of materials and could therefore also differ in the recycling difficulty and rate compared to a product made fully from one material type. Another way to determine how complex a case study is in this setting, is the amount of involved actors and stakeholders within the supply chain. More complex products could have more actors and stakeholders involved rather than a more simple product. For example, a computer consists of many parts made by many different manufacturers that all need to share information about the materials for supporting recycling processes. Simultaneously, a product made up of one material may only be developed by a singular manufacturer, clearly a more simple case.

Another selection criterion for the case study is accessibility. I.e. that the researcher should have access to the organisation, process or anything else that is the unit of study for a proper case study analysis [Crowe et al., 2011].

Based on the criteria of accessibility and simplicity, the PEF bottle supply chain is selected as a case study. For this supply chain, there is access to relevant data and information about this supply chain, and the unit of investigation is hospitable to the inquiry, as interviews are possible with multiple key stakeholders such as the producer Avantium, the bottler Refresco and the recycler CuRe. The case also boasts a relatively big amount of visibility, as bottles as produced within this supply chain are usually returned to supply chains in a deposit based system. Figure 5.3 illustrates where in the provided overview of circular models, this case study is situated. The case study considers the individual deposit structure, a structure in which the aim is to have the material returned to the same producer for reselling purposes.

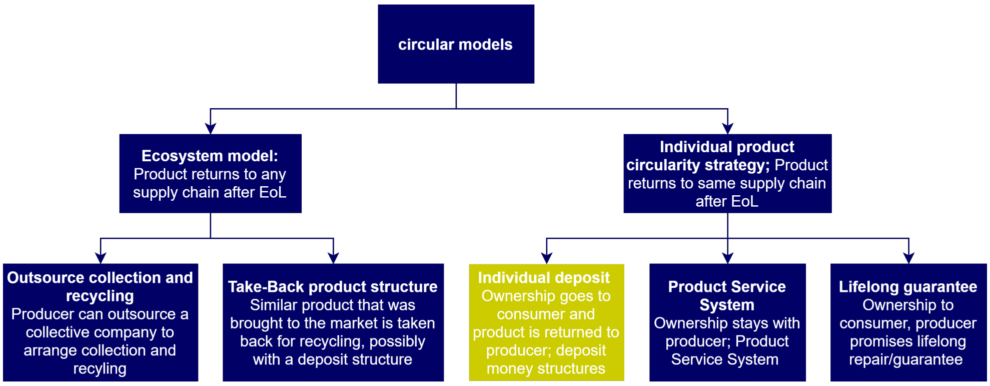

Figure 5.3: Overview of different circular business models and the location of the case study in this framework

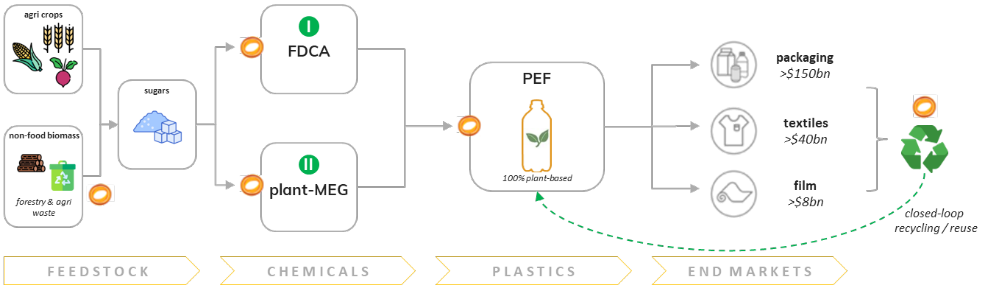

Figure 5.4: Overview of development process of PEF [Avantium, 2021]

5.3 CASE STUDY INTRODUCTION

The chosen case study is a case study with Avantium Renewable Polymers, they have multiple product lines that compose of different supply chains. Hence, the specific product of bottles was selected. This is a supply chain in which a bottler, Refresco, is also involved and a recycler, Cure. These actors are all part of the PEF bottle supply chain that will be the scope of this design phase.

5.3.1 Key actors

Producer: About Avantium and PEF

In 2000, Avantium was founded with a technology originally developed by Royal Dutch Shell that was then transferred to Avantium [Gruter and van Aken, 2021]. The technology was initially created to accelerate catalysis research and development Gruter and van Aken [2021]. The company started to focus on applying biotechnology and the use of enzymes and whole-cell technology in fermentation processes. Avantium developed an acid catalyst technology (YXY technology) that is capable of producing a wide set of materials by converting plant-based sugars Hernández et al. [2014]. The catalyst technology is used by Avantium for developing the next generation of bioplastics based on 2,5-Furandicarboxylic Acid (FDCA) [de Jong et al., 2012]. The development process of PEF is illustrated in Figure 5.4 [Avantium, 2021].

The bioplastic can be produced with sugars and other non-food carbohydrates. At the same time, globally there is an overshot of sugar, as more and more countries are taking measures to reduce sugar consumption. Therefore, the technology can use sugar as an input that is currently available in excess.
With the production of the bioplastic PEF, Avantium aims to develop the replacement for fossil-fuel based polyesters like Polyethylene Terephthalate (PET) in a broad set of applications that include e.g. bottles [de Jong et al., 2012].

PEF has great barrier properties with regards to bottling or packaging, implying that it could really be competitive with materials like PET. Barrier properties are important for packaging beverages as they ensure that carbon dioxide gas - responsible for the fizz in drinks - remains in the bottle. Firstly, the oxygen barrier of PEF is twice as good as that of PET, secondly, the carbon dioxide barrier is up to ten times better than that of PET and lastly, the water barrier is twice as good as that of PET [Avantium, 2021]. According to de Jong et al. [2012], PEF can compete with PET and in doing so, achieve reductions in fossil fuel use and carbon dioxide emissions.

Bottler: About Refresco

Refresco is the world's largest independent bottler [Nair and David, 2021]: meaning that it handles the bottling process for various brands. the company helps brands with the production of amongst others, ready-to-drink teas and coffees, juices, energy drinks, but also beers [Nair and David, 2021]. According to Nair and David [2021], it is the largest independent bottler in Europe and North America. The company has over 10.000 employees in over ten locations. Refresco collaborates with a company like Avantium to provide the materials for the bottles that they fill for the brands that they collaborate with.

Recycler: About CuRe

The recycler CuRe is based in the Netherlands and has the capability to recycle used polyester back to virgin grade polyester [CuRe, 2021]. It is also in their capability to perform a PEF-to-PEF recycling process. According to CuRe [2021], the technology as developed by CuRe consumes considerably less energy than the traditional recycling methods for polyesters. Therefore, it can contribute to reducing carbon dioxide emissions. CuRe has a factory based in Emmen (the Netherlands) to handle recycling. Being allowed to recycle bottle-to-bottle is very challenging for a recycler, as it requires compliance with many legal processes before recycled materials may be reused in packaging of food. Therefore, if information can also be shared with regulators, the assurances about the quality of the materials within the supply chain can make compliance easier.

Retailers

A retailer is also a key actor within the PEF bottle supply chain. The retail point of the bottles is the most complex part of the supply chain; the set of bottles goes from one owner to a multitude of various owners: the consumers of the beverages. After consumption, these consumers will need to return the bottles to the retailer for collection via deposit systems. On top of this, there can be multiple different retailers involved in this process, these can be different. Nevertheless, PEF hasn't been commercialized and therefore isn't sold in supermarkets yet. This implies that this part of the case has to be imagined by the researcher. Whilst this may decrease the applicability to a real life setting, it does give more design opportunity towards optimizing the process. The advantage of designing this architecture prior to commercialization might be that there is not yet an architecture in place that poses a barrier or adds complexity to the implementation.

5.3.2 Case study perspective

The case study is approached from the perspective of Avantium, the producer, but the entire supply chain is considered for the analysis. The producer is the actor that has the ability to influence the entire supply chain. They are in the center of supply chains and interact with the government, with suppliers, but also with retailers and financiers. The producer – Avantium – is therefore the designated problem owner in the case study. As PEF is commercializing, pilots of implementing PEF in commercial retail stores such as supermarkets will be amongst the first steps that will be taken. Likely, this will start on a local level, with a few supermarkets offering the product and handling it's return on a local level. At a later stage, when more PEF is being developed, this commercialization can be expanded to regional or even national levels. An infrastructure that works on this small scale but could also be extended to facilitate a larger scope is therefore important.

5.3.3 About the PEF bottle supply chain

The PEF bottle supply chain is illustrated in Figure 5.5. The figure illustrates that there are some raw materials that need to be supplied in order to produce PEF. These are materials extracted from sugarcane production. Figure 5.5 illustrates that the scope of study is narrowed down to the circular supply chain activities. Hence, this is the process occurring after the raw materials have been supplied for the production of PEF.

The virgin material supply is left beyond the scope of this research. The return handling is conducted through a method in which the consumer returns the product to the seller or distributor and the seller of distributor returns the product to the return handling actor. A seller in this case is a supermarket that sells bottles to consumers and offers a deposit system for their return. This type of deposit system based return handling is one of the most sophisticated that is already in place in our society, making it suitable for demonstrating the functionality of an information system. Because this case study will assume the distributor being a supermarket, a Business-to-Consumer based supply chain model is considered. In a model such as this, deposit systems are in place for the collection of bottles, currently this is only available for PET bottles, however, the objective is to add PEF bottles

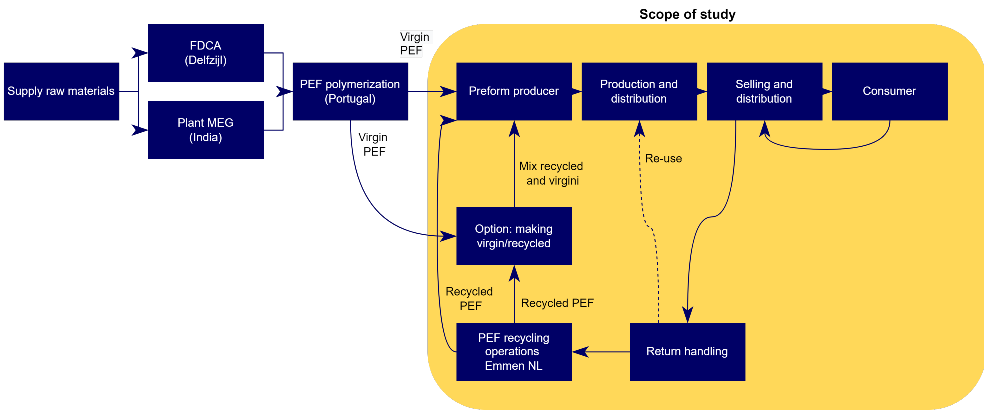

Figure 5.5: Overview of PEF bottle supply chain and scope of study

to this stream. To properly introduce PEF bottles to this stream of collected bottles, and separating it from PET, quality controls have to be put in place to preserve the purity of streams.

