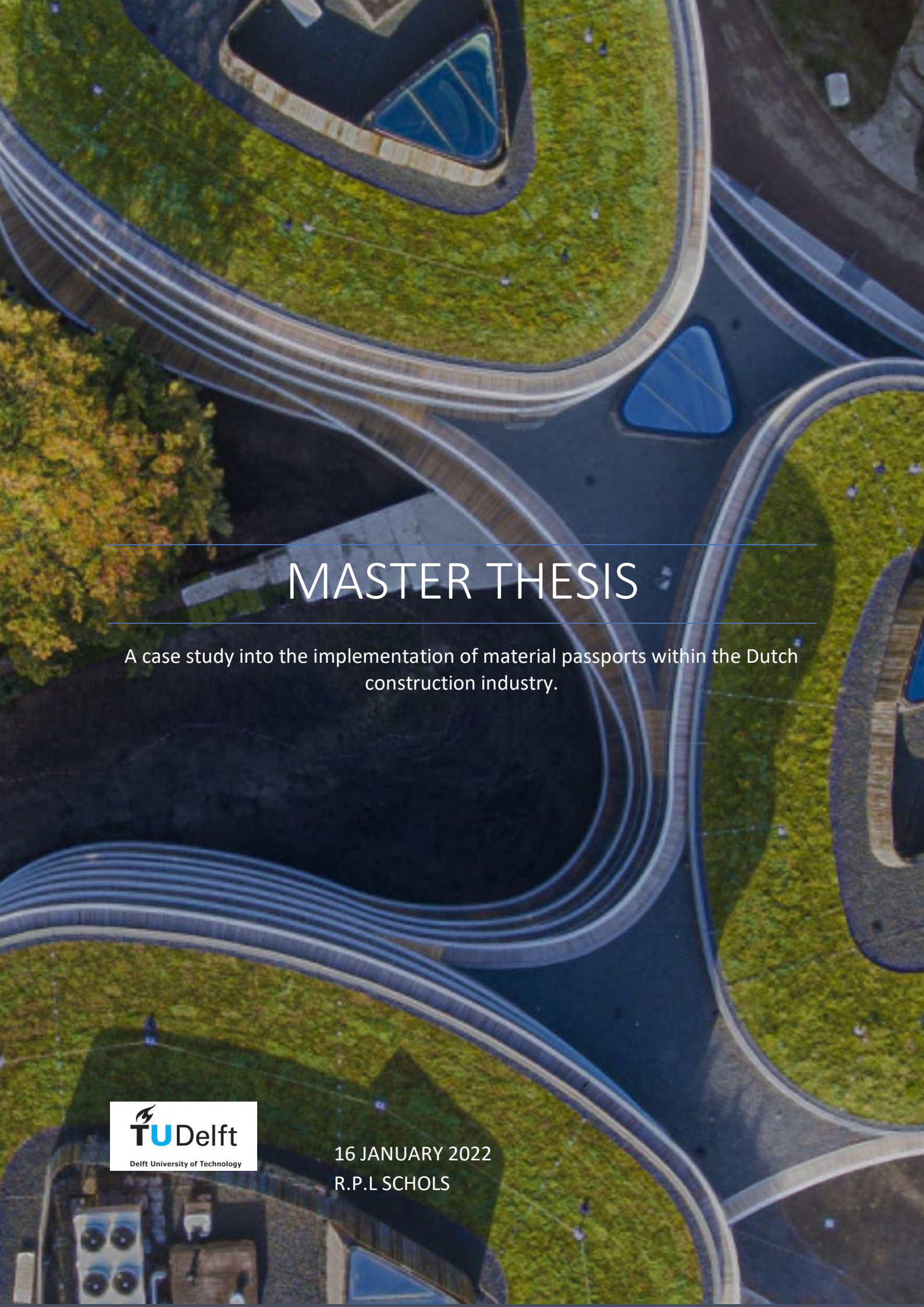

MASTER THESIS

A case study into the implementation of material passports within the Dutch construction industry.

TU Delft
Delft University of Technology

16 JANUARY 2022

R.P.L SCHOLS

Colophon

Title	A material passport as a means to support the circular transition? *–"The proof of the pudding is in the eating"–*
Location & Date	Delft, 16th January 2022
Author	R.P.L. (Roland) Schols
Email	Roland.Schols@gmail.com
Telephone	+31630566844
Student number	1526618
Master Track	Construction Management and Engineering (CME)
Faculty	Faculty of Civil Engineering and Geosciences
University	Delft University of Technology
Graduation Committee	
Chair	Prof.dr.ir. M. J.C.M. (Marcel) Hertogh
1st supervisor	Dr. D. F.J. (Daan) Schraven
2nd supervisor	Dr.ir. A. (Ad) Straub
Institution	Delft University of Technology Civil Engineering and Geosciences Stevinweg 1 2629 CM Delft www.tudelft.nl

TU Delft
Delft University of Technology

TABLE OF CONTENTS

PREFACE

The past 24 months have been challenging reading articles, having interviews, assessing feedback and writing respective documents for my thesis. Fascinated by constructions and buildings both in The Netherlands and abroad I decided to study Civil Engineering at the Technical University of Delft. During my bachelor I gained a broad knowledge of technical disciplines relating to engineering, mechanics and materials. I thoroughly enjoyed the technical approach and emphasis on logic problem solving. After my bachelor I decided to view the construction sector from a broader perspective, one that also takes into account the social, legal and process aspects within the construction industry. In retrospect these interests have fully come to fruition within the master programme of construction, management and engineering (CME).

Since I was a child I have had a wide range of interests in a variety of subjects. Therefore the decision what to choose as a research topic was not clear from the start. What I knew for sure was that I wanted to concentrate my study on the practical part of the building industry with a particular interest in how people in practice cope with and respond to the issues that our world faces. One of the most prevalent challenges that we are currently facing is the way we approach sustainability. Our societies' and built environments' ambition to keep developing and constructing "new" structures and infrastructures does not necessarily go hand in hand with sustainability. To address our sustainability challenges a radical different concept known as the circular economy (CE) could decouple development in the broadest sense from climate change, resource depletion and waste issues. Our government also supports this approach aiming towards a similar economic structure by 2050. Some may argue that we have enough time to make the transition towards such an economic structure. I questioned how we might achieve such a significant shift in a sector that relies heavily on resource throughput.

To aid the transition towards a circular construction industry (CI) the capturing and sharing of basic and circular relevant building information will be essential. A practical tool that can retain and share this basic and additional information layer within the CI is a Material Passport. Because this topic was still within its infancy and it was evident for me that if we want to achieve the set ambition the transition should have started yesterday instead of tomorrow, this became my research topic. I hope that within this research I have helped the construction industry in getting one step closer towards becoming more circular. I have showed within this research that although all parties share the circular ambitions of our government the practical implementation is not always straightforward and easy. As a person with a technical background this study learned me that there is not always a technical or logical solution for every problem. Every transition takes time and solutions are sometimes much more abstract and intangible.

Before you start reading my thesis I want to express my gratitude to a few people who are important to me and have assisted me during this process. First and foremost I want to express my sincere thanks to my graduating committee: your feedback has been really valuable in assisting me in completing my thesis. Your constructive feedback, advice, humour and patience during this sometimes difficult process gave the needed perspective and guided me towards reaching the finish line. A special thanks to Daan for always believing, supporting me and respecting my personal barriers; to Ad for his perspective of the built environment and sense of calm and to Marcel for his constructive helicopter view which helped me contextualise my research.

Additionally I like to thank the representatives of parties involved with the material passport development for the Triodos Bank project De Reehorst in Driebergen-Rijsenburg for sharing their experiences so openly with me. Also to the representative of Rijksvastgoedbedrijf for his

constructive feedback on my findings and providing the perspective of public clients with respect to MP adoption and development.

Not to mention the ones closest to me who provided the much needed moral support. These people are my parents, brother (Maarten), Lisa and Alexander for being there for me and cheering me up, motivating me and from time to time pulling me away from my computer. Thank you!

In loving memory of Paula, you left me beautiful memories.

EXECUTIVE SUMMARY

Introduction

The construction sector generally makes use of linear value chains based on the notion of the ‘take, make, use and waste paradigm’: in which energy, labor and capital transform natural resources into products with a single life cycle (Esa et al., 2017; Geraedts & Prins, 2015). Given the intrinsic mechanics of this linear economic system, with its wasteful paradigm and dependency on the throughput of natural resources, it cannot sustain our growing societies and resource consumption “without compromising the ability of future generations to meet their own needs" (Sariatli, 2017; World Commission on Environment and Development, 1987, p. 16)

As an alternative to the linear economy concept over the last few decades the circular economy concept has gained popularity among academics, legislators and businesses. It is promoted as an economic model that may facilitate economic growth while having low environmental effect (Geng & Doberstein, 2008; Korhonen et al., 2018; Ness, 2008). “The circular economy replaces the ‘end-of-life’ concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and the consumption processes” (Kirchherr et al., 2017, p. 229). It provides our economic system with an alternative flow model, based on circular value chains that maximise the value retention of materials and by design is less wasteful (CIRIAG, 2015; Ellen MacArthur Foundation, 2013). The transition towards a circular economy (CE) requires a systematic change of the current organisation and business models of our economic systems (Kirchherr et al., 2017).

Within the construction industry there is an information gap regarding materials and product information, leading to suboptimal recycling and reuse of materials. Information of the material composition of our building stock is essential to support a circular economy and increase resource efficiency. The necessary data to transition towards a circular built environment is already partly available within the construction value chain. However, this information is not stored within a centralised data system. Information that is not available that could promote the transition towards a CE is either not known or locked behind intellectual property (Heinrich & Lang, 2019). To fill these data gaps, the built environment has to standardise data gathering and storage procedures for building materials during the course of a building's lifespan and share it with all the relevant stakeholders (Heinrich & Lang, 2019). A material passport is a digital information system and can be seen as a tool that can bridge the current information gap in order to close circular loops and bring stakeholders together (Heinrich & Lang, 2019).

Within scientific literature there is little research with respect to the practical application of a material passport (MP) in the construction industry and there is currently no standard material passport protocol or process. The tool landscape of MP’s is not fully matured and is within an experimental phase (CB’23, 2019). “The transition towards a circular economy is an interdisciplinary task and can only work with the involvement of all the relevant actors along the construction value chain” (Heinrich & Lang, 2019, p. 50). According to Weisenfeld “differences in perception between stakeholders will require information exchange and a willingness to learn from each other, although different interests will require negotiations and the willingness to compromise” (Weisenfeld, 2003, p. 219). Failing to acknowledge these dynamics could compromise the effective implementation of material passports within projects. Within the Netherlands implementation of material passports is in its experimental phase, whereby in the meantime Platform CB’23 is developing and communicating its vision and principles to standardise implementation of material passports within the construction industry (CB’23, 2020). The objective of this research is to capture lessons learned, experiences, identify objectives for implementation within practice, and investigate possible barriers for implementation within practice. With the goal of sharing these insights of practice

in order to assess the work agreements of the guidelines for practical applicability and achievability and further development. As MPs are implemented with a common goal, namely to facilitate the transition towards a circular construction sector and facilitate the circulation of materials, this research will have a secondary goal, namely to aid in this development. In order to achieve this objective the main research question is formulated as follows:

> *"What does the implementation of a first of its kind material passport imply for guidelines and the development of material passports within the Netherlands?"*

Methodology

This research has implemented a qualitative research strategy to collect, contextualise and analyse non numerical data with respect to the learning experiences and barriers encountered in practice with the implementation and development of a first-of-its-kind material passport and the guidelines. In doing so it has implemented multiple methods of data collection. As there is limited knowledge gained and shared with respect to the implementation of MP's within practice, this research will use inductive reasoning to gather and present the knowledge of practice. Within this research deductive reasoning will be implemented with respect to available scientific literature on the topic and most recent guideline for MP's. From literature it is envisioned that MP passport will face barriers with respect to facilitating circular value chains relating to the topics such as legal, financial, technical, cultural, collaboration, and organisational.

From the scope demarcation only one project, the Triodos Reehorst, fits within the boundaries of a first-of-its-kind material passport implementation, where the use of BIM was the limiting factor to include other cases. The learning experiences and barriers for implementation are gathered through the use of Semi-Structured interviews, where topics of interviews are defined with the use of the literature framework. For this research, the sampling process or choosing the part of the population that will represent the project, is done with the use of the snowball technique (Creswell, 2013). The same set has been applied in all interviews with 8 representatives having been involved with the development and implementation. Semi-structured interviews (SSI) combine open-ended and closed-ended inquiries with why and how follow-up questions (W. C. Adams, 2015). Whereas the implication for guidelines and development of material passports within the Netherlands will be captured with the use of a document analysis of the most recent guideline for MP. Since it is envisaged that interests and perspectives of private parties differ from public parties it has been decided to validate outcome of research of base case versus the evaluated discrepancies with the guideline with an expert from one of the main public members involved in the Platform CB'23. Below an overview is provided of the research methodology.

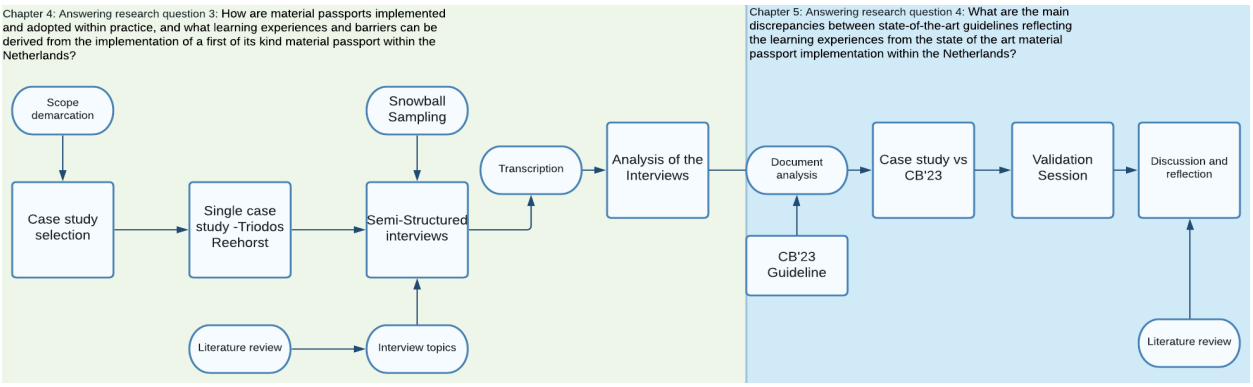

Figure 1 - Flow diagram of the research methodology (own illustration).

Results

When reflecting the findings of the first-of-its-kind MP against the broadly accepted work agreements of the guideline, it can be concluded that implementation within practice is much more unruly and ad hoc than the suggested implementation guideline and road towards standardisation as described in the work agreements. Within this research multiple discrepancies have been found that could create a barrier for effective implementation with respect to ease of use and could impact the added value of the tool over the lifetime of the construction. Within a decentralised data architecture the parties that generated and registered the data and incurred the cost are not the parties that benefit from the enriched data. Therefore parties found it difficult to assess the additional efforts from their respective social and economic perspectives going forward.

Within the guideline it does not become clear how the perspective from a social and economic are weighed against the possible added value of implementation. Not properly balancing these social and economic perspectives implies that a situation could arise where all parties will try to maximise their own CE project related social and economic values, while neglecting the data architecture as a whole.

The envisioned governmental involvement in order to facilitate the process towards standardisation must be addressed. The guide is written with in hind sight that governmental support will impose mandatory material passport in the near future suggesting 2025. When the implementation of the Triodos case is set against the maturity model of CB'23 it can be analysed that for this case it is located on level 1 (individual, ad hoc). The next step in the development will be to reach maturity level 2 which implies already registration according CB'23 principles. The guide does not make clear how governmental involvement leads to creating better shared views and how barriers such as interoperability are achieved nor whose responsibility it will be. This implies that stipulation versus market force should be more critically managed by the guideline.

The guideline is not clear about the role and responsibility of material passport (platform) providers within the development and road towards standardisation. It is unclear how the obligation of a material passport is in line or is hindered by current development path and market force. Also the guideline does not clarify how owners and parties registering and managing data are incentivised to openly share data in case passports become mandatory.

The private and incidental client objectives to apply a material passport in order to promote CE, capture circular value and score the circularity of constructions corresponded. The decision of the incidental client (Triodos Bank) to implement MP was mainly based on goodwill considerations to aid the transition towards CE within the construction industry rather than being based upon a proper cost benefit and environmental impact analysis. Within the construction industry it is hard to assess the added value from an economic perspective as materials are locked away for considerable time and secondary markets are not omnipresent. One may argue that not all private parties would decide accordingly without direct governmental involvement. RVB bases its decision upon other considerations that do not align with the case study nor the guideline of CB'23. RVB first intends to assess how to keep material passports and data up to date given the current organisation and assesses that MP should originate from its own data structure. Therefore it might be questioned if the broadly accepted working agreements are properly aligning the values and objectives of development of MP's and road towards standardisation between incidental clients and public clients. This implies that development of standardisation and implementation could be segregated between private and public clients both with different approaches.

The evaluated discrepancies suggest support of the work agreements by market parties and private and public clients are not all aligned. Cooperation, support and sharing of the CB'23

vision and ambitions from partners and members in the value chain is a prised good because it will require the cooperation of the entire value chain.

Currently the material passport is far from an automated process and requires considerable efforts from parties to generate and enrich all the relevant data and circular value with respect to facilitating CE. Nevertheless parties recognise the need of data registration in order to transition towards a circular economy. However having a material passport does not make the design approach and construction of the building and its end of life scenarios circular. The guideline should work towards creating the essential committed cooperation of all parties in the value chain, as within a circular economy the whole value chain is involved. This could either mature through governmental involvement, but balancing the economic and societal values of stakeholders within the value chain will become necessary to ensure the full potential of the tool to facilitate circular material flow within the construction industry.

Discussion and recommendations

The construction industry is becoming increasingly aware of acting sustainable and increasingly circular driven. Some participants even reflected that circularity has become one of the new buzzwords within the construction sector. Similarities can be drawn between international studies and this research (M. Honic et al., 2019). As both indicate that current data interoperability limit effective implementation and the collaboration within the value chain will become increasingly important.

It is recommended that the guideline and development of MP looks towards shared visions and balances societal and economic factors in order to create a value chain that supports and can implement a MP. It is recommended that Platform CB’23 integrates this phenomenon and lessons learned into the discussions and in respect to the envisaged timeline. The financial qualification and quantification of costs and efforts versus potential additional rest value at end of life in combination with realism of achieving circular ambitions can be beneficial for parties in the value chain to become convinced and supporters.

This research shows that there is very limited knowledge sharing with respect to MP implementation within science and practice. Therefore, future research should gather and share more empirical knowledge. Because it is unclear how private and public perspectives are weighed within the CB’23 guideline, it may be of additional value if project applications in both the public and private sector are evaluated. The guideline sees the MP as a means to facilitate the information requirement for a CE transition. Research should determine whether the MP is the most cost-effective and efficient tool for facilitating the CE transition. Research should also define the minimum and desired information requirements to best facilitate the circular potential of materials versus the availability and accessibility of this information within the value chain.

1. INTRODUCTION

The construction sector provides our society with the tangible necessities to prosper and flourish. However in doing so the construction sector “consumes more than half of the total global resources; is responsible for more than a third of the total global energy use and associated emissions; and generates the greatest and most voluminous waste stream globally” (Iacovidou & Purnell, 2016, p. 791). Within the next 30 years our population is expected to grow from 7.3 billion in 2018 to 9.7 billion in 2050 (United Nations, 2017). The increasing population and prosperity in combination with the industrialisation of our economy has resulted in a tenfold increase in resource consumption and its associated waste and greenhouse gas emissions from 1900 to 2010 in Europe and has resulted in an increase in global temperature of 1°C (Circle Economy, 2019). It is projected that our growing population will continue to prosper and will double its global resource consumption by the year 2060 compared to 2017 (OECD, 2018).

The construction sector generally makes use of linear value chains based on the notion of the ‘take, make, use and waste paradigm’: in which energy, labor and capital transform natural resources into products with a single life cycle (Esa et al., 2017; Geraedts & Prins, 2015). Given the intrinsic mechanics of this linear economic system, with its wasteful paradigm and dependency on the throughput of natural resources, it cannot sustain our growing societies and resource consumption “without compromising the ability of future generations to meet their own needs" (Sariatli, 2017; World Commission on Environment and Development, 1987, p 16). In addition to climate change and environmental degradation the economic ramifications of this linear paradigm are beginning to emerge, with increased price volatility of resource prices due to increasing scarcity of commodities (UNEP, 2014).

As an alternative to the linear economy concept over the last few decades the circular economy concept has gained popularity among academics, legislators and businesses as an alternative to the linear economy strategy. It is promoted as an economic model that may facilitate economic growth while having low environmental effect (Geng & Doberstein, 2008; Korhonen et al., 2018; Ness, 2008). It provides our economic system with an alternative flow model, based on circular value chains that maximise the value retention of materials and by design is less wasteful (CIRIAG, 2015; Ellen MacArthur Foundation, 2013). “The circular economy replaces the ‘end-of-life’ concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and the consumption processes” (Kirchherr et al., 2017, p. 229).

In order to achieve a transition towards a circular economy, the European Union adopted a circular economy action package in 2015 (European Commission, 2015). In doing so the first goal is to reduce the use of primary resources and fossil fuels by 50% in 2030. The ‘Grondstoffen-Akkoord or Resource-Agreement’ signed in 2017 by the Dutch government and public parties, education and knowledge entities and private parties was the first concrete step in creating commitment for the circular economy ambition within the Netherlands. This agreement was the basis and inspiration for the construction industry to define its transition agenda that sets out the strategy and recommendations for the construction sector (Transactionteam CBE, 2018; Wiebes & van Veldhoven, 2018). The construction industry can be seen as a key player in addressing the challenges that our societies will face in the future (Taskforce Bouwagenda, 2016). The transition towards a build environment that makes use of high quality reuse is the current focus of the transition agenda. It is envisioned that our constructions and infrastructure should be designed and constructed in such a way that all materials can be reused with the use of clean energy at their highest possible functional level.

The transition towards a circular economy requires a systematic change of the current organisation and business models of our economic systems (Kirchherr et al., 2017). A transition towards a CE should be more than just a focus on reducing waste, but should "aim to inspire innovation throughout the whole value chain, rather than relying solely on waste recycling at the end of value chains" (European Commission, 2014, p. 6). Within the construction industry there is an information gap regarding materials and product information, leading to suboptimal recycling and reuse of materials. Information of the material composition of our building stock is essential to support a circular economy and increase resource efficiency. The necessary data to transition towards a circular built environment is already partly available within the construction value chain. However, this information is not stored within a centralised data system. Information that is not available that could promote the transition towards a CE is either not known or locked behind intellectual property (Heinrich & Lang, 2019). To fill these data gaps, the built environment has to standardise data gathering and storage procedures for building materials during the course of a building's lifespan and share it with all the relevant stakeholders (Heinrich & Lang, 2019). A material passport is a digital information system and can be seen as a tool that can bridge the current information gap in order to close circular loops and bring stakeholders together (Heinrich & Lang, 2019).

1.1 PROBLEM DESCRIPTION

The Dutch government has set the ambition to function within a circular economy by the year 2050 in order to become a zero waste economy (Transactionteam CBE, 2018). In line with this circular ambition the central government's goal is to reduce the use of primary resources by half and to procure all construction projects based on circular economy principles by 2030. The transition towards a circular construction economy will require close collaboration within the construction value chain, a shift in mindset towards system-thinking, and the introduction of new business models, regulations and new technological advancements (Carra & Magdani, 2017). As described the CI will need tools to measure and close the CE information gap, which leads to suboptimal recycling and reuse within the construction value chain. As such the transition agenda for the Dutch construction industry promotes the use of material passports in order to close the information gap in order to bring residual value to the market and reduce requirement of primary resources.

Material passport development and implementation are led by the market. The current tool landscape of material passports consists of multiple material passport initiatives, all with their own approach and own information platform, with limited to no harmonisation between MP's. According to Rudolphi this results in a situation where clients are cautious about implementing material passports because of their experimental character and unproven added value (Rudolphi, 2018). That is why governmental agencies have given room for material passport implementation within pilot projects in order to provide the right framework based on transparency, privacy, availability and governance from which material passports can be realised (Transactionteam CBE, 2018).

Results are promising, but many initiatives are still ongoing. The Transition Team concludes that there is insufficient insight to justify a legal obligation in the year 2020. There is insufficient experience with the material passport and with alternative solutions, so crucial questions have not yet been answered. The transition team therefore recommends conducting more empirical research, precisely because practical experience, involvement and support from the market are crucial (Transactionteam CBE, 2020). The government followed the advice of the Transaction team and postponed the decision if it is going to make MP compulsory for the CI (Ollongren, 2020) to 2022.

Because the circular economy is a relative new concept, its application in the construction industry is still in its early stages. Although there is a lot of study on advantages of a circular economy, there is not much about its broad application in the construction business (K. T.

Adams et al., 2017). The majority of CE research in the construction sector has focused on reducing construction waste, optimising recycling possibilities and improving energy efficiency. The marketing and probable reuse of items and components within a modern constructed environment has received less attention (K. T. Adams et al., 2017). Within scientific literature there is little research with respect to the practical application of a material passport in the construction industry and there is currently no standard material passport protocol or process. The tool landscape of MP's is not fully matured and is within an experimental phase (CB'23, 2019).

Passports must be comparable and interchangeable to facilitate information flow throughout the value chain (CB'23, 2019). Because agreements between passport developers are lacking there is the risk that this will not be self-evident and will result in limited implementation and less impactful adaption. Within the Netherlands there is an initiative to stimulate the use of material passports by developing guidelines for standardisation and work agreements for MP implementation within the CI (CB'23, 2019).

According to Honic, who researched the use of an automated BIM-based material passport, the main challenges for the implementation of automated MP's are the lack of standardisation and inconsistencies within data and the need for strong internal and external communication within CI practices. Material passports could be seen as collaboration tools in order to enable value recovering at the end of life (Hart et al., 2019). There is limited research into how material passports are implemented and how their implementation and collaboration lead to the effective facilitating of value recovery within a circular economy and towards a reduction of primary resources and waste.

"The transition towards a circular economy is an interdisciplinary task and can only work with the involvement of all the relevant actors along the construction value chain" (Heinrich & Lang, 2019, p. 50). Failing to acknowledge these dynamics could compromise the effective implementation of material passports within projects and within the value chain.

Concluding MP is under development within the Netherlands, guidelines are written to facilitate the standardisation and realising work agreements within the market. However limited knowledge of practical implementation of material passport within practice and possible barriers can be found within scientific and grey literature.

1.2 RESEARCH QUESTION

This paragraph will first provide the main research question of this thesis. To answer the main research question 4 sub-research questions were formulated. Where after the objective and goal of this research will provide depth and further understanding regarding the research question to be answered.

Value transferability is the extent to which an implemented material passport (through its form and content of material information) can transfer stakes of stakeholders within the construction value chain from one party to the other.

Main research question:

What does the implementation of a first of its kind material passport imply for guidelines and the development of material passports within the Netherlands?

1.3 SUB RESEARCH QUESTIONS

1) What is the state of the art with respect to the generation and application of material passports within the construction industry to enable circular material flows?
2) How to analyse and collect the learning experiences of the adoption and implementation of material passports within the construction value chain ?
3) How are material passports implemented and adopted within practice, and what learning experiences and barriers can be derived from the implementation of a first of its kind material passport within the Netherlands?
4) What are the main discrepancies between state-of-the-art guidelines reflecting the learning experiences from the state of the art material passport implementation within the Netherlands?

1.4 OBJECTIVE AND GOAL

MP's are seen as a tool to close the CE information gap in the CI and aid the transition towards a more circular construction sector. Within the guidelines for material passports for the construction sector it is mentioned that in order to harmonise material passports and work towards the effective implementation of MP's stakeholders should share experience with the implementation of MP's (CB'23, 2019). Furthermore it is mentioned that the lack of collaboration between stakeholders could be seen as one of the major barriers towards material passport adoption and effective implementation. This viewpoint is endorsed by the government and the circular transaction team that explain that more practical and empirical research into the implementation of material passports has to be conducted before decisions concerning the stipulation of MP's can be taken (Transactionteam CBE, 2020).

Given the above and the fact that MP implementations are scarce and limited knowledge sharing is taking place, coupled with the fact that limited insight can be gathered from scientific and grey literature on the implementation of MP within practice, the objective of this research is to capture these learning experiences, identify objectives for implementation within practice, and investigate possible barriers for implementation within practice. With the goal of sharing these insights of practice in order to assess the work agreements of the guidelines for practical applicability and achievability. As MP's are implemented with a common goal, namely to facilitate the transition towards a circular construction sector and facilitate the circulation of materials, this research will have a secondary goal, namely to aid in this development.

1.5 SCOPE OF THE RESEARCH

A material passport is seen as a tool that could promote circular value recovery and close information gaps within the context of the built environment. The objective of this research is to gain insights into the learning experiences and barriers of the MP implementation within practice. To guide this research and demarcate the topics of interest to be researched within this thesis, multiple scoping decisions were formulated.

The built environment can be generalised into two major sectors, being the civil engineering sector (Dutch: grond-, weg- en waterbouw (GWW)) and the residential and non-residential construction sector (Dutch: burgerlijke en utiliteitsbouw (B&U)). The transition towards a more circular built environment will present a significant number of challenges that apply to both sectors and ideally should be addressed collaboratively. However both sectors also have unique characteristics that sometimes hinder a collaborative approach. According to exploratory interviews and grey literature MP development is fragmented between both sectors (van den Berg & Castelijns, 2020). This fragmented nature of development has mainly to do with the fact that data structures are more complex in the infrastructure sector than in the B&U sector (Cobouw, 2020a). This complexity barrier could be one of the reasons that most MP initiatives started within the B&U sector. Given the GWW's characteristic of

significantly longer project lead times the B&U industry has gained a lead in terms of MP development and expertise (Transactionteam CBE, 2018). Given the above the choice is made to focus on the MP implementation within the practice of the B&U sector.

It has to be noted that this decision takes into consideration that stakeholders and financing differ in both sectors. Where projects in the GWW sector often involve public clients and the number of stakeholders is small and often homogeneous. Projects in the B&U sector are both privately and publicly financed and the number of stakeholders is larger and less homogeneous. This leads to more discrepancies between incidental private clients and professional governmental clients within the B&U sector compared to the GWW sector. Furthermore private financing also implies that most projects do not have an obligation to follow the European procurement rules, leading to more underhand relationships and less barriers for implementing new innovative techniques (Buur, 2008).