This section has given a brief introduction about the case study which will be applied for the design of a BCT-based infrastructure.

5.4 THE DESIGN PROCESS

The design process is split into different layers of system architecture, adapted from Wang et al. [2020] and Venkatesh et al. [2020] (Figure 3.4) towards this case. A user layer, an application layer, a blockchain network layer, a perception layer, and the circular supply chain itself. The blockchain layer will consider the BCT-based configurations and the perception layer will consider the physical elements needed to inform the blockchain layer. Also, a user layer depicting the involved actors, and an application layer specifying the interface functionalities towards users are considered.

5.5 USER LAYER

The user layer contains all users of the applications in the system architecture. In this particular case, the actors as were introduced before for the case of the PEF bottle supply chain have to be included in the user layer. These are the producers, bottlers, retailers, distributors and recycling bodies. Moreover, monitoring agencies are also potential users in the system architecture. Monitoring agencies are e.g. governmental agencies, auditors and financiers. Governmental agencies could be users as transaction data of companies would be a potentially valuable tool at the foundation of regulatory instruments and incentives. The transaction data can also be shared with auditors, such that it can be verified that no fraudulent behavior is occurring. Information from the system can also be shared with financiers, to provide assurances on the future income streams from the materials in reverse logistics processes.

5.6 APPLICATION LAYER

The application layer is the bridge between the blockchain network and the users of the network. It depicts the usage of the network as a functionality of the user. The main applications are the product management, transaction management and audit trail exportation. The application layer considers the interface of the network towards the users. The product management interfaces consider product management on two aspects, first of all, the product quality (purity of material stream) and second of all, the product traceability (the location and quantity). The transaction management application depicts the exchanges of materials between the different involved actors. Lastly, the audit trail exportation application allows for a log of transactions of users to be exported in a yet to be determined format, which can be forwarded to auditors or other monitoring agencies such as financiers, for review.

5.7 BLOCKCHAIN LAYER

The digital infrastructure is divided into four main design areas. The blockchain grouping is discussed, the blocks and the data they contain is discussed, the network is discussed and lastly, the consensus mechanism is discussed.

5.7.1 Blockchain grouping

There are four different groupings of BCT based architectures, as defined by Tasca and Tessone [2017]:

- Digital currencies
- Application stacks
- Asset registry
- Asset-centric

These four groupings of BCT all have different characteristics. Based on the proposed requirements, for this architecture design, an asset-centric technology is the relevant grouping for the BCT-based architecture. In asset-centric technologies, the architecture is based on digital tokens that represent assets [Tasca and Tessone, 2017], such as in this case, PEF resource streams. The asset-centric technology is in specific fitting to this case because in asset-centric technology, nodes are not anonymous to each other, but are cryptographically identifiable [Tasca and Tessone, 2017]. In this case study, the stakeholders involved should not be anonymous to each other, they have an ambition to work together towards a common goal.

5.7.2 Blocks

A block is usually a file that permanently records data related to the Bitcoin network. A block records some or all of the most recent Bitcoin transactions that have not yet been recorded in previous blocks. Each time a block is "completed," it makes way for the next block in the blockchain. In this way, all data is stored in a permanent way on the blockchain. Each block contains data about some or all of the recent transactions and a reference to the block that preceded it. This combined with Bitcoin's peer-to-peer verification system ensures that the transactions that have been made are very difficult to be tampered with. Naturally, a BCT-based architecture functions under the leading principles of non-repudiation and irreversibility of the stored transactions. Transactions are very difficult to temper with due to one-way cryptographic hash functions and the irreversibility of transactions [Tasca and Tessone, 2017]. This natural function of BCT supports the design principle of assurance and the requirements forthcoming from it.

Header of the block

The header of a block in the blockchain consists of a variation of possible components [Liu and Li, 2018], of which the following are proposed for the design:

1. The hash of the preceding block: The hash of the preceding block is incorporated into the hash of the succeeding block in a chain. Including the hash of the preceding block in the succeeding block, ensures that the blocks of the chain all build onto each other. The hash of the preceding block is included in the proposed design for the header of the block in this case study.

2. The time which is defined in seconds: This is also called the time stamp. The timestamp is included in the proposed design such that it is clear when a transaction takes place.

3. The root hash: The combination of transactions in a block can be merged into a hash. The hash in a new block can therefore be based upon the combination of all preceding transactions and this is defined as the root hash of the Merkle tree. The Merkle tree ensures that transactions are immutable. The root hash is included in the proposed architecture design as it is one of the standard building blocks of the blockchain.

To conclude, the header of the block will be configured in quite a standard configuration for the BCT based architecture, with a hash of the preceding block, the root hash of the merkle tree as well as a timestamp.

Body of the block

The body of the block can be considered as the 'loading space of a truck'. The body of the block contains the transaction data. For each transaction, the necessary information should be stored. Data storage can be implemented either on chain or off chain. On chain storage is more expensive as the amount of data that you are storing is stored by every full node. It is common practice to store raw data off-chain and on-chain only metadata or hashes of the raw data [Xu et al., 2017; Hepp et al., 2018]. Off chain storage solutions should be implemented for transaction data that is too large to be stored on chain.

- **On chain storage:** With regards to the data that is stored on the chain, in each transaction, there is a sender, a distributor as well as a receiver involved. The sender is the actor that has ownership of the PEF prior to the transaction and the receiver is the actor that receives the PEF and its ownership, from the sender. Both the sender, distributor and the receiver consent needs to be documented. A sender is e.g. the retailing supermarket, while the receiver can be a recycler. Another combination of sender and receiver is the recycler as a sender and the producer as a receiver. The distributing actor is also involved in each transaction as it distributes the material from sender to receiver. All these involved actors need to consent to the transaction being added to the chain. To ensure that the consensus has actually come from the actor involved in the transaction, each involved actor has to encrypt their consensus within the transaction with their private key. The public keys of each actor can be used to verify that it was indeed that actor that consented to the transaction. The ID of each involved actor is also stored in the transaction data. Also, the amount of PEF being exchanged in the form of tokens (explained in the next section) is stored in the body as well as the price of the transaction (in euros). After each transaction, the total PEF balance can be altered for each involved party in the transaction. Next to the metadata storage that has just been explained, some way to store the raw transaction data in a tamper proof way is also desirable. Storing all the raw data within the body would not be scalable and take up a lot of storage. Therefore, the blocks should contain a hash pointer of the off chain stored transaction data. The disadvantage of storing raw data in the body by using a hash pointer is that the URL data to which the pointer leads can still be altered, however, one can know that the data must be altered if the hash is incorrect. In choosing this design configuration of a hash pointer, priority is given to the scalability of the architecture rather than it being fully tamper proof.

- **Off chain storage:** Off chain transaction data is the more specific data consisting of the number of bottles as well as their ID's. The total weight can be calculated based on this sum of bottles and their individual weights. The governance of the off chain database should also be considered when it is to be implemented. The governance of this database is left outside of the scope of this research but may be interesting for future research to consider.

The resulting block structure for the proposed design is summarized in Figure 5.6, adapted from [Liang, 2020].

Tokenization

Assets that need to be traced on a supply chain can be traced by means of tokenization. According to Bekrar et al. [2021] ,a token can be defined as: 'a digital twin that depicts products and materials in the form of a token that can trace the materials in a supply chain'. According to Narayan and Tidström [2020], tokenization can enable improved cooperation between actors involved in circular supply chains. Physical assets can be linked to digital

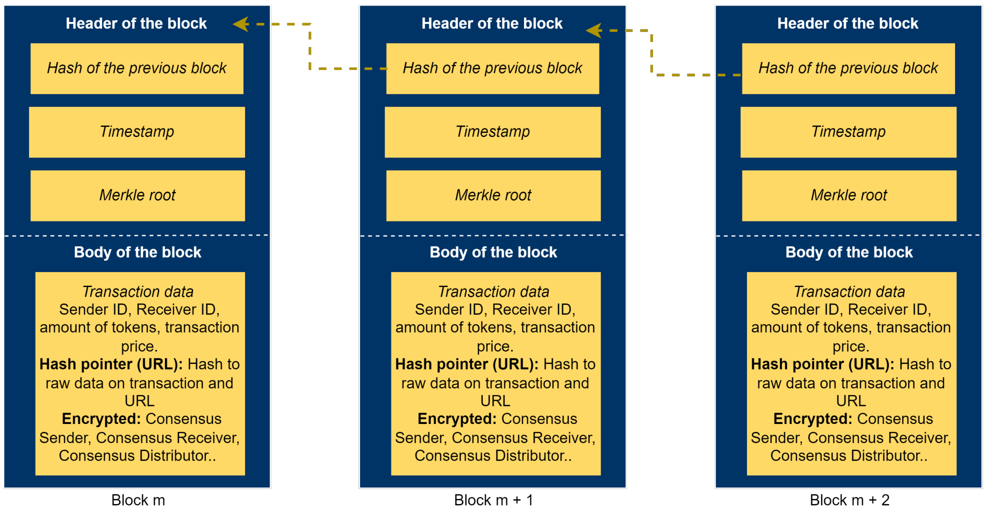

Figure 5.6: Block structure for architecture design adapted from [Liang, 2020]

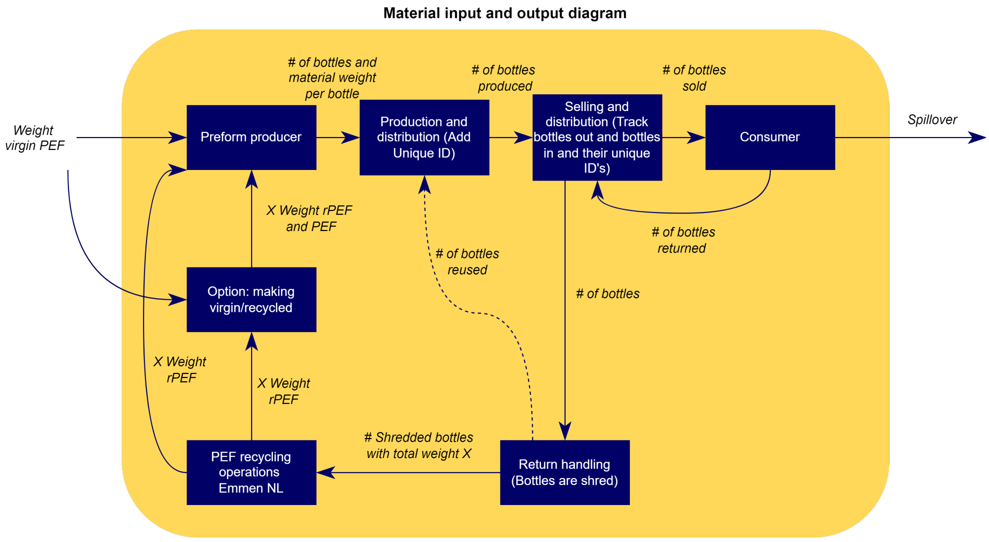

Figure 5.7: Input and output in the PEF bottle supply chain

tokens, exchanged on the architecture. Tokenization can also improve coopetition in circular supply chains [Narayan and Tidström, 2020]. Coopetition implies that cooperation and competition occurs simultaneously. For example, recyclers and other actors in the supply chain collaborate to create audit trails and preserve quality of materials in the supply chain. At the same time, actors can compete for materials and trades.