Although MP implementation is not country bound as developments and studies are initiated in different countries, the decision is made to study MP implementations within the Netherlands. The experiences gained within practice must have implemented and developed a material passport with the use of digital data or BIM to facilitate circular ambitions for the project. Because MP implementation is limited and linked to project delivery this means that little experience is shared or available of completed MP implementations within practice. Therefore this research will only investigate MP implementations that have been completed and delivered so that retrospective learning experiences can be collected and analysed. Furthermore the decision is made to only investigate MP implementation for new construction projects and not for renovation or demolition projects.

Summarising:
- MP application in the B&U sector
- MP application in the Netherlands
- MP application with the use of digital data or BIM data
- MP application for new and completed structures

1.6 THESIS OUTLINE

Below an overview is provided of the thesis outline used as a guide to answer the main research question: "*What does the implementation of a first of its kind material passport imply for guidelines and the development of material passports within the Netherlands*?".

Chapter 2 will present a literature review of the state of the art with respect to the implementation and development of MP within a circular built environment. Chapter 2 will answer the first sub-research question and by doing so it will provide a theoretical framework for this research. Within Chapter 3, the methodology of capturing and analysing the practical experiences within the built environment with respect to the implementation and development of MP will be explained, answering the second-sub research question.

The theoretical framework created in Chapter 2 will provide input for the generation of the interview questions and topics of interests for this research. Following the Methodology, Chapter 4 will present the analysed case study result of the learning experiences and barriers of the first of its kind MP implementation and answer the third sub-research question. This chapter will provide the input for Chapter 5, which will describe and validate the findings of the case study versus the guidelines for material passport standardisation and work agreements including the reflection of findings. The last chapter of this research will present the conclusions and answers the sub-research and main research questions respectively. Furthermore, the final chapter will describe the limitations of this study and indicates suggested recommendations for future research.

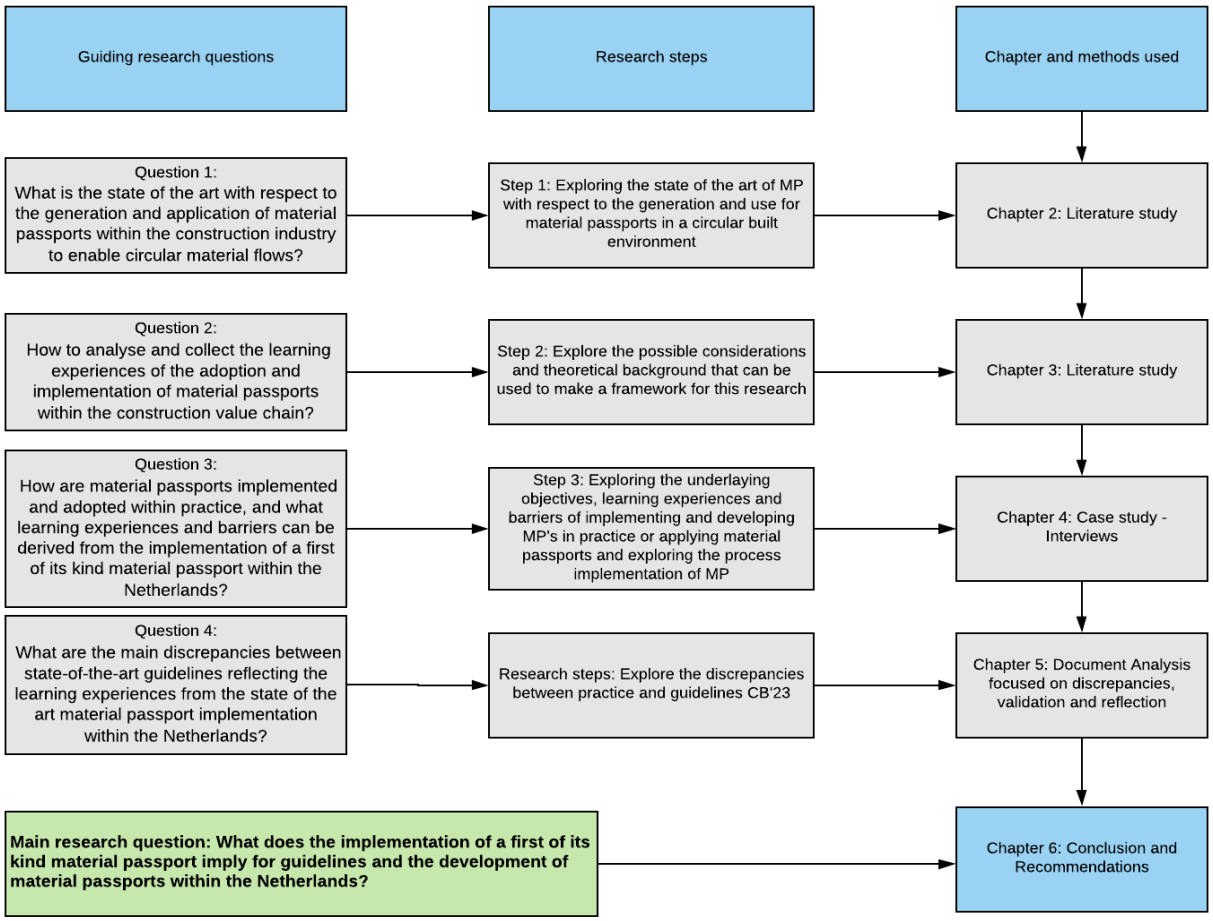

Figure 2 -Thesis outline (own illustration).

2. LITERATURE STUDY (THEORETICAL FRAMEWORK: CIRCULAR ECONOMY AND MATERIAL PASSPORTS)

Within this chapter the state of the art with respect to the generation and application of material passports within the construction industry in order to facilitate a circular economy transition within the built environment is presented. Fist the circular economy and the current approach with respect to material recycling and reuse in the construction industry will be explained. Whereafter the concept of material passports will be described and the basic factors influencing its adoption. Whereafter it will be described how material passports are developed within science and practice.

2.1 WHAT IS CIRCULAR ECONOMY

The circular economy is not a new concept and has origins in many schools of thought, so it cannot be credited to one author (Geisendorf & Pietrulla, 2018). In 1972 the club of Rome illustrated that a combination of resource depletion and pollution could limit economic growth within a time span of 100 years. In order to keep the consequences of population growth and increasing ecological footprint within the physical limits of our earth it is stressed that a sustainable world will require technological advancements in combination with behaviour changes (Meadows, D. H., Meadows, D. L., Randers, J., Behrens, W., 1972). A notion that Boulding already raised awareness for in 1966, where he criticised the wasteful and unsustainable open economic system and proposed a transition towards a closed economic system. “In a closed system the outputs of all parts of the system are linked to the inputs of other parts” (Boulding, 1966, p. 3).

The closing of cycles or economic systems can also be found back in concepts like biomimicry and industrial ecology. Where biomimicry inspires societies and technical problems to learn from nature as many issues have already been solved by nature (Benyus, 1997). The circular economy can learn from nature as within its ecosystem nutrition streams have no waste and therefore have no negative influence on the environment. Closed loop thinking is also at the heart of the concept of industrial ecology, which emphasises the necessity of having a holistic, systemic view of our industrial social behaviour and natural systems in order to maximise resource and energy flows within industrial systems (Frosch, 1992). This holistic approach of economic systems, learning from nature and closed loop thinking can also be found back in concepts like the blue economy. This philosophy builds around local economies and promotes the use of innovative business models in order to address our societal issues to facilitate the basic needs of our communities (Pauli, 2010).

Cradle to cradle (C2C) is a concept that may have the most in common with circular economy. It focusses on closing material cycles throughout design and recycling practices. Within its philosophy it distinguishes between biological and technical cycles. The goal of product reuse should be to retain the highest functional level (Baumgartner & Zielowski, 2007). The design principles used within cradle to cradle and circular economy can also be found back in the concept like regenerative design. The use of regenerating materials and energy is emphasised in this systematic approach to design, which also builds on closed loop systems in order to reduce waste (Lyle, 1994). The performance economy illustrates an economic model that also has similarities with a circular economy. Within the performance economy a behaviour change of our consumption is sketched. Where user moves away from ownership of the product but rather pays for functionality. Within such an economic system revenue is not made by selling products but rather shifts towards providing services and maintenance (Stahel, 1994).

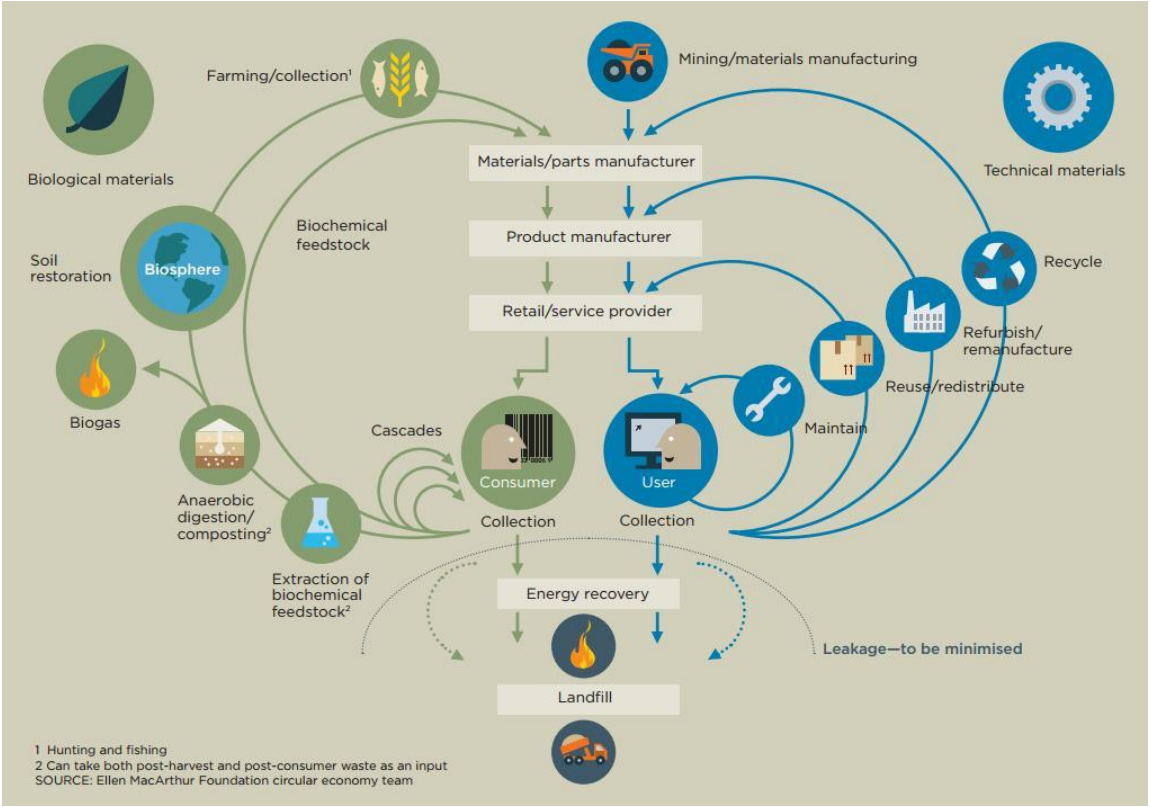

Figure 3 - Circular economy graphical illustration (Ellen MacArthur Foundation, 2013).

A circular economy builds on previous concepts like cradle to cradle, industrial ecology, biomimicry and performance economy. Topics like closing loops, co-operation, copying nature, re-use and recycle, product as a service were used in describing the core theory of a circular economy (Ellen MacArthur Foundation, 2015). In figure 3 above the linear 'end of life' concept is presented by the central production process whereas the circular economy is portrayed by the alternative circular flow models for the use of materials and energy in a circular value chain, hence waste is designed out of the system. "A circular economy is one that is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value level at all times, distinguishing between technical and biological cycles" (Ellen MacArthur Foundation, 2015, p. 1). A circular economy "attempts to minimize value destruction in the overall system and to maximize value creation in each link in the system" (Bastein et al., 2013, p. 4).

Soft aspects that should be included into the circular economy include the elimination of hazardous chemicals, reducing leakage to the external environment, and the utilisation of renewable and sustainable energy (Ellen MacArthur Foundation, 2013). According to Ghisellini "the ultimate goal of promoting CE is the decoupling of environmental pressure from economic growth" (Ghisellini et al., 2016, p. 11). A CE would require a significant shift in behaviour from consumers to users in line with the performance economy. To move away from the present linear paradigm or 'the-end-of-life concept', the shift to a circular economy necessitates a systematic change in the current organisation and business models of our economy systems (Kirchherr et al., 2017). This holistic view or system thinking will be necessary to close circular value chains as actors and processes do not function alone within an economic system. These systematic changes should take place on multiple scale levels and should be incorporated over the entire life cycle of the process (Kirchherr et al., 2017). Building resilience through diversity, according to the Ellen MacArthur Foundation, is a price condition for the adoption of circular processes and products in a fast-changing environment. Where through the use of adaptive design or modular design products are given the possibility to be altered or partly replaced (Ellen MacArthur Foundation, 2013).

Within science the use of the so called R-models, also referred to as the waste hierarchy within a circular economy, provided a practical overview for practice on how to implement different circular approaches (Kirchherr et al., 2017). Within literature multiple scale levels of actions or so-called R principles, varying from 3-9R's, can be defined (Geisendorf & Pietrulla, 2018; Kirchherr et al., 2017). Where the main 3'R principle is a recurrence within all other models and stands for Reduce, Re-use and Recycle, and respectively flows from lower to higher environmental impact and resource use. Below an overview is provided of the 9-R framework.

Within this framework it can be seen that different approaches have a different impact on the transition from a linear towards a circular economy. It is interesting to see that the most impactful approaches are to refuse, rethink, and reduce focus on decisions to be taken with respect to the manufacturing, use case, and design of products before any materials are even consumed. The other approaches focus on recapturing material and product value from a circular perspective when these values are locked within the economic system. The least circular approaches or most linear approaches focus on material recovery and material recycling. Higher circular approaches focus on retaining the value within the circular economy by extending the lifecycle of products or reusing products within the economic system while focusing on keeping the functional level of products as high as possible.

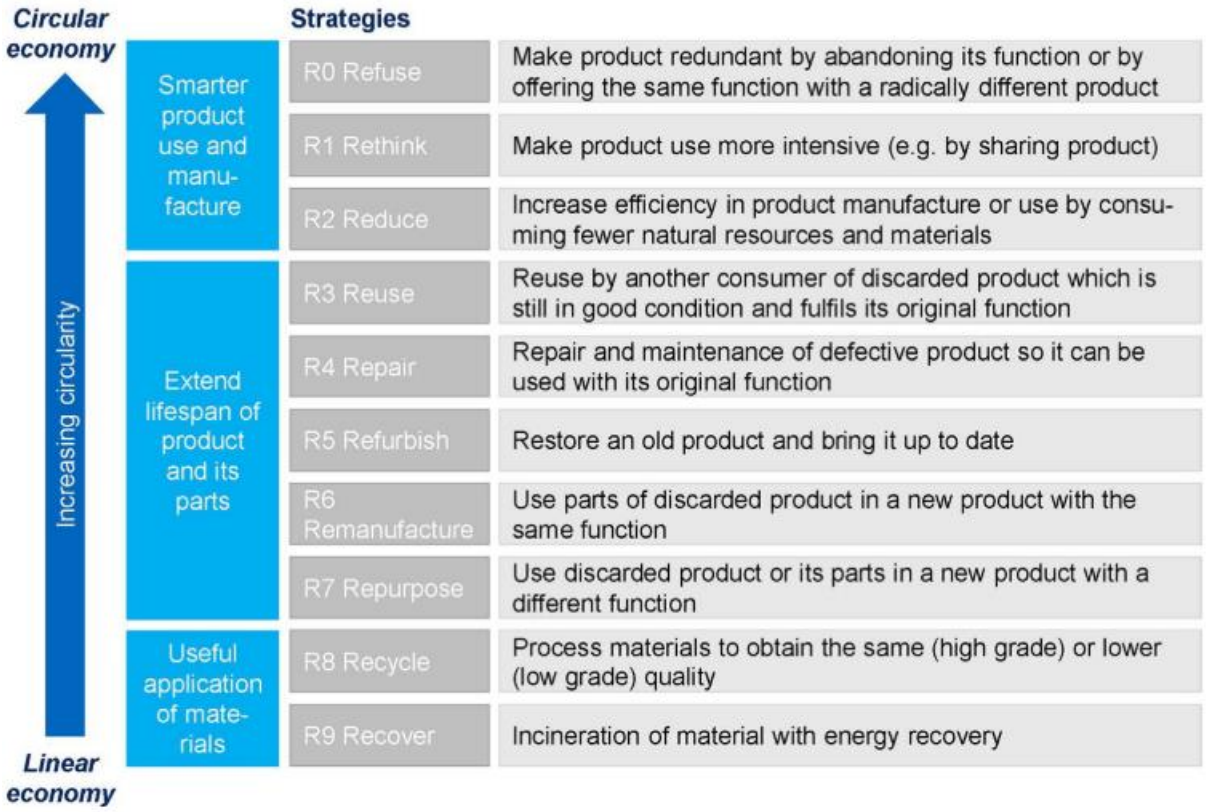

Figure 4 - 9 R framework overview (Kirchherr et al., 2017).

2.1.1 Dutch construction sector from recycling towards re-use

The construction sector in the Netherlands consumes approximately 50% of all raw materials and generates 37% of waste stream within the Dutch economic system, and is for 96% dependent on the use of non-renewable fossil fuel (Circle Economy, 2014).

The construction industry in the Netherlands is one of the frontrunners with respect to recycling, but clear guidelines with respect to material and product re-use are absent. The recycling percentage lies between 95-97, which is far above the 70% as indicated in the EU Waste Framework Directive (Circle Economy, 2014). Although the recycling percentages are

quite impressive its approach is suboptimal from a circular economy hierarchy level perspective as previously described in the waste hierarchy model in section 2.1. Recycling can be seen as suboptimal approach because it often means that products lose their function and therefore is often referred to as downcycling. Within the construction sector most of the constructions and infrastructures that reach their end of life cycle are fractured into aggregate to act as foundation material within new constructions.

This overview of recycled content flow can be seen below. It can be seen that a large share of the recycled materials is used in infrastructure projects, and only 3 percent stays within the residential and non-residential buildings sector. This means that the B&U sector is dependent for 97% of raw or virgin materials. This disproportionate share of secondary resources towards the infrastructure sector could lead to oversaturation of the secondary resource market within the near future, because the aggregate in the infrastructure sector can be re-used in future projects with limited to no loss of function (Rijkswaterstaat, 2015). Furthermore it needs to be mentioned that the construction sector as a whole uses more materials as input each year than it discards. Because materials are locked within the construction for decades this means that our current buildings stock and thus materials locked within our infrastructures and constructions is growing annually.

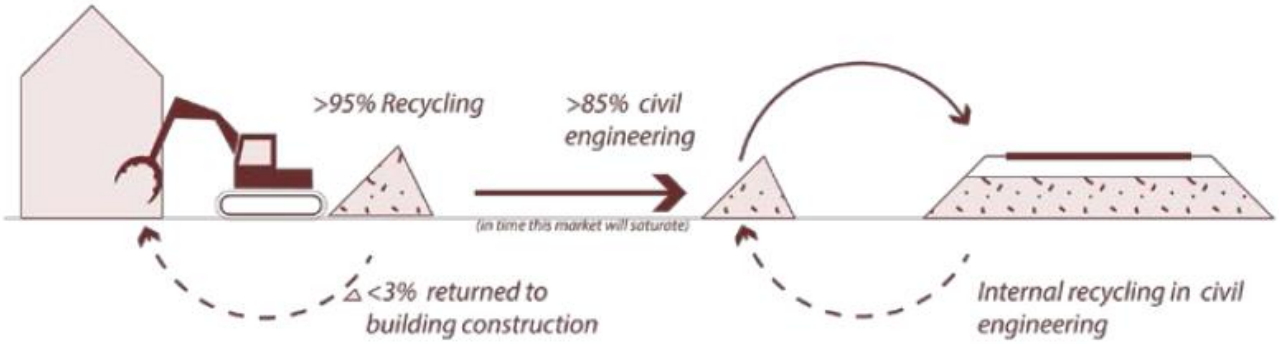

Figure 5 - Material recycling within building construction and civil engineering (Rijkswaterstaat, 2015).

2.2 CIRCULAR ECONOMY WITHIN THE CONSTRUCTION INDUSTRY

Because the circular economy is a relative new concept, its application in the construction industry is still in its early stages. Although there is a lot of study on advantages of a circular economy, there is not much on its broad application in the construction business (K. T. Adams et al., 2017). The majority of CE research in the construction sector has focused on reducing construction waste, optimising recycling possibilities, and improving energy efficiency. Where the marketing and probable reuse of items and components within a modern constructed environment has received less attention (K. T. Adams et al., 2017).

Within literature digitalisation is repeatedly mentioned as a key enabler towards closing circular loops by connecting supply and demand, store and handle the large amounts of data in a circular economy (Antikainen et al., 2018). The construction industry is often generalised for being a conservative industry that is pragmatic and reluctant to change (Vrijhoef & Koskela, 2005). Within the construction industry the commonly used ‘make to stock’ like in manufacturing seems absent which means there is often no stable supply chain and there are few strategic relationships. The building processes used in the construction industry can be categorised as ‘loosely linked’ and sequential involving many different actors (Vrijhoef & Koskela, 2005). The coordination of different actors across a sector that has an unusually large number of players and where relationships are often temporary and based on procurement and contracts has been given as a major problem for the effective adoption and diffusion of new developments (Heintz & Wamelink, 2015). These characteristics make a circular transition complex as it will require the close collaboration of all stakeholders within the construction industry. Furthermore similar to science there is the lack of a generally

applied definition of what circular economy and circular measures entails (Eberhardt et al., 2019).

Research conducted on the barriers and enablers of a circular economy in the construction industry seem to conclude that there are many technical and regularity challenges still remaining. The real challenges lay within the culture and market issues, where the collaboration within the supply chain and demonstrating of a strong business case for circular implementations seem to be the real obstacles towards a circular built environment (Hart et al., 2019).

According to Weisenfeld “differences in perceptions require information exchange and the willingness to learn from each other, differences in interests imply negotiation and require the willingness to compromise” (Weisenfeld, 2003, p. 219). Multiple stakeholders' needs and expectations may conflict since project based environments within the construction industry are complex, making it unlikely that all expectations will be met (McManus, 2004). The partners may have different goals and ambitions which can hinder an effective collaboration to facilitate the successful development and implementation of a material passport aiming to minimise the use of primary materials and reduction of waste. Failing to acknowledge these dynamics could compromise the effective implementation of material passports within projects.

As described a transition towards a circular economy will also require the construction industry to take a systematic approach and should be implemented on different scale levels. These scale levels can be defined as the micro, meso and macro level where micro takes place on the level of companies and singe consumers, products and materials, the meso level encompasses a higher hierarchical level such as buildings and the macro level overarches the previous levels and represents the level of regions and cities (Alhosni et al., 2022; Ghisellini et al., 2016; Kirchherr et al., 2017).

“The transition from a linear to a CE in the construction sector requires a focus on systemic thinking that encompasses the building life cycle and the construction value chain. The availability of structured information on material composition, building stock and material flow is critical for supporting this change” (Munaro & Tavares, 2021, p. 768). Within the construction value chain some of the information needed to facilitate circular material circulation is already available, however it is not stored within a centralised place. Other relevant information with respect to CE is not always known or locked behind intellectual property (Heinrich & Lang, 2019). To fill these data gaps, the built environment has to standardise data gathering and storage procedures for building materials during the course of a building's lifespan and share it with all the relevant stakeholders (Heinrich & Lang, 2019). A material passport is seen as a tool that can act as a platform and a repository for information storage which can close the information gap within the construction value chain and provide the relevant data to relevant stakeholders (Heinrich & Lang, 2019).

2.3 WORKING DEFINITION MATERIAL PASSPORT

Similar to the circular economy concept, there is a lack of a generally applied definition for material passports within science. As a result, this section will define the working definition for material passport within the context of this research.

Within the construction industry there are several tools already in use that have a conceptual link to MP’s and are developed to provide information within the value chain. For instance the Life Cycle Analysis (LCA) tool providing relevant information with respect to environmental impact of product and materials lifecycle and other tools like Energy Performance Certificate (EPC) which aims to optimise the amount of energy used in buildings (Atta et al., 2021; L. M. Luscuere, 2017).

The research of Damen into resource passports for a circular economy is one of the first scientific researches written about the topics within the Netherlands (Damen, 2012). Within this research the necessity for information sharing in order to close circular value chains and reduce material scarcity is stressed. Within the research a resource passport encompasses a tool that can act as an information exchange between different sectors. It emphasises the need of integrating all participants in the supply chain since the majority of the information needed to alleviate scarcity is already present within the supply chain. This research focussed on understanding the information requirements of different stakeholders and the format of such a tool. The data should be stored in a centralised database with online access, kept up to date throughout its life cycle, and its creation and operation should not come at a considerable cost.

Within the research of Luscuere material passports are described with the concept of 'nutrient certificates' which originated within Germany in 1997 (Atta et al., 2021; L. M. Luscuere, 2017). Where nutrient certificates can be defined as: "sets of dausta describing defined characteristics of materials in products that give them value for recovery and reuse. The certificates are a marketplace mechanism to encourage product designs, material recovery systems, and chain of possession partnerships that improve the quality, value, and security of supply for materials so they can be reused in continuous loops or closed loops or beneficially returned to biological systems. This is done by adding a new value dimension to materials quality. This new dimension is based on the suitability of materials for recovery and reuse as resources in other products and processes" (Hansen et al., 2012, p. 25). According to Luscuere a MP builds upon nutrient certificates and should be seen as an active tool for value tracking with the goal to capture and share the relevant information to the stakeholder that can act on it in order to promote circularity within practice. Luscuere explains, similarly to Damen's resource passports, that every action taken throughout the lifecycle of products and materials will have an impact on the possible value for recovery and therefore should be recorded and shared.

Building As Material Banks (BAMB), agrees in their report there is no broadly accepted definition of material passports and access the need to build platforms with the use of BIM information (Heinrich & Lang, 2019). Where the difference between BIM and MP's will be discussed in section 2.5. The definition they use is similar to the definition of 'nutrient certificates', it includes both material characteristics and a value aspect: ''Material passports (MP) are (digital) sets of data describing defined characteristics of materials and components in products and systems that give them value for present use, recovery, and reuse. MP's are an information and education tool that addresses questions often not covered by other documents or certifications related to building products, especially in relation to the circularity of products. MP's do not assess the data output and are not an evaluator of data. Instead, they provide information that supports the assessment and certification by other parties and allows existing assessments and certifications to be entered into the passport as uploaded documents" ((Heinrich & Lang, 2019, p 3) cited from internal non-public BAMB document (Mullhall et al., 2017))

As there is not yet a commonly accepted definition for MP's for the context of this research, the following definition based on the research of Luscuere, Damen, Mullhall et al. and BAMB is used: *A material passport is a (digital) set of data describing defined characteristics of materials and components in products and systems that give them value for present use, recovery and reuse. MP's for the build environment aim to facilitate the reduction of the use of primary resources, optimise circular value potential and a reduction of waste within constructions* (Damen, 2012; Heinrich & Lang, 2019; L. M. Luscuere, 2017; Mullhall et al., 2017).

2.4 VALUE CHAIN AND CONSTRUCTION PHASE

A material passport can thus provide the industry with a reliable set of information in order to facilitate the circular flow of materials within the construction value chain and give insight into the potential value of materials and components of buildings within a circular economy (L. M. Luscuere, 2017). Material passports constitute multiple hierarchical levels, including the level of materials, components, products, and systems that make up a construction. “For products and systems it can define general characteristics that make them valuable for recovery such as their design for disassembly, but it can also describe specifics about a single product or system in its application” (L. M. Luscuere, 2017). Circularity extends beyond the life cycle of buildings, therefore material circulation will necessitate collaboration from all stakeholders throughout the manufacture, realisation, usage, destruction, and new life cycle phases. Not every user or environment will require the same level of material circulation information (L. M. Luscuere, 2017).

“The transition from a linear to a CE in the construction sector requires a focus on systematic thinking that encompasses the building life cycle and the construction value chain” (Munaro & Tavares, 2021, p. 768). During the many phases of construction and the life cycle of buildings, a material passport inside the construction value chain will give varied functionality to different stakeholders. The most relevant stakeholders are depicted in the diagram below to offer an idea of which stakeholders could benefit from a material passport during the building process.

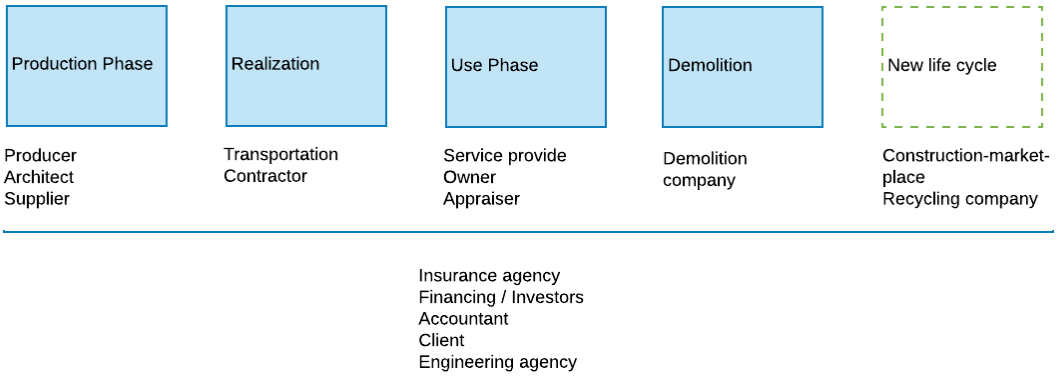

Figure 6 - Overview stakeholders value chain (own illustration based on (CB’23, 2020)*).*

The implementation of a material passport within construction projects requests the gathering and managing of information. Where information is often readily available and sometimes extra information is necessary this will require the agreement on how to exchange and structure the relevant digital or BIM information and clear demarcations on who delivers what kind of data needed. According to Honic and Aguiar this could lead to new roles within the construction process where new stakeholders such as harvesters or material passport managers could arise (Aguiar et al., 2019; Meliha Honic et al., 2019)

As previously described within (section 2.1) the waste hierarchy model, the most impactful decisions with respect to ‘how to’ implement a circular economy focus on the phase before materials enter the economic system. Simply put if constructions are not designed to be reused material recirculation at high function levels is hard to achieve. Taking this into account during the design cycle is of importance to facilitate the possible circular potential and the information that needs to be incorporated within a material passport (Kovacic et al., 2017).

Within the research of Honic, Kovacic & Rechberger a BIM based material passport was implemented (M. Honic et al., 2019)**.** The BIM-based MP has varying purposes throughout

the life cycle, where within the research four stages of the building process where highlighted as can be seen in the figure below. Within the conceptual design stage the MP serves as a rough analysis and optimisation tool, where variant studies are carried out, in order to decide about the most suitable construction in terms of the recycling potential and environmental impact. The MP functions as an optimisation tool in the preliminary design stage, allowing the individual layers and their thicknesses to be altered. This stage has the greatest influence on the life-cycle performance in terms of recycling and waste, as well as the environmental impact. During the tender phase the material passport was used in order to assess the exact material composition. Within the research of Honic the final document representing the material inventory of a building, which also serves as a basis for a secondary raw materials cadaster, is delivered at the handover to the operation.

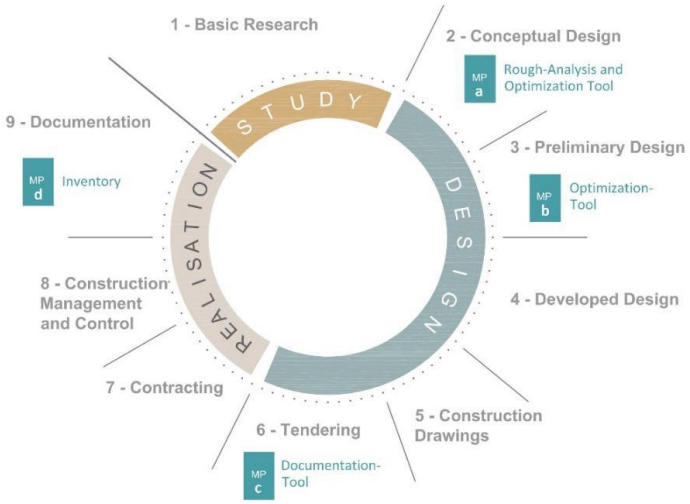

Figure 7 - Overview phases and material passport scope (M. Honic, Kovacic, & Rechberger, 2019).

2.5 DIFFERENT BIM MODELS TO POSSIBLY USE AS INPUT

Within the research of Honic it is envisioned that material passports are filled with the use of BIM. Therefore it is necessary to understand the difference and possible similarities between BIM and MP's.

Where BIM or building information can be defined as "an information-based system of processes involving the generation and management of digital representations of physical and functional characteristics of construction projects creating long-term value and enhancing the possibility of innovation" (Project Management Institute, 2016, p. 26). BIM may be used for a variety of purposes, including design validation, planning, asset management, and so on. As a consequence, BIM may be considered as more of an activity than a tool since it promotes information sharing among all stakeholders throughout the project life cycle. In terms of MP's, the commonality with BIM is that they are both information-based systems attempting to give long-term value and potential innovation. Where BIM activities often focus on the design, cost and planning during the projects life cycle, the material passport focuses primarily on the generation of value during and after the duration of the life cycle of constructions in order to promote the optimal reuse and recycling. Furthermore the interaction with BIM is that material passports need to be completed with important information about materials and compositions and will rely on available BIM data and information to be filled (Aguiar et al., 2019).

2.6 MP INFORMATION REQUIREMENTS AND HIERARCHY LEVELS

In figure 8 below an overview is provided of the relevant information that could be contained within a material passport. According to Manuaro and Tavares research there is no defined collection of information or standards recognised throughout science that represents the essential information for the recovery and reuse of data (Munaro & Tavares, 2021). Although

this overview provides some oversight of what information could be included within a material passport.

1 General data	
Product/commercial name	Use recommendation/restrictions
Manufacturer's name/details	Performance characteristics
Composition/materials	Technical data (strain/weight)
Product properties (physical, chemical, biological)	Temporal inf. (manufacturing date, expected lifetime)
Product picture/product main function	
2 Material health (safe data sheets)	
Security information (warnings/recommendations)	Handling and storage instructions
Material composition (toxicity, additives)	Product certifications and labels
Risk identification/fire protection	Legislation and policy
3 Sustainability	
Environmental declaration	LCA results and interpretation
Life cycle assessment (LCA)	
LCA boundaries and methodology	
Material criticality	
Renewable/non-renewable, treated/untreated	
4 Design and production	
Manufacturing process and techniques	Traceability (RFID tags, barcodes)
Installation and handling instructions	Logistics (packaging, supply chain managements, transportation requirements)
Certifications (energy labeling, material testing)	
Digitisation (BIM)	
5 Use and operate phase	
Positioning and location in the building	Warranties and expected use times
Cleaning and maintenance instructions	Monitoring and consuption (energy, water, outside influences)
Connections details and requirements	
6 Disassembly guide	
Disassembly instructions (removal/replacement of pieces)	Packaging/storage requirements
	Transportation instructions
7 Recycling and re-use potentials	
End-of-life considerations (reuse/recycling/remodeling)	
Disposal options/decomposability	
8 History	
Use period	Latest uses/operations
Verifications made during use	Updates during operations
9 Other information	
References used/standards consulted	Complementary material

Figure 8 - Overview of information requirements MP (Munaro & Tavares, 2021).

It is important to note that a MP can be made of different hierarchy levels within constructions such as the material level, component, product, system and building level as can be seen in figure 9 below (L. M. Luscuere, 2017). From a technical standpoint the higher hierarchy levels dominate the lower hierarchy levels. A MP for a building thus can consist of multiple subsets of information on different hierarchy levels. This approach can be brought back to the concept of Brand's buildings layers (Stewart Brand, 1995). This looks at buildings from a dynamic perspective where different building layers, cycle through the economy with different technical and functional lifetimes. Where higher building hierarchical levels or layers such as the foundation have to remain within the construction until it is demolished, and lower level layers such as isolation material are more dynamic and can flow back into the economic system more freely during for instance renovation.

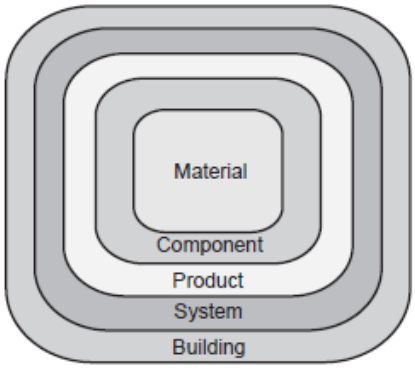

Figure 9 - MP hierarchy level (L. Luscuere & Mulhall, 2018).

A material passport composes information that comes from different documents and tools such as the bill of materials, BIM and LCA and categorises this information into different sections with the goal to capture the circular value potential *(Munaro & Tavares, 2021)*. It must be noted that a MP adds an additional information layer as not all information is available within the value chain with respect to circularity or locked behind intellectual property (Heinrich & Lang, 2019). A material passport should provide stakeholders with information about general data such as the material composition, location and characteristics of material properties. Within the overview above it also provides parties with safety

information and environmental indicators. The execution process of the project is located under design and production process and could contain the whole process from manufacturing until delivery. Whereas a material passport can also provide users of the building with relevant information with respect to the maintenance phase such as warranties and maintenance instructions. With respect to circular value potential a material passport should make clear what the connections between different building layers are and how they can be disassembled. Furthermore it could add an additional circular information layer by making clear what possible future reuse or recycle strategies can be implemented. With respect to future circulation of materials a material passport could contain information with respect to checks and maintenance during the lifecycle (Munaro & Tavares, 2021). According to SBRCUR a material passport should also contain information with respect to economic value which is not represented in the overview of information requirement (SBRCUR, 2016).

2.7 MATERIAL PASSPORT PATHWAY

In order to promote reuse of materials, products and elements material passports are seen as a priced tool to facilitate a more circular construction sector (CB'23, 2019).

Material passport initiatives are developed within different pathways and have their own identity. According to CB'23 there is a diverse supply of MP tools for different requirements. Within their report they describe that to achieve a circular transition within the built environment the actual exchange of construction objects and materials within the built environment is an essential step to be taken. Therefore they suggest that there has to be a certain degree of standardisation between different material passport initiatives. Because objects and materials must be exchanged and in order to accomplish this the data and information also have to be exchangeable. However within the current development pathway there seems to be little harmonisation between different material passport initiatives. This could lead to suboptimal use of end-of life time exchangeability and thus harmonisation could create added value for material passport initiatives. That is why CB'23 initiated a preliminary framework on which material passport initiatives can build upon in order to achieve harmonisation. Furthermore, the framework gives an insight into what boundary conditions and ways of registering data should be incorporated within the development and use of materials.

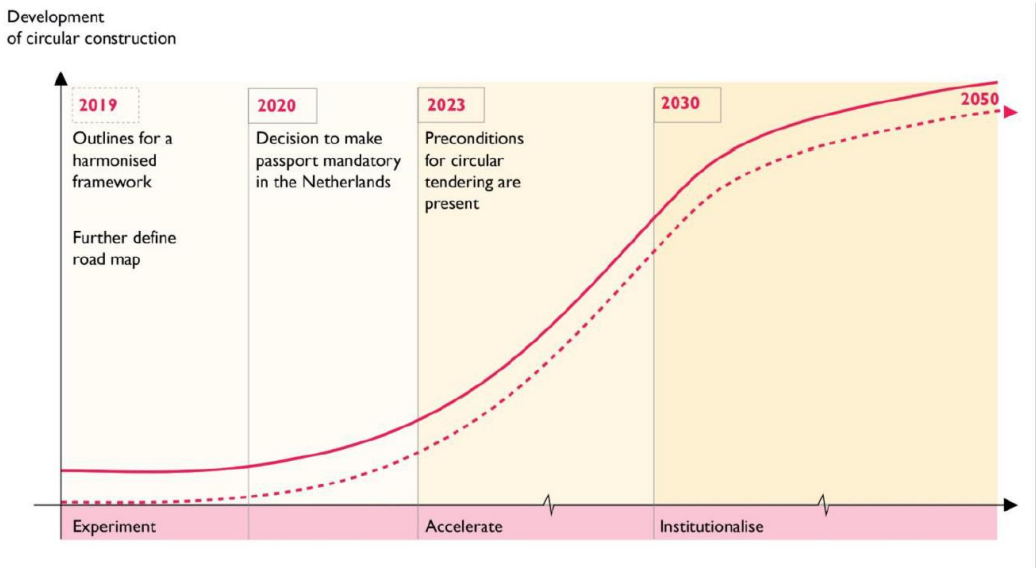

Figure 10 - Timeline of Passports for the construction sector (CB'23, 2019).

2.8 MAIN BARRIERS AND TOPICS OF INTEREST FOR SEMI-STRUCTURED INTERVIEW

The objective of this research is to capture the learning experiences within practice, identify objectives for implementation within practice, and investigate possible barriers for implementation. Objectives for implementation can be derived from the working definition of this literature study based on the research of Luscuere, Damen, Mullhall et al. and BAMB : *A material passport is a (digital) set of data describing defined characteristics of materials and components in products and systems that give them value for present use, recovery and reuse. MP's for the build environment aim to facilitate the reduction of the use of primary resources, optimise circular value potential and a reduction of waste within constructions.* The main objective can be explained as closing circular value chains within the construction industry. Other objectives are indicated by Honic, such as optimising the design for circularity potential and the assessment of circularity of materials, products and constructions.

The most interesting findings from scientific literature can be brought back to the barriers for implementing material passports as indicated by science. Below the findings of this literature study are summarised in order to define the most important barriers found with respect to MP and closing circular value chains.

"The circular economy replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and the consumption processes" (Kirchherr et al., 2017, p. 229). Sharing, capturing, and storing information about the material composition of constructions is required to aid the circular economy transition, where digitalisation is recognised as a critical enabler for circular building(Antikainen et al., 2018; Heinrich & Lang, 2019). Material passports could be seen as **collaboration tools** in order to enable value recovering at the end of life (Hart et al., 2019). Multiple stakeholders' needs and expectations may conflict since project based environments within the construction industry are complex, making it unlikely that all expectations will be met (McManus, 2004). The partners may have different and/or common shared goals and ambitions which can hinder an effective collaboration to facilitate the successful development and implementation of a material passport aiming to minimise the use of primary materials and reduction of waste. Failing to acknowledge these dynamics could compromise the effective implementation of material passports within projects.

According to Honic, who researched the use of automated material passports, the main challenges towards the implementation of automated MP's are the lack of standardisation and inconsistencies within **data** and a need for strong internal and external communication within CI practices (M. Honic et al., 2019). Research conducted on the barriers and enablers of a circular economy in the construction industry seem to conclude that there are **many technical and regularity challenges still remaining**, however the real challenges lay within the **culture and market issues**, where the **collaboration** within the supply chain (or not), and **demonstrating of a strong business case** for circular implementations seem to be the real obstacles towards a circular built environment (Hart et al., 2019). The implementation of a material passport within construction projects requests the gathering and managing of information. Where information is often readily available and sometimes extra information is necessary, this will require the agreement on how to exchange and structure the relevant digital or BIM information and clear demarcations on who delivers what kind of data needed. According to Honic and Aguiar, this could lead to new roles within the construction process where **new stakeholders** such as harvesters or **material passport managers** could arise (Aguiar et al., 2019; M. Honic et al., 2019).

Analysing the literature study it is assessed that the most prominent barriers as indicated within science are the lack of standardisation and inconsistencies within data, which for this research is translated as a technical barrier. With respect to barriers for circular economy adoption, technical barriers are indicated with respect to circular material application and design for circularity. The interoperability of different information systems has been identified

as a technical challenge to MP adoption in the literature. The inclusion of the entire value chain is important within a circular economy, and as such it is assessed that the complex and fragmented value chain of the construction sector could create a barrier for the implementation of MP's. Because a circular economy is radically different than normal design, construction and life cycle approaches cultural barriers within the supply chain could frustrate smooth adoption of MP's. Scientific research indicates that with MP new roles and stakeholders could emerge. In essence this is not necessarily a barrier for MP adoption, however could implicate a different stakeholder engagement and possible different internal structure of organisations and co-operations, and hence it is decided to integrate this topic within the interviews. Because possible cultural barriers and organisational factors influence collaboration within the value chain, it is categorised as collaboration. Other barriers for circular adoption can be found within legal or regulatory issues for the MP. Intellectual property is assessed as a current barrier for the sharing of free information.

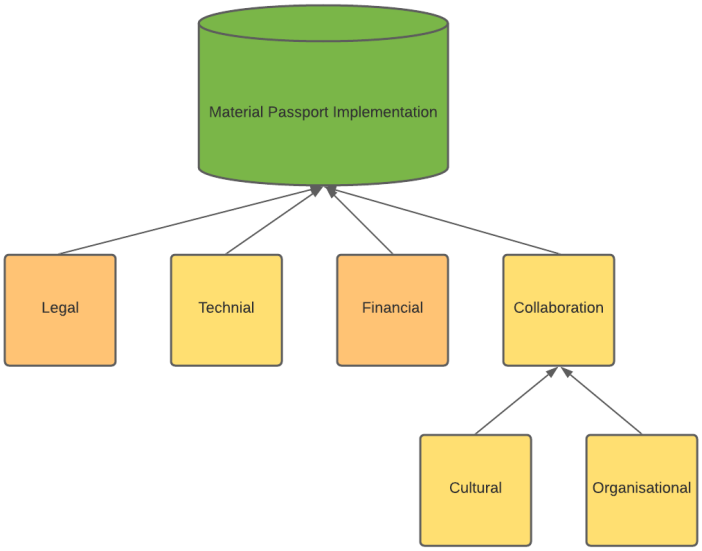

Figure 11 - Topics literature study (own illustration).

3. METHODOLOGY

This chapter elaborates on the research methodology adopted in this research to collect, contextualise and analyse the learning experiences and barriers encountered in practice with the implementation and development of a first-of-its-kind material passport. To answer the main research question these findings will be reflected and analysed against the most recent material passport guidelines. Within the first section of this chapter the research approach is explained. Whereafter the subsequent sections will give insight into the different steps and approaches used to answer subsequent sub-research questions and the main research question.

3.1 RESEARCH APPROACH

The application of material passports is a subject that has received little attention in the scholarly literature. Within science MP is often viewed from the perspective of theory building and development of the MP tool (M. Honic et al., 2019; L. M. Luscuere, 2017). Grey literature provides some insights into the development and practical implementation of MP's, however their subjectivity should be tested. Within the Netherlands there is an initiative to stimulate the use of material passports by developing a guideline for standardisation and working agreements for the implementation of material passports within the construction industry (CB'23, 2019).

Within this research a qualitative research approach will be implemented to gather and analyse non-numerical data. Within scientific literature there is not one commonly accepted definition for qualitative research. Within the research of Aspers and Corte 82 sources of input are used to define qualitative research: "as an iterative process in which improved understanding to the scientific community is achieved by making new significant distinctions resulting from getting closer to the phenomenon studied" (Aspers & Corte, 2019, p. 155). It must be noted that improving the understanding of the scientific community and coming up with new and significant findings should be the goal of every research. It is therefore easier to explain qualitative research as an iterative process that focuses on getting closer to the phenomenon studied. Qualitative research is "an iterative process" because knowledge that is learned at one point in the research process will flow into the rest of the research. "Getting closer to the phenomenon studied" will mean for this research that it will focus on capturing and analysing the experiences and internal feelings of people within the context of the construction sector of the Netherlands. More specifically it will capture the gained knowledge and evaluated barriers of people within its natural setting, talking directly to people that have implemented and developed a first of its kind material passport within practice.

There are various methodologies that can be used in qualitative research, but in general they use a flexible structure or framework with a focus on capturing rich and depth of meaning when interpreting the data (Naderifar et al., 2017). Qualitative research applies "data analysis that is both inductive and deductive and establishes patterns or themes" (Creswell, 2013, p. 44). As there is limited knowledge gained and shared with respect to the implementation of MP's within practice, this research will use inductive reasoning to gather and present the knowledge of practice. Within this research deductive reasoning will be implemented with respect to available scientific literature on the topic and most recent guideline for MP's.

Qualitative research has several common characteristics according to Creswell of which below some are provided that are reflected within this research.

- Multiple methods: "Qualitative researchers typically gather multiple forms of data, such as interviews, observations and documents, rather than rely on a single data source. Then they review all of the data and make sense of it, organizing it into categories or themes that cut across all of the data sources" (Creswell, 2013, p. 45).

- Holistic account. “Qualitative researchers try to develop a complex picture of the problem or issue under study. This involves reporting multiple perspectives, identifying the many factors involved in a situation, and generally sketching the larger picture that emerges. Researchers are bound not by tight cause-and-effect relationships among factors, but rather by identifying the complex interactions of factors in any situation” (Creswell, 2013, p. 47).

- Participants’ meanings. “In the entire qualitative research process, the researchers keep a focus on learning the meaning that the participants hold about the problem or issue, not the meaning that the researchers bring to the research or writers from the literature” (Creswell, 2013, p. 47).

To create a holistic account of the issue within this research, multiple methods for capturing data will be implemented to analyse the participants meanings. As the main research question states: *“What does the implementation of a first of its kind material passport imply for guidelines and the development of material passports within the Netherlands?”,* the learning experiences and barriers with respect to the implementation of MP within the Netherlands will be captured and analysed with the use of a case study approach. Whereas the implication for guidelines and development of material passports within the Netherlands will be captured with the use of a document analysis of the most recent guideline for MP.

A case study is an empirical qualitative research approach that explores a bounded system (case) or multiple cases to capture in depth perspective of practitioners with an issue in its’ natural context (Creswell, 2013). When a researcher wants to investigate the contextual conditions of an issue or when the contextual relationship is blurry and unknown, a case study is a suitable research strategy (Yin, 2002). Case study approaches often address research questions that are explorative and start with ‘why’, ‘how’ and ‘what’, such as ‘how is the intervention implemented within practise’ (Crowe et al., 2011; Yin, 2002). Within a case study research the behaviour of those participating cannot be manipulated (Yin, 2002). Within case study research there is a differentiation between single case studies and multiple case study research. Where multiple case studies focus on finding the differences and similarities between cases (Stake, 1995). Single case studies often challenge existing theories or inform science of new phenomena that have not been addressed within science. Because single case studies have a narrower focus and the researcher only has to address one case. The researcher can present and gain a deeper and richer understanding of the subject (Dyer & Wilkins, 1991).

Given the above a case study research seems very suitable to answer the third sub-research question: “*How are material passports implemented and adopted within practice, and what learning experiences and barriers can be derived from the implementation of a first of its kind material passport within the Netherlands*?”. With the use of the iterative information flow it also is suitable to contextualise the document analysis of the guideline answering the fourth research question: *“What are the main discrepancies between state-of-the-art guidelines reflecting the learning experiences from the state of the art material passport implementation within the Netherlands?”.* Respectively answering the ‘how’, ‘what’ and main research question.

3.2 CASE STUDY SELECTION

An important and defining part of case study research is the case selection (Creswell, 2013). Because the sample size and case study selection have an influence on the generalisability and transferability of the research results, case studies should be selected based upon certain characteristics that can be found within a case. These characteristics must be applicable to the practical or theoretical issues that the researchers want to investigate (Denscombe, 2010). The criteria used to select the case study are defined in the scope

demarcation of this research described in chapter 1.5. The scope demarcation is shortly summarised below, followed with the explanation of the process of the case study selection.

- Project within the B&U sector within the Netherlands
- The project has developed and implemented a material passport with the use of digital data or BIM data, with the goal to facilitate circular ambitions for the project.
- New built project
- Retrospective so that learning experiences and barriers can be analysed.

The selection was based on participating in two circular development days, of which one was specifically focused on the development of material passports within the Netherlands. During these sessions it became clear that MP implementation is still within its infancy, whereby these days were mainly focused on convincing future clients and small and medium-sized enterprises (SMEs) to use MP within forthcoming projects. Parallel to these development days explorative interviews were conducted with representatives of projects within the Netherlands that, according to their websites, had implemented material passports for their projects. Two potential projects within the B&U sector were analysed to fit the scoping criteria. The Triodos Reehorst in Driebergen and the Circular Pavilion in Utrecht. However during the explorative interview with the project leader of the Circular Pavilion it became clear that no advanced tools had been used nor development of tools had been undertaken. During the explorative interviews with Triodos facility employees and the project developer it became clear that extensive efforts had been undertaken into the development and implementation of a MP for this project. These findings during the early phase of the research reflect the fact that MP implementation within practice is limited. Because the Triodos case extensively made use of BIM data to generate a MP, this case can be considered as a first-of-its-kind implementation within the Netherlands. Given the above, the decision was made to focus on a single case study. Because this first-of-its-kind MP implementation could provide the needed learning experiences and insights into MP implementation and development within practice in relation to the working agreements and guidelines under development.

3.3 DATA COLLECTION

3.3.1 Approach of Interviews

Qualitative research theory indicates that there are multiple approaches for conducting interviews within qualitative research. Three primary interview approaches can be distinguished when they are placed on a continuum that reflects the extend of control over a structure in the interviews, namely, structured, semi-structured and unstructured interviews (Mathers & Nick Fox, 1998). Structured interviews are often used to collect large quantities of data with the use of predefined closed questions. It is frequently connected with quantitative research, but it can also be used in qualitative studies. Unstructured interviews have little structure at all and make use of a small number of interview topics that are explored with the use of predefined open-ended probe questions (Mathers & Nick Fox, 1998). The open nature of a unstructured interview aims to capture the world views of the interviewee and should allow questions to develop and topics to emerge during the interview. Semi-structured interviews (SSI) combine open-ended and closed-ended inquiries with ‘why’ and ‘how’ follow-up questions (W. C. Adams, 2015). SSI has a comprehensive list of questions and topics to cover during the interview. It should, however, be flexible enough to allow interviewees to develop ideas and investigate questions raised by the interviewee (Denscombe, 2010). The goal of semi-structured as well as unstructured interviews is to elicit people’s experiences, opinions, and beliefs (Mathers & Nick Fox, 1998). By letting interviewees develop their own thoughts, these interviews are often used for the discovery of complex issues (Denscombe, 2010). According to Denscombe semi-structured and unstructured interviews are on a continuum, and within practice interviews frequently slide between the scales.

This research is interested in the learning experiences and barriers within practice of development and implementation of material passports. This topic is largely unexplored within science and grey literature, and its implementation and development takes place within a construction project, which can be seen as a complex context. Multiple stakeholders have to work together, all with their own culture, interests, objectives and worldviews. Given the above it has been chosen to extract and analyse these learning experiences and barriers within practice with the use of a semi-structured interview approach. When implementing a semi structure interview this will allow the researcher to objectively evaluate learning experiences and barriers within practice while on the other hand allows for the deepening of topics with respect to specific participants interests and expertise.

For this research the sampling process or choosing the part of the population that will represent the project is done with the use of the snowball technique (Creswell, 2013). The snowball technique involves initial contact and interviews with a limited sample size of the group. After the interviews, the participants were asked which stakeholders may contribute unique perspectives and insights, and which stakeholders were most involved in the implementation and adoption process.

Due to the COVID pandemic the majority of interviews are conducted by videoconference and will be video/audio taped with consent of the participants. Recording of interviews aids with the reliability of the transcript and allows the research to focus on the content of the interview (Creswell, 2013). The learning experiences, motivations and behaviour of stakeholders within a sensitive context are explored within this research, Therefore all participants have been made anonymous in order to protect them from any harm that could result from this research.

3.3.2 Structure of interview structure, questions and topics.

Below the overview of the structure of the interviews and the discussed questions and topics is provided in three tables. All interviews follow the same structure and are based on a semi-structured approach. The introduction part of the interview starts with a short introduction of the researcher and the participant, followed by a short explanation of the research, the structure of the interview, and the topics of interest that are to be discussed. Subsequently all participants were asked the same introduction questions with regards to company objectives, circularity, and possible CE tools already in use within companies. With respect to MP's participants are questioned about their experience with MP implementation and general questions regarding MP implementation and development.

The middle part of the semi-structured interview follows the introduction. The topics to be discussed are based on the theoretical framework generated within the literature study. The main themes that were defined are legal, financial, technical, cultural, collaboration, and organisational. Depending on the knowledge and viewpoints of the subjects and themes of the respective representatives some questions were further explored and some questions were not entirely pursued. During this part of the interview there was more room to ask ‘why’ and ‘how’ questions. Subsequently in the semi-structured interview the representatives answered the predefined closing questions, addressing the evaluation of MP implementation for this project and their viewpoints with respect to future MP application and value of the tool for circularity ambitions. As reflection the question is asked what the view of interviewees is in case MP application is obligated.

Interview: Introduction
Background interviewer and participant
Explanation of research and interview structure
What is your organisation about, goals and objectives?
What is your perspective/understanding of Circular Economy?
What impact and adjustment of processes and use of tools does CE have for your organisation?
Have you used the tool of MP within this project and what added value have you experienced for your organisation?
Which opportunities do you envision using MP in general?
What are the Critical Success Factors for implementing MP?

Table 1 - Interview introduction questions (own table).

Interview: Topics (middle part)	
Legal	Procurement, Access to MP, Ownership data/materials, Intellectual property(IP), Contracts, Legislation
Financial	Payment models, Residual value, Renovation, Financial risks, Revenue streams
Technical	Design, Demountability, BIM, Other
Cultural	Understanding and knowledge MP, Competences, Conflicting interests, Other
Collaboration	Change of partners in value chain, change of role partners in respective phases, “win-win” opportunities, Threats, Integration within process, Responsibility data deliverance and management, Impact phases, Trust, other
Organisation	Internal organisation, New roles, other

Table 2 - Interview topics including probing questions (own table).

Interview: Closing questions
What is your perspective with respect to the future implementations of MP and the possibility to aid the CE transition?
Did the implementation of the MP meet your expectations?
How do you view an obligation for a materials passport?

Table 3 - Interview closing questions (own table).

3.4 DOCUMENT ANALYSIS

Document analysis is a systematic technique in which the researcher examines and interprets documents in order to obtain a better grasp of a topic and elicit meaning in order to produce empirical knowledge (Bowen, 2009; Corbin, 2008). To contextualise the findings within practice and give a deeper meaning to the research, a document analysis of the most recent guidelines with respect to the standardisation and implementation of material

passports within the construction industry will be conducted. For this research the guidelines of CB'23 will be used as a second input of data for the triangulation. The analysis concentrates on the discrepancies between feedback of respective interviews and the guidelines.

3.5 DATA ANALYSIS AND VALIDATION.

The data analysis will make use of all the relevant data captured within the respective interviews and the analysis of the guidelines. After the transcription of the interviews the different viewpoints and learning experiences will be analysed along of the predefined interview and topics. This will give the reader a depth of understanding of the learning experiences and barriers with respect to the different topics related to MP within practice. The issues of validity and reliability of the findings are addressed with the use of triangulation. Triangulation is defined as "the use of more than one method or source of data in the study of a social phenomenon so that findings may be cross-checked" (Bryman, 2008, p. 700). The analysis of the guidelines is along the topics and experience from practice cross-checked in order to conclude the potential discrepancies.

To further contextualise and validate the findings of the case study versus the guidelines an expert session will be planned. As explained in the scope of this research in chapter 1.5. the decision is made to focus on the MP implementation within the B&U sector. Therefore this research should take into account the characteristics of both private and public clients. The Triodos project is governed by an incidental private client (Triodos Bank) assisted by a project developer acting as advisor and director. The viewpoints from a professional public client should be reflected to contextualise the findings. A prerequisite for the expert is that he/she must have knowledge of MP implementation and the development of the guidelines within the Netherlands.

3.6 OVERVIEW METHODOLOGY

This section presents an overview in the form of a flow model that visualises the research methodology and the subsequent steps taken throughout this research. The flow model is subdivided into two parts.

The left hand side scheme (green) represents the different steps taken to capture, contextualise and analyse the learning experiences and barriers within practice. With the use of the scope demarcation the Triodos case was selected as a suitable case to be researched. Because only the Triodos case was examined as a project that implemented a first-of-its-kind material passport, it was decided to conduct a single case study. A snowball sampling approach was used to fill the sample size of participants and representatives for this case. The interview protocol used for this research is based on a semi-structured interview approach. Where the topics to be discussed are distilled from the theoretical framework generated in the literature review of chapter 2. After the interviews are conducted they are transcribed. The results of interviews are analysed and presented along the semi-structured interview approach with introduction questions, topics and closing questions. In doing so, these steps in the green scheme answer the third research question and its analysis can be found in chapter 4.

The gathered and analysed information from practice flows into the right-hand scheme (blue). It is used to conduct a document analysis of the most recent guidelines with respect to standardisation and implementation of MP's within the Netherlands (CB'23 guideline 2.0). The analysis focusses on the discrepancies between the practical experience and views and the procedures and views described in the guideline. To contextualise and validate the reflection of the findings within practice versus the guidelines an expert session will be held integrating public experience of the use of MP's and involvement in the development of the guideline. For the readability of this research it is chosen to integrate the reflection and

discussion into chapter 5. Therefore it is also incorporated in right hand scheme as the last step.