To achieve tokenization in the sense that tokens represent physical assets, physical assets will have to be tracked along the supply chain in such a way that they can be represented by tokens. It will be important that tokenization is implemented to ensure ownership being distributed as well as traceability.

A diagram representing the input and output materials has been developed for the PEF bottle supply chain in Figure 5.7. The producer and distributor can trace the materials by tracing unique ID's on the bottles, whilst during the return handling, these bottles are shredded and the unique ID's scannability is lost. To achieve tokenization, at many points in the supply chain there would have to be a measuring point for the physical assets, to ensure that the physical assets are consistent with the digital tokens that are exchanged. The tokens could therefore represent a number of bottles or can represent a certain weight of material. Having all similar tokens represent individual bottles is not feasible as not each bottle has the same weight or the same value. However, a unique token is also not feasible as that would cause scalabiltiy issues. On top of this, another reason not to have a token represent a single bottle is that the bottles get shredded and molded whilst in the supply chain, this would mean that new tokens have to be issued often. The weight of the PEF is the something that remains measurable throughout the entire supply chain, weight in plastic can potentially be used as a tokenization mechanism. For example, a token can represent one kilogram of PEF.

Nevertheless, storing only the weight of bottles may also not suffice to preserve quality of materials. The weight measured when the bottles leave a retailer may be different from a weight that is the eventual input for recycling. The bottles can have contamination before recycling (e.g. remaining liquid), hence after the bottles have been cleaned by the recycler, the total weight of materials will reduce to only the net bottle weight.

In this case, tokens represent responsibility and accountability and therefore create opportunities for improved cooperation. Tokens can't be handed out as a reward for validating transactions because the tokens in this case represent physical assets that are physically traded. The money that is paid for an exchange of PEF is stored in the transaction data though.

There is a lack of research into tokenizing materials, so the exact tokenization design for this architecture cannot be made Van Engelenburg et al. [2022]. Future research should consider how to tokenize materials to ensure that traceability of raw materials is made possible.

5.7.3 Networks

This section on networks will consider how the BCT network is shaped. This entails whether the infrastructure is public or private, who has access and what nodes support the validation process.

Roles of involved nodes

The network of involved nodes is illustrated in Figure 5.8.

All involved actors in the supply chain have access to the architecture, however, not all actors have the same rights to validate or access transactions. Nodes who can directly exchange materials with each other are defined as ''trading nodes', nodes who only have a function of accessing transaction information are 'information nodes' and nodes who only arrange the distribution of material from one trading node to another trading node are defined as 'distributing nodes'. Trading nodes have a trading certificate, distributing nodes have a distributor certificate and information nodes have an information certificate. These three nodes have different functions within the architecture. Two trading nodes and a distributing node verification are needed to validate a transaction of material.

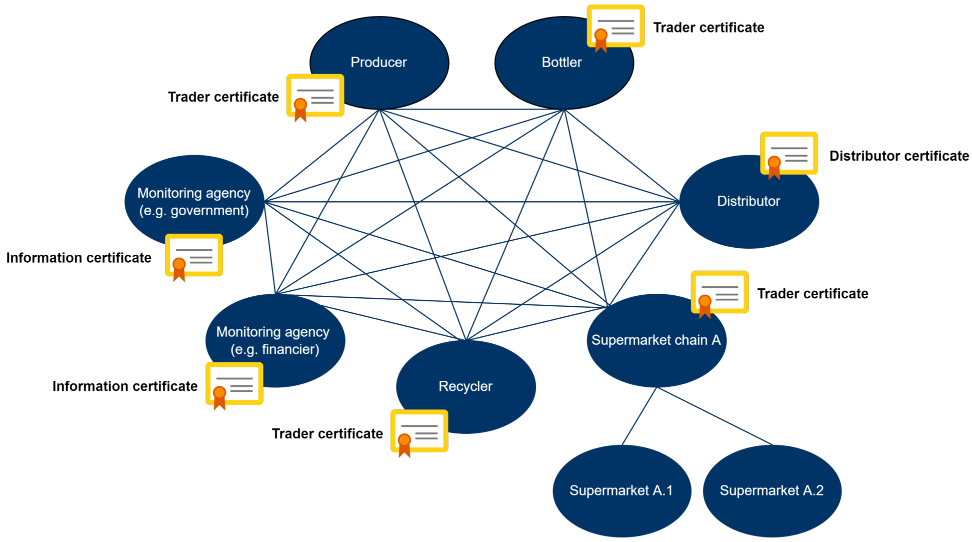

Figure 5.8: Architecture network

Information nodes represent actors that have a need to verify the transaction data, but don't transact themselves. The actors representing information nodes are amongst other, banks and monitoring agencies. The information nodes, if given access to the blockchain infrastructure, can view all data that is stored in the body of the blocks. Therefore, with a design configuration like this, it will be important to establish a governance model with regards to how access rights are allocated to nodes. However, this is outside of the scope of this research but may be considered by future research.

Access and control

There are multiple ways in which the access and control can be configured: public, permissioned public, consortium and permissioned private.

A public blockchain is the best known and most widely used. Public blockchains are completely decentralised and open-source. Anyone can participate in the network and anyone can view the code used to write the blockchain. Anyone can send transactions over this blockchain and can assume that these transactions will be recorded in the blockchain. Because there are usually more people connected to a public blockchain than a private or consortium blockchain, public blockchains are often more secure. A public blockchain allows anyone who wants to participate in the information architecture access to read and write transactions. Also, in a public blockchain, nodes are homogeneous and can perform the same actions, whilst, in this case, it has already become clear that traders, distributors and information nodes have in-homogeneous roles. A public blockchain is thus not suited for this case.

A public permissioned blockchain fills the void between private and public blockchains; it combines the permissioned nature from private consortiums with a more decentralized governance model.

In a private blockchain, one central authority decides who has access to the network. However, to enable the system to expand, it may not be desirable to have only one central authority in control of the identity management. Therefore, a configuration on a private blockchain is proposed, namely, a consortium blockchain. Consortium blockchain configurations have received a lot of attention recently, due to their good scalability and modest costs [Li et al., 2017]. A consortium is a collaboration between different parties, such as banks or companies. A consortium blockchain is therefore a blockchain that originated as part of a collaborative venture. The blockchain is not public, but does have multiple owners. Sometimes a consortium blockchain can be viewed by anyone, but not everyone has the opportunity to change data.

In this specific case, it is likely that at first, the deployment of the information architecture will take place on a local level and gradually expand to include more entities on a bigger scale, such as more supermarkets and recyclers. Therefore, the excellent scalability properties of a consortium based blockchain architecture make it the most suitable here. With regards to how access to the blockchain network is granted, having each involved node verify that an actor can receive access to the network may not be a scalable design if the number of nodes keep growing. Therefore, a form in which a selected amount of nodes need to verify access to a new actor would be the most feasible solution. The governance aspect of a consortium architecture, namely, what nodes are in control of who receives access to the blockchain architecture is outside of the scope of this research but can be considered by future research.

In this specific case, only actors participating in the PEF supply chain can also participate in the information architecture by performing transactions or validating them. Therefore, access to the information architecture is only granted to a limited set of actors.

User verifyability

In this case, the nodes on the information architecture will present entities within businesses participating in it. It is important that transparency is created about the participants, such that they know with who they are transacting. Participants not being anonymous to each other allows a data owner to allow a participant access to data. Therefore, measures to verify identities of other participating nodes can be implemented. Mechanisms such as Know-Your-Customer (KYC) or Anti-Money-Laundering (AML) ensure that user information is verifiable and not anonymous [Tasca and Tessone, 2017].

Security and Privacy

In accordance with Tasca and Tessone [2017], the security and privacy of a blockchain based architecture depends upon two components; data encryption and data privacy. Both have different possible configurations.
With regards to data encryption, the encryption can be based on either a Secure Hash Algorithm (SHA-2) or on a Zero-Knowledge - Succinct Non-interactive Argument of Knowledge (ZK-SNARKS) configuration [Tasca and

Tessone, 2017]. An SHA-2 is the most common data encryption method implemented for blockchain based infrastructures and the zksnarks encryption method enables more anonymity for users, as it doesn't require a piece of information from the user. In this specific case, users are not individual users but are part of a business that is connected to the architecture. Also, because the architecture aims to improve cooperation between the involved actors, the actors aren't fully anonymous to each other. Hence, the SHA-2 configuration for data encryption suffices. This also requires less computational power, in line with the NFR.

With regards to data privacy, privacy can be built into the blockchain architecture or it can be designed as an add on to the blockchain architecture. With built-in data privacy based configurations, privacy is built in and therefore obfuscation of information is provided. With add-on privacy, the architecture must rely on external ways to preserve privacy. Data privacy is important for the architecture in this case, as a secure audit trail must be generated by the architecture, however, the audit trail may only be accessed if permission is provided by the actors involved in the transactions. Therefore, data privacy should be configured on a built-in basis. For example, Mohanty [2019] propose a built-in data privacy solution in which exclusively the actors directly participating in a transaction have access to the transaction data. External parties like monitoring agencies may in this configuration only get access to the data (for an audit trail) if by invitation of the actors involved. Audit trails can be desriable to prove that no fraudulent behavior has occured and the quality of the materials can be assured for futures use in the same product. As company sensitive information is involved in these transactions, it is important that a configuration like this is implemented, to incentivize the actors to participate in the architecture and securely share data.

5.7.4 Consensus mechanism

Proof of authority immutability structure

The consensus immutability structure can take on six different forms as defined by Tasca and Tessone [2017]. Proof-of-Authority consensus mechanisms in particular, fit well with consortium type architectures, hence, this consensus immutability structure will be applied in the design. On top of this, this is not the most electricity consuming consensus immutability structure, in line with the requirements considering the minimization of electricity usage by the architecture. In Proof-of-Authority, nodes are selected in advance, after which they may add blocks to the blockchain forever. The adding or consenting of blocks being added to the chain can be automatized by the authorized nodes. Namely, the blocks can use algorithms to control that each transaction presented to the chain complies with the necessary requirements:

- Encryption of consensus trader A, distributor and trader B is verified by public key

- Hash corresponds to hash that results from the data available when going to URL in the hash pointer
- The ID of all three involved participants in the transaction is known
- The amount of tokens exchanged is documented

For example, checking that the encryption has been executed by the mentioned actors and not by others (by verifying with public keys) as well as checking that the hash pointer corresponds with the hash of the raw data stored on the URL. If all these requirements are met, the block can be approved and the header data can be added to the block.
Thus, ultimately only a few nodes are responsible for the operation of the entire blockchain. When a consortium blockchain uses Proof of Authority, nodes are chosen by the founders of the blockchain. This often requires a rigorous selection process, as the machines of the nodes are under the control of the founders of the blockchain.
This again touches upon a governance aspect of of the architecture. What specific actor or group of actors should be in charge of this allocation of authority can be considered by future research. Nevertheless, in this research it may already be interesting to consider two possible ways that this could be achieved, without needing to define exactly which actors are in charge. Authority certificates can be added to the network to define what actors receive authority rights. These authority certificates can be handed out to actors that also have other certificates like e.g. traders or distributors which are directly involved in transactions 5.9. On the other hand, the authority certificates could also be handed out only to those nodes that aren't directly involved in transactions, for example the actors with information nodes 5.10. Another possibility is that only external actors with no other involvement in the network receive authority certificates to consent transactions 5.11. An external actor could be some third party company hired for only the purpose of consenting blocks being added. The choice as to what configuration is included in the design can be considered by future research.

5.8 PERCEPTION LAYER

To facilitate the market in secondary PEF the BCT-based architecture has to be supported by physical elements in the perception layer. The products themselves should be physically altered in a way that unique ID's are added to them. The actors involved will also have to implement physical artefacts to ensure the quality and quantity of the materials is measurable. This section will first consider product identification and second, the physical artefacts. Before considering the physical artefacts, it is important to consider at what point in the supply chain the material control is most important. Figure 5.12 illustrates the complexity of the supply chain related to how many actors are involved. The shape of the supply chain is a diamond that is at it's most wide when the bottles are in the ownership of consumers. Therefore, the most complex point in this supply chain is the return handling at the retailer, where the consumer returns the products. This is also the moment

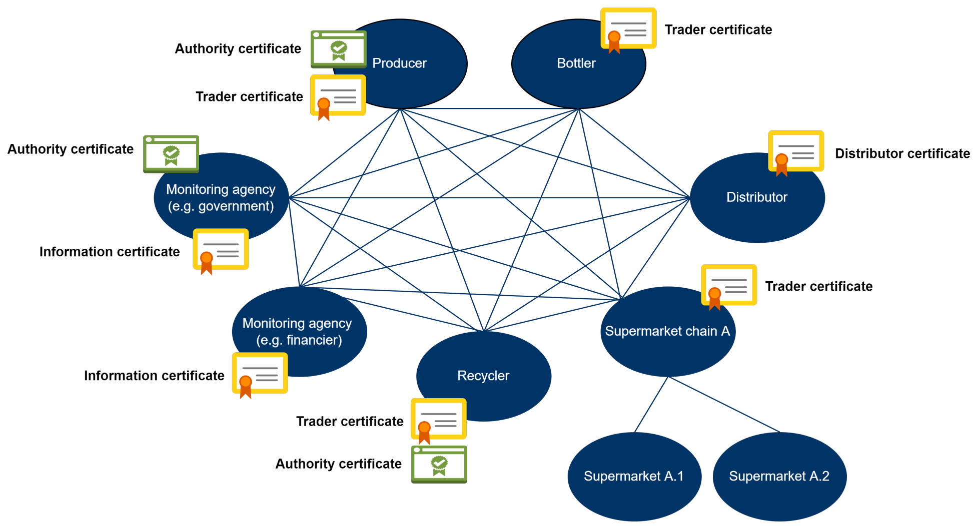

Figure 5.9: Authority structure scenario 1: Involved actors that can also include traders themselves, appointed as authority

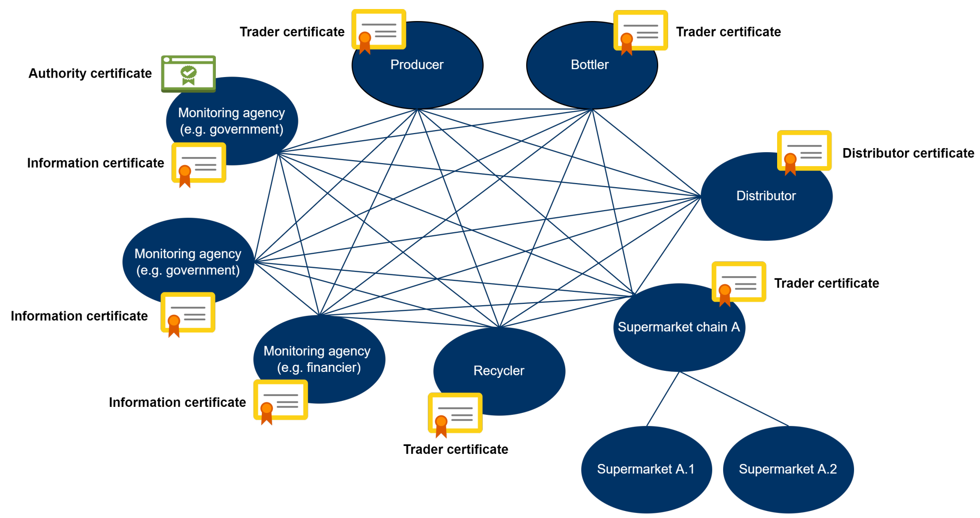

Figure 5.10: Authority structure scenario 2: monitoring agency appointed as authority

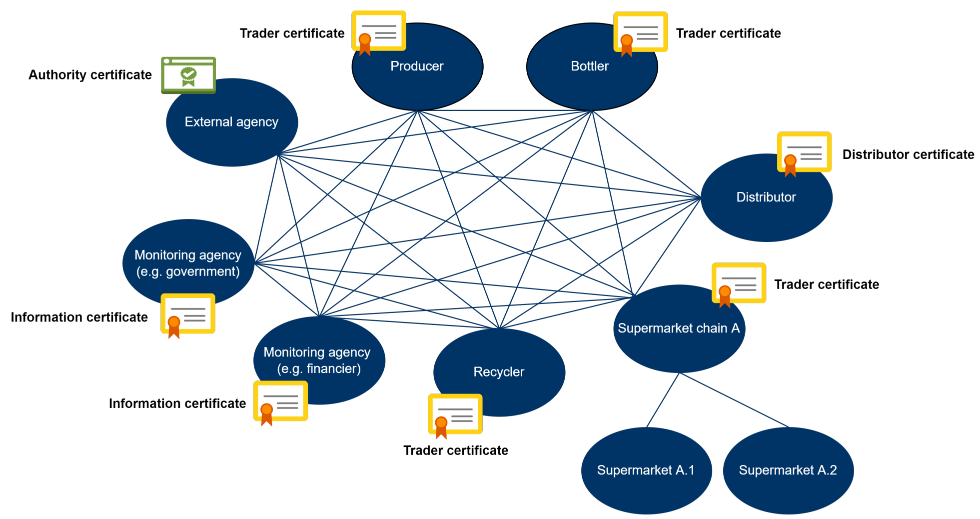

Figure 5.11: Authority structure scenario 3: External agency appointed as authority

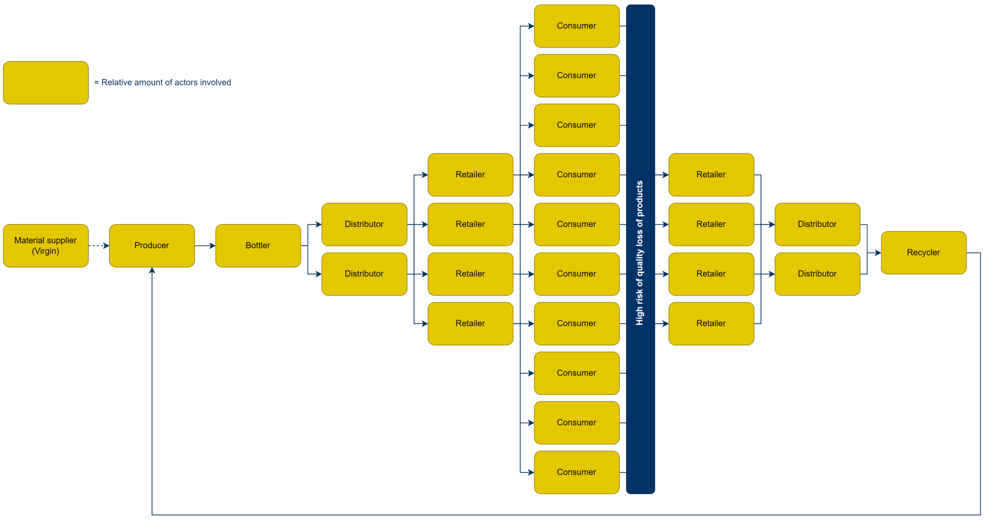

Figure 5.12: Bottle supply chain diamond shape

in the supply chain that the most contamination can occur. Hence, specifically at this point of return to the supply chain (consumer back to retailer), extra quality controls should be put in place. The implementation of IoT devices equipped with sensors, and physical markers on products is essential towards creating quality controls for the materials [Damianou et al., 2019].

5.8.1 Bottle ID

The products, in this case defined as bottles, should be traceable back to their materials. To achieve this, the requirement of the product having an ID was already touched upon. How this requirement can manifest into design choices is explored in this section. To consider how to ID a PEF bottle, one should first consider if all bottles of the same type receive the same ID, or if each individual bottle receives an individual ID. It has become clear in the previous section that preserving storage space is desirable in transactions on a BCT-based infrastructure, or on any infrastructure for that matter because it preserves resources. Therefore, each individual bottle having it's own unique ID would be very storage inefficient, because each individual ID would have to be stored in a certain database containing the corresponding product information. However, giving each single bottle of the same type the same ID might also not be desirable as in that case, no information is available about the age of the material - when it was produced. This whilst material age can play a role in the material quality and how suited the material is for recycling. To compromise between these two matters of storage preservation and available data on material age, ID's could be placed on the bottles in batches corresponding to when the bottles were produced. ID's could be changed yearly, bi-annually, quarterly or even monthly based on when the bottles were produced. It would be recommended to change the ID's at least bi-annually to have relatively detailed information on the production moment. This saves a relatively large amount of storage space because the product information can be stored for a sum of ID's and therefore a data set containing information on materials can be smaller. On top

Production period	Amount	ID (integer)	Total weight (Kilograms)
1	50	X	0,5
2	30	X	0,3
2	40	Y	0,2

Figure 5.13: Transaction data

Figure 5.14: Example of EAN-13 code [Wikimedia, 2022b]

of this, the transaction data is also decreased in size as these batch ID's can also be stored as sums. For example, for a very single transaction containing 50 bottles with ID equal to X produced in the first half of 2021, 30 bottles of ID equal to X produced in the second half of 2021 and 40 bottles of ID equal to Y produced in the second half of 2021, storage can be reduced as illustrated in Table 5.13. The data in this table illustrates that a transaction has occurred that totals a sum of 1 kilograms of PEF.