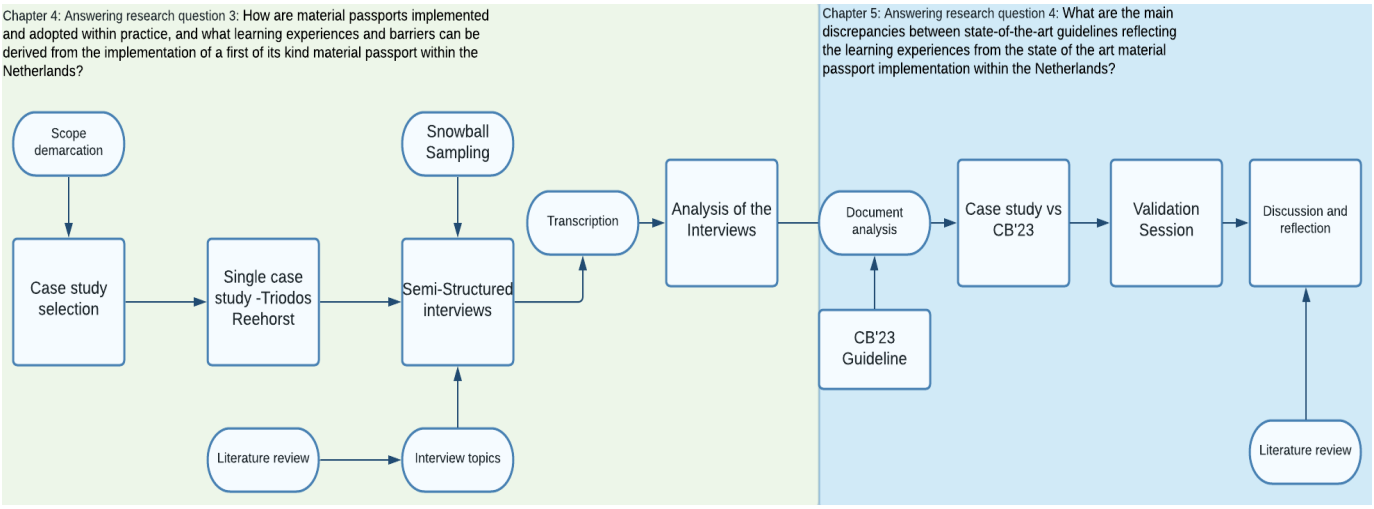

Figure 12 - Topics literature study (own illustration).

4. CASE STUDY RESULTS

For this thesis the Triodos Bank material passport implementation is taken as the central focus for this analysis. All major players involved in the development and implementation of the material passport have been interviewed with the use of a semi structured interview approach. This made it possible to discuss and evaluate the relevant stakeholders viewpoints with respect to the MP implementation and adoption within this project. Within this chapter the case study interviews are presented in order to gain a better insight into the adoption and implementation of the material passport. Specifically also the defined themes related to MP are presented.

4.1 BACKGROUND PROJECT TRIODOS BANK – DE REEHORST

The Triodos Bank has initiated the construction of a new office on the estate of de Reehorst, Driebergen-Rijsenburg in the Netherlands to facilitate its growing number of employees. The estate Reehorst runs in the roots of the organisation as the organisation Triodos Foundation was founded here in 1971. The office consists of three towers that can be accessed by two entrances, where all workspaces have access to direct sunlight and a view of the estate. The layer of each workplace is structured around a shell where all utilities are placed within the center of the workplace.

The office building is energy positive, which means that it creates more energy than it uses due to 3000 m2 of solar panels, the installation of 120 smart bi-directional charging stations, and the use of heat and cold storage. “The buildings consist of sustainable materials and a demountable wood-hybrid construction, which is designed by Rau Architecten and constructed by J.P. van Eesteren” together with its installation subcontractor Bosman Bedrijven (EDGE, 2019). To develop the project the client Triodos Bank and the project developer EDGE formed a joint venture. With respect to sustainability certificates the office scores outstanding within the BREEAM framework (EDGE, 2019).

Figure 13 -Triodos Bank view from the roof, picture taken (Architectweb, 2019).

On September the 6th of 2019, more than nine years after the conclusion of the cooperation agreement between Triodos Bank and EDGE, the building was completed and formally delivered (Cobouw, 2019).

Figure 14 - Front view walk through nature to get to your office (Architectweb, 2019).

The building was built on the principle that materials and components should be able to flow back into the economy. The use of renewable wood in combination with a demountable and modular structure where the majority of the connections are put together using 165.312 screws illustrates this design concept. According to Rau a circular construction is a ‘temporary storage and assembly of products, components and materials with a documented identity’ (Cobouw, 2019). Within the project a new innovative tool was initiated known as a BIM-based material passport. With the goal to register materials and provide value for recovery at the end of the lifecycle.

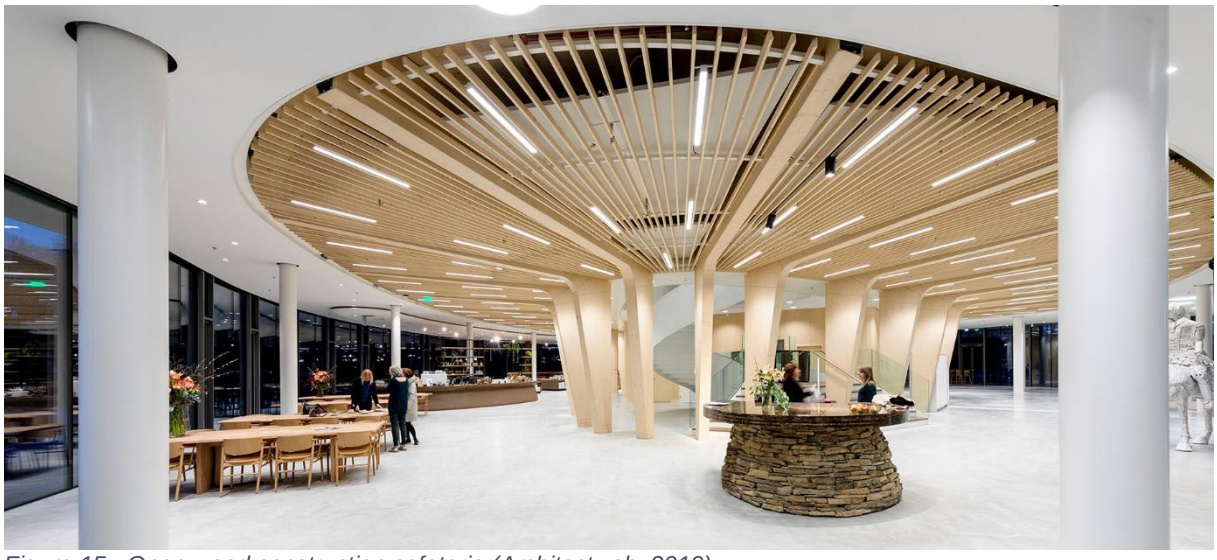

Figure 15 - Open wood construction cafeteria (Architectweb, 2019).

The office was designed with the Estate's natural surroundings in mind (EDGE,2019). Building heights were reduced to avoid obstructing bat flight pathways, and an unique lighting scheme was devised to prevent confusion and safeguard the local species. The green roofs collect rainwater for toilet flushing and estate irrigation (Placetech,2020).

The project Triodos Bank at the Reehorst has won awards for being the best office of the year 2019 and won a price for the most sustainable project in The Netherlands in 2020 (Architectweb, 2019; Bouwwereld, 2020). The use of the hardwood inner structure and core in combination with glass façade is praised for creating a sense of spaciousness and

connection with nature. The concept's circular material usage and demountability, ecological integration into the forest environment, energy efficiency, and climate resilience were all grounds for the jury to award the project.

Figure 16 - Helicopter view Triodos Head office (Architectweb, 2019).

4.1.1 Stakeholders in the Triodos Bank project

For this case study a snowball sampling process has been used to establish the main stakeholders for this project.

The first interview in the research was with the project developer at EDGE during the contract. According the interview it became clear that parties involved with assisting in the development and the implementation of the material passport were:

The civil contractor J.P. van Eesteren. The contractor had the contractual obligation to provide a material passport as stipulated within the Design & Build contract. Furthermore the installation contractor, Bosman Bedrijven, as well as Madaster.

Worthwhile is that in the interviews with respective established stakeholders the client is not really mentioned as main player in the implementation process. Suppliers referred to in interviews were Derix and Octatube. As such these parties are represented within the value chain for this project. Several attempts have been made to have a representative of Octatube become involved in this research, however proved not to be feasible. New finance concepts have been explored for this project like product as a service. With this concept ownership remains with the supplier, whereby the client pays for functionality during a specified time. Finally it was concluded that this concept proved economical not feasible and realistic for the project. Consequently no interviews with respect to finance structures have been entertained with financial institutions nor with insurance companies.

For the design and construction of the Triodos Bank building at De Reehorst including the requirement to develop and implement the Madaster material passport the stakeholders involved are:

- Triodos Bank — Client
- EDGE — Real Estate Developer
- Madaster — Material Passport Provider
- Rau Architects — Architect
- J.P.van Eesteren — Civil Contractor
- Bosman Bedrijven — Installation Contractor
- Derix — Wooden Structure Supplier
- Octatube — Façade Supplier (*not participated in research interviews)*

An overview of the stakeholders and contractual structure for the construction phase is as per scheme below.

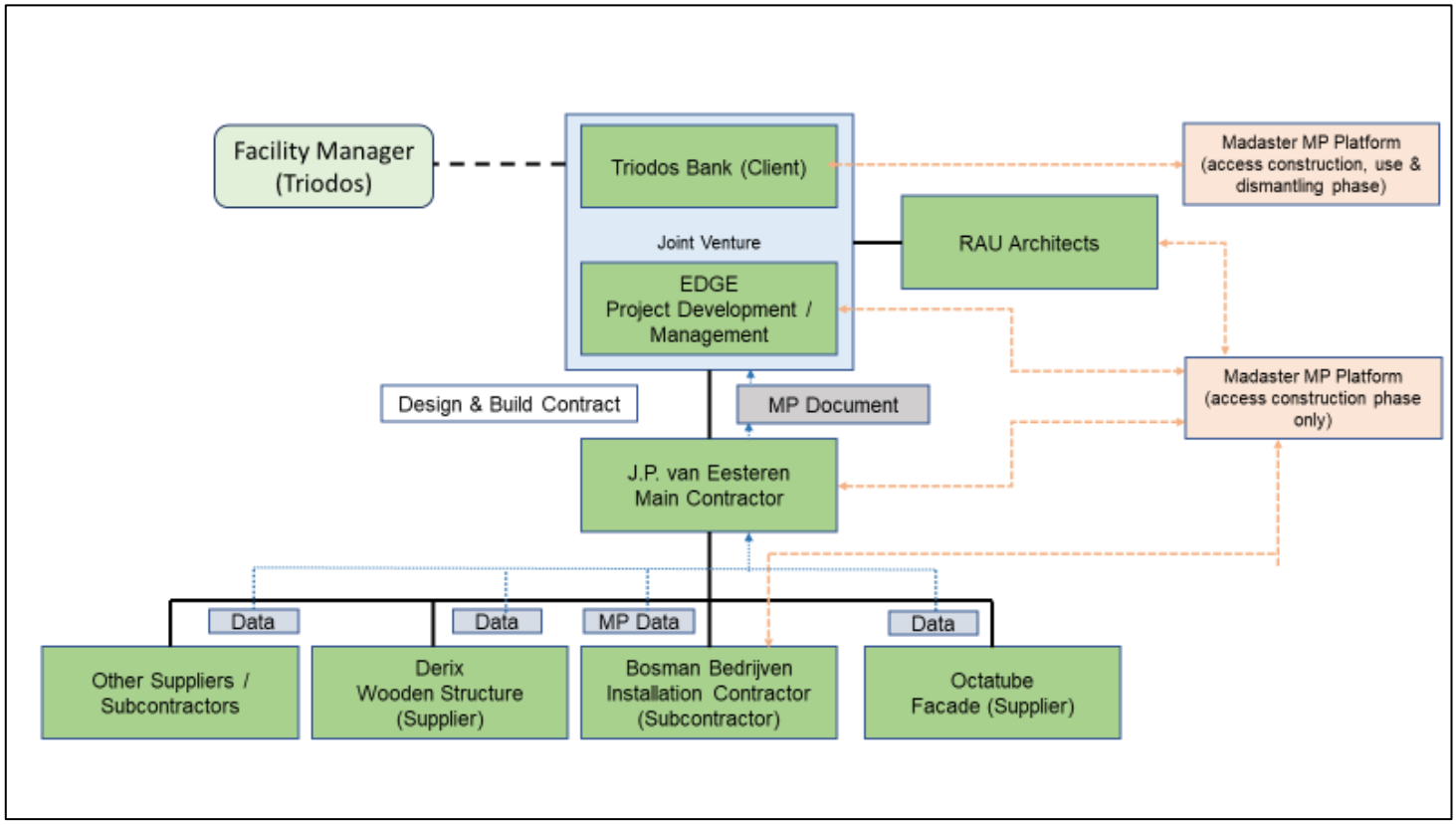

Figure 17 - Scheme of stakeholders Triodos Bank Project (own illustration)

4.1.2 Objectives and goals of stakeholders according interview with representatives

When asked for company objectives with respect to sustainability, environment or relating to the MP tool representatives of stakeholders did not impulsively refer to these, but responded the question from their own perspective and involvement in the project and process of MP implementation. The view with respect to their perceived objectives is as below.

Party	Company	Objective / Goal
Client	Triodos Bank	Encourage worldwide sustainability and social initiatives and developments with money and streams of money
Project Developer	EDGE Technology	Frontrunner sustainability; slogan “EDGE Technologies, the world needs better buildings”
MP Provider	Madaster	Eliminating waste in the building sector / Achieve complete circular construction economy by registration
Architect	Rau Architects	Our vision is to build for the underprivileged. Build high tech where possible and apply for the less fortunate people. Objective to make “state of the art” buildings
Civil Contractor	J.P. van Eesteren	Circularity by TBI, respectively J.P. van Eesteren, declared as one of the strategic pillars. As contractor main focus on realising buildings
Installations Contractor	Bosman Bedrijven	Engineering and realising installations for buildings
Wooden Structure Supplier	Derix	Promoter biobased construction

Table 4 – Objectives and Goals according representatives stakeholders.

4.1.3 Process towards decision to implement material passport for project

The project Triodos – Reehorst, was initiated in 2009. At that time a material passport or parties like Madaster did not yet exist.

During the construction process Triodos Bank initiated a separate trial with Madaster focused on making material passports for their existing office buildings in use. It was concluded that it was hard or even impossible to develop detailed and accurate material passports for these buildings, mainly because relevant data such as building information and drawings were not actual or not easily available. Furthermore it proved that there were differences between “as is” and “design data”.

Subsequently Triodos Bank has decided to apply the material passport for the construction of the new project in 2017 at the stage of choosing partners for the construction and after the design had been completed. Partners had to apply the platform and format of Madaster. The civil contractor became contractual obligated and responsible to deliver the material passport. During the construction process it was not clear how and to what specifications the material passport had to be developed and applied. It became evident that time investments and efforts were significant to provide the client with a comprehensive and extensive material passport entailing all the information contractor, project developer and Madaster thought necessary and aligned upon. Accordingly the client has agreed the associated scope for development and application of the agreed functionality of the material passport as variation order including associated funding needed for contractor and its partners.

4.1.4 Introduction questions

4.1.4.1 *Perspectives and understanding circular economy*

In the introduction of the semi-structured interviews all representatives were asked what their perspective or understanding is of circular economy. In line with the research of J.Kirchherr most stakeholders had non-aligned viewpoints and understandings of what a circular economy entails. Personal beliefs and values often colour participants perspectives for the necessity to take a different approach towards construction and behaviour and to become more circular.

According the client a circular economy should maximise the reuse of products and/or materials with minimum loss or waste. Close the circle and if possible reuse manyfold over the lifecycle rather than once. The client further mentioned that from a circular perspective it is important to evaluate if an envisioned intervention is necessary. Not intervening does not require any resources and as such is circular preferable. Interventions that are deemed necessary should have minimal environmental impact.

The Building industry is responsible for large quantities of waste and material use. Therefore the project developer states that the transition towards a circular economy is not possible without the full commitment of the building industry. Circular Economy relates to preservation of materials and value. A project developer is involved as of the start of the design and construction phase and has to take responsibility for acting sustainable. It is important to take circularity into account during the tender phase with architects and contractors. It has to be made sure that materials applied in constructions have a maximum recycled content or are reused. Furthermore to construct in such a way that the value of materials and components is maximised and can flow back into the circular economy at the end of their use.

Present business models for material recirculation of recycled materials and components is not always feasible and clear. Nevertheless it is important to look beyond this barrier and start building constructions in such a way that the material value is maximised in the transition towards a circular built environment. The financial non-attractive outcome of circular business and revenue models should not be a reason to overlook the importance of the circular economy during the construction process. It is important to give room for experimentation and look for partnerships that are not always as obvious within traditional construction combinations. The contractor validated this vision and explained that entering into partnerships with for instance a demolish/reuse party can provide added value during the construction process knowing best how to reuse materials and components at the end of the life cycle. The project developer further noted that it is important to keep circular approaches practical and not to overcomplicate and over conceptualise.

The contractor mentioned that in essence the construction sector needs to preserve materials and to optimise and facilitate reuse. This implies that the sector needs to change its way of designing and constructing buildings. This represents a challenge for parties in the construction sector still being quite conservative and traditional. Within the construction industry decisions are often short term and profit oriented, whereas more attention for lifecycle approach is required. Due to the present short term and profit oriented approach a lot of unnecessary waste is produced and effective use of materials is not achieved.
The first step towards reuse of materials and facilitating of circularity at the end of lifetime of constructions is to start registering and documenting the materials that are applied within constructions. The application of BIM can be seen as a tool that can give materials an identity in order to optimise end of life decisions.

The contractor noted that the lack of a general applied working definition makes the implementation of circular approaches within the construction industry difficult. To apply

circular economy in practice the contractor has defined its own general definition. This working definition has already been adjusted several times due to learning experiences. Based upon the definition the contractor establishes its operational plan. The plan focusses on respective phases in the process, like design, construction and end of life. Start anyhow with a general approach after which to divide and approach its constituting aspects resulting into CE approach and benefits.

Only Madaster refrained from giving a CE perspective noting that personal viewpoints and the lack of a general working definition is not beneficial for the implementation of circular economy. Discussions about CE where every stakeholder has a different perspective makes it difficult to effectively establish shared solutions and put CE into practice. This barrier can be overcome when parties join or align their perspectives with initiatives that are developing working definitions for the construction sector. Therefore Madaster refers to use the definition developed by CB'23 within the lexicon circular construction.

The view of the architect on circular construction is that constructions should be designed to be demountable so that all materials can be reused without loss of value. Most value can be retained and flow back into the economy when products are reused on their highest functional level.

From the perspective of resource scarcity the consultant of the wooden structure supplier noted that a transition towards a more circular construction industry will be inevitable. However during the transition it is important to be critical on what stakeholders and parties define as circular implementation. Because many products and project greenwash themselves as "circular" alternatives or approaches, while in reality not much impact is achieved and often downcycling is applied.

According the installation contractor the transition towards a CE requires a shift in mindset. The Dutch Government intends to have The Netherlands circular latest by 2050. This seems far away, however this date approaches quite quickly, not only for big companies but especially for smaller companies. The CE transition will come at a cost and not all parties will have the knowledge, ability or funding available to immediately take circular approach decisions, but all small steps help. If clients have the choice between a new product consisting of raw materials with proper quality and the required lifetime with an attractive price versus a product with reused materials with no guarantees of lifetime or same quality and a higher price the choice is clear: the client will often favour the new product with a lower price. More is required to have clients and stakeholders in the construction chain to adapt and work along CE approach and principles. Legislation and/or financial stimuli or possible restrictions may be necessary.

As such some representatives share doubts about the realism and achievability of the ambition of the Dutch government to become fully circular by 2050, versus the traditional approach of designing and construction. However all parties share the concern of depletion of raw materials and realise that CE application will be inevitable.

4.1.4.2 *The impact and adjustment of processes and use of tools for CE and organisation*

The circular economy is a relative new concept. As such the companies that were interviewed can be seen as frontrunners within the field of circular building. In general, all parties asses that the circular economy concept requires them to act and become acquainted with this new approach and its possible tools accordingly.

The contractor noted that clients within the construction industry are becoming increasingly sustainability and circular economy driven, and that circularity can be seen as one of the new

buzzwords within the construction sector. For all upcoming tenders of J.P. van Eesteren circularity is included as one of the award criteria. This forces companies involved within the building construction chain to incorporate the circular economy principles into their business practice, action plans and strategies. The contractor further mentioned that circular economy approaches also have impact on the partnerships pursued. Circular economy approaches sometimes require a different perspective or creative approach. That is why the contractor mentioned that in order to optimise the chances of winning tenders partnerships with parties are sought with whom they are not familiar to work with. The contractor noted to realise that participation in the early phase of the circularity trend is essential in order not to miss the boat and the opportunity to distinguish versus its competitors.

It is noted that CE and sustainability require new competences and new or changed roles may evolve of functions and people active within the organisations of companies in the construction chain, such as the contractor and project development company. Furthermore the awareness of sustainability and CE becomes more and more common practice and part of the business as usual.

The project developer mentioned that incorporating CE principles into projects and development sometimes has an experimental character, whereby pilots and new CE approaches are introduced and evaluated. For projects it is important to set the ambitions for circular incorporation as early as possible in the process, so that CE principles can be incorporated into the design philosophy and in the requirements to the market.

For this Triodos project several concepts have been examined, such as product as a service. Product as a service implies a change in ownership of products and as a consequence a change in finance and risk allocation. After serious efforts and legal due diligence the application of this concept was not further pursued. The client had major legal reservations with respect to leasing the façade. In case of bankruptcy of the façade company curators or debtors could claim the elements of the façade. Also the concept of incorporating many reused materials proved to be challenging. According to the project developer it is quite possible that the market is not yet ready for these new concepts and challenges and is still quite traditional.

The client addressed the impact of the circular economy from a project perspective as well as from a business operation perspective. Within the office environment Triodos is focused on the reduction of administrative paper usage, optimisation of transportation and mobility, and the reduction of energy consumption and water usage. In line with the company's sustainability ambitions the client thought it important to apply reused materials for this project and make the construction demountable so that circular potential is optimised. In case of no interest for buying or leasing the building after its usage this allows Triodos to sell and transfer components back into the economy.

The architect mentioned that from his perspective circularity is not a relative new concept, and that parts of the circular concept are already embedded in their core values for a very long time. Where the market nowadays promotes a development as a circular construction, a couple of years ago this was labelled as building as sustainable as possible. When the architect views a solution as normal and logical, other stakeholders often regard this solution as forward thinking and very circular. This project was designed before the concept of circularity was commonly used within the construction sector. Therefore the word 'circular' in the programme of requirement only referred to the recirculation of air. Core principles of circularity were however prescribed by the requirement for demountability and the prohibition of toxic materials. Furthermore by the requirement that materials needed to be reused and as generic as possible.

In addition, the architect mentioned that there are not many tools to assess circularity. Some tools for scoring of demountability are under development. Within common practice the architect makes sustainability decisions during the design phase based on objective sources such as NIBE and shadow cost pricing.

For companies like Madaster, that act as an advocate for more circularity within the construction sector, the wider acceptance and support in the market for circularity and tools such as the MP directly impacts their business.

4.1.4.3 *Added value of material passport for organisation*

The implementation of the material passport has provided the client with a tool that provides an overview of the quantities of materials and components and their connections within the construction. The material passport was implemented as a registration tool and was handed over as part of the delivery of the construction. As such the use of the MP has not changed the clients viewpoints nor approach how they wanted to develop or build the project. The added value of the registration of materials and components into the delivered tool will only materialise when it will be used to facilitate the circulation of materials back into the economy during renovations or dismantling at the end of the lifecycle. As such the added value of the MP is regarded by the client as focused on the future potential added value. How the material passport is used during the life cycle of the building is not yet clear for the client. The client adds the focus on circularity and the decision to implement the material passport as a registering tool of the building has contributed to the focus and awareness of circularity within the organisation aiming amongst others to minimise wastage, energy and water consumption.

The information contained within the MP is gathered and enriched by several parties throughout the implementation process. Upon completion the material passport has been delivered and handed over to the client. During the hand over moment of the MP the responsibility of the MP and ownership of the data is transferred to the client. Therefore the contractor argued that the real added value of the MP (i.e. the facilitation of circular reuse) is not within their scope. This reasoning is reflected in the fact that many parties found it hard to assess the added value of MP implementation for this project from their perspective.

Although some parties had already worked with material passports before this project the implementation for the Triodos Bank Project was different. For this project the focus was to register as much as possible relevant information regarding circular and sustainable characteristics of materials and based on connecting BIM information with the MP. The parties involved during the generation and enrichment of the tool mentioned that the real added value for them has been the learning experience and the sharing, gathering and gaining of knowledge. Where they were given the opportunity to get acquainted with the MP platform and gain insights how to generate the MP using BIM information. Parties mention the added value of being involved in this process of MP development and implementation is the project reference in their respective portfolio of circular projects distinguishing them from the competition during forthcoming tenders requiring MP and circular experience. Executing parties like contractors and the suppliers in general noted that the added value of MP for the project seems limited versus traditional processes using BIM application.

The consultant of the wooden structure supplier assessed the added value of the material passport implementation as a step towards increasing transparency and circular awareness for suppliers. Tools such as the use of MP and the requirement for circular approach of design and construction motivates awareness among suppliers. They have to think about demountability, lifecycle thinking, circularity and sustainability of their products. To gain the overall perspective suppliers and producers have to think and become more proactive within their own value chain. Failing to act proactive could make clients hesitant to work with a particular supplier.

4.1.4.4 *Threats and risks envisioned using MP in general and possible adjustments to minimise these*

Material passports and MP platforms within the construction industry are relative new tools that are still under development. Madaster recognises the risk of the perception of stakeholders that the current passport is perfect or want it to be perfect, and subsequently promote and accept the tool, while in reality the MP and its platforms still have to be further improved before it is fully crystalised. When applying the tool parties have to realise it is a learning by doing process accepting incompleteness and uncertainties of the current status of this tool. Only in this way and by lessons learned the tool may further improve.

For this project the material passport has been implemented as a registration tool. The risk is that the added value at this stage is not clear. Only at the end of the life cycle of the construction or during possible renovations the added value may become apparent. The BIM modeller of the contractor mentioned that only at the end of the life cycle it can be assessed if the added value of a material passport will outweigh the extra efforts invested during early phases of the project.

The client envisaged a risk in the development of the construction market towards a market where circular constructing and building with reused materials is the norm. In case the market is not willing to uptake and reuse materials and components from the Triodos project little added value for the client will result, while having invested in the implementation of the material passport.

Working with BIM is standard practice for the civil and installation contractor. The implementation of the Material passport took substantial more effort as initially envisioned. The contractor assumed that after uploading the BIM model into the Madaster platform a functional MP would be generated. However in reality the generation of a MP is not a fully automated process.

According the installation contractor the managing and coordination of the application and use of MP and BIM data of sub-contractors can be a risk for a smooth implementation of MP's. Not all subcontractors and suppliers have the means or knowledge of working with higher level BIM formats that are necessary to generate a MP. Some subcontractors only handed over digital CAD drawings which are not enriched or contain extra information that is relevant to make a higher level BIM Revit model, which is necessary for generating a MP out of BIM information. Enriching and upscaling these simplified BIM models or technical drawings takes a lot of effort and makes it more difficult to deliver a MP as an end product. Furthermore the information that needs to be enriched within Madaster is not as easily accessible or not known by subcontractors and suppliers.

According the civil and installation contractor clients often misjudge the time and effort required to make and alter BIM models. MP implementation requires considerable time and cost investments. A risk is that future clients request a MP neglecting the associated extra efforts and costs.

Some parties doubt the added value of MP in case clients will not keep material passports up to date over the lifecycle of the construction. A material passport may lose its value if renovations and changes during the lifetime are not actualised and the passport is only used at the end of the lifecycle. The project developer suggested an incentive for clients to keep material passports up to date during exploitation.

The architect recognised proliferation of MP and MP platforms as a risk. Within the domain of MP and MP platforms there is little standardisation between different initiatives. This can impose a risk for both ease of use as well for future MP added value. The project developer expressed the same reservations and stated that within the construction sector parties can

only share information efficiently using one systematic approach and one system. Especially if a future tool is envisioned that links all MP's into a data bank for a secondary market of building materials.

The consultant of the wooden structure supplier did not see in general terms a direct risk of MP implementation. For this project take back agreements have not been applied. In case take back agreements are considered this will imply a shift in risk allocation towards suppliers. In itself this is not necessarily a wrong way of thinking from a circular perspective. Also the consultant mentioned that some suppliers may have reservations to share information in order not to disclose intellectual property. A solution for this reservation can be found in the field of certifications. Suppliers can disclose all information about what is in their products under a non-disclose agreement and take full responsibility for their products.

4.1.4.5 *The Critical Success Factors (CSF's) for implementation of MP*

Stakeholders noted there are multiple factors influencing the successful implementation of material passports. According to the contractor and client it is important to clearly state and agree the ambitions and goals with respect to the application and implementation of the material passport at the early stages of the project in order to align all stakeholders. Within traditional construction practice there is segmentation and phasing of stakeholders involved and participating during the design and construction process. At the time of design for the Triodos project material passport platforms were not yet available. Upon the design completion and into the engineering phase the use of the Madaster material passport for registration purpose was decided to implement. Due to the sequence of events the BIM format used for the design was as such not material passport proof. As a consequence of this sequencing the contractor had to enrich and make the BIM models material passport proof. In order to mitigate additional efforts and nuisance in data and coding the alignment and agreeing ambitions by all major stakeholders in the integral process at the earliest stage of a project is regarded as critical and essential.

The project developer and the client assess data as the main critical success factor. Data is referred to as the input of the correct data as well as the adequate coupling of data between BIM files and the MP. It is critical that data input is done with due diligence and a systematic approach with the use of BIM protocols in order for the BIM file and MP to communicate as efficiently as possible.

A critical success factor for a broad acceptance by parties involved is the ease and simplicity of use of the MP's. The civil and installation contractor mentioned in addition the wish for further automation of MP generation using the BIM information.

The architect and Madaster expressed as a critical success factor the broad acceptance of the use of MP's by all stakeholders in the entire construction value chain. In order to achieve the broad acceptance and development of MP's and MP platforms the contractor and the architect assess the collaboration and sharing of experiences and lessons learned with each other and within the MP platform as a supporting critical success factor. From their experiences as so called "Kennedy" partners or early adaptors of the Madaster platform they share this opinion. Within this platform for every new project parties convene and may participate to provide input and feedback resulting in a step by step improvement of the development and implementation of the MP and the overall platform.