This transaction data can be stored off chain to preserve storage as mentioned in the digital infrastructure section. A hash of the raw transaction data is stored in the block such that the traded amount can't be altered.

Now for the type of ID with which to equip the bottles. A product ID for circular purposes can be referred to as a physical marker [Khadke et al., 2021]. There are a variety of different types of physical markers that a product can be equipped with. An exploration into the varying types of physical markers has been conducted, the resulting findings will be outlined in the next section.

5.8.2 Physical markers

There is a variety of physical markers that could be implemented. This section will consider the findings from literature.

European Article Number

One of the most common physical markers used on products is an European Article Number (EAN) based code (A barcode) on products. An EAN-13 code is something that is already present on most products (Figure 5.14). Therefore, this code would only have to be linked to a database containing product information. A disadvantage of these codes is that they leave a residue with recycling, as they usually are placed on a label with ink. Another disadvantage may be that some labels get taken off bottles or become damaged, thus making the code not traceable anymore.

Figure 5.15: Example of QR code [Wikimedia, 2022c]

QR-code

A Quick Response (QR) code is another physical marker that could be applied (Figure 5.15). A QR code can directly link to an URL. Therefore, an additional functionality may be that customers can scan the QR code and in doing so directly view information about the product online [Kouhizadeh et al., 2020].

Disadvantages of the QR code are similar to those of the EAN-13 physical marker. With a possible residue being left behind during recycling and the marker possible becoming damaged and unreadable. The advantage is that QR codes can be used to store a lot of information as they can be linked to a URL page.

Radio Frequency Identifier

Another physical marker is an Radio Frequency Identifier (RFID) tags. An RFID can be integrated into the bottle and the tag can be recognized by specialized readers. There are active RFID and passive RFID tags [Weinstein, 2005]. Active RFID contain their own source of power. Passive RFID tags would be sufficient for the architecture, as the tags don't have to be able to send messages to readers, they only need to be readable. Most RFID tags are used to store an identification number. An advantage of these RFID tags is that they can store quite complex identification numbers. The reader can then extract information about the identification number from a specified database and act accordingly. An RFID tag is illustrated in Figure 5.16.

Another advantage of RFID is that one reader can communicate with multiple RFID at the same time [Weinstein, 2005]. Therefore, for an entire container load, all the included RFID tags could be read by a reader. However, as in this case there is usually not a container load considered but individual bottles that are handed in to a deposit system, this advantage is not relevant to this specific case. It might however be relevant to use in other cases.

A disadvantage of RFID tags are that they leave a residue when recycling occurs. For sustaining the purity of materials, the RFID tag would have to be removed prior to any shredding of the bottles occurring at the retailer. This process is infeasible and therefore RFID tags don't seem feasible in this case.

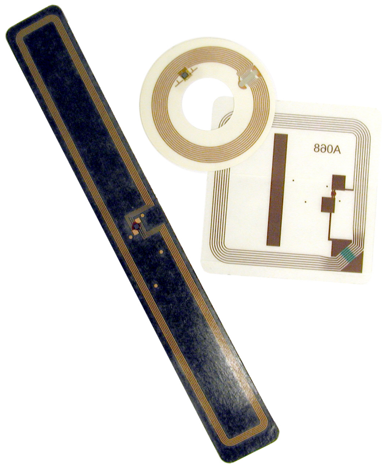

Figure 5.16: Example of RFID tags [Wikimedia, 2022a]

Figure 5.17: Example of watermark being used on glass wine bottle [Keith, 2022]

Watermark

Another physical marker could be the use of 3D watermarks, an example is illustrated in Figure 5.17. For example, CurveCode applies this by raising a number of dots to allow the type of bottle to be identified [Filigrade, 2022]. The dots can be identified by camera's.

An advantage of watermarks like CurveCode is that they leave no residue when recycling processes occur. A disadvantage may be that storing a lot of information in dots may not be possible, as they are binary, so a big variety of ID's on bottles may not be feasible. Another disadvantage may be that the mark can't be scanned by customers themselves but only by specialized systems and software, although it could be imaginable that some application may be developed to read these types of watermarks in the future.

Near infrared without physical marker

It is also possible to use near infrared methods to separate and identify products. Near infrared methods are currently already deployed in quite some systems to analyze materials. These methods are quite far developed and make detailed recycling possible. Nevertheless, a disadvantage of these type of methods is that there is no available information as to when the bottle was manufactured, as well as who manufactured it. The exact material composition may also be difficult to determine if multiple materials are used, although in this specific case, only one type of material is considered. The creation of assurances and an audit trail of where the materials came from is also not feasible with this method because there is no unique ID to trace.

Edge-computing to integrate data from IoT devices

As described by Damianou et al. [2019], IoT devices are essential when aiming to gain transparency over circular supply chains and the materials flows within them. Upon the product returning to the retailer (supermarket), these IoT devices are important to identify the returned materials. However, these IoT devices often hold little storage capacity, and are therefore not suited to be a node on the blockchain network. Therefore, edge-computing can be used to store the ledger information.

Conclusion on physical markers

To conclude, various physical markers have been taken into consideration. The physical marker with the most potential is considered to be the watermark methodology. It leaves no residue on the product for the recycling process. Also, it allows to store information about the product ID on the bottle. Camera's and corresponding software can be deployed to detect the physical marker.

5.9 SYSTEM ARCHITECTURE

Based upon the presented design choices and layers of architecture, the architecture is summarized in Figure 5.18. The figure illustrates how the perception layer, blockchain network, application layer as well as the user layer are connected.

5.10 SUMMARY OF DESIGN CHOICES

The sum up the design choices made in the previous section, a table containing all the functional requirements and corresponding design choices has been created (Table 5.1). A similar table has been created to depict how the design choices correspond with the NFR identified in the previous chapter 5.2.

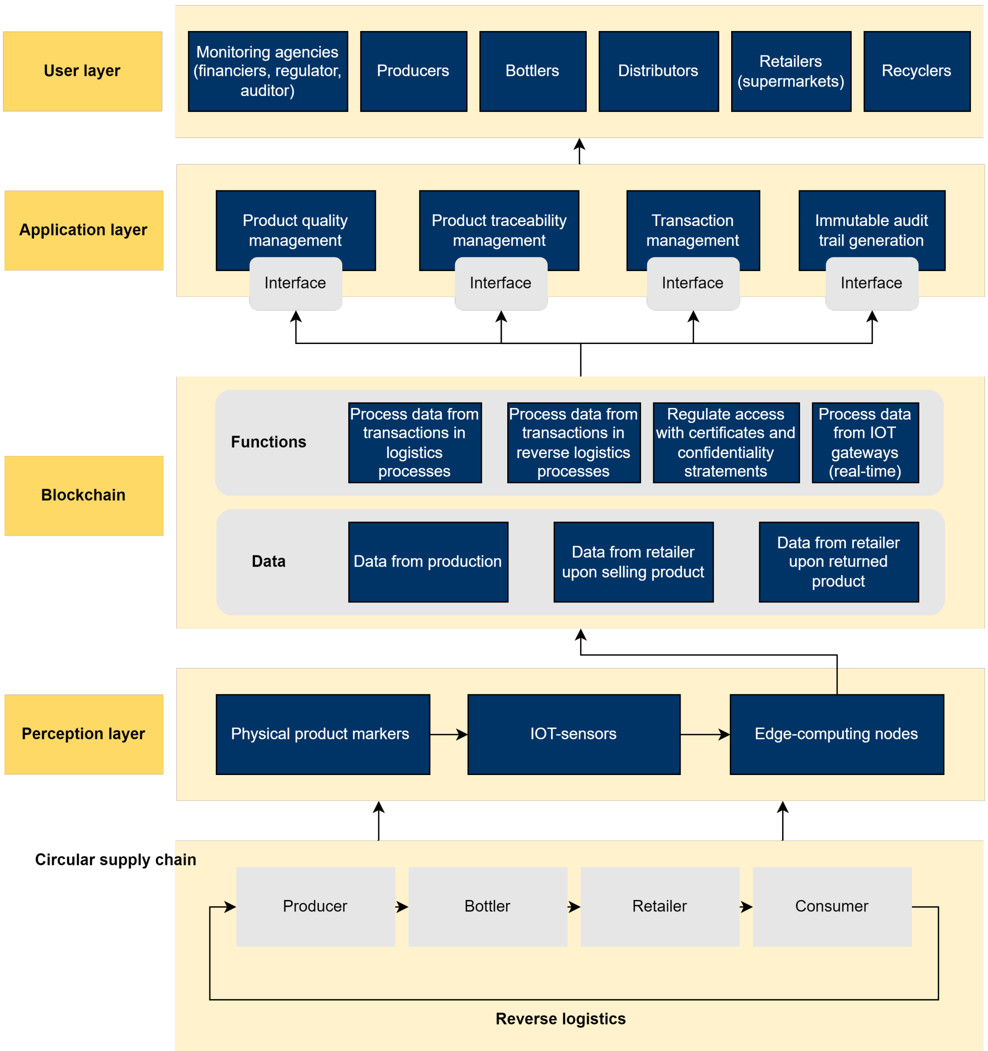

Figure 5.18: System architecture for case study, adapted from Venkatesh et al. [2020]; Wang et al. [2020]

Requirement	Design choice
FR.A.1 The architecture shall include involved stakeholders as a node on the network	Involved actors are designed to be a node on the system
FR.V.1 The architecture shall provide information about the inventory of products and materials as well as their quantity in weight to all involved stakeholders in a circular supply chain	Processing data towards interface and tokenization structure
FR.V.2 The architecture shall update total product quantity inventories of nodes after a transaction of products has occurred.	Processing data towards interface based on exchanged tokens
FR.L.1 The architecture should provide real-time data on the availability of materials and the buy and sell orders.	IoT devices report directly to the network
FR.I.1 The architecture shall embed each product with an unique identifier	Physical marker on product
FR.I.2 The system shall link each unique ID to an information source where the relevant data about the product or material is stored	Off chain storage of product information
FR.I.3 Sensors should store information about the location of the product upon the Unique Identifier being 'scanned' and update a record of the total volume of product for that location.	IoT devices report to network through edge computing nodes
FR.C.1 The architecture should only allow actors access to the blockchain if they provide a signed certificate containing a pledge of confidentiality	Consortium will not allow access if no confidentiality agreement
FR.T.1 Each to be traced item by the architecture should be traceable with a sensor that links the unique identifier to an information source where product data is stored	Due to water markers, sensors already present in deposit machines (camera's) can be used. equipped with new software to detect the markets
FR.P.1 Personal information will only be processed by the system if: **FR.P.1.1** the person it belongs to has unambiguously given permission **FR.P.1.2** the data processing is necessary for the performance of a contract to which the data subject is a party **FR.P.1.3** the data processing is necessary in order to comply with a legal obligation **FR.P.1.4** the data processing is necessary in order to protect the vital interests of the data subject **FR.P.1.5** data processing is necessary for the proper performance of a public law task **FR.P.1.6** data processing is necessary in order to safeguard the legitimate interests of the interest of the responsible party or of a third party to whom the data are disclosed	Network doesn't require individuals with personal information but business entities to join the network, information can be traced back to companies.
FR.A.1 The transactions on the architecture must be immutably stored and not be repudiated.	Nature of Block Chain Technology itself
FR.A.2 The architecture shall enable an audit trail to be exported which can be verified by an auditing body.	Overview of transactions can be exported on the interface
FR.S.1 The architecture shall implement a consensus mechanism that processes transactions in an energy-efficient manner	Proof-of-Authority implemented as it needs little computing
FR.S.2 The architecture shall balance off chain storage and on chain storage in such a way that the most important transaction data remains immutable	Detailed product information off chain. But with a hash pointer to the off chain information. On chain, only critical transaction information.

Table 5.1: Summary design choices and functional requirements

Non-functional requirement	Design choice or trade-off
NFR.V.3 Availability	Information available to all actors who have been granted access to the consortium blockchain
NFR.I.4 The unique identifier should impact the quality preservation of the product and the materials it contains as little as possible	The recommended unique identifier (physical marker) is that of a watermark, because it can be made without adding any different materials to a product.
NFR.P.3 Data minimization	On-chain, only the most important transactional data is stored as well as a hash to the off chain data. Off chain, more detailed product information is stored.

Table 5.2: Summary design choices and non functional requirements

5.11 THE SYSTEM ARCHITECTURE IN RELATION TO SUPPORTING SPOT MARKETS

Overall, the system architecture serves the purpose of enabling spot markets in SRM. By putting quality controls in place for the materials as well as instruments to verify that a product is composed of a certain material, and not contaminated with other possibly unknown materials. This certainty of a product being of a certain material increases the possibility for the trading of homogeneous goods and the development of standard grading schemes for them. This homogeneity of materials and the possibility to create standard grading schemes based on it, are at the core of the functioning of spot markets underlying futures markets [Brorsen and Fofana, 2001]. Moreover, this architecture only considers the technical design, whilst to ensure implementation feasibility, the governance choices will have to be aligned. The alignment of blockchain design and governance design is very important [Engelenburg et al., 2020].

5.12 TECHNICAL EVALUATION

An evaluation of the architecture was conducted with an expert on blockchain technology for traceability (Personal Communication, Van Engelenburg, August 15th 2022). A summary of the design choices as well as the resulting architecture were discussed in correspondence with evaluation questions. The following are the results of this evaluation:

1. **Are the design choices consistent and not contradictory?** As far as can be seen, there are no direct inconsistencies in design choices. However, this cannot be fully guaranteed based upon the available information.

2. **Is it expected that the proposed design could support markets in SRM?** A complete answer is not possible on this question, but it is expected that the proposed artefact could increase the traceability of materials, as long as problems related to tokenization are resolved. However, solving the tokenization issue of materials is very complex and future research should consider this.

3. **Are there any potential negative externalities that should be taken into consideration?** A potential negative externality that can be taken into account is that the use of hardware for storing data is not very sustainable. Nevertheless, the Proof-of-Authority is already a lot more energy preserving than Proof-of-Work would have been. Solutions that could be considered for this are storing data only for a certain necessary period of time as well as using electricity from sustainable sources.

4. **Do you think the implementation would be feasible?** Currently, it cannot be said whether the implementation would be feasible, because governance choices are vital towards implementation feasibility. Two crititcal governance choices are who is part of the consortium as well

as who can issue new tokens. Moreover, the issues related to how to tokenize materials will also have to be solved before implementation is feasible.

This evaluation illustrates the consistency of the design choices made is in order. Some potential negative externalities could lie within the storage resources needed. Moreover, it further illustrates that the governance of the architecture will be an important topic for future research as it determines feasibility of implementation. Lastly, it confirms that the topic of tokenization will be important for future research to take into account.

5.13 CONCLUSION DESIGN CHAPTER

The sub-question that was addressed in this chapter is : ***What artefact can be developed that addresses the explicated problem and fulfils the defined requirements?***

A system architecture was created based upon the FR and NFR. It takes into account different layers that are relevant in system architecture design for circular supply chains. The blockchain network layer was set apart in detail, with a consortium blockchain proposed in addition to the tokenization of products to facilitate exchanges of materials.

To conclude the chapter, the system architecture was illustrated by combining the layers and the design choices were set apart corresponding to the requirements they address. The system architecture addresses the explicated problem by supporting spot markets. The more accurate traceability as well as the quality controls on materials allow for more homogeneity of materials to be traded on spot markets, and homogeneity of materials is at the foundations of spot markets.

6 CONCLUSION

This concluding chapter will include a discussion of the results, the limitations of this research as well as an exploration of future research topics. Lastly, a recommendation will be given to the involved main stakeholder under whose wing the research was executed, the department of Circularity and Sustainable Energy, at the Dutch Ministry of Infrastructure and Water management.

6.1 MAIN FINDINGS OF THE DESIGN SCIENCE RESEARCH

The starting point of this research considers the Ministry's interest into the potential of futures markets for the CE as well as how they could be achieved through technological interventions. This led to the choice of a DSR approach, allowing for a problem exploratory phase prior to designing an artefact to address the explicated problem.

There was an emphasis on the potential of futures markets for the CE facilitated with technological interventions, as it was the main point of interest from the Ministry perspective. Therefore, a literature review was first conducted into this topic and it became clear that there was little to no prior research. Accordingly, it was chosen to implement a problem-focused DSR approach. Because the research followed a DSR approach, the sub-questions of the research were also structured according to this (problem-focused) approach. In this section, the answers to the sub-questions will first be considered, afterwards, the main research question will be answered.

Sub-question 1: Problem explication *What is the problem as experienced by stakeholders involved in circular processes and are futures markets needed?*
In order to answer the first sub-question, interviews as well as desk research were implemented.

The results from the interviews illustrated that the interest in futures markets is perceived to be of a latent nature. For example, although recyclers do experience a price risk that futures markets could address, they do not believe that futures markets would be beneficial considering the perceived administrative burden. Moreover, financiers would also like assurances about price risk, which indeed futures markets could provide, but also perceive that there is currently no societal demand for them, because futures markets arise naturally, when there is demand for them. There were signs however, pointing to a latent need for futures markets; an unconscious need that could arise in the coming years and become conscious. Reasons that this latent need could grow out to be a more conscious need are growing global resource scarcity and resource dependency. Some of the interviewees also pointed out that futures markets are an extension of spot markets. Moreover, it became clear that organized spot markets in SRM do not exist yet either. Furthermore, some interviewees also questioned whether futures markets are even desirable in the context of achieving a CE, as they are commonly non-delivery based markets and can have a destabilizing effect on markets. Their non-delivery characteristics implies that futures markets only trade in risks, and not in resources.

It was identified that one of the critical factors towards a need for futures markets is an active underlying spot market with many buyers and sellers. The need for organized spot markets to create potential for futures markets is reinforced by the results from the interviews as well. Hence, it could be concluded that in the current environment, the need for futures markets isn't very present yet, because the markets are not shaped towards it. Nevertheless, there were also signs identified that point towards a growing need for spot, as well as futures markets in SRM. The current market that only operates in the form of bilateral transactions in SRM is not sufficient for widespread achievement of the CE. And to reuse materials already present in the economy, (spot) markets in secondary materials will be essential in making SRM available to many buyers and sellers.

To conclude, it becomes clear that the current need for futures markets may not be present yet, but there are signs that the need may arise. However, a clear need for spot markets in SRM was identified. Therefore, an artefact is to be designed in order to support the functioning of organized spot markets to ultimately create a need for futures markets in SRM.

Sub-question 2: Requirement analysis *What artefact can be a solution for the explicated problem?*
In order to answer sub-question two, an analysis was conducted to determine what type of artefact should be designed to support markets in SRM. The main factors to take into account for supporting spot markets in SRM were considered to be 1) the need for supply chain visibility 2) the need for collaboration between a complex network of actors and 3) the need for confidential handling of information. Based on these factors, it was identified that innovative digitized tools can be designed to support the development of spot markets in SRM. Furthermore, the artefact was narrowed down to in specific a BCT based architecture, because there were many publications emphasizing that BCT can be vital in enabling a CE by facilitating trust between actors in complex supply chains. BCT is very suited in situations where confidentiality is important, as well as in complex supply chains were a large amount of stakeholders need to collaborate whilst they sometimes don't have insight into any other actor then the actor who supplied them and the actor who they supply to. To conclude, a BCT-based architecture is the proposed artefact to pose a a solution for the explicated problem.

Sub-question 3: Requirement analysis *Which requirements on this artefact are important for the stakeholders?*
To address this third sub-question, an overview of requirements was made based on the before mentioned interviews as well as on desk research. The

functioning of spot markets in primary raw materials was investigated to identify what could be crucial in enabling markets in SRM. Moreover, the requirement analysis was split into a section considering high-level design principles as well as a section considering the corresponding scope-specific FR and NFR.

To start off, a focus was put on investigating design principles. Three main areas were identified within which design principles were defined: supporting the functioning of spot markets, enhancing success factors for spot markets as well as a circular economy perspective. Within the functioning of markets, the most important design principles were access and information provision to enable transactions. Enhancing success factors considers the design principles liquidity of investments, traceability and identification of materials. Within the stakeholder needs, confidentiality and privacy-by-design are important to include. Lastly, from an circular economy perspective, assurances and energy-efficiency are the most important design principles. These design principles can be used to guide (design) research for enabling spot markets in secondary resources that can be at the basis of futures markets.

Throughout the research, it became clear that the design principles traceability and identification of products are crucial for enabling markets in SRM. This is the case because traceability and identification of products allow for the trading of homogeneously accepted materials. This creation of traceable and homogeneously accepted secondary materials flows, allows markets to move away from only bilateral trading with trusted actors of whom the product quality is quite well known, towards trading with a broader body of actors. Assurances on the quality and traceability of materials should therefore become possible with the implementation of the to be designed digital infrastructure.

Following these design principles, a more narrow focus was implemented to derive FR and NFR, a more specific focus was put on material flows within the manufacturing sector of finite materials as well as the most important design principles being traceability and identification. Important requirements that came forth from this analysis were that the the materials have to be equipped with some type of unique ID, as well as that architecture has to be equipped with some type of sensing technology to detect materials and the information about composition and quality. Also, the architecture has to calculate amounts of materials present in certain locations based on the sensing data. The resulting outlined set of requirements can be used in guiding research efforts regarding the design of digital infrastructures to support the emergence of markets in secondary raw materials through mainly enabling traceability and identification.