The contractor noted that several parties develop their own passport and formats. However ultimately there has to be one standard material passport and implementation preventing any ambiguity between several passports and/or formats.

4.1.4.6 *Implementation Process*

However not specifically noted as introduction question representatives were questioned about the respective phases of the implementation process and the view on the exploitation phase including the assessment of keeping the MP up to date.

With respect to implementation the project developer and Madaster stated that the initiative and decision to implement a material passport should be by the client. It is important to take the possible implementation into consideration at the very start of the process. The project developer emphasised to take responsibility at the very beginning of the project in order to achieve maximum circularity. Because the project developer is involved from the beginning of the construction chain it is important to request contractors to use materials within their constructions that are reusable and that materials can easily be recycled.

It became quite evident that the implementation process should start as early as possible. All parties involved with the implementation of the MP agreed that this could have saved valuable time and could have it made easier to generate a material passport. The main point of departure should be the information requirements and who should provide these during the implementation process. Furthermore contractor and subcontractor stressed the importance of an early BIM protocol during the implementation process.

To transition towards a circular economy within the built environment it is key to set the right boundary conditions at the beginning of the project. According to the contractor and project developer this means that during the design circularity should be taken into consideration. The materials and construction should facilitate circular material flows whereby boundary conditions like standardisation and building modular are important. It is also important to set boundary conditions for material use: for instance toxicity and recycled content of material input can promote the use of circular materials.

Business models are not always obvious during the life cycle of constructions, this has mainly to do with the fact that the construction industry is very fragmented and traditional. However in order to promote a circular economy it is important to take responsibility for the materials that are used and how constructions are built.

4.1.4.7 *Exploitation phase and keeping the MP up to date over lifecycle*

The goal of the material passport implementation was to register the most relevant information of materials and components applied in the construction in order to facilitate the transition towards a circular economy. Within data structures the information requirements within building information systems differentiate from that of asset management information. Therefore it is hard to use the current material passport information in order to link it with asset management programs. The facility manager found it hard to see the extra added value during the exploitation phase of the construction already working with different programs.

The focus of Madaster is that the MP should not become an asset management program but is mainly focussed towards facilitating circularity over life. Madaster explained that the platform does not yet support time stamps within the material passport. Time stamps are necessary to gain insight when upkeep or new components or products have been added or renovated. Ultimately the client is responsible for updating the information in the MP over the lifetime of the building. If the client does not envision much added value of the MP, than updating is regarded as not essential and added value of a time stamp is neglected. The contractor and facility manager mentioned that the 3-D viewer does not provide the necessary overview of location of components in the construction and is hard to manage. The knowledge of the material passport stays with the ones developing the material passport. There is currently no training given to clients that receive a material passport and it could be argued if this would be necessary. Madaster mentioned this could be a good idea.

The client also argued that a material passport in essence is a working document and should be kept up to date over the years. Triodos thinks that market parties will arise that could deliver an upkeep service. Triodos explained that training personnel to work with MP is not very likely because the turnover of personnel and possible associated costs are too high. Nevertheless the client has not decided yet if and how to apply and work with the MP during the use phase.

Questioning how to upkeep the MP and how to organise the upkeep answers remained rather blurry. Madaster explained that currently its business activities are not focussed on facilitating upkeep services. Triodos aims to keep the intrinsic value up to date. However it is not intended to educate and train inhouse personnel about the use and application of the MP. Triodos explained that they will monitor the market and see what parties arise that could offer these services.

The installation contractor explained that the current BIM structure is not supporting linkage with asset management systems making it hard to automate upkeep records with the asset management systems

Overall it remains a question for the project and other projects having implemented a material passport which policy is decided upon in order to keep up information up to date during the exploitation phase of the property and if the MP generated is a static document or becomes a dynamic and living document.

4.1.5 Collaboration, Cultural and Organisation

4.1.5.1 *Collaboration, new roles and competences*

The implementation of a material passport did not have a fundamental impact on the way parties collaborated during the construction process. However new information requirements and the experimental character of implementation added a different dynamic to the collaboration. This resulted in the fact that parties needed to work more closely together and created a collaboration environment that was perceived by project stakeholders as being less hierarchical.

Although the MP implementation process increased the workload for stakeholders and more information needed to be registered this did not result in the generation or creation of new roles or functions or competences. It can be argued that Madaster, the material passport facilitator, can be seen as a new player or consultant within the construction process. For this project is aided with the development of the MP and MP platform. Madaster did not act as an information manager and left the further development and implementation of the MP to the contractors.

It is noted that for the Triodos project the evaluated option of a leased façade was not chosen. As such the conclusion and evaluation of participants that MP does not imply any new roles and/or functions may not be representative. The example given by Madaster regarding van Wijnen realising temporary houses in Groningen involved collaboration with a circular financing party. Although parties express that in order to make the transition towards a circular economy partnerships should be searched that are not always obvious within the traditional construction industry. For this project relationships remained rather traditional. The contractor had requested input of recycle and demolish companies on the information requirement of the MP, however this did not provide many fruitful insights.

Although no new roles or functions originated the role of BIM directors and coordinators became increasingly important in order to correctly implement the MP. For the BIM coordinators from the contractor this meant that they had to aid and train suppliers with their information management and provide BIM protocols for the delivery of information. BIM is

becoming increasingly integrated within the construction process and therefore the contractor is currently training more personnel such as work planners with BIM implementation and modelling. This may reduce workload for BIM coordinators and directors and make it possible that more people on project level can work and model with BIM and respectively can aid and generate MP's. As such a shift of focus, competences and activities is envisaged within the functions in the organisation.

The implementation of the MP did require BIM coordinators to educate themselves and aid the development of the MP so that information is correctly portraited and linked between MP and BIM files and protocols. The addition of life cycle thinking and the uptake of data surrounding circularity within the MP are relatively new concepts. Therefore stakeholders that were responsible to enrich the material passport had to gain competences and understanding of what characterises and make materials circular. These insights of the circularity of materials relate for instance on topics: recycled content, possible recycle options/reuse strategies, demountability and toxicity are not always self-evident and cannot be entirely derived out of suppliers data. Therefore assumptions had to be made during the enrichment process, because suppliers did not all have the means and knowledge to gather and deliver all the relevant circular data necessary for the enrichment process.

For this project the data is internally controlled by the BIM coordinator with the use of clash control, however the enriched data with respect to circularity is not audited or controlled by other parties such as Madaster. This added layer of verification could aid future implementation of MP's as it would allow for the generation of possible circular certifications of construction. Furthermore it would add to the credibility of information that is registered within MP's. After delivery of the material passport it is unclear how the client is going to maintain and keep the MP up to date over the life cycle of the construction. Madaster does not provide such services and the client is hesitant to train in house personnel on this topic. The client takes on a passive role and will assess which parties may provide these services and expertise on MP upkeep within the future market space.

4.1.5.2 *Collaboration, Responsibility of data delivery*

For this project the civil contractor had the contractual obligation to deliver the material passport to the client. Although the commitment was made before subcontractors and suppliers were contracted not all suppliers had the means and capacity to deliver to the contractor all the required information with respect to the circularity insights.

Not all suppliers work with the same BIM format or do not register all the information requirements within a material passport. Therefore there was resistance from suppliers because this also implies extra work. This had mainly to do with the fact that the MP implementation did take place after the engineering process. Therefore the contractor and the subcontractor assisted suppliers with a framework on what information needed to be delivered. As a consequence the civil and installation contractor had to enrich loads of files and information and request information.

According to Madaster the responsibility to deliver information should be put towards the suppliers and product manufactures, parties having most of the knowledge of their materials and products. The contractors agreed as they mentioned that within the next project they will provide a better information protocol and support suppliers more proactively who cannot deliver.

4.1.5.3 *Collaboration, Conflicting interests*

Nearly all parties agree that there were no real conflicting interests with respect to the implementation of the material passport for this project. The experimental character of implementation could explain the lack of conflicts during the implementation phase. According to the developer the contractor had to be persuaded to make the time and efforts

available to implement a MP that provided real added value and contained as much as possible relevant circular information. The client agreed during the process to allow a variation order for funding the necessary additional costs and efforts and as such taking the barriers away for reluctancy or frustration. The consultant of the wooden structure supplier explained that the request for additional information with respect to MP for suppliers often does not come with additional funding.

It may be assumed that the experimental character and being one of the front runners in the developing circular market smoothened the path of cooperation rather than entering in any conflicts. Also no new concepts like product as a service and leasing concepts proved attractive to parties and as such did not imply possible areas of conflicts.

As described in chapter 4.1.4.3. executing parties evaluated that they doubt the added value of the MP as implemented for the Triodos project in reference to the process using the BIM tool. The contractor noted that being involved in circular new conceptual approaches is added value in order to gain knowledge and experience in facilitating reuse and MP implementation but mainly to add innovative projects for the reference list for future qualifications.

For this project the partnerships and contracts remained rather traditional. However representatives discussed that different circular approaches could lead to conflicting interests within the value chain. Take back agreements would shift risk allocation towards the suppliers. The developer explained that circular development and keeping materials in the ownership of the original supplier would imply a entirely different development process with different revenue models. This would greatly impact the business case for developers according to the developer, however it is assessed that the market is not yet ready for this change. The architect reasoned that when suppliers remain owner and facilitate the construction and demolition of their products this could imply a threat to the traditional contractors business case.

Madaster explained that intellectual property, ownership and transparency of data are a legal topic however may imply conflicting interests between parties in the cooperation. The client aims to act sustainability and circularity responsible and facilitate the maximum reuse of materials and minimise consumption, depletion and waste. This ambition may be hindered by intellectual property issues and imply conflicts of interest.

It is noted that both the civil contractor and the project developer have joined the Madaster platform as a “Kennedy”. In this platform lessons learned and possible improvements are shared with colleague parties and the concept of the material passport promoted internally as well as externally.

4.1.6 Legal

All representatives confirmed that no major legal barriers are envisaged for the implementation of the material passport within the construction sector. Within this chapter the interview topic of legal, tender procedure and contractual obligations are elaborated. The legal perspectives with respect to intellectual property and transparency, ownership and access of data is described. Also viewpoints with respect to legal approaches that could stimulate the use of MP’s within the construction industry.

For the Triodos project the contractor had the contractual obligation to deliver a material passport. During the procurement phase and within the contractual specifications it was not stipulated what the form and requirements were of material passport to implement.
Early on during the engineering phase it became clear that the client and project developer wanted more than just a summary of the applied materials into an excel format. For this reason both the contractor and the project developer entered into a partnership agreement

with Madaster in order to make use of their platform and knowledge with respect to material passports and their application. Because additional efforts had to be pursued to implement the Madaster MP the client agreed to allow a variation order to cover the extra costs of man hours for the contractor and its subcontractor.

During the tender phase the material passport did not belong to the award criteria and therefore it is hard to say how the MP fits within the framework of the European tender procedure. According Madaster there are no legal barriers for taking up the implementation of a material passport as an award criterium. However the contractor argues that it could be hard for clients to evaluate and define what they require from a material passport because of the experimental character. The contractor also mentioned that a MP as a tool has little distinctive character and that most main contractors have taken up Madaster as a partner making it hard to incorporate the MP application as an award criterium within European tenders. From a non-discrimination principle it could be hard to incorporate such an experimental tool because not all contractors have MP experience and there are no real alternative tools on the market. The client mentioned that as a private corporation they have more freedom during the tender phase compared to public parties that have to follow the rules of the European directives. Therefore it has to be assumed that Madaster referred to the inclusion of MP as a requirement instead of a award criterium during the tender phase, and that data handling and use of BIM protocols that are necessary to implement a MP can be one of the award criteria. When clients include circularity as an award criterium, stakeholders can refer to the implementation of a MP as a way to describe their plans, ambitions and circular strategies for the project.

The contractor referred to other parties claiming to be circular. However there is limited objectivity and the use and evaluation of a circular index is still relative. As such references used in qualifications for tenders are not always objectively to compare in order to evaluate the companies applying for tenders. The current version of Madaster contains a kind of circular scoring mechanism and index, however this index is not sophisticated enough nor objective and auditable in order to compare indices between several projects.

The request for information with respect to the MP implementation was part of the contracting of suppliers and purchasing agreements with suppliers by the contractor. According to the contractor all parties were aware that some kind of added commitment and effort was requested from them. During the implementation process of the MP the civil and installation contractor did not encounter suppliers that were unwilling to share and facilitate the additional information needed to enrich the MP.

Madaster explained that intellectual property, ownership and transparency of data are a legal topic and as such a concern for conflicts of interest. The concern of suppliers to provide total transparency about the materials and components is emphasised by the consultant of the wooden structure supplier. He explained that some of his suppliers have in house expertise or intellectual property that would have to be disclosed when total transparency is to be provided. With providing this information it may imply that competing parties learn the added value of materials and/or components and/or processes and may harm the advantage the supplier has in relation to its competition. This reservation of suppliers could be taken away when proper measures are taken to protect the privacy of data and the intellectual property by the incorporation of added non-disclosure agreements. According to Madaster suppliers can alternatively provide higher abstract levels of information so that suppliers' concerns are covered and IP's remain protected. However it became not clear during the interviews how relevant this abstract information level is for the end of life scenario's. According to several parties it is important to have full insight and knowledge of materials and products in order to take responsibility for its implementation and future actions. Therefore Madaster and the architect suggest that the party that holds the responsibility for the product should have total transparency of what is within their products in order to take appropriate actions. They

suggest that when suppliers keep the responsibility for their products e.g. maintain ownership of the product they do not have to provide full transparency to the client. When responsibility is transferred to the client there should be some rules or conditions with respect to transparency of suppliers. How this is organised within the current legislation remains blurry. A different alternative to facilitate transparency within the value chain would be that suppliers enter into a non-disclosure agreement with certification organisations that provide insight into the circularity of products or materials. This could provide insight into for instance the use of non-toxic materials without having to comply to providing full transparency towards the client.

The civil and installation contractor noted that they created and developed new and additional data for their contribution into the material passport. When final delivery of the passport to the client is processed, the ownership of the data is transferred to the client. The information is stored on the servers of Madaster and the client pays a subscription fee in order to access the information during the lifetime of the construction. After the MP becomes property of the client the responsibility to maintain the MP is also transferred to the client.

For this project the MP is a linkage of BIM data, such as geometry, volume and location, with enriched database of product and material specific data with respect to circularity. The installation contractor noted that because ownership of the entire model is transferred to the client the contractor cannot use their enriched information within the Triodos project database for future projects. For the installation contractor who frequently uses the same parts in different projects this would reduce the workload for the enrichment process as it could link the Madaster database with respective BIM models. For the civil contractor this is not a major barrier as their products are quite project specific. Madaster explained that this project data lockup is part of the current platform and within future developments they will try to facilitate the decoupling of the enriched databases from the project specific MP. By doing this it would allow contractors to make specific data bases and link them to the project.

Data that was gathered and enriched within the material passport was only accessible and available for stakeholders that had entered into a subscription with the Madaster foundation. This meant that the civil and installation contractor could not let suppliers enrich the information directly into the material passport. The transfer of ownership after delivery furthermore implies that the client has the right to decide who retains access to the material passport.

Several parties envision an open online platform that links all material passports for parties to get a better understanding of when and where future materials may become available. However in the current data and ownership structure this would imply that clients have to be willing and give permission to use their data within such a derived platform. The client was not opposed to the sharing of the MP information within such a platform, however said that it would be only interesting for them when the construction reaches end of lifecycle.

From a security perspective one can imagine that a client with strategic processes and strategic buildings may have problems with sharing associated data within such an envisaged platform. The client did not really address this issue within its response.

With respect to privacy of data and intellectual property the participants did not have a clear and shared vision how to solve possible transparency issues and overcome possible distinction and competing issues when implementing and developing a material passport. The privacy of data is of course impacted by who has the ownership of the data and access to the MP. It did not become entirely clear how this privacy of data is guaranteed and the contractor noted that it could be quite possible that suppliers are not aware how the information will be handled in the future. According the developer the contractor had some reservations with respect to privacy of data because it feared that from analysing the delivered MP other parties could extract their BIM protocols and procedures. In order to

apply material passports stakeholders have to agree a proper way forward to overcome these possible conflicts of interest as evaluated by involved stakeholders in the value chain.

According to the transition agenda the government must also stimulate circular construction. Clients within the construction industry can make use of the Environmental investment deduction (EIA) and Arbitrary depreciation of environmental investments (Vamil) subsidies for investments into circular constructions and sustainable implementations. One of the boundary conditions for being able to receive this subsidy is that materials within constructions should be registered within a material passport. These subsidies in effect thus stimulate the implementation of MP within the construction industry as without a MP no entitlement on governmental funding may be claimed.

4.1.7 Financial

Considering a construction as a material bank materials and components ideally should remain valuable over the life cycle of the construction and therefore should not be depreciated to zero within a circular build environment. According to the contractor expressing residual value in monetary terms is an important stimulus for the transition towards a circular build economy. The contractor further noted that estimating the residual value of materials and especially that of reuse of components is rather difficult to assess, mainly because experience with second hand reuse is lacking within the construction industry. Furthermore due to the fact that most of the material circulation will only materialise within the far future after the decommission of the building. An additional risk for estimating residual value is the uncertainty how the market for second hand materials will develop. The flexibility of exploitation period (40, 50 or more years before end of life) have a major impact on the net value of respective scenario's. Accordingly the assessment of residual value choices is quite subjective.

Residual value is incorporated within the material passport for the Triodos project. During implementation however this overview was not yet fully developed and usable. Therefore this overview was added as an additional tool after completion. For the Triodos project residual value is defined within the tool as the current spot market value of raw materials discounted with the costs of extracting the materials out of the construction. This approach is suboptimal as it focusses only on raw materials while within a circular economy the value retention should come from higher level reuse instead of material recycling only.

According to the architect and project developer the materialisation evaluation for this project was based on finding the optimal balance between initial cost investment and exploitation cost over the lifetime of the construction. The project developer explained that there was an incentive to choose for durable materials that require less maintenance over their lifetime. The architect further explained that an additional consideration for materialisation choice was the use of shadow cost calculation which allows environmental impact (CO_2 emissions) to be monetarised and taken into consideration.

For this project the project developer evaluated different circular contracting and financing strategies with the client such as pay per use and take back agreements. Together with the façade company it was investigated to make use of a buy back agreement for the façade. Meaning that the façade company would lease the façade of the project to Triodos while keeping full ownership of the façade whereby at the stage of dismantling the company would take back the façade. Nevertheless the financial construction was not applied for this project because there were to many legal uncertainties. The client explained that it was hesitant to follow this path. In case of bankruptcy of the façade company the risk could be that the façade would be claimed by curators. The architect and contractor further explained that this alternative way of financing products is currently financially unattractive when a construction has a long exploitation or lifetime and there is sufficient equity. These financial constructions are in fact a deferment of payment with significant interest rates and additionally contain a

risk markup and as such are not financial attractive. To give an example: the implementation of a pay per use elevator was evaluated and resulted in 30% more costs than if the elevator was financed, owned and maintained by the client.

The points of view of stakeholders on the development of circular financing are contradictory. On the one hand Madaster explained that their MP acted as a legal and notary document for a project they did with van Wijnen Noord to ensure financing for a temporary construction with buy back agreements. The project developer however did not see these kind of developments in financing for constructions that have a normal exploitation period (50-100 years) because there are too many uncertainties.

In perspective of the above the client explained that it is currently unattractive to initiate alternative circular contract forms and incorporating residual value into their investment decision during the early stages of the project, because there are too many legal and accountancy uncertainties and risks. Although not implemented it can be concluded that incorporating circular ambitions with the use of alternative contract forms comes at a higher total cost than the traditional financing approach. It can be concluded that the implementation of the material passport did not impact the perception of risk and reward from a financial perspective.

According to the contractor the implementation of the material passport did come at a considerable additional cost and time investment. The MP implementation is part of the clients ambition to aid in the development and transition towards the circular build economy. From a financial perspective however it is not clear if the benefits will outweigh the initial cost investments and possible costs of upkeep the material passport up to the end of use of the construction.

4.1.8 Technical

4.1.8.1.1 How is circularity incorporated into the project?

The period between the initial design and the drafting of the programme of requirements (POR) in 2011 and the commissioning of the building in 2019 is almost a decade. The tender based on technical specifications and design was in 2017. According several representatives a lot has changed with respect to the use of the terminology circular economy and the awareness of the concept in the built environment. The architect and project developer both involved during the early stages of design noted that in 2011 the term “circular economy” was not known or used. The term is absent in the POR. Also the tool of material passports in order to optimise circular economy ambitions and its potential development and implementations as such were not known at that date. It is only somewhere about 2017 that the possible use of material passports were considered. That is when the Madaster foundation was founded, just one year before the start of construction of the building.

Given the fact that the term was absent at design stage the question arises how circularity is addressed and incorporated into the design decisions and during the construction phase. The architect explained that the construction was conceptualised as a material bank containing and describing valuable materials. The material bank concept extends upon the cradle-to-cradle ideology, with the goal of reducing waste and promoting reuse. Based upon this approach the construction was designed to be fully demountable. The project developer noted that when analysing the POR in retrospect many decisions were made that nowadays would be categorised as circular building. At that time this was called building “as sustainable as possible”, such as building demountable, without toxic materials, and with materials that can be easily reused. Additionally design decisions were based on shadow cost calculations, whereby construction costs and associated emissions are expressed in monetary values. For this project this resulted in the application of a wooden support structure instead of concrete. It should not be a surprise that MP has not been used during the design phase given the tool

or concept were then not known yet. Nevertheless the mindset to provide materials with an identity in order responsibility can be taken for future use of materials has been present as of the start of the project.

4.1.8.2 *What information needed to be included in MP with the use of BIM?*

The Client has decided to apply and implement a material passport for the project. The purpose of the passport is to register data in order to facilitate the reuse of materials at the end of life of the building. No decision yet has been taken by the client how to manage and actualise the data and potential renovations during the use phase of the building. The civil contractor became contractually responsible for developing, implementing and commissioning the passport. The specification and requirements for the format and content of the envisaged material passport however was not clear nor detailed. Within the collaboration the project developer, Madaster and the contractor formed a partnership to develop the passport with the goal of making a success of the implementation. From an operational perspective monthly consultations were held addressing the development and implementation and problems encountered. The BIM manager mentioned that due to the lack of specifications the civil and installation contractor, project developer and Madaster have set the target quite high. Trying to make something usable for the client, quite detailed and containing as much relevant information as possible to facilitate future reuse. Several parties confirmed that the total process to develop the material passport has been quite intensive and long.

According the BIM manager it was not clear at the start what information the MP should contain. The goal of the implementation was to deliver the client a registration tool for the ‘as built’ situation containing as much relevant information as possible to facilitate future recovery, re-use, and recycling of materials and products in the building. To generate an online accessible material passport the Madaster platform was used. For this project the goal was to compile this passport with the use of BIM data.

Before further describing the use of BIM data for the MP development and implementation it is good to elaborate why a MP is applied as a registration tool for this project. The MP provider explained that in a regular BIM modelling process relevant information (geometry, material, location, connection) is captured and registered. These data may be of value for facilitating future recovery, reuse and recycling of materials, but is not complete and adequate for this purpose. Additional information relating to material characteristics is required to optimise the potential of facilitating reuse. As example additional information relates to heritage, demountability, toxicity, circular-content, etc. The material passport is as such a more comprehensive set of information that is not normally found within BIM data sets. As such the MP adds an additional layer of information to the data as registered in BIM models. This comprehensive set of information is of added value in order to facilitate the future recovery, reuse and recycling.

Furthermore it is mentioned that a MP can be seen as a platform that can manipulate and display this information in such a manner that additional tooling can be applied. For this project different tools in the MP have been developed such as the ability to estimate residual value, assessment of demountability, circular score of the building and the 3D viewer.

To compile and link information from BIM models into the MP so-called BIM-IFC files must be uploaded. IFC files are the international exchange formats for BIM models and contain both 3D elements and information (parameters) associated with these elements. These IFC files can be generated from any modelling program.

The BIM manager explained that IFC files must meet certain requirements before they can be linked into the MP. Knowing a MP had to be delivered all the necessary Information Delivery Specifications (IDS) were communicated to stakeholders using a BIM protocol. This

protocol specifies that all elements should have a NL-SFB classification: this code is used to categorise elements into certain building layers within the MP. Other Delivery specifications that are necessary to generate a MP out of BIM data are the materialisation, geometry and quantities of materials.

The BIM manager explained that IFC files of different models can be compared with PDF files for text documents. Everybody can read the PDF file, but when the files need to be edited, this can only be done within the source file. During the BIM modelling process IFC files can be generated by either design/performance models (architect, civil and installation contractor) that describe what is to be constructed or production models (supplier) that describe how it will be built.

For design models there are only a few programs (Revit, ARCHICAD) in use. However for production models there are 20 to 30 programs available. According the BIM manager production models represent the most comprehensive information set of the 'as built' situation and are preferable over design models when making a comprehensive MP. Contractors and suppliers select for their operations BIM packages that meet their demands and goals best. In practice this may imply that packages used differ between respective partners and the architect. With respect to data handling to generate the MP the respective models used were different which caused several issues. An issue with production models is that generally they do not excel at generating accurate IFC files that portrait the correct information in the correct format necessary to make a MP. Another issue was that not all suppliers have the same knowledge, experience and capacity to deliver the required information specification needed to make the MP.

The civil and installation contractor realised and accepted that involved parties used different models and applications not generating accurate IFC files and that not all parties could deliver the required information specifications. Consequently the BIM manager and the installation contractor had to manually alter any incorrect IFC files in order to link and categorise before uploading data into the MP. They also had to request and include all of the information that suppliers were unable to incorporate into their models. These efforts mainly concentrated on the data in the BIM models.

A further step consisted of enriching and manipulating the data within the MP itself. Within the Madaster platform a material and product library is provided. Evaluating the enclosed standard materials are all "virgin" materials and as such have a poor circularity score. For example steel or concrete may already contain a percentage of recycled materials. In order to achieve a better circularity score it was necessary to update and enrich this materials database manually.

A next step was to categorise elements into materials or products (a subset of different materials). According the BIM modeller and installation contractor classifying elements was not straightforward. This required substantial additional efforts to enrich products and their composition and material quantities. It is difficult to asses when a product differentiating just a little bit becomes another product. An example is a sewer pipe with slightly other dimensions. Or a window frame being 5 cm wider. To overcome this problem and reduce the workload a workaround for some products has been introduced. For some elements a product was created in MP and a Global Trade Item Number (GTIN) was coupled with this product. This product can then be linked with a location allocation within BIM so that at least the location is known. This GTIN code can be used later to identify what product or materials were applied for potentially enriching within future MP updates.

The last step is to link the MP with the IFC files and check the mapping. At the start of the process this mapping contained numerous omissions. Therefore it was decided to manually

link and manipulate the codes so that the correct IFC files are linked with the correct materials or products in the MP.

The BIM manager explained that not every element of the construction is modelled in BIM. During completion phase it proved that mainly suppliers and subcontractors did not use BIM models. Also the installation contractor mentioned that not every detail is modelled, for instance not all cables, pipes and suspension brackets are incorporated in BIM and as such in the MP. For these elements the design models (less specific models) of the architect or constructer are uploaded into the MP. Other elements like the interior and furniture are not included within the MP as these are not modelled in either BIM model. The client explained that for the interior they use an internal facility management tool.

Due to the experimental character and development of the MP implementation the BIM protocol describing the specifications and the requirements did not proof bulletproof. As such subsequent additional requests for information were issued. These requests mainly concerned information to enrich certain products and materials for incorporation of respective data in BIM as well as in the MP. The additional information was not always known by suppliers. It is noted that suppliers did not have direct access to the MP in development. As such the required enrichment has been performed by contractors themselves.

In retrospect all parties participating in the enrichment process and the material passport development did not anticipate the substantial additional efforts and associated costs to deliver the envisaged comprehensive MP. Parties mentioned that current implementation process is yet far from automated and future applications must be more simple and transparent.

The contractor mentioned that having been involved with the MP implementation has given the opportunity to learn from and to reflect the process and evaluate possible improvements. The BIM manager and the installation contractor noted that currently they are developing an implementation plan and are revising BIM protocols improving potential future MP implementations. It is important to remain aware of required ability and knowledge of suppliers and realise that what is requested from suppliers is clear and achievable.

4.1.8.3 *Tooling using MP*

As described in article 4.1.8.2. above the MP can be used as a data model to generate additional tooling.

4.1.8.3.1 Circular Building Indicator (CBI)

The circularity of the Triodos project was indexed based on the systematics of the Ellen MacArthur foundation. By enriching and uploading data into the MP the applied “algorithm” generates the so called Circular Building Indicator (CBI) of the project. The CBI scores elements and the construction on their circular impact during the construction phase, use phase and end of life phase. The contractor was quite sceptical about the method and objectivity of the CBI score. When defining the recycled content indicating what percentage can be reused without specifying how reuse is envisaged the definition becomes subjective. When concrete is grounded into granulate which can be reused for 100% is nice, but cannot be regarded as high level reuse. The algorithm does score products higher that have a circular end of life scenario, however no differentiation is made between re-use and recycling. According the contractor this gives a distorted view of real circularity and does not promote stimulating designing and constructing higher level circular scenario’s. The Madaster representative confirmed to be aware of this problem. It is envisaged to further develop this kind of tooling for its passports with partners.

The objectivity of the CBI is further at stake. The MP requires different kind of details and data as normally used applying BIM models. The civil and installation contractor noted that circular information requested from suppliers is not always known and available. For topics such as recyclability and the use of toxic materials suppliers need to go back into their value chain, whereby some detailed data may not be available at all. The consultant for the wooden structure supplier mentioned that when suppliers are not compensated for requested additional efforts may demotivate suppliers and may result in suboptimal feedback. This feedback may often be provided on basis of “logic reasoning” or guesswork. Another concern with the scoring system is the lack of data for filling in the end of life scenarios. This information is also based on “logical reasoning” of the people that enrich the data and is not linked nor supported with demolition plans or deconstruction plans. Contractors have to incorporate data received of products and materials which do not belong to their core knowledge and competences. As such they cannot always evaluate the correctness of data received and incorporate these data as received. As such data registered is not audited and may not be correct. As such the quality and auditability of CBI generated by the applied algorithm may be at stake and not be representative for the project. The auditability and validation of CBI may also benefit to facilitate an objective ranking of projects realised with tenders and include in project references.

4.1.8.3.2 3D Viewer in MP

The 3D viewer from a BIM model has been applied in the MP tool. However it is mentioned by representatives that identifying the location of elements and components was not easy and not efficient.