To conclude, the set of design principles can be a guiding tool in future research on the facilitation of markets in SRM with the use of BCT. These design principles can be generalized to quite a broad body of research considering the facilitation of markets in SRM through a digital infrastructure. Simultaneously, the resulting FR and NFR can be used as a more specific set of requirements for a BCT-based architecture to enable product traceability and identification in the finite materials manufacturing sector.

Sub-question 4: Design and Develop *What artefact can be developed that addresses the explicated problem and fulfils the defined requirements?*

To come to an answer to this sub-question, a design for an artefact was made in the form of BCT-based architecture. It became clear that to design this architecture, a broad scope was not sufficient, because there are many different types of supply chains and business models that may require a different artefact design. An artefact could only be designed on a very abstract level if implemented within the current scope. The broader socio-technical system is very complex, therefore designing an artefact to address the entire system is not feasible. For this reason, implementation of the requirements on a simple case study was the selected design method during this phase. For a simple case study, it will be possible to make more specific recommendations. A selection of possible case studies was considered, a case study with the bio-plastic producer Avantium was selected based upon having access to various stakeholders in the supply chain and the relative simplicity of the supply chain and the simplicity of the products (i.e. products consisting of only one material type). The specific supply chain considered was the PEF bottle commercial supply chain with a deposit system present at retailers. This created a good basis for an initial design of the artefact and therefore, a demonstration of implementing the set of requirements.

The resulting designed artefact was devised out of different layers of system architecture, user layer, application layer, perception layer, blockchain network as well as a perception layer. E.g. a perception layer consists of physical markers on products and camera's or scanners at the deposit stations. It is important that research considers that the different layers of the architecture should be intertwined, because dissimilar from e.g. cryptocurrency, the traded asset is a physical asset rather than a fully digital currency. What this design also illustrates, is that the developed set of requirements can be implemented in the design of a BCT based architecture. Other researchers may therefore also consider taking the set of requirements as a basis for the design of BCT based architectures in support of traceability and identification of material flows in the support of spot markets. One of the fundamentals of organized spot markets is that the commodities traded upon them are homogeneous of nature as well as being associated with standard grade (quality). The architecture supports the development of commodity spot markets in SRM on regulated exchanges (that could be extended with futures markets) by enabling increased information accessibility about products and materials in supply chain, and in specific about their quantities and quality. This reduces the chances of market failures that can occur on markets with little available information.

6.2 SUMMARY OF THEORETICAL CONTRIBUTIONS

The leading contribution that this research makes is the generation of new knowledge for the BCT-based architecture design to support the CE knowledge base. It is believed that this is the first research linking the concepts of futures markets to the circular economy by developing a design for a system architecture. These contributions may be relevant to architecture designers that aim to develop immutable and reliable BCT-based architectures to support markets in SRM.

Moreover, the set of contributions of this research is threefold, 1) insights into the playing field and experienced problems by stakeholders with regards to futures markets in secondary raw materials, 2) a set of design principles and 3) a solution concept in the form of an artefact developed for a specific case study.

The research into the organization of futures markets for secondary raw materials was set apart and insights were provided into the potential of futures markets to enable the CE. The results show that the current societal need for futures markets may not be high, whilst there is a variety of signs that do point towards the need for them being latent and likely becoming conscious in the future. Circular businesses could use futures markets to hedge parts of their price risk and hereby securing parts of their future income stream. These securities in relation to income stream can make it easier to receive investments from financiers towards growing their business.

The design principles derived from desk research and interviews can be used by future design research in the context of developing spot and futures markets in SRM. Design principles for SRM differ a lot to those that would be relevant for primary raw materials, as material quality has to be preserved across entire (complex) supply chains such that standardized grading schemes can be applied for trading. There, the design principles come in play. Especially the principles *identification*, to ensure that materials can be recognized as well and their quality and composition be known, *liquidity* to facilitate real-time transactions, *Confidentiality* to ensure that businesses are willing to share information about product quality and composition and *supply chain visibility* to ensure that information about inventory is up to date for trading to occur, are crucial to facilitate spot markets. Prior to this research, there was an absence of design principles that could be used to guide efforts in supporting spot markets for raw materials, this is one of the first researches taking steps to conceptualize these design principles. Although the set of design principles may not be exhaustive, it adds to the knowledge base for designing architectures supportive of spot markets in SRM.

Making recommendations for an architecture design to address the full class of problems is not feasible due to the varying nature of supply chains and products making up this complex socio-technical system. To deal with the complexity of the complex system, a small part of the system is considered by making recommendations about a single case study. The designed artefact could play a role in solving parts of the problems faced by circular businesses. The architecture ensures that the product quality is preserved across the entire supply chain, as visibility is provided along the chain. However, solving all the CE problems related to the case study with this artefact is not possible, because the case study is part of a much broader and complex socio-technical system which is hard to impossible to influence. The artefact can facilitate spot markets in SRM towards being extended with futures markets in SRM for the single case study. The futures markets in SRM can enable a circular business to hedge their future price risk and secure future income streams. This allows a circular business to deal with price volatility up to a certain degree. However, at the same time, futures markets can also have destabilizing effects on commodity prices, potentially increasing the volatility, although researchers do not agree upon whether futures markets have stabilizing and destabilizing effects on global commodity prices [de Jong et al., 2022]. Whether such an artefact would potentially support the circular economy in a broader sense is therefore hard to discern. By implementing this artefact, some steps could be achieved towards facilitating the CE by providing the involved circular businesses with more means to hedge price risk and hereby generate investments for their businesses, however, the circular supply chain will keep competing with linear supply chains. In order to achieve the CE, a fundamental change in the system, rather than only the implementation of an artefact facilitating futures markets will have to take place.

6.3 LIMITATIONS AND RECOMMENDATIONS

This section will highlight the limitations of the research and provides suggestions for future research. The limitations of this research are present in the data derived from interviews, the scope of the research and some assumptions that were made.

6.3.1 Limitations

Firstly, the problem explication resulted in two potential research directions to support spot markets in SRM; designing regulatory instruments or innovative tools for supply chain visibility. Due to resource restrictions as well as the greater relevance to the MSc. program that requires a technical or engineering component, the design of regulatory instrument(s) was left outside of the scope of this research.

Secondly, due to resource restrictions, only a limited amount of interviews were conducted with varying stakeholders. This could have led to a biased view on the problem as it is experienced by stakeholders as well as the resulting design principles. Also, it became clear that many stakeholders weren't familiar with the concept of futures markets and this may have influenced their perception on the need for futures markets. Moreover, the real need for futures markets may be higher then presented in the results from the interviews due to this unfamiliarity of interviewees with the concept. However, this limitation of possibly biased results from the interviews was taken into account during the research; the results from interviews were also tested against available literature on the topics, therefore steps have been taken in decreasing the risk of generating biased results. Nevertheless, it can't be proven that this testing against literature is sufficient to take away any bias, because of the relative novelty of the concept and the small knowledge base that could be drawn from.
Moreover, this research does not consider the governance aspect of the architecture. Nevertheless, governance is crucial in the proper functioning of

architectures. For example, it is not defined who will be in charge of access to the system as well as who is the responsible party when something goes wrong. In a consortium based architecture, multiple actors can decide upon who joins the platform, what actors receive this role should be defined. Moreover, the governance of the off chain database has not been addressed, whilst off chain storage is less secure, so there should be governance in place to ensure the reliability. Furthermore, it should be considered who should pay for the platform, first of all for the development, but also for the resources consumed by transactions (energy mainly). Correspondingly, it could be the case that from a governance perspective, the architecture design may not be feasible, but this is with the current design not known.

Another limitation is that the research does not provide a detailed way to design tokenization of materials. Whilst, tokenization of materials is very important towards achieving traceability of materials. This could not be included because there lacks research considering how tokens can be used to represent materials in BCT-based architectures.
On top of this, the research aims to provide solutions toward enabling the CE, whilst having a perspective of improving the sustainability of the global resource supply. Nonetheless, the energy footprint of BCT has been more and more disputed over the past year. There are signs that some forms of BCT consume large amounts of energy for transactions to be supported. There could be a risk with designing BCT-based architectures like this artefact, that the benefits or enabling markets in secondary resources may go at the expense of unforeseen energy consumption. However, to take steps in addressing this energy consumption issue that BCT-based architectures may have, the guiding design principle of sustainability was developed. On top of this, choices on the design of the artefact were purposely made to reduce the energy footprint of the underlying architecture, such as minimizing the amount of data stored within a transaction and storing all not essential data off the chain. In spite of this, no certainty can be created on the real-life energy footprint of the BCT-based architecture as it has been designed, as there is limited research that quantifies the energy consumption of different types of BCT-based architectures.

Lastly, a limitation of the research is that it may be difficult to generalize the designed artefact towards other supply chains, because it is such a specific case. Especially the generalization towards a supply chain in which more complex products circulate is expected to be very difficult, as the materials are increasingly intricate and information about how to take apart the products into individual materials may also have to be stored. Nevertheless, purposely, the design principles and requirements have been formulated in such a way that they can be generalized, and the purpose of the designed artefact is to provide an example of how the requirements and design principles may be used in a case specific setting. Also, it is believed that a concrete design that can be generalized is not possible, as it became clear that there is no one-size-fits-all blockchain-based solution for enabling markets in SRM; each product has different components, each supply chain is different and has a variety of characteristics that require a tailor made supporting architecture.

6.3.2 Future research recommendations

Based on the limitations that were addressed, the future research topics can be explored.

Firstly, it became clear that next to innovative tools for supply chain visibility, regulatory instruments could also have a role in supporting the development of spot markets. However, this research did not consider their design. Therefore, future research can consider the design of regulatory instruments in support of spot markets.

Secondly, future research may further explore the potential of futures markets for the CE. This research made the assumption that futures markets for the CE would be desirable, however, the amount of data to support this assumption was limited as it became clear that the interview data could be biased and the available literature not extensive. One of the interviewees also mentioned that futures markets may not be desirable in the support of the CE, being that these markets are usually non-delivery based markets and could therefore have a destabilizing effect on the (secondary) raw materials supply. Future research could therefore consider the practical potential of futures market for supporting the CE by means of interviews with experts in futures markets, exploring the needs of more actors active in circular supply chains. Moreover, it would be very valuable if the potential could be quantified by analyzing the benefits and costs in a quantitative manner rather than only qualitative like this research was. Furthermore, there were signs that the potential of traditional non-delivery markets may differ from non-traditional delivery futures markets. Hence, in researching the potential of futures markets for the CE, it would be valuable to make a differentiation between the generally implemented non-delivery futures markets, versus the scarcely occurring delivery futures markets, a non traditional type of futures market. It it important to take away from this that futures markets in secondary raw materials may have to be designed inherently different from the traditional futures markets in raw materials.