4.1.8.3.3 Demountability

As mentioned by the architect demountability has been adopted as main principle in approach during the design phase for designing as sustainable as possible. A MP however does not provide a detailed plan of how materials can be salvaged best. It is mentioned when demountability is integrated into the design the associated demountability strategy should be clear and preferably developed as well. For the project a dismantling plan from the façade (Octatube) was requested, however has never been supplied nor implemented. This may be relevant, since views of the demountability of the building differ between representatives. The architect and client are convinced that every component in the end can be dismantled without serious damage to the integrity and quality of the component. The BIM manager however is more sceptical. As noted not all details are incorporated in BIM as well as in MP, like cables, ducts and supports. The construction method is envisaged to use dry connections. In practice however PUR foam is used and cement is used to level areas. The project developer and BIM manager added that some parts of the construction use fixed connections; for instance, the cast concrete basement and the occasional use of kits and adhesives. When dismantling this may imply substantial efforts removing adhesives and making the many nuts and screws accessible and subsequently unbolt and unscrew the connections. As such also integrity and quality when dismantling elements may be harmed. As such despite the application of the design principle the actual dismantling of elements and the building may become a costly process. Another aspect was noted by the contractor. The building is designed with many curves and circles. It can be doubted that the potential reuse of elements of the building can simply be applied in new future buildings.

4.1.9 Closing Questions and Remarks

4.1.9.1 *Mandatory use of Material Passport*

The view of representatives with respect to the mandatory use of material passport within the construction industry is not aligned. It is noted there is a distinction between passports for all type of projects or specific for new projects.

The client does not favour a mandatory use of MP’s for new constructions. In case clients are obliged to apply a passport, but lack the intrinsic motivation to implement and actualise

during the life cycle, the risk of becoming an administrative “check the box” procedure with associated extra costs is realistic. When the client over the lifecycle leaves the documents and MP in the drawers there is not much added value from implementing the passport. The installation contractor confirms this opinion. He addressed that more awareness must be given to the handover process of the material passport so clients gain a good and better understanding of the tool and how to use it.

Madaster and the architect both favour the mandatory use of the passport. According to them now is the time to start registering and documenting materials within constructions to become more circular oriented and aware within the construction industry.

The architect notes that introduction of a mandatory use requires the parallel introduction of financial incentives, like stimulation or taxation or similar. The parallel introduction of incentives motivates the sector to become more circular.

All parties evaluate that currently the tool as well as the implementation processes are not yet fully developed and require further improvement. Also there is still a lack of standardisation between different MP’s and MP platforms. As such the contractor is convinced that a mandatory use is currently too soon for the construction industry and more iterations and improvements are required for the matureness of the MP development before considering the mandatory use.

The installation contractor and the modeller of the contractor are not against the mandatory use of the passport, however recognise that it is too early to decide if the current tool is implemented in the correct manner and if data are complete and adequate for its purpose. Additionally they noted that the reliability and workability have to be further improved and that it has to become easier to implement the MP.

In summary the stakeholders do not share the same opinion, whereby some parties argue that the current immatureness and possible lack of intrinsic value to use the MP over the lifetime represent major risks for early governmental involvement. These considerations are also taken into account with parties stating not to be against a mandatory use, however are concerned about the ease of use and the ability to implement MP’s. Madaster suggests that legislation has to take these concerns into account. In case something becomes mandatory it must be manageable for everyone regardless of education and role within the chain. The main challenge will be to find the balance between simplicity without compromising the core idea and philosophy of the material passport.

4.1.9.2 *Perspective future material passport and opportunities of implementation*

Both the introduction question and closing evaluation question of the interview relate to the subject of future perspective and the envisioned opportunities of the material passport implementation. It is chosen to merge these two topics due to similarity of these two topics and answers from representatives. Most representatives viewed opportunities of MP implementation from a perspective of further development and improvements of MP’s.

Most parties asses that a material passport is a valuable tool to register and share the information of materials that are incorporated and stored within buildings. According the client a material passport facilitates the evaluation of easiness to dismantle the building without losing materials and products potentially reusable in other buildings. In order to realise the reduction of waste and transition towards a more circular construction sector, Madaster viewed a MP as a boundary condition. Materials are limited and registration is the first step into giving materials an identity. The transition should start from the principle that stakeholders have to know what they have, before they can do something with it and take responsibility for their actions.

In essence a material passport is a digital tool. Based on assessed further required improvements most parties envision that the future material passport will be generated automatically and only limited enrichment is required. According to Madaster automatic information delivery and processing will be interwoven in the future construction process. In the supply chain products and materials will be available with associated material or product passports. Parties within the construction chain may choose from and compound these passports and link them with the building geometry into an integrated and automated material passport of the building. Parties noted that standardisation is required in order for the material passport to become a widely accepted tool. Standardisation is defined as the standardisation of one universal system or material platform with a standardised systematic implementation approach.

Most representatives see opportunities by linking respective material passports of buildings in order to ensure the creation of a business model for recirculation of secondary materials within the construction sector. Parties envision an open online platform as a step change for an efficient marketplace and a grid of smart logistical and temporary storage hubs for secondary building materials and products. As such stakeholders can analyse when and where materials and products incorporated and stored in buildings become available or where these are stored and available within smart hubs.

For this project and in general the contractor argued that the focus of the MP implementation as a registering tool is on facilitating rather than stimulating a circular economy within the construction industry. An extension of a circular scoring mechanism to the MP tool can stimulate the contractor to engineer and build more circular constructions. This would allow the contractor to build up a portfolio of circular projects for reference purposes in order to distinguish the company from its competitors. The current version of Madaster contains a kind of circular scoring mechanism and index, however this index is not sophisticated enough nor objective and auditable in order to compare indices between several projects.

Currently the material passport for this project is implemented as a registration tool after the design and selection of components and materials has been completed. Among other stakeholders the architect envisions an earlier use of the material passport in the design and construction process. Where material passports can be used as a guidance tool for the objective scoring or generating of a circular index in order to aid the development and optimisation of circularity of the construction within the design phase. The implementation of a ‘design phase MP’ can have a major impact, as the architect stated: ‘you cannot actually build circular, but we can build and design our construction with the optimal circular potential’. Because it is inherent to the design process that less information and less detailed information is available compared to the construction phase, it is recognised that the MP for the design phase can be a simplified version of the ultimate ‘as built MP’ version. The project developer confirmed this vision and also recognised the opportunity that also the implementation of the MP during the design phase for renovation projects may optimise the use and reuse of available materials and products within the building. With respect to the design phase both the contractor and the architect envision that the creation of a market place is an important step to integrate secondary building materials and products into designs. By linking the design phase MP and the materials in the secondary market database these materials could become the point of departure for architects in order to come up with circular design solutions and facilitate circular material usage.

Besides the implementation of the material passport during the design and construction phase the installation contractor mentioned the opportunity to extend the application into the exploitation phase. Where a material passport could act as an asset management tool and a viable solution to stimulate clients to keep the material passport up to date while effectively maintaining the building. Currently the material passport is not suitable for use as an asset management tool. In order to integrate this functionality into the material passport relevant

data with respect to asset management and circularity must be gathered and enriched during the construction phase. The project developer added that an “asset management” MP tool enabling a good overview of the status of materials or products and their location in the building may contribute to optimising maintenance and upkeep. In line with this reasoning Madaster explained that in order to allow stakeholders a better insight when changes are made in the MP and in order to keep the material passport up to date the first step should be to integrate time stamps as a functionality into the passport. This would allow stakeholders to track when changes are made within the passport or when for instance parts are repaired or replaced.

In case the application of material passports becomes mandatory the passport will become part of legal documents within the construction sector. Madaster recognised the potential of a MP as a legal document that can be used as a supporting tool for legal, financial and economic documents. It is envisioned to couple MP’s with cadastral information. Currently cadastral information only specifies the location, dimensions and ownership of a building. Coupling cadastral information with MP’s can easily extend and include the data with information of materials and components and their location within the building.

From an economic and financial perspective opportunities are envisioned to use the material passport as a tool to ensure financing for circular construction projects. Approaching the construction as a material bank a MP may be used to provide insight into the demountability of constructions and potential of reuse in order to assess the collateral or residual value of a construction. Reference is made to an example where a contractor, Van Wijnen Noord, deposited the MP as part of documents deposited with the civil law notary to ensure financing for a temporary construction project. The project developer added there are opportunities to use MP’s during purchasing of new development objects. Insight in the quantity and condition of materials and components are valuable for developing parties to assess the value of new investments.

According the consultant of the wooden structure supplier the implementation of a material passport has opportunities for creating more transparency and circular awareness within the value chain.

4.1.9.3 *Did the material passport satisfy your expectations and requirements?*

The implementation of the material passport for the Triodos Bank Project had an experimental character and for some parties this was the first encounter with the application of the tool. The goal for the MP implementation was to gather and register as much as possible relevant information with the use of BIM information in order to facilitate the circulation of materials at the end of lifecycle. The coupling of BIM with MP has not been implemented before and as such added to the experimental character of the implementation for all stakeholders. Consequently stakeholders encountered no real requirements for the application of the MP and its implementation process. The project developer and installation and civil contractor noted that the client gave them the freedom and additional funding to develop and implement the material passport. Although the client was part of the development process the parties had the impression that the client did not have many requirements for the implemented tool and left the development in the hands of the parties involved with developing the tool.

Reflections with respect to expectations are mixed whereby these expectations have to be managed given the experimental character of the implementation. The client was satisfied with the delivered product, however the proof of the pudding is in the eating. We can only evaluate if the passport has been perfect or that it still contains omissions when we will use it at the end of the life cycle of our construction. All parties that were involved with the generation of the material passport did not foresee the substantial extra efforts and time needed to implement the tool. The project developer confirmed this evaluation and advises

parties not to underestimate the efforts and work associated to apply a material passport. Especially considering that the generation and enrichment of the passport is presently not part of the scope of the primary construction process. The contractor encountered several issues with respect to coupling of the MP with his BIM model and mapping information within the Madaster platform. The installation contractor shared similar experiences where additionally it was expected the Madaster platform to supply a larger generic data base of building materials. Furthermore the installation contractor found it odd that within this data base of Madaster only virgin materials were provided. Most steel the installation contractor uses in constructions contains a certain quantity of reused steel and as such not only consists of virgin materials. The architect expected more feedback from the material passport in the form of a workable objective circular indicator of the design and the construction. The architect regards this topic important since having a material passport does not make a project circular if the adopted design and construction philosophies did not take circularity into account. Providing this feedback to parties involved during the project could motivate them and could be used as an incentive to make circular choices.

The consultant of the wooden structure supplier was not involved with the application of the material passport for the Triodos Bank Project. He referred to a project in Venlo in which he assisted with the enrichment of a material passport in the form of an excel format. After handing over the information the supplier did not get any feedback. Feedback is welcome in regard of the learning process or as an appreciation for no additional funding for enriching the data. Additionally information that needed to be enriched was information not easily accessible or unknown which could lead to unreliable information within a material passport.

4.1.10 Main observations and remarks research Triodos Bank Project

The circular economy is gaining momentum within the construction sector however the concept is still relative new and a challenge for all stakeholders. The transition towards a circular economy will require a shift in mindset, the development of new competences, processes, collaboration and operation of all the involved actors.

All representatives support and see the necessity for the transition towards a circular economy. Within practice the sector lacks a generally applied and accepted working definition for CE. Individuals and parties have different views due to their own personal and subjective perspectives and values. To facilitate the transition it is important that the sector works towards a general applied and accepted working definition for CE. An accepted and clear working definition will make discussions more effective and have all noses of participants in the same direction.

The material passport is a registration tool that may assist achieving circular economy ambitions preserving value, minimising use of materials and waste.

During the design phase of the project in 2011 CE was not yet broadly known and applied, whereby MP was only developed and evaluated as a possible tool in 2017. The design approach as such was based on the principle to design as sustainable as possible. Focus has been to introduce the concept of demountability into the design. In retrospective principles of circularity have been integrated into the design process and design decisions. Respective innovative concepts such as pay for use and take back options for façade have been evaluated in the design, however appeared not financial attractive and shifting risk to the client. The total cost of ownership has been adopted focussed on the proper balance between investment costs and exploitation costs. As such a relative conservative and traditional approach has been implemented and makes it clear that business models for CE are not always evident within the CI.

The Client has decided to apply and implement a material passport for the project. The private client can be categorised as an incidental rather than a professional and structured

employer of constructions. The main motive for the client to apply a material passport was to support initiatives towards the circular economy transition in line with its company ambitions to be the most sustainable bank in the world. The purpose of the passport is to register data in order to facilitate the reuse of materials at the end of life of the building.

At the start it was not clear what information the MP should contain. The implementation of the material passport for the Triodos Bank Project as such had an experimental character and for some parties this was the first encounter with the application of the tool. The goal for the MP implementation was to gather and register as much as possible relevant information with the use of BIM information in order to facilitate the circulation of materials at the end of lifecycle. The coupling of BIM with MP has not been implemented before and as such added to the experimental character of the implementation for all stakeholders. To generate an online accessible material passport the Madaster platform was used for the development of the MP.

The implementation of a material passport did not have a fundamental impact on the way parties collaborated during the construction process. However new information requirements and the experimental character of implementation added a different dynamic to the collaboration. This resulted in the fact that parties needed to work more closely together and created a **collaboration** environment that was perceived by project stakeholders as being less hierarchical. Parties noted that entering collaboration partnerships with new disciplines and parties is envisaged to be successful and creative approaching a more integral and circular approach. Since innovative concepts such as pay per use or take back guarantees appeared not effective during the design process the consequence has been that no new roles and functions became apparent for this project. It can be argued that Madaster, the material passport provider, can be seen as a new player or consultant within the construction process. The importance of the role of the BIM engineer was quite evident. For this project the civil contractor had the contractual obligation to deliver the material passport to the client. Although the commitment was made before subcontractors and suppliers where contracted not all suppliers had the means and capacity to deliver to the contractor all the required information with respect to the circularity insights. The contractor and the subcontractor assisted suppliers with a framework on what information needed to be delivered. Nearly all parties agree that there were no real conflicting interests with respect to the implementation of the material passport for this project. The experimental character of implementation could explain the lack of conflicts during the implementation phase. It is noted that intellectual property, ownership and transparency of data are a **legal** topic however may imply conflicting interests between parties in the cooperation.

Legally the implementation was a prerequisite in the tender for construction. However the specifications for format and content of the passport were not detailed and rather vague. The contractor as such became contractually responsible to develop and commission the passport. As such a rather traditional contractual structure has been adopted. No decision yet has been taken by the client how to manage and actualise the data and potential renovations during the use phase of the building. When clients include circularity as an award criterium, stakeholders can refer to the implementation of a MP as a way to describe their plans, ambitions and circular strategies for the project. However there is limited objectivity and the use and evaluation of a circular index is still relative. As such references used in qualifications for tenders are not always objectively to compare in order to evaluate the companies applying for tenders. Madaster explained that intellectual property, ownership and transparency of data are a legal topic and as such a concern for conflicts of interest. The concern of suppliers to provide total transparency about the materials and components is emphasised by the consultant of the wooden structure supplier. Data that was gathered and enriched within the material passport was only accessible and available for stakeholders that had entered into a subscription with the Madaster foundation. This meant that the civil and installation contractor could not let suppliers enrich the information directly into the material

passport. The transfer of ownership after delivery furthermore implies that the client has the right to decide who retains access to the material passport. Several parties envision an open online platform that links all material passports for parties to get a better understanding of when and where future materials may become available. However in the current data and ownership structure this would imply that clients have to be willing and give permission to use their data within such a derived platform. The client was not opposed to the sharing of the MP information within such a platform, however said that it would be only interesting for them when the construction reaches end of lifecycle. With respect to privacy of data and intellectual property the participants did not have a clear and shared vision how to solve possible transparency issues and overcome possible distinction and competing issues when implementing and developing a material passport. In order to apply material passports stakeholders have to agree a proper way forward to overcome these possible conflicts of interest as evaluated by involved stakeholders in the value chain. Since new and innovative concepts implying the introduction of new parties are not considered in the project related legal aspects were not further addressed. Reference was made to a project of temporary houses where material passports are used for legal and notary documents. In conclusion parties mentioned that more clients may request for material passports and circularity in their tenders without realising the associated substantial additional costs and efforts to date.

Financially considering a construction as a material bank materials and components ideally should remain valuable over the life cycle of the construction and therefore should not be depreciated to zero within a circular build environment. It is noted that estimating the residual value of materials and especially that of reuse of components is rather difficult to assess, mainly because experience with second hand reuse is lacking within the construction industry. Furthermore due to the fact that most of the material circulation will only materialise within the far future when decommissioning of the building. An additional risk for estimating residual value is the uncertainty how the market for second hand materials will develop. For the Triodos project residual value is defined within the tool as the current spot market value of raw materials discounted with the costs to extracting the materials out of the construction. This approach is suboptimal as it focusses only on raw materials while within a circular economy the value retention should come from higher level reuse instead of material recycling only. The materialisation evaluation for this project was based on finding the optimal balance between initial cost investment and exploitation cost over the lifetime of the construction. There was an incentive to choose for durable materials that require less maintenance over their lifetime. The architect further explained that an additional consideration for materialisation choice was the use of shadow cost calculation which allows environmental impact (CO_2 emissions) to be monetarised and taken into consideration. For this project the project developer evaluated different circular contracting and financing strategies with the client such as pay per use and take back agreements. Options were declined as not being cost effective and being risk increasing for the client and associated legal uncertainties. It can be concluded that the implementation of the material passport did not impact the perception of risk and reward from a financial perspective. According to the contractor the implementation of the material passport did come at a considerable additional cost and time investment. From a financial perspective however it is not clear if the benefits will outweigh the initial cost investments and possible costs of upkeep the material passport up to the end of use of the construction.

Technically the material passport is a digital data registration tool for circular material characteristics of materials and products incorporated. As such the passport establishes an additional layer of information and data as used in BIM tools. In a regular BIM modelling process relevant information (geometry, material, location, connection) is captured and registered. Additional information relating to material characteristics such as heritage, demountability, toxicity, circular-content, etc. is required to optimise the potential of facilitating reuse. It is noted that information in the passport is also not the same kind of data as in asset management tools, and actualising data during exploitation phase may imply

double and unnecessary administration and efforts. In practice the market offers 20 to 30 different type of BIM models and protocols. Data between respective BIM applications differ and are as such not comparable and exchangeable. These data are also not circular and material specific. Furthermore the database of Madaster platform contained characteristics of “virgin materials” only, whereby in practice products or materials applied already contain reused or recycled materials and as such database does not present circularity content as finally used for calculating the Circular Building Index. Also some suppliers refrain of supplying and exchanging of data based upon intellectual property and competitive edge considerations. Parties involved in the project use their own BIM models and databases, whereby also some suppliers did not use a model. As such the efforts and costs to evaluate and enrich data from respective parties as supplied and linking IFC files into the data of the passport were substantial. Also the qualification of level of scale was not straightforward. Additional costs and efforts have as such been underestimated and are substantial. Additional to the many different type of BIM models available on the market it is noted that several parties develop their own passport formats. Standardisation of use and definitions of BIM and MP is regarded as critical.

Within the MP **technically** several tools have been applied, such as demountability, 3-D viewer and calculating Circular Building Index and valuation of residual value. Demountability without a proper dismantling strategy in practice however may not prove to be realistic and achievable and as such can be costly and difficult to recover products with proper integrity and quality to reuse in other structures. The manipulation of data and assessment of circular content further may result in a CBI index not being correct and comparable. Also the assessment of residual value is subjective given that exploitation period may be quite longer or shorter as envisioned and not knowing if there will be a proper market for second hand materials. The 3-D viewer applied in the passport was also evaluated as not efficient.

Data as such are not easily and free accessible, comparable and exchangeable. When the passport was commissioned ownership transferred to the client. Enriched data by parties are after commissioning not accessible for parties and cannot be reused for future projects. The owner can only access his database in the passport via a subscription structure. It is noted that the client does not want to have his data accessible for other parties not earlier than at the end of life of the building.

Parties evaluate that the use of the passport can assist in achieving circular ambitions, however to apply and maintain and actualise the passport and data as of design phase up to exploitation phase may prove costly. The client was satisfied with the delivered product and regards the passport as an added value. It is noted that the long term and final value at this stage is not yet definitive and the ultimate proof of the pudding is in the eating. Other parties reflecting the added value of implementation of the passport referred to the additional costs and efforts versus the potential residual additional value resulting. Also costs for maintaining and actualising data during the exploitation phase must be considered. Having a material passport does not make a project circular if the adopted design and construction philosophies did not take circularity into account. The main added value for parties involved in implementing and developing the passport was the learning experience and being one of the front runners in a new development and trend and the addition of references in their portfolio.

A risk mentioned is that a material passport is applied with a view of future usage, whereby to date reuse is not yet facilitated. Specific for the Triodos project it is a risk that during the use phase the passport is not actualised and the passport may remain on the shelves until the building will be dismantled. Critical Success Factors mentioned are a clear working definition of CE, a shared vision of parties within the value chain, the early involvement of parties in the process with a clear ambition envisaged and clarifying what is expected from respective parties in the process and thereby minimising the risk of double efforts by parties.

It is assessed that future passports should be further developed, improved and standardised, increasing simplicity and transparency and more focus on generating data with proper and objective characteristics of circularity of materials. Also the generation of data for the material passport needs a more generic and automated process. Mandatory use of passports currently is evaluated as not the proper way to achieve the circularity ambitions, where the risk is that the process may become a “tick in the box” process.

5. ANALYSIS CASE STUDY VERSUS GUIDELINE, VALIDATION, DISCUSSION AND REFLECTION

This chapter will contextualise the findings of the case study by reflecting it against the most recent guideline for MP standardisation, development and implementation within the Netherlands. Furthermore this chapter will validate, reflect and discuss the outcomes of this research. First a short introduction and explanation of the structure and background of the guideline is presented. Whereafter the document analysis is summarised and the main discrepancies between the case study findings and the guideline will be presented. These findings will then be validated with the use of a expert session. Whereafter the last section of this chapter will discuss and reflect the findings of this research.

5.1 INTRODUCTION

To contextualise the learning experiences and barriers with respect to the implementation and development of a first-of-its-kind MP within the Triodos case study it is found prudent to reflect these findings against a document analysis of the most recent guidelines with respect to the standardisation of MP's and work agreements for the implementation and development of MP's in the construction sector. Furthermore, this approach was also implemented to shine a light on the practical implications of the guide because there is limited knowledge sharing with respect to MP implementation experiences in practice within the construction industry. Therefore it is chosen to mainly focus on the discrepancies between the guideline and practice.

Platform CB'23 (CB'23) is an abbreviation for Circular Building in 2023 and has been initiated by "Rijkswaterstaat, the Dutch Central Government Real Estate Agency (Rijksvastgoedbedrijf), De Bouwcampus and NEN (Netherlands Standardization Institute)" (CB'23, 2020). The stakeholders who have joined the platform represent a broad cross-section of the construction value chain, including both public and private parties. The goal of CB'23 is to work towards commitment within the market for the circular transition and in doing so has multiple work groups. For this research, the guidelines of the action team with respect to MP development and standardisation for the construction sector have been reviewed against the findings of the case study. The outcome of the guideline reflect shared and agreed upon work agreement for MP implementation and visions of development towards standardisation (CB'23, 2020).

The platform thus brings together public and private parties with the goal to reach broad accepted working agreements for the circular built transaction. In doing so the platform has different action teams that focus on different topics such as the measuring of circularity and material passports. Parallel to these action teams, CB'23 believes it is critical that all stakeholders share the same technical vocabulary and meanings when it comes to data (CB'23, 2020).

In order to maximise the full circular potential against the effort of registering and sharing data captured within MP certain essential preconditions are not fully mature within the construction industry. The transition towards a more circular construction sector will require the sharing, capturing and storage of comparable and interchangeable information about building materials. A material passports can be seen as a tool that could provide significant value within the circular construction transition as it could promote and facilitate the circular potential of constructions and the elements, materials and products that are locked within them. The development of MP is currently led by market force, therefore there is the risk that development occurs fragmented and non-aligned. If the development of MP's remains

unaligned, there is the risk that the implementation of different MP's has limited added value from a circular perspective and implementation remains ad-hoc.(CB'23, 2020).

The material passport guideline was written to aid developers and users of material passports and provide insight into the requirements for creating and using passports. The guidance is intended for both public and private parties in the GWW or B&U sectors who may initiate (clients) or have to work with a material passport (contractors, suppliers) (CB'23, 2020).

The first guideline of the CB'23 action group was presented in July 2019 (CB'23, 2019). This guideline 1.0 of CB'23 presents a possible structure of material passports within the construction industry. For this analysis the last actualised version 2.0 released in July 2020 has been evaluated (CB'23, 2020). This most recent guide includes all of the updated and revised information from guideline 1.0, as well as three additional areas of focus, which are: passport versions, preconditions and data governance.

This research has been conducted in parallel with the developments with respect to guidelines for material passports within the Netherlands. None of the parties involved in the Triodos project, except for Madaster, founded by Rau Architects, have been members of the platform and did not refer to the developments and actions of the platform. As such, the processes of CB'23 and the research have been conducted in parallel, whereby lessons learned and feedback from the Triodos Bank project have not been integrated into the development of the guide nor vice versa. Below an overview is presented of the different design and construction phases of the Triodos Reehorst project in relation to the founding of the Madaster platform and the distribution of the CB'23 guidelines. It can be seen that around the same time as the tender phase, where the decision was made by the client to implement a MP, the Madaster foundation was founded. It must be noted that it is unclear how the involvement of Rau architects (by which Madaster is founded) during the design phase for this project has coloured the decision to choose this platform.

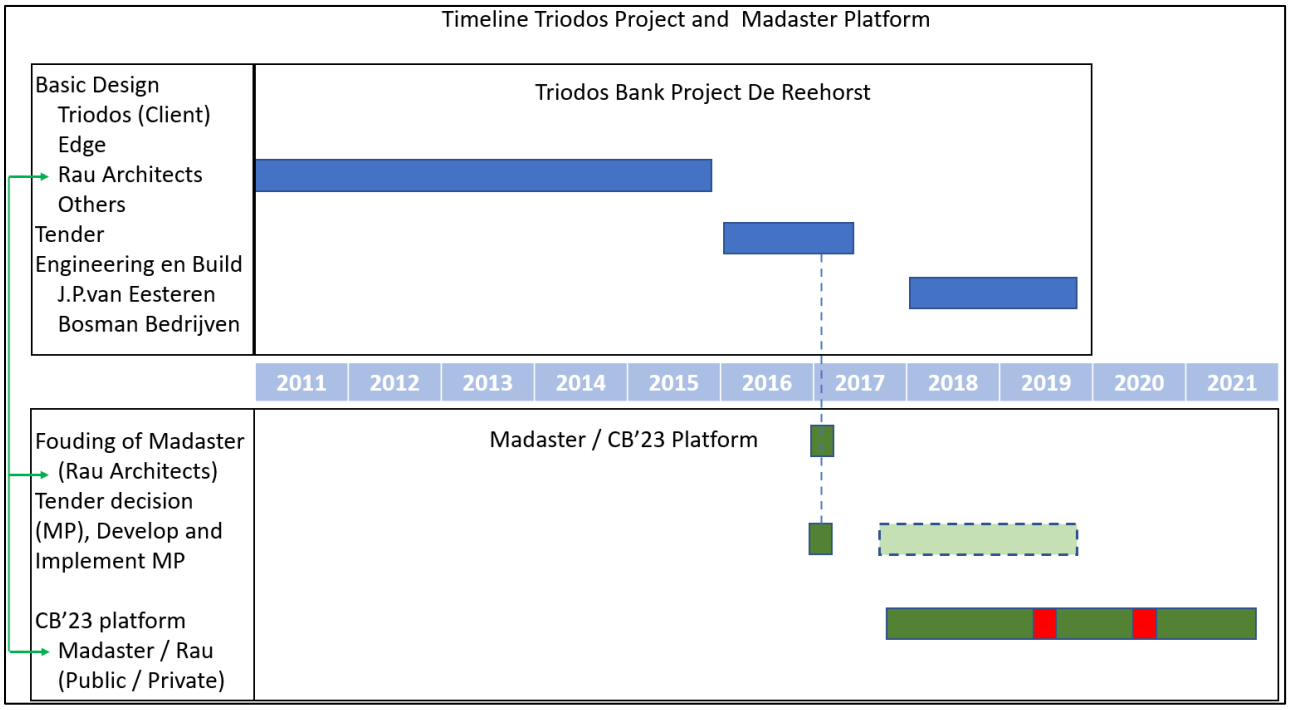

Figure 18 – Timeline Triodos project, Madaster platform and CB'23 guidelines (own illustration).

It is noted that the Triodos project is a contract within the private sector. The Triodos Bank, a private entity, is the client. Acting as client or employer in the construction sector is not the core business and as such is incidental. The CB'23 guideline is developed for the construction sector in general, whereby public clients in general are more professionally organised and structured to process and manage respective construction contracts and their assets.

Subsequent to the evaluated potential discrepancies between the findings of the research and the guideline it has been chosen to have an expert meeting with a representative of a public client having gained experience with the implementation of passports and has been involved in the development of the CB'23 guideline as well. This meeting has been performed with a representative of Rijksvastgoedbedrijf (RVB) in order to validate and reflect the findings of the research. Subsequent the chapter concludes with further discussion and a reflection of this research.

5.2 MAIN DISCREPANCIES BETWEEN FINDINGS CASE STUDY VERSUS CB'23 GUIDELINE

When comparing CB'23 guide 2.0 and the case study findings it may be concluded that the practical implementation experiences are much more unruly and experimental than described in the guide. However the policy and approach of applying and implementing a material passport as described in the guide are logical and theoretical sound and understandable it appears that within practice the implementation and development of MP is much more experimental and ad hoc. It must be mentioned that certain lessons learned within the case study are not fully addressed in the guideline and vice versa.

Below a summarised analysis of the main discrepancies between the Triodos case study findings and the work agreements of the CB'23 guideline are presented. The entire guideline has been analysed against the case study in appendix A.

As described in the introduction of this chapter, the material passport guidelines goal is to ensure that parties within practice, implement and develop material passports in a similar way. The work agreements are intended to reach an equilibrium in which parties all structure their information the same way, with the same approach. This should ensure that the added efforts of capturing the circular value within material passports retains its value over the lifetime of the construction.

The correct data and completeness was given as one of the critical success factors for MP implementation within practice. This is in line with CB'23 which adds that data should also be comparable and interchangeable to facilitate information flow between MP's in the future and between information tools used within practice. Furthermore the guidelines explain that "a clear structure is important for the effective use of passports for the construction sector" (CB'23, 2020, p. 15). This should reduce information burden and the effective sharing of information within the value chain. Furthermore this should ensure that MP's are complete and accurate. To maximise the circular value within MP's, CB'23 envisions MP's used within an open and public data architecture (CB'23, 2020).

5.2.1 Availability of data and interchangeability

The guideline indicates that most of the data necessary to enrich a MP is already available within the value chain and tools used within practice (CB'23, 2020). Within practice the interchangeability and the availability of data cause barriers for the implementation of MP's. Although the adoption of BIM has come a long way within the CI, not all stakeholders have the same knowledge and standardisation within their information exchange models and object trees. The information exchange between the design models of contractor and architect is rather standardised. However the interchangeability between supplier models and design models remains sub-optimal. For the case study this resulted in additional effort for the contractor to enrich and manipulate data.

With respect to the availability of data, most of the prescribed information in the BIM protocol was available such as: quantities and materialisation. However information with respect to circularity information such as toxicity and recycled content is a new information requirement. As this CE information requirement is relatively new stakeholders have to go back into the value chain and try to gain the required data or information.

From the Triodos case study it can be assessed that the accuracy of this new information requirement also relies heavily on the competences of the party enriching the data and has an inherent subjective character. Practitioners described that the use of for instance circular certifications for materials could create a level playing field were materials can be easily compared. How this barrier of possible subjective information or guesstimates can be eliminated is not addressed within the CB'23 guideline. Within practice parties assessed the possible need for audits to ensure that correctness of data can be assured. As this circular information requirements provide the input for the KPI's of measuring circularity this possible subjective character should be eliminated.

Although the measuring of circularity is reflected in a different action team, the importance of a standardised and objective CE indicator is assessed as crucial within the Triodos case study. As this would create the ability to compare different projects on CE and balance the possible higher associated costs for material reuse against their circular benefits.

5.2.2 Structure: passport versions, life cycles

CB'23 describes different passport versions for MP because datasets will need to be created and maintained in accordance with the predominant implemented levels of scale (pyramid structure) along the subsequent four lifecycle phases (CB'23, 2020). Within practice these levels of scale follow the BIM structure used within the CI. However within practice parties found it difficult to assess when a building object should be qualified as a material or as a product (containing multiple materials).

In the structure supposed by CB'23 is also described that MP's can be generated during different life cycle phases in line with NEN-EN 15804 (the four phases of the life cycle: production phase, construction phase, use phase, demolition and processing phase) (CB'23, 2020). This approach of CB'23 supposes the gradually enriching and creating a MP during the different life cycle phases of the project where suppliers already deliver a MP or so called product passport. Within this case study suppliers did not deliver a "MP" or product passport, because data access to the MP remained limited (this will be discussed later). But delivered information in the form of BIM files, as specified in the contractual agreements. As compiling this information into a MP is not an automated process for the Triodos case but came at a considerable time and effort investment. The decision was made to generate the MP at the end of the construction phase in order to reduce possible iterations of their MP and reduce the possibility of omissions due to design alterations and possible different materialisation decisions. Furthermore it must be noted that throughout the life cycle phases the information will become more detailed and complete. Although the approach of CB'23 is not implemented for the Triodos case, practitioners all agreed that a shared vision of parties within the value chain, the early involvement of parties in the process with a clear ambition envisaged and clarifying what is expected from respective parties at the start of process is beneficial and thereby minimises the risk of double efforts by parties.

5.2.3 Structure: dynamic element in relation to asset management

CB'23 describes that a MP consists of static and dynamic elements that can be kept up to date over the lifecycle to guarantee the data quality (CB'23, 2020). This should make sure that changes during the lifetime and information with respect to maintenance is actualised. According to practitioners actualising of the MP over the life cycle of the construction is given as a critical success factor to insure that MP will retain maximum information value over the constructions' lifetime. However within practice implementing a dynamic MP is rather difficult

as the data of the MP has limited interoperability with asset management software and there are no market parties that offer the service of MP upkeep. A lack of standardisation between asset management software and MP could lead to double bookkeeping. When these additional efforts are not undertaken a MP could run the risk of becoming a static document and in effect reduce its possible future potential value.

It was mentioned during the case study that it is not possible to apply a time-indicator to indicate when for instance a door has been replaced. Practitioners would also advocate for the optimization of the 3-d viewer and its hierarchical structure. As it is currently hard to pinpoint an object within the building without knowledge of the BIM structure used to generate the MP. Therefore updating and using the tool might be a difficult task for facility managers that are not trained with MP's and BIM. Because there are no market parties that facilitate this service, it is unclear how small and medium-sized clients can cost-effectively keep the material passport up-to-date. CB'23 suggests that "where tracking and tracing of materials is concerned, a combination of distributed data system technology and the use of barcodes, QR codes and/or RFID technology will help to make information about products, components and materials available both reliably and securely" (CB'23, 2020, p. 25). It is noted that in practice these suggested codes are not common practice and as such may be not as straightforward and easy to apply by parties in the value chain as suggested.

5.2.4 Factors influencing accuracy and completeness

Several factors that influence accuracy and completeness are described in the guideline of which most overlap with practice (CB'23, 2020). For instance the ability to keep the material passport up to date has been described. The guideline does not indicate that completeness and accuracy is highly dependable of persons having the required knowledge, commitment and experience to work with passports and enriching data. Furthermore the logical reasoning with respect to governmental obligation leading to better accuracy and completeness has to be investigated further. Within practice some participants asses that this could lead to a 'check in the box' process in which intended goals of guideline could not materialise.

The guideline and practice furthermore indicate that the accuracy and completeness depend upon the material passport being generated before/during the construction phase or after. Because within practice data is lost over the lifecycle of constructions and it is thus more cost effective to register during construction.

Furthermore CB'23 and practice indicate that data and accuracy is dependent on the effort and time investment to generate the MP (CB'23, 2020). Although within practice the possible circular added value of the tool with respect to circular optimalisation and circular has not matured it is suggested by practice and the guideline, that the quality and amount of data gathered and captured within a MP and will influence possible added value when implemented. As this is impacted by the amount of data gathered and to a certain extend the data quality captured and locked within a MP. As the amount and quality of data gathered and captured within a MP has a significant impact on the value that can be achieved while implementing the tool (CB'23, 2020).

For this case study, the client has decided to apply the passport mainly for registration purposes. With the goal to aid the development of the circular construction industry, capture the circular information and asses the circularity. Although the tool used also took into account residual value only focussing on material value instead of product reuse. It must be mentioned that for the client it is not easy to weigh the cost investment of a MP against the added value. As materials are locked within practice for a long time and unclear how secondary material markets will develop in the future. Therefore it is unclear if investments for implementation and possible MP upkeep can be recuperated by additional residual value at the end of the lifecycle. It is interesting that within the guideline of CB'23 no cost benefit analysis is presented or envisioned for future guidelines.

As described the material passport was only applied for registration purposes, whereby principles described by CB'23 are not really addressed. Goals as incorporating planning application, mortgage, lifecycle analyses and insurance were for goal of passport neglected nor necessary. It should be mentioned that parties within practice already indicate that compiling and enriching all the relevant data with respect to materials and products to facilitate circularity is a difficult and time consuming task. Therefore adding additional information layers may complicate the ease of implementation.

5.2.5 Access of MP, ownership data and open and public data structures

"In order to enable access to passport data, it is important that the party that benefits most at the moment in question records the necessary data, or has it recorded by the person who produces or manages the object, with minimal effort and at the right time" (CB'23, 2020, p. 14). Within the guideline of CB'23 mutual benefit for participants in the value chain is sketched. However, in principle, the client benefits the most from the recorded data as indicated within practice. Within practice data delivery and the recording was rather traditional and contractual. To put it into perspective, CB'23 does not make clear how, for instance, suppliers should be compensated or stimulated to deliver product passports or MP's. Within practice, the contractor had the obligation to deliver the MP to the client, and the suppliers had to deliver the requested BIM specifications. Therefore, stakeholders found it difficult to see the added value of a MP's role beyond the obtained learning experience and possible competitive advantage in the market.

With respect to access to the MP not all parties had access to work in the MP. The subscription based access of Madaster refrains suppliers from directly accessing the MP, where the contractor thus acted as an intermediate. This is contrary to vision CB'23 which describes that MP should be open and accessible to the public (CB'23, 2020). Ownership of the data also plays an important part in having access to the material passport. For the Triodos project the delivered passport becomes property of the client. As information cannot be saved in a decoupled corporate library, the subcontractor cannot reuse the enriched product passport and data within other future passports. For the contractor this was not a real problem as most of its products are unique for every project, but this approach does not reduce the information burden for parties that generally work with the same products in different projects. Additionally the Client has decided not to transfer its data to a (shared, public accessible platform) not earlier than end of life. Therefore it is not clear how owners will link their data in the future to a material database or link to a second-hand marketplace. Within the CB'23 guideline it does not become clear how MP owners should be stimulated in sharing their data.

5.2.6 Responsibility data delivery, privacy, transparency and arbitration

Within the guideline it is envisioned that the party who has to provide or deliver the data for the MP remains responsible for this data. This would imply that for instance suppliers remain the owner of the information until the end of the warranty period. According to CB'23, "this perspective of data ownership leads to shared ownership as a logical next step" (CB'23, 2020, p. 38). For the Triodos project the supplier did not have access during and after the commissioning of the project as data is fully owned by the client. Practical being responsible for data and updating in this initiative as such is not straightforward c.q. needs additional (contractual) requirements, which is not indicated within the guideline. Furthermore parties mentioned that freely giving access to their data may be subject to intellectual property or competitive edge considerations and as such is a barrier. CB'23 suggests arbitration, however it is noted that impact is project specific and suggestion as such may not be simple in its approach (CB'23, 2020). The use of for instance circular certifications and/or the use NDA's were suggested by practitioners. CB'23 acknowledges privacy concerns, but argues that by separating personal information from the MP and storing it in separate files, privacy should be guaranteed (CB'23, 2020).

It should be mentioned that CB'23 is currently conducting an impact study to determine the remaining risk of privacy issues (CB’23, 2020). Without disclosure of this assessment the timeline set by CB’23 might not be achievable. Concern for parties about intellectual property for this project appeared limited, however the contractor explained that suppliers could not be aware of the fact that data could become publicly available. Ownership and the procedural consequences in practice could be more challenging as suggested in guideline.

5.2.7 Transparency

CB’23 states that in order to be able to take advantage of the available materials and their properties, the database must be transparent (CB’23, 2020, p. 28). As described in the previous paragraphs the current applied model is based on a decentralised passport builder and owner. This will mean that within practice parties should be convinced to share data with for instance contractual conditions according to CB’23. Given the reservations of practice with respect to privacy and intellectual property as previously noted the sharing of both public and private information is currently difficult. “However, without central management and a marketplace, it will hardly be possible for users to find data on materials” (CB’23, 2020, p. 28).

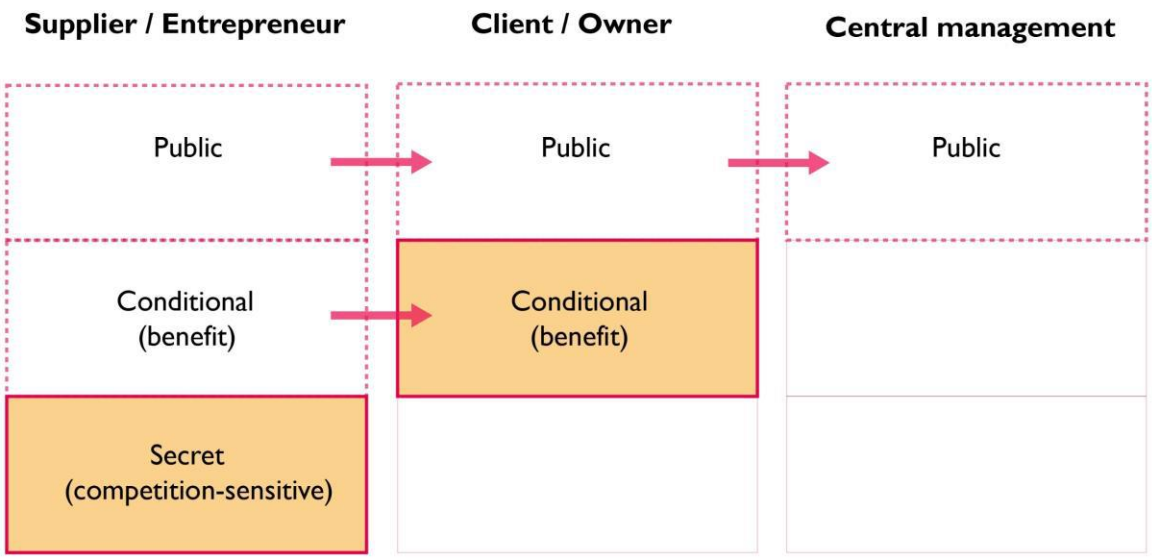

Figure 19 - Envisioned centralised model CB'23 (CB’23, 2020).

CB’23 envisions that all information must be public and traceable within a circular economy. “This will have to be stimulated and coordinated” (CB’23, 2020, p. 28). “Some form of management will have to be set up for a storage standard and for parties which store this data. This can be assigned to several parties (with central management of decentralised parties) or to a single party (fully centralised management)” (CB’23, 2020, p. 29).

Many practitioners foresee a similar structure in the future. However, it must be noted that this approach is radically different from the current applied approach and therefore can take a considerable amount of time to materialise. Above this, an envisioned central data structure to improve transparency is portrayed. Where secret (competition-sensitive) information is retained by the supplier, and where conditional information is relayed to a client when there is a risk because of management, the rest of the information becomes publicly available.

5.2.8 Standardising ID management and stakeholders roles

"The interchangeability of data is guaranteed by firstly standardising the ID and product codes used, and secondly by proper management. There should be an obligation to exchange data. If this hinders a business interest, the possibility of arbitration must be set up" (CB'23, 2020, p. 25). Arbitration has previously been described with respect to data ownership and should be approached with some reservations, mainly due to balance of business interests. The legislation with respect to an obligation to exchange data seems logical, however it is unclear when this would materialise as the legislative process is far from developed. This could also impact the timeline set by CB'23 for stipulation of material passports.

The implementation of a standardised ID is a good way towards standardisation of MP. This has not be implemented in the Triodos case adequately. Within practice, this would ensure that data enclosed within MP can be easily located and can become easily interchangeable between MP's. For the Triodos case, this approach could have reduced omissions or mistakes, although an ad hoc ID management system was implemented with standardisation. Within practice, omissions such as a door that was located within the system in Lelystad (another project they were doing) which was actually applied within the Triodos Project.

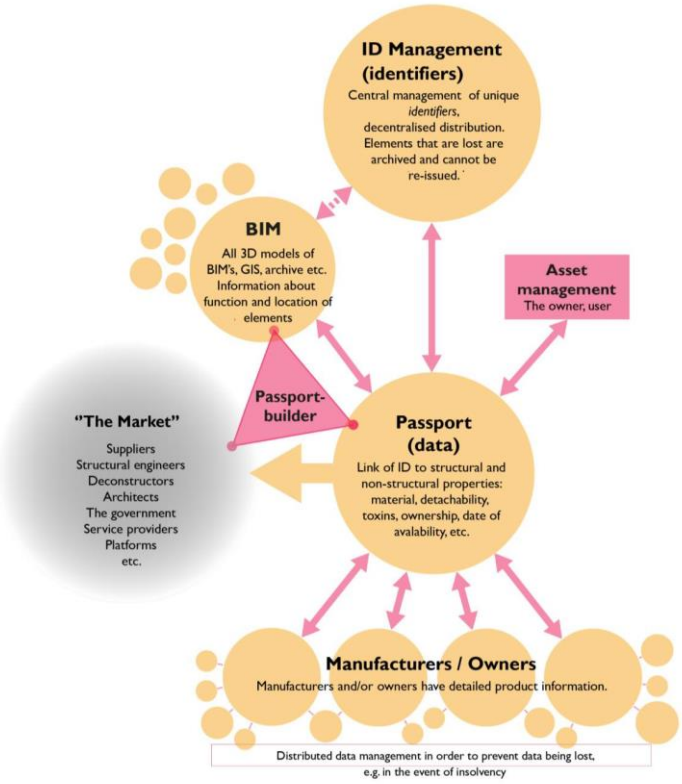

Figure 20 - ID management, stakeholders and roles (CB'23, 2020).

The ID management is shown in relation to MP and BIM information systems in figure 20 above. This overview furthermore provides insight into the value proposition of a MP and the interaction of the different stakeholders with the generation and use of MP's as envisioned by CB'23 (CB'23, 2020). As described the roles with respect to data recording remained rather traditional for the Triodos case. The supplier does not directly insert his information into the MP and does not have access to the MP. But the BIM manager acts as an intermediate. Furthermore the access after delivery is restricted due to the ownership structures. The asset management connection within practice remains questionable because of a lack of interoperability. Furthermore parties explained that for asset management other information

requirements are necessary that are for this project not incorporated in the material passport. Therefore it is suggested to analyse what these possible differences in data requirements are for MP and asset management and how requirements may be balanced.

5.2.9 Reducing information burden and long list

CB'23 states, "that in order to reduce the information burden, it is advisable to retain references to the product information and to capture them at source in standards, similar to EAN (European Article Numbering) information" (CB'23, 2020, p. 24). This would ensure better information quality and a better chance for the information to be upcycled .
To reduce the information burden of suppliers and producers they should be protected to facilitate the same information for different information inquiries (CB'23, 2020). These points of CB'23 are valid and are assessed within practice as possible barriers. Where the contractor had to iteratively go back and forth between suppliers in order to fully enrich the material passport with the required data. As described CB'23 assesses that all the relevant data is already available within the supply chain (CB'23, 2020). For the Triodos case this was not always the case. For instance, not every supplier knows the percentage of recycled content within his product or advises which products represent the best possible circular strategy after demounting. For the Triodos case this information was therefore mostly enriched by the passport builder.

CB'23 envisions that the basic concept to reduce complexity and information load is to divide the minimum information requirement from the desirable set of information (CB'23, 2020). For this the guideline describes "the Long List of passport items tool has been developed to collect all the ideas, proposals and needs for passport items mentioned by stakeholders and structure them in a "long list" that can be included in a passport, depending on their intended use" (CB'23, 2020, p. 6). It is noted that most parties involved in the project were not aware of actions and guide of CB'23 nor aware of any longlist suggested. The required and potential data for the MP of the project evolved during the process by logical thinking between involved parties. The described longlist is important for parties applying a MP, however it is not clear and defined what the minimum information need is to establish a proper passport. Ideas, proposals and needs for passport items imply that solutions still have to be developed and MP's as such are not standardised yet. Because CB'23 indicates that different passports depend on different intended use cases, this implicates that different information requirements are deemed necessary. A minimum requirement for material passport could be of great value for the standardisation and implement ability of MP's within practice. This is also assessed within practice, where the risk of ad hoc implementation of different passports is given as a possible risk that could reduce possible future added value.

Parties mentioned that efforts for generating and enriching data were substantial and costly. The economic balance of value of materials versus possible additional costs and efforts are not really evaluated with respect to value and value at the end of lifecycle. The balancing of cost-benefit should be considered when defining what is minimal requirement and what is desired. It is noted that CB'23 is not really clear how costs and efforts for developing a proper material passport are evaluated to decide requirements.

5.2.10 Topics not disclosed in guideline (roles and balancing perspectives)

The guideline envisages "as soon as passports with sufficient content become more widely accessible, new user groups will emerge. New (possible user groups) roles envisioned are: Management, Financial services, Consultancy services (marketplace for information) and Storage" (CB'23, 2020, p. 24). Parties within practice envision similar possible roles to be established when MP's become widely accepted. Some of the new roles imply that information and data will become publicly accessible and available. With current ownership of information at the Triodos project (limited to Client only) this could imply a hinderance for further development and new roles. Currently, no real new roles or parties have been

encountered in the project. Passport development has mainly become an activity as part of the function of the engineer, mainly the engineer for BIM applications.

What is interesting is that the role and the responsibilities of the MP platforms provider within the development of the guidelines and the road towards standardisation are not discussed. Madaster mentioned, however, that they do not see a special role for themselves other than facilitating the platform. What their responsibility is with respect to MP upkeep, certifications and controls is not clarified and, according to Madaster, not within the current business model of the platform. Within CB'23, no distinction is made between private and public clients within the B&U sector. Because Triodos is a private customer, European tender guidelines played no role. It is unclear how the innovative tool can currently be included in a European tender without any obligation from the government. Because no distinction is made between private and public parties, it is not entirely clear how perspectives are balanced within the guide.

5.2.11 Data governance

Data governance has been described in much detail within the CB'23 guideline. Within the case study this topic was much less addressed. Governance suggestions, as working towards a standardised definition for CE by making a circular lexicon, seem sound and valid when reflected against practice (CB'23, 2020). Furthermore, the guide suggests working towards standardised concept libraries for BIM and between tools, in addition to making sure that information delivery specifications with respect to CE become standard. This approach is logic, but it should be taken into account that data requirements are still far from being standardised. Furthermore, it is not yet clear if all the data is available according to practice versus CB'23. However, to increase interoperability and possibly reduce the information burden, this seems like a good approach. Because, in practice, BIM system interoperability was cited as a major barrier for implementation.

5.2.12 Different perspectives CB'23 versus practice

The guideline describes **"**soon after the development of different passport versions was started, it became apparent that opinions and perspectives on the content of passports still differ considerably" (CB'23, 2020, p. 6). Several subsequent sessions were required during the project to agree the content for developing the passport. With the use of logical reasoning the ad hoc content list was made. Although parties all had different interests and objectives no major deviating opinions with respect to the content record are mentioned. Perspectives of parties within practice mainly differ with respect to the future development and possible additional information requirements that this may bring. Evaluation is that added value of the MP implementation is hard to assess and not all parties recognise the added value from their perspective. It is not clear how the guideline works towards creating a win-win situation for all stakeholders for MP implementation, that is not stipulated or involves governmental involvement.

5.2.13 Timeline and follow up steps

The guideline describes "it should come as no surprise that further steps will need to be taken as part of the circular transition in order to standardise passports for the construction sector" (CB'23, 2020, p. 10). This can be seen in line with this research where multiple barriers for implementation and standardisation within practice are assessed and implementation remained rather experimental. The decision to make MP mandatory has been postponed until 2022 (Ollongren, 2020). Within practice the views on governmental involvement are not aligned, the current immatureness and possible lack of intrinsic value to use the MP over the lifetime represent major risks for early governmental involvement. These considerations are also taken into account with parties stating not to be against a mandatory use, however are concerned about the ease of use and the ability to implement MP's. More than merely harmonising passports is needed to promote CE, according to CB'23. Public usage of passports and some obligation should be encouraged by the government.

CB’23 viewpoint is that the government must identify a clear approach for achieving a mature passport system. Actions must be taken before 2025 to create value and advance the circular economy. That is why CB’23 suggests that a mandate to make MP mandatory should be made before 2025 (CB’23, 2020). The new requirement for MIA/VAMIL in this perspective is also surprising. Where to apply for subsidies a MP must be provided so there is already some form of incentivising legislation (RVO, 2021).

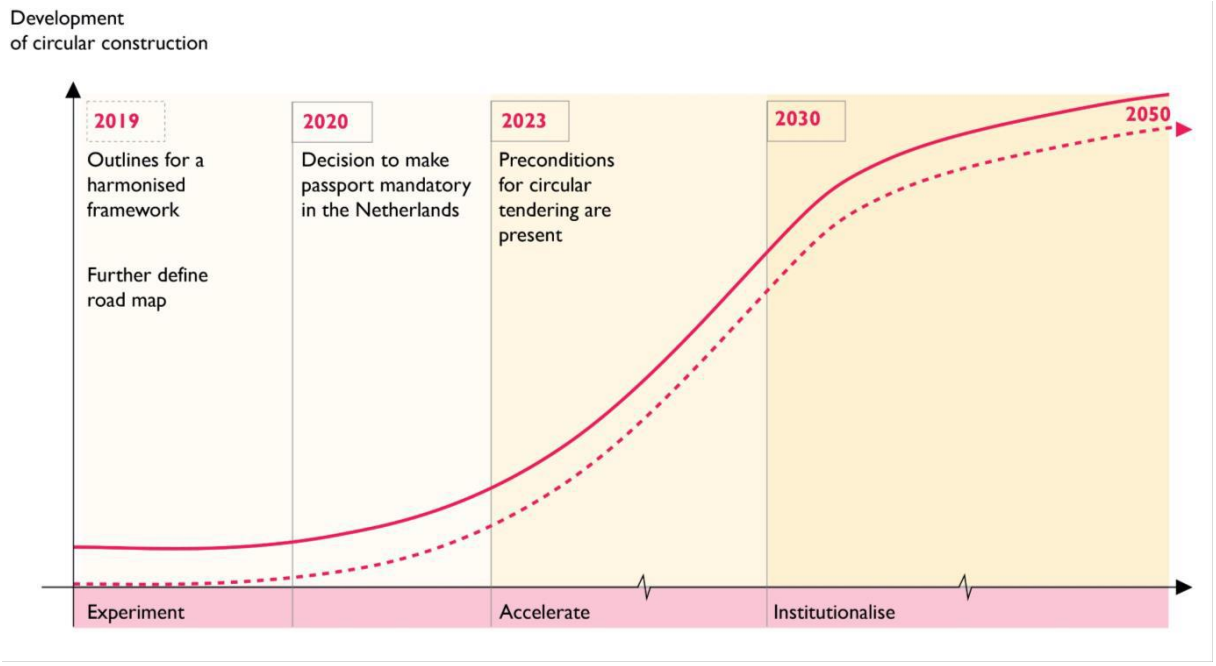

Figure 21 - Overview timeline CB'23 (CB'23, 2020).

It is noted that the guideline indicates several actions, that need to be addressed further in order to standardise the MP. It may be assumed these actions will possibly still take substantial efforts and time and as such may influence the timeline and realism of indicated timeline by CB’23. Parties noted that MP has to be further optimised, standardised whereby wish for a more simple and automated process.

The follow up steps as recognised by CB’23 mainly focus on managing the long list of requirements (CB’23, 2020). This will be an essential step in harmonising and balancing the minimum requirements versus the desired requirements. As within practice the added value is not always clear from both an economic standpoint as well as from respective stakeholders perspectives. To make this more clear from an economic standpoint the longlist should be reflected against a cost benefit analysis. To create some better understanding and necessary support in how stakeholders can reach a win-win situation when implementing a MP. It could be advisable to look beyond obligational and contractual interventions and make it more clear how different parties can retain and achieve value from MP implementation. Follow up steps like preparing a measurement tool to measure the quality and quantity of data are in line with the reservations with respect to possible omissions and human guestimates within practice.

5.2.14 Maturity

Multiple preconditions will have to be met, according to the guide, in order to make the implementation and adoption of MP commonplace within the construction industry. It will happen more organically if uses will start to indicate the information requirements of MP. However for instance Triodes as an incidental client did not have specific information requirements. Therefore incidental client might find it hard to assess the information requirement from their perspective compared to an non incidental client.

”Similarly to how the circular economy has developed, the use of passports has matured gradually and topics and relevant actions have to be considered for each stage of maturity” (CB’23, 2020, p. 12). For the development of maturity preconditions are required for subsequent phases, as indicated in figure 21 above. For experimental phase the following topics and actions are distinguished, being “radically new way of thinking” and “radically new way of acting” (CB’23, 2020). For the acceleration phase “connect alternatives” and “more people will switch over” (CB’23, 2020). And for the institutionalising phase “new structures will become visible”, “transition no longer a subject of debate”, “the new norm (thinking and acting)” and “consolidate new structures” (CB’23, 2020). Guideline clarifies its maturity model as below.

0	1	2	3	4	5
Linear	Individual	Connection	Decentralised	Economy	Network

Figure 22 - Maturity model CB'23 (CB’23, 2020).

Guideline in principle describes the ambition for level 5 of the maturity model. The Triodos project can be qualified to be in the early stage level 1, characterised by “set up individual registration”, “experiments” and “benefit/necessity is clear to specialists”, when reflecting the guideline topics and the current situation (CB’23, 2020).

5.3 VALIDATION GUIDELINE CB’23

5.3.1 Motivation

Platform CB’23 indicates that its members, both public and private companies in the construction sector, have based their guideline and working agreements, including principles and approach to standardise for applying material passports in the construction sector, on the support of the members.

The discrepancies between the principles and approach as described in the CB’23 guideline and the interviews with representatives of the private sector indicate that visions and experience between parties are not always congruent. The main question of this research is: “What does the implementation of a first of its kind material passport imply for guidelines and the development of material passports within the Netherlands?”. Before conclusions can be presented it has been thought prudent to validate the process and the approach by performing an additional interview with an expert representative of a major public member of the Platform CB’23, namely Rijksvastgoedbedrijf. The representative interviewed has been involved from the start of the Platform and has been member of action team(s). Furthermore representative has been involved with several MP (pilot) implementations.

The transcript of the full interview with the representative of Rijksvastgoedbedrijf has been enclosed in chapter B.9 of Appendix B. There is chosen to disclose appendix B within a separate non-public document to guarantee the privacy and possible disclosure of sensitive information.

5.3.2 Summary and main feedback validation interview

Representative of Rijksvastgoedbedrijf (RVB) has been involved with Platform CB’23 from the start of the process. He has been member of the Passport for the Construction Sector action team as well as member of the Measuring Circularity action team. Furthermore representative is within the organisation of RVB responsible for the development and implementation of circularity.

Within RVB not many MP's have been implemented. Only a few pilots, mainly dismantling projects. As such experience is yet limited.

RVB is committed to achieve the circular ambitions 2050 of the government. As such the focus is on closing circular cycles. Three goals for material passports are distinguished: facilitate and guarantee re-use, performance measurement and of course circular management. As professional client it has a substantial quantity of assets and associated data for which an organisation is responsible to manage these with own (asset management) systems. As such evaluating the value of material passports or enclosed data must fit and correlate with the own asset management systems and structure of asset management. Even stronger, data and passports should originate from own data systems. A passport does not have the form of a prescribed method, but as a dataset facilitating and guaranteeing the circular ambitions. And the data as such should originate from own systems to prevent double bookkeeping and efforts. For RVB the main value of current developments is the circular characteristics of materials applied which as such are normally not integrated in the respective BIM models. As such the organisation has first to define its policy with respect to material passport and data. Which data are relevant and how to manage and apply material passports and/or datasets within and by the organisation.

As member of Platform CB'23 representative has been active and present in several meetings and action teams. Representative is not aware if all other members have experience with implementation of passports. Representative misses vision regarding value and function of passports. Everybody focusses on the product of material passport rather than agreeing on the architecture in the Netherlands to generate value. Everybody is self-occupied rather than how to cooperate and collaborate to give value with a minimum of efforts. Opinion of representative is policy should be to have one (central) database. At present all kind of complexity and details are discussed, whereby a more general overview and strategic perspective should be leading. In principle there should be one central database where clients, contractors and suppliers can link and get via a qr code their data. And data can be actualised if major changes are applicable, or in constructions or in circularity, or current financial data, and when becoming available. As such this central database can take the form of a central marketplace. This also minimises the size and complexity of material passports, databases and digital data with individual parties.