Furthermore, this research didn't take into account the governance of the designed architecture, whilst, governance is a key aspect in designing information architecture, especially for blockchain-based architectures. The focus of this research was in illustrating how a blockchain based infrastructure could enable markets in SRM, whilst, not considering how it should be governed. The alignment of blockchain-based design choices and governance is important to support the proper information sharing structure. In the design section of this research, some examples were given of how the governance could be designed, but no data was collected to underly any governance design choices, so these could not be made. Future research can therefore consider the governance design choices for an information architecture supporting markets in SRM. These governance choices could include, amongst others, who maintains the architecture and who decides if someone can access the architecture, but also, who should pay for the architecture.
Also, this research developed a design for a rather simple product, because it consists of only one material type. Moreover, most products don't consist of only one material, but are more complex, containing a multitude of mate-

rials. Even just a simple water bottle can contain multiple materials. Hence, future research can look into the design of a blockchain-based information architecture to support markets in SRM for products with a higher material complexity. There will be an important trade-off to be made in this research, because with higher product complexity, comes more data, and storing data on the blockchain may be costly in terms of energy consumption.

Also, future research should consider how tokens can be implemented to facilitate traceability of materials. This will be very important towards achieving a feasible architecture.

The last recommendation for future research comes forth from a limitation of the research, namely, the limitation of not knowing if the blockchain-based architecture would have a net positive impact on the environment, because of the uncertainty regarding the energy footprint of the technology. It is widely known that the blockchain technology underlying bitcoin has an energy footprint equaling that of Denmark. However, whilst this research has certainly taken steps in choosing an architecture design that would likely have a much lower energy consumption, certainty on this subject may be necessary to decide if implementation would be desirable. Some researchers even state that all blockchain implementations - regardless of the consensus mechanism - should be inhibited due to its large energy consumption [Beck et al., 2018]. Therefore, future research should quantify the energy consumption of a blockchain-based architecture such that a cost benefit analysis can be made. This could validate whether the benefits from using blockchain would outweigh the negative environmental impacts it may have.

6.4 PRACTICAL RECOMMENDATIONS FOR THE MINISTRY OF INFRASTRUCTURE AND WATER MANAGEMENT

Firstly, the most important take-away is that there are no active organized spot markets in SRM. The spot market should be well developed and active, before a futures market can be developed successfully. Markets in recycled materials are currently underdeveloped and can't compete with the dominant primary markets [Sadowski, 2010]. Identifying the prospects for developing a spot market for recycled materials is a complex and extensive task [Sadowski, 2010]. Hence, a recommendation would be to firstly focus on supporting the development of an active spot market, before putting a focus on the development of a futures market in SRM. To support the development of spot markets, a crucial point of action is the development of standardized grading schemes to preserve the homogeneity of materials traded on exchanges. The Ministry could look into incentizing the development of these grading schemes.

Moreover, it has become clear that there may be some uncertainty regarding the desirability of futures markets. This research assumed them to be desirable for achieving a circular economy, because there are certainly signs pointing towards this, but there is not enough evidence to be certain of this. Therefore, before making investments in information architectures in support of these futures markets, it would be recommended to consider firstly, the potential benefits of futures markets and secondly, the design characteristics of a futures market. A futures market in secondary raw materials may need to have different design characteristics than a futures market in primary raw materials. These design characteristics may have to be enforced by means of regulatory instruments. This is in line with research by Dewick et al. [2020] who emphasizes that regulatory instruments need to be in place before the implementation of innovative financing instruments, to prevent the circular economy from becoming an ineffective sustainability concept. Regulatory alignment may thus be needed to ensure that futures markets may be implemented in a responsible manner. For example, it could be considered whether regulation should address the non delivery nature of futures exchanges. Making delivery or actual distribution of ownership mandatory on futures exchanges could potentially decrease the speculative and their financialized nature.

Lastly, it has become clear that there are two research directions, the design of regulatory instruments as well as the design of innovative tools for supply chain visibility. Because the design of regulatory instruments was left outside of the scope of this research, it is recommended to be explored more. For example, the development of standardization with regards to product and material quality is very important towards supporting (spot) markets, but was not taken into account in this research.

6.5 PRACTICAL RECOMMENDATIONS FOR AVANTIUM

For the specific case of Avantium, it has become clear that there may be potential in supporting the bottle supply chain with a blockchain-based architecture. Bottles could become more traceable within the supply chain, enabling improved return handling processes with more homogeneous material streams. Homogeneous materials streams paired with assurances about the overall material quality can support trade of the material. Especially with the relatively high price of PEF combined with it being recyclable for multiple life-cycles, it is valuable to arrange reverse logistics processes.

It became clear, that to implement the architecture, not only a digital infrastructure but, also a physical infrastructure has to be implemented, physical markers and sensors to detect them will be important. A variety of sensors to detect physical markers can likely be integrated into existing supermarket return handling systems. The physical markers on products are important for traceability and would have to be accommodated by the bottle producing entity; Avantium. A variety of physical markers were explored, the watermark as a physical marker was considered most promising to integrate within the BCT architecture. Therefore, a practical recommendation is to explore the watermark as a potential physical marker of the bottle. How the process of applying physical markers could be integrated into the current production processes as well as performing a cost benefit analysis can both be relevant here.

By implementing the architecture, Avantium the materials produced by Avantium could potentially be trade-able after their life-cycle on futures markets. By trading their materials on futures markets, Avantium could further secure their future income stream.

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A ACTOR ANALYSIS CIRCULAR ECONOMY AND FINANCING

A.1 ANALYSIS OF THE ACTOR PLAYING FIELD RELATED TO FINANCING AND THE CIRCULAR ECONOMY

To start the exploratory phase, an actor analysis is presented. Actors are outlined if they have an important role within circular supply chains in the manufacturing sector. To support this actor analysis, interviews were conducted that centered around exploring the role of the actor in the CE. Exploratory interviews were conducted with a standardization body, a recycler, an auditor and a national authority. The results of the interviews have been integrated into the actor analysis results. The following interviews were implemented for this analysis:

- **Standardization body** Pollemans, C. (2021, May, 11th). Program Manager Circular Economy at NEN. [Phone interview]
- **National authority policymaker** Meester, T. (2021, May 10th). Policy Officer Ministry of Infrastructure and Watermanagement. [Phone interview]
- **Recyler** van der Giessen, T. (2021, April 30th). CEO at van Werven recycling. [Phone interview]
- **Auditor** Hurks, P. (2021, April 29th). Director International Affairs at NBA. [Phone interview]

To simplify the actor analysis, the analysis was executed in such a way that actors were split into three groups. One group of actors being active within supply chains mainly, responsible for physical materials flows, the other group being active as regulators and lastly, a group being active as financing bodies.

A.1.1 Actors directly involved in supply chains

- *Producers* Producers have a central role in the CE as they directly decide on business models being linear or circular in nature. The associated products that producers bring to the market can be of low or high cyclical nature, meaning that products have a short or long lifecycle. There can also be a differentiation in the value of the products and the resources incorporated in the products, this also has implications for the closed loop business model. One producer may also sell a product part or material to another producer for further manufacturing.

Hence, producers can source products from other producers and material suppliers. From a legislative perspective producers are defined as all manufacturers, sellers, but also importers of products [Kunz et al., 2018].

- *Waste operators* Waste operators are responsible for the collection and treatment of waste. Also, this category of stakeholders can be divided into waste collectors and waste treaters. Collection is usually arranged separately from treatment of waste. Dutch companies active in collection and treatment are e.g., Renewi, Remondis and Attero. The Dutch Waste Management association represents the interests of waste operators in the Netherlands.

- *Consumers* Consumers consist of a large and diverse group. Consumers can be influenced in their behavior by certain aspects of products. Consumers can have a role in the closing of loops by contributing to the collection and distribution of (used) products. This can manifest in e.g. deposit systems.

- *Retailers* Retailers act as an intermediary between producers and consumers of the products. Therefore, they can be defined as a channel to buyers in the distribution process. An example of a Dutch retailer is e.g. Albert Heijn.

- *Carriers and transporters* The product distributors and carriers are also important actors, they ship the products and in the context, can have a role to preserve the value of products and enable the traceability of products. Transport is usually carried out from distribution warehouses.

- *Recyclers* Recyclers can act as an intermediary, recycling products and retrieving the raw materials back. The producer can also take on the role of recycler themselves. The raw materials can be redistributed to producers for the production of new products. Examples of recycling companies in the Netherlands are Jansen Recycling Group, CuRe, van Werven and NRK (Nationale Kunststof Recyclers). In the Technosphere, materials can't cascade back into nature, hence, recyclers have an important role in recycling the products into new raw materials; secondary raw materials.

A.1.2 Regulating bodies

- *Municipalities* Municipalities locally arrange the collection of waste [Kunz et al., 2018]. They can choose to do this personally, or they can hire contractors to perform this function for them. They are also responsible for the waste treatment strategies on a local level, e.g., how the separation process is arranged by collection.

- *Standardization bodies* Standardization is very important in the context of CE. Standardization bodies develop guidelines for non-financial reporting standards. Standardization bodies can also have roles in water branding, certification and tracing products in an improved manner. An example of a standardization body that is currently active in the CE transition standard setting is the Dutch NEN. The definition of the role of the NEN in the CE transition is the following; 'NEN is an instrument that can be applied to set standards about circular performance, on a national level, we have a lot of influence to set these standards, but on an international level this influence is smaller'.

- *The European Commission* The European Commission (EC) wants to incentivize the transition to the [European Commission, 2018]. The EC sets out guidelines for national governments to implement in legislation. E.g. The EC has imposed Extended Producer Responsibility (EPR) legislation on national governments to implement. This legislation feeds the concept of 'the polluter pays' [Kunz et al., 2018], making the producer increasingly responsible for the end of life phase of products brought to the market.
- *National authorities* National authorities have the responsibility to transform EC directives into national legislation. National authorities also decide on legislation to achieve goals as defined in the Paris Agreement. In the Netherlands, the Ministry of Infrastructure and Water management is mostly in charge of CE legislation. The Dutch EAA is an important monitoring agency for the circular performance of businesses.

A.1.3 Financing bodies

- *External financing bodies* External financing bodies can provide businesses with equity investments or debt investments. There are various types of external financiers. Central banks and other financial regulating bodies can start integrating circular aspects in risk calculations. They could integrate these aspects in less conventional ways that are used for linear models, such as green quantitative easing [EllenMacArthurFoundation, 2016]. There are also 'green' banks specifically for circular and green investments, there are also banks like 'Rabobank' and 'ING' and lastly there is the DNB (The Central Bank of the Netherlands). Financiers currently have inadequately reliable information for the creation of innovative vehicles to transition to the CE [Dewick et al., 2020].
- *Auditing firms* Auditing firms control the financial statements of businesses. Auditors can ensure the reliability of reporting, control uniformity and control proper reporting standards . In the case of non-financial reporting – when reporting is conducted about circular processes – auditing firms will have to change their methodologies.

A.1.4 A formal chart illustrating the relationships between actors

Based on the actor analysis, a formal chart was developed. The description of this as well as the illustration have been included in the main text.