Currently representative is of the opinion that material passports should contain all kind of data including also data on circularity. However a substantial quantity of data is already available in respective tools. As such, it becomes too complicated and extensive. Keeping data up to date over the lifetime of so much data is a major effort with questionable added value. As example an inventory has been made of camera's in a building for future sale. However, the value of those cameras at the end of their life is negligible. In the meantime, enormous sums of money are spent on actualising data. It is more effective to concentrate on the future circularity strategy and a second lifetime and reuse of certain elements and relation to demountability in buildings and adopt the dataset and management accordingly. As such a policy of deciding the goal of the use of data is essential and minimise management to what is regarded as really necessary.

CB'23 refers to static and dynamic elements to manage. Dynamic elements is closely related to maintenance management and renovations. However data are not corresponding with asset management data used by RVB. As such RVB is reluctant to request the market for passports or datasets when data are not from RVB. Preferably data are actualised in line with future circular data strategy and linked to the central market place. So not for everything and only when mutations and/or renovations have occurred. With identification code this can be managed by the use of the qr code procedure envisaged and also may overcome the problem encountered by Triodos project that using time stamps in passports appeared not possible.

Accessibility of data is not always secure and guaranteed. Representative has performed some pilot MP implementations. When giving a presentation of MP he discovered that his data was blocked and log in codes were not actual anymore. As professional public organisation he realised that the organisation can for data not be dependent from others. Data within data management systems of RVB are different from data by other parties. As such the comparability, interchangeable, accuracy and completeness pursued by CB'23 is at stake and the assumption to link to each parties object libraries is far stretching.

Representative has been involved in a passport implementation. When after registering data in your passport the user has made some changes and replaces some smoke alarms without informing than within a few weeks your data is not actual anymore. What is the value at the end of life accordingly. The Triodos team has decided to register data only at the end of the construction phase according as built in order to mitigate omissions and to minimise costs. Triodos has not used the MP during design, nor actualises data yet during use phase. CB'23 pursues to use the MP for the four life cycles of the construction process. As such the representative questioned the timing to generate a passport. Furthermore the difference between the strategy of a private party of managing and actualising of data of the full lifecycle differs from a professional public party in perspective of circularity ambitions. As such perspectives between private parties and public parties may differ.

Representative has been involved with some pilot implementations. For some projects passports were requested to be applied. At this moment representative however does not see real added value yet. It is more a kind of homework and becomes a paper or digital tiger. For reasons referred to above representative is reluctant to ask market for material passports before RVB has decided its policy. Pilots for new buildings and registration of passports executed are not really used. For the short term more interested in low hanging fruit. Maybe more environmental burden in for instance the main supporting structure. Representative mentioned that pilots for demolition and major renovations passports may prove more valuable, since materials are assessed for imminent reuse and as such more practical.

Representative replied that team of Triodos may have tried to develop the passport as detailed as possible for everything which may have consumed considerable extra time and efforts. The market has to go along with the circular ambitions, however to focus requests for data or passports which can be used more practical, whereby reference is made to the value assessed for existing buildings at their end of life time.

First the internal policy and strategy has to be decided upon by RVB after which RVB is prepared to gradually request MP services from the market, however not yet for the complete package. Growing and learning and developing over time in line with CB'23.

5.3.3 Evaluation Validation Interview

The representative of RVB is not yet ready to adopt and apply a material passport in his organisation, a major public party active in the B&U sector and member of the Platform CB'23. The main interest is to receive data of constructions whereby the RVB adds respective data in its own systems.

Furthermore representative recognises and confirms most of the comments and evaluation of parties involved in the Triodos project.

Summarising his main considerations are as below.

MP Perspective:

- MP for new structures has to date no real added value
- MP does not really relate and correspond to asset management data

- Not clear how to actualise and keep up to date over life cycle of the structure

Organisation (RVB) Perspective:

- MP should be originating and developed from the own data management organisation aiming to mitigate double registering of data in own systems
- Not MP as a tool is the issue, but data and quality of data
- First a clear vision on the architecture and how to manage data within the own organisation is required before proceeding with requesting MP's from the market

5.3.4 Validation

It is noted that research has evaluated some discrepancies with the guideline as well that RVB indicates respective discrepancies. Below in bullets the corresponding main discrepancies between practice (parties involved in Triodos project and RVB) and the guideline are provided.

- The case study and validation session with RVD confirm that data is not freely accessible, easily comparable, interchangeable and its accuracy and completeness still have some subjective character.
- Balance of efforts and costs versus added value in perspective of circular ambitions has to be further defined and agreed upon. Focus to be more on future circular strategy approach and practical (low hanging fruit) rather than suggestion to generate a full material passport for a building for all materials and details.
- Current added value of material passport is financially doubted.
- Registering and management of dynamic elements is maintenance and asset management related and potentially implies double bookkeeping and additional costs and efforts disregarding real balance with additional value at end of life.
- Evaluating the feedback of interviews of the research and analysing the guideline it is doubted if vision and principles are shared and supported by all members of the Platform CB'23. RVB confirms that members are focussed on their own interests and perspectives instead of cooperating and agreeing a shared strategy and architecture of the MP in order to give value to the tool.
- Information is not publicly available within a centralised platform
- Private (incidental) parties may have other considerations for adopting a tool as material passport than public (professional) parties.
- However guideline is theoretical and logical sound practice appears challenging and less straightforward.
- Timeline as per guideline seems ambitious. Analysis of guideline learns CB'23 has to perform additional activities to develop its final vision and approach. RVB mentions that with current status and their own organisation first to decide its policy upon which gradually requesting MP services from the market indicates timeline is ambitious.
- Guideline does not make clear how ambitions are shared and benefits are balanced between stakeholders within the value chain from a social and economic perspective.

5.4 Discussion and reflection

The construction industry is becoming increasingly aware of acting sustainable and increasingly circular driven. Some participants even reflected that circularity has become one of the new buzzwords within the construction sector. Nevertheless Circular Economy and Material Passport are for many parties within the value chain relative new. Although all individuals and parties have their own personal perspectives with respect to the transition, they support and see the necessity for the transition towards a circular economy. In practice the sector lacks a generally applied and accepted working definition for CE. To facilitate the transition it is important that the sector works towards a general applied and accepted working definition for CE. An accepted and clear working definition will make discussions more effective and have all noses of participants in the same direction. The transition

towards a circular economy will require a shift in mindset, the development of new competences, processes, collaboration and operation of all the involved actors.

Implementations in practice are still experimental and mainly performed during construction phase. Public pilots also addressed existing assets in view of imminent reuse and recycle potential. Theoretical the guideline describes to apply the passport over the full lifecycle in the four consecutive phases (design, construction, use-phase and dismantling) of a building. However implementation is in its infancy and at the early stages, where no experience is feasible and available evaluating application of passports during the full duration of the exploitation phase.

In order to support a circular approach in the construction sector the material passport is seen as an effective, adequate and transparent tool by members of Platform CB'23, a cooperation of public and private parties. The Guide 2.0 as developed and presumably supported by the members of the Platform based on working agreements, describes the approach and principles for applying and implementing the material passport. The approach and principles appear to be logical and rational with respect to the intended goals and objectives of the guideline. The guideline describes a predefined timeline indicating that within a certain time span when the use of material passports will become mandatory to facilitate wide spread adoption. The guideline assesses that a MP is the means to effectively capture and transfer CE information requirements. In essence a MP can be seen as a tool that adds additional CE information to the tools and information already used within the CI. The guide does not critically asses other tools already used within the CI or creative options which serve the same CE ambitions potentially being more cost effective such as BIM or the enrichment of own portfolios or asset management systems of public governmental bodies.

Both the private parties involved in the Triodos project as well as Rijksvastgoedbedrijf being a main public organisation and member of the Platform CB'23 realise and support the need and requirement for a Circular Economy and the associated ambitions. The Triodos Bank is a private entity incidentally confronted with construction and exploitation of buildings. The decision for applying the MP was not necessary made with respect to the associated cost versus benefits but has been taken in line with their strategy of being one of the most sustainable banks in the world. The main objective is to promote CE, capture circular value (at the end of life) and circular scoring. As such only decided to implement MP at the end of the construction phase, however not yet decided to maintain and manage the passport during the use phase. RVB is a professional public entity where the core of the business is to manage governmental assets over their lifetime. The ambition is to achieve the governmental circular ambitions as set for 2050. Where the objective of implementation should be to facilitate and guarantee re-use, performance measurement and of course circular management, which was in line with the case study. However the public party reflects how circular management of assets is relatively different than current applied asset management that focuses on optimising the life cycle of assets within governmental bodies. Given the above the objectives to implement a MP from clients perspective seem aligned.

A public client owns a substantial quantity of assets and governances most of its asset management and data systems internally. This largely differs from incidental clients that often have external asset management contracts and do not keep or have sophisticated internal data systems. RVB assesses similar to the Triodos case that asset management systems cannot be linked with MP's. Therefore there is uncertainty if MP will lead to double bookkeeping because the optimal value within a MP can only be obtained when maintenance and changes are logged over the lifecycle of the construction. The analogy to a car can be made where you would not buy a second hand car without a log of the service executed. Within the current situation there is a risk that MP therefore becomes a static document. RVB is of the opinion that data have to originate from their own data base and asset management systems or data generated to be corresponding and along their own definitions and

registered by their own organisation. Therefore the client is hesitant to request a MP within tenders as this should first be researched internally. RVB being a main public party and member of the CB'23 Platform as such has a deviating approach from the platform. It is not clear what their position implies for the progress of developments by the platform and what their positioning implies for private parties, especially when RVB starts requesting different specifications from market parties which differ from requests as for the envisaged material passports by the guideline. For instance RVB could only focus on the extra additional information with respect to circularity within its passport requests to the market. This could weaken the position of incidental private clients as they generally have a weak internal data registration of building information where the risk of data decoupling may arise. It is not clear from the guideline how objectives and perspectives of private and public are properly balanced in order to share the same perspectives and visions. Despite the fact that the guide indicates to be supported by shared work agreements by public and private parties.

During the hand over moment of the MP the responsibility of the MP and ownership of the data is transferred to the client. As the client remains the only party that can access the passport where other stakeholders cannot store the information within a company library. Within this situation the parties that generated, enriched and registered the data and incurred the cost are not the parties benefitting from the transmitted data. Therefore it is not surprising that all parties except the client found it hard to assess the added value from their social and economic perspective. The guide does not make clear how it will stimulate or entice the sharing of information within the value chain without the direct governmental involvement. Furthermore it does not make clear how it balances benefits of private and public parties throughout the value chain. The guide does not clarify how it creates broadly accepted support towards the implementation of the tool. As such it is questionable if without the balancing of social and economic perspectives and interests a broad accepted situation may arise without the involvement of governmental regulation.

Partly due to the fact that current business models and innovative circular economy concepts do not match in the traditional construction sector. Partly due to the fact that materials applied in a building remain a considerable time integrated before they become available for potential reuse. Currently there is not a professional marketplace where substantial quantities of materials to reuse and second hand products are available and availability in the (long term) future is unknown and uncertain. As such parties struggle to translate the efforts to apply the material passport versus the revenues along economic parameters and defining the net present value. The guideline does not clarify how parties have to approach this challenge. It is noted that also the term added value is used in the guideline without clarifying the explanation in financial and social values. Furthermore the guideline does not specify how parties are (e.g. financially) incentivised to apply the passport. It is noted that in the current situation the party who enriches and registers the data bears the costs however does not benefit from the supplied data.

The guideline describes logical preconditions that have to be met to effectively implement a material passport in practice. Information and data have to be accurate and complete, the tool must be interoperable, accessible and reliable. Privacy should be respected and stored centrally whereby information can be accessed publicly. Based upon research and validation with RVB is can be assessed that practical implementation is more unruly and ad hoc compared to the envisioned implementation in principles described in the guideline. Within practice data is not easily interchangeable nor always accessible or complete with respect to circular information requirements. As a result, implementing a MP that focuses on registering as much relevant information as possible requires significant effort, where the effort during the lifetime is ambiguous with respect to whether a MP is a dynamic or static document.

CB'23 envisions an open and transparent MP stored centrally. Within practice these boundary conditions are not yet met. Where information is managed decentralised and

where access to a material passport is locked behind currently used subscription based access. The importance of ownership of data with respect to open and transparent data should also not be disregarded. For Triodos the ownership of passport and associated data is transferred to the client upon commissioning, after which the client may decide what to do with the tool and information. This has implications on access for parties to the MP such as the supplier or subcontractor not being able to reuse own enriched data for future projects and/or actualise. A decentralised ownership structure also implies that data is not open to public. The guideline describes a centralised model of information sharing but does not clarify how parties are stimulated to share publicly their information under centralised and/or decentralised ownership.

The guideline describes that it is developing a Long List of information requirements, which is still under further development implying additional time requirement. The described longlist is important for parties applying a MP, however it is not clear and defined what the minimal information need is to establish a proper passport. A minimum requirement for material passport could be of great value for the standardisation and implement ability of MP's within practice. This is also assessed within practice, where the risk of ad hoc implementation of different passports is given as a possible risk that could reduce possible future added value. The economic balance of value of materials versus possible additional costs and efforts are not really evaluated with respect to value and value at the end of lifecycle. The balancing of cost-benefit should be considered when defining what is minimum requirement and what is desired. It is noted that CB'23 is not really clear how costs and efforts for developing a proper material passport are evaluated to decide requirements.
Another approach that is proposed by CB'23 is the implementation of an ID management system that can be used to transfer data between material passports and BIM formats. (e.g. door in Lelystad, while applied in Driebergen). Implementing this in practice could reduce omissions and potential errors, as well as prevent future omissions, based on the assumption that material passports cannot communicate autonomously.

The Platform CB'23 consists of representing parties and members, however parties involved in the Triodos project were not aware of the initiative nor aware of any publications. How the platform CB'23 communicates and integrates learning experiences outside of its action groups is unclear. RVB member of CB'23 has its own position and knowledge of MP implementation and associated datasets, but is not aware of perspectives and lessons learned by other parties and members. Parties involved in Triodos felt obligated to enter into partnership agreements with Madaster in order not to miss possible developments. It is noted that Madaster is not the only platform provider. Also other parties are active in developing separate MP platforms that given the experimental character of current implementation could also be developed on the basis of ad hoc decisions. It is not clear what the vision of CB'23 is with respect to the respective MP developments and how standardisation may be achieved between platforms. The business model of Madaster is based on a subscription structure. When a transition towards a centralised model is envisaged this may imply potential conflicts of interests of MP platforms as the information is no longer stored on their servers. It will be beneficial that CB'23 develops a vision and strategy how to integrate all lessons learned and respective perspectives of parties in the value chain of the construction sector and how interests and objectives are balanced.

The Triodos project is according the maturity model described by the guideline to be qualified in the early stage level 1. CB'23 describes that the government should make the MP application mandatory by 2025. This may be motivated by the maturity model and indicated life cycle. It has to be evaluated if forcing parties by mandatory obligation in order to achieve ambitions to standardise is effective and if not the natural way of development is preferable. The analogy of a BIM maturity model can provide some additional insight, where within the construction industry BIM has been introduced and applied for quite some time. However

from analysing the case study it can be assessed that even this tool struggles with interoperability and comparability.

It is realised that the research may be critical about the several barriers evaluated and the evaluation that in practice, the implementation of the material passport appears much more unruly and ad hoc as envisioned and described in the guideline. With respect to the use of BIM still interoperability and interchangeability and comparability results in substantial problems within the current CI. Disregarding this phenomenon and enforcing MP application could be counter effective to a natural development and does not contribute to shared ambitions and win-win situations.

Circular economy is based on potential innovative concepts like pay per use and leasing concepts. It is noted that not yet many innovative concepts may have been performed and described new parties and or new roles are not yet active. Future developments with respect to legalisation, finance and new parties in the chain as such may be delayed.

Within literature it can be seen that within science there is a lack of a generally defined CE definition. This can also be found back within practice were different stakeholders view the circular economy from personal perspectives. Literature also indicates that there is not yet a defined minimum set of requirements for a material passport. This can also be found back within practice where within the case study the information requirement was generated by logical reasoning. The guideline does not yet define the minimum requirements for implementation a MP.

Similarities can be drawn between international studies and the Triodos case and the guidelines. Honic's research focused on the implementation of an automated BIM-based material passport within Austria. It is suggested that barriers for implementation are the lack of standardisation and inconsistencies within data and a need for strong internal and external communication within CI practices. This has also been found to be a barrier within the Netherlands. Where interoperability between data systems creates barriers for implementation and possible future added value, The need for collaboration in order to work towards standardisation and ease of implementation was also seen as an important aspect of MP implementation. Within literature, it is suggested that a MP is filled from different information sources, such as LCA, bill of materials, and BIM. Within practice, the sole information source is based on BIM information. Within literature a material passport can be implemented during different life cycle phases of the construction. Where it could for instance act as a tool to optimise the design with respect to circularity. However within practice this was not yet assessed as possible.

Main topics and themes for Semi Structured Interviews were deduced from literature study and focused on barriers for implementation. These topics focused legal, technical, financial and collaboration (including cultural and organisational). As this research focused on the learning experiences and barriers it can be reflected that not all topics derived from literature were assessed as being equally important. Nearly all parties agree that there were no real conflicting interests with respect to the implementation of the material passport for this project. The experimental character of implementation could explain the lack of conflicts during the implementation phase and a collaboration environment perceived as being less hierarchical. However partnerships and contracts remained rather traditional. Therefore the willingness to collaborate was not seen as a barrier. However it is indicated that collaboration is extremely important to fill all the necessary data. This can also be said about the vision of the guideline. It is thus stressed that all parties within the value chain need to provide some kind of input to be able to generate a material passport.

With respect to legal barriers all representatives confirmed that there are no major legal barriers for the implementation of the material passport within the construction sector.

However when questioned more into detail parties did arise and point out topics that could become barriers. Such as intellectual property, access to material passport and ownership of information, as also indicated within science, and the willingness to share information freely. From this research it did not become clear how MP can be integrated into public procurement and legal frameworks.

The Triodos case was implemented with the goal to aid the circular transition as such the client acted out of goodwill. Therefore the implementation of the material passport was not reflected against a rigid cost benefit analysis although parties explained that the implementation came at a considerable cost and time investment. From a business model it was hard to assess if a MP can aid in closing circular value chains from a financial perspective.

With respect to technical multiple barriers for implementation where assessed such as the interoperability between BIM and the MP and the MP and Asset management software. Furthermore the importance of the design aspect that should incorporate circular thinking were seen as verry important to give a building circular potential.

6. CONCLUSIONS

Within this research the implementation and development of material passports within the Dutch construction industry has been analysed. The research is structured in such a way that by answering all the subsequent research questions the main research question can be answered. Below the subsequent sub-research questions will be answered whereafter the main research question is answered. Subsequently the limitations and recommendations for practice and future research are described.

6.1 SUB-RESEARCH QUESTIONS

The four sub-questions as presented within the introduction of this research (chapter 1) will be answered within this section.

6.1.1 Sub Research Question 1

What is the state of the art with respect to the generation and application of material passports within the construction industry to enable circular material flows?

Within the literature study the state of the art with respect to the generation and application of material passports has been brought into perspective. When looking at the data, it is clear that the majority of the scientific literature on MP's focuses on the broad principles of MP's, the potential that they provide to close circular value chains, and the objectives for implementing them. With regard to the practical and empirical proof of its implementation and the closing of circular value chains or reduction of primary and waste limited empirical evidence is presented and remains at a higher scientific abstract level.

Material passports could be seen as collaboration tools in order to enable value recovering at the end of life (Hart et al., 2019). Multiple stakeholders' needs and expectations may conflict since project based environments within the construction industry are complex, making it unlikely that all expectations will be met (McManus, 2004)*. The partners may have different and/or common shared goals and ambitions which can hinder an effective collaboration to facilitate the successful development and implementation of a material passport aiming to minimise the use of primary materials and reduction of waste. Failing to acknowledge these dynamics could compromise the effective implementation of material passports within projects. According to Honic, who researched the use of automated material passports, the main challenges towards the implementation of automated MP's are the lack of standardisation and inconsistencies within data and a need for strong internal and external communication within CI practices. Research conducted on the barriers and enablers of a circular economy in the construction industry seem to conclude that there are many technical and regularity challenges still remaining, however the real challenges lay within the culture and market issues, where the collaboration within the supply chain (or not), and demonstrating of a strong business case for circular implementations seem to be the real obstacles towards a circular built environment (Hart et al., 2019). The implementation of a material passport within construction projects requests the gathering and managing of information. Where information is often readily available and sometimes extra information is necessary this will require the agreement on how to exchange and structure the relevant digital or BIM information and clear demarcations on who delivers what kind of data. According to Honic and Aguiar, this could lead to new roles within the construction process where new stakeholders such as harvesters or material passport managers could arise* (Aguiar et al., 2019; M. Honic et al., 2019)*. The same research indicates that the main barriers are collaboration and quality of data in respective object libraries and information management related. To overcome analysed barriers support of the complete value chain is crucial. In summary in literature the state of art can be qualified as experimental and under development.*

A material passport is in principle an additional layer of information specifying characteristics of materials over the information already included in respective BIM models. As there is not yet a commonly accepted definition for MP's for the context of this research the following definition based on the research of Luscuere, Damen, Mullhall et al. and BAMB is used : *A material passport is a (digital) set of data describing defined characteristics of materials and components in products and systems that give them value for present use, recovery and reuse. MP's for the build environment aim to facilitate the reduction of the use of primary resources, optimise circular value potential and a reduction of waste within constructions* (Damen, 2012; Heinrich & Lang, 2019; L. M. Luscuere, 2017; Mullhall et al., 2017).

6.1.2 Sub Research Question 2

How to analyse and collect the learning experiences of the adoption and implementation of material passports within the construction value chain?

Within science and grey literature knowledge with respect to learning experiences within practice is limited and subjective. The Dutch government intends to decide in 2022 if the use of a material passport becomes mandatory within the construction sector. As such there is an urgency to investigate learning experiences from practical implementations and share these. Meanwhile Platform CB'23 has developed a guideline describing its vision and principles for standardisation of material passport implementations.

Within this research a qualitative research approach is implemented to gather and analyse non-numerical data. Qualitative research is "an iterative process" because knowledge that is learned at one point in the research process will flow into the rest of the research. "Getting closer to the phenomenon studied" means for this research that it captures the gained knowledge and barriers of people within its natural setting, talking directly to people that have implemented and developed a first of its kind material passport within practice. As there is limited knowledge gained and shared with respect to the implementation of MP's within practice, this research uses inductive reasoning to gather and present the knowledge of practice. Within this research deductive reasoning is implemented with respect to available scientific literature on the topic and most recent guideline for MP's.

The criteria used to select the case study are defined in the scope demarcation of this research, shortly summarised below.

- Project within the B&U sector within the Netherlands
- The project has developed and implemented a material passport with the use of digital data or BIM data, with the goal to facilitate circular ambitions for the project.
- New built project
- Retrospective so that learning experiences and barriers can be analysed.

After participating in two circular development days and explorative interviews it has been decided to select and focus on the Triodos project De Reehorst at Driebergen as a single case study. This project fits the selection criteria and is the first-of-its-kind MP implementation using BIM data in the Netherlands.

For data collection the semi-structured interview (SSI) is chosen, allowing for objective evaluation of participants' points of view and arguments while also allowing for spontaneous exploration of themes significant to that specific candidate. The sampling process or choosing the part of the population that will represent the project is done with the use of the snowball technique.

Prior to the interviews a structure of questions has been prepared which has been used in the same way for all interviews. Introduction questions, a middle part containing topics by deductive reasoning generated in the literature study being legal, financial, technical, cultural, collaboration and organisational, followed by closing questions.

To contextualise the findings within practice and give a deeper meaning to the research, a document analysis of the most recent guidelines with respect to the standardisation and implementation of material passports within the construction industry is conducted. For this research the guidelines of CB'23 version 2.0 is used as a second input of data for the triangulation. The analysis of the guidelines is along the topics and experience from practice cross-checked in order to conclude the potential discrepancies.

To further contextualise and validate the findings an expert session is planned. This research should take into account the characteristics of both private and public clients. The case study is related to the private sector. The viewpoints from a professional public client is reflected to contextualise the findings and put them into perspective. A prerequisite for the expert is that he/she must have knowledge of MP implementation and the development of the guidelines within the Netherlands.

6.1.3 Sub Research Question 3

How are material passports implemented and adopted within practice, and what learning experiences and barriers can be derived from the implementation of a first of its kind material passport within the Netherlands?

The Triodos Bank project De Reehorst at Driebergen-Rijsenburg is the first project in The Netherlands where the Client has decided to apply the material passport registering as much as possible circular information with the use of BIM information. The development and implementation was a legal requirement in the tender documents. Parties have decided to apply the format of the Madaster Platform. The strategy of the private client Triodos Bank is to be one of the most sustainable banks in the world. In line with its strategy the client has decided for its incidental investment in its office to apply the material passport in order to achieve its circular ambitions. The goal was to generate and commission a material passport for registration purposes at the end of the construction phase and in line with as built status in order to optimise the potential to maximise the reuse of products and/or materials with minimum loss or waste at the end of life of the building.

Contractually the main (civil) contractor was responsible for commissioning of the BIM-based material passport. The format and content were not specified in the tender documents. Subcontractors and suppliers had to generate, enrich and deliver data (both BIM data as well additional circularity data and characteristics) of materials and products supplied and applied. During the process it appeared that parties lack a shared working definition of CE which hindered proper communication and agreeing format and content of the passport. Many sessions were required to agree the format and content of data and associated (circular) characteristics. A variation order was granted by the client to reimburse the associated additional efforts. The lack of working definitions of CE and the format and content not specified in tender documents contributed to a process qualified as experimental and ad hoc. However the type of contract is traditional the requirement for a material passport implied a collaboration between parties less hierarchical and objective orientated improving evaluated collaboration.

Within the value chain parties use their own BIM-IFC models and architecture of data. Some subcontractors and suppliers however do not use these models or no models at all. Requested data from suppliers and subcontractors could as such not be delivered according the same architecture and definitions used by contractors. Contractors not being non-core product specialist had to understand, enrich and manipulate data received to incorporate in the material passport. Consequently some data may not be audited and circular not correct. As such it is envisaged that for future applications auditing and validation of data is required as well as a process of standardisation of characteristics, data and format. Data quality as such is essential where in the implementation as adopted quality of data may not be objective representing the circularity of the building. With respect to architecture of data

parties experienced difficulty to define levels of scale, for instance to qualify materials as a product or a material. Seeking data in the platform for certain materials it appeared that only characteristics of virgin materials were available, while actual materials applied contained a circular content (incorporating reused and/or recycled materials). Technically the used algorithm generating the Circular Building Index (CBI) is evaluated as subjective. Accordingly credibility of data becomes dubious. However not really applicable for this project suppliers noted that legally and financially they are reluctant to be open and transparent with supplying data when intellectual property and competitive edge considerations are at stake. Not all parties had access to the Madaster platform which is subject to subscription requirement. Upon enriching of data by parties they are not in a position nor allowed to use their enriched data for future projects. At present data from respective parties as such are not yet freely accessible, comparable, interchangeable and complete. It is noted that due to use of several BIM tools with their own architecture and definitions introduces efforts to generate uniform and unique codes and data. Representatives mentioned that also other material passport providers and formats are available in the market which are not uniform to each other and not standardised.

Innovative concepts like pay for use, leasing of the façade or take back guarantees with shift in ownership and responsibility and potential introduction of new roles and parties have been evaluated however proved to be more costly and risk increasing for the client and as such not pursued. Legally the contract as such remained traditional. Consequently also no new finance parties or financing structures were applicable. In case innovative concepts are applied in future projects it is noted that associated business and revenue models will change and shift including a redistribution of importance in the value chain implying potential conflicts of interest. The MP provider is a new party, however the real added value is questioned. Coaching of parties and personnel, supply of MP services, improvement of passport formats and standardisation are seen as possible added service for this role. With respect to competences and functions within participating parties it is noted that activities mainly are executed by respective BIM engineers.

At the time of design MP was not yet available. It is noted that in retrospect design has been with an as sustainable as possible approach, including focus on demountability to achieve circular ambitions and as such with circular approach and principles. The material passport has been established at the end of the construction phase representing the as built situation in order to mitigate mistakes due to respective design changes and omissions and to minimise the efforts. With respect to the material passport and associated data development and registration focus has been on the building as such and its constituting elements and products. Demountability in approach of design is assessed as beneficial for achieving circularity ambitions, however strategy of dismantling elements has to be integrated in approach. The development and implementation by focusing on a complete material passport (all products and elements in the building) has required substantial more additional costs and efforts as anticipated. With demountability as criterium it is noted by representative RVB that strategy of passport development should focus on elements, materials and products to be reused at the end of the life cycle. It may be expected that the balance of additional costs and efforts versus generated additional added rest value of materials may be favourable when a circularity optimisation strategy is adopted. As such defining what is minimum required versus nice to have is essential. For future applications a clear strategy and the ambitions should be jointly decided and shared by all parties involved at the early start of the process, which will be beneficial for process, collaboration and development of the passport. Furthermore BIM protocols including all the necessary Information Delivery Specifications (IDS) have to be developed prior to development and implementation. The 3D viewer applied in the passport appeared not to be effective for tracking and locating certain elements in the building. The choices have been based upon a total cost of ownership concept. It is noted that the duration of the exploitation phase is quite flexible and the availability of a professional and substantial market place for materials to reuse is not

existent and unknown. As such the balance between associated efforts to develop and manage a material passport over the lifecycle versus the generation of additional end value is rather subjective. The use of the material passport is assessed as beneficial for awareness of circularity, not only with respect to the building but also for awareness within normal operations of parties.

One may assume that with respect to circularity and optimising rest value of material bank at end of life cycle a material passport is applied in all phases of a building, the design-, construction-, use- and dismantling phase. However this is not the concept the client has chosen. After commissioning of the material passport the client has become the owner of the passport and its data. The client has not decided yet how and if to apply the material passport during the use- and dismantling phase. The client does not have personnel experienced to work with the passport and no parties in the market supplying MP services. Furthermore the additional costs for actualising data during use-phase are questioned versus the potential additional generated added value at end of life. As such the possible risk is that the material passport will remain on the shelves as a static document till dismantling the building and possible reuse and recycling becomes opportune. Data may prove not to be accurate and actual anymore and results suboptimal. Characteristics of data for the material passport are different from data used for asset management. Actualising data during use-phase may as such imply double bookkeeping and ineffectiveness.

Contractors have difficulty to assess the current added value of implementing the material passport based upon their experience and encountered barriers. The application is mainly seen as a learning experience in process of achieving circular ambitions. More pilots and learning experiences are needed to optimise and integrate lessons learned in order to standardise and generate a more simple and automated registration tool assisting in the ambition of the Construction Industry to achieve CE ambitions. The implementation may be qualified as experimental and is in phase level 1 of the maturity model presented in the CB'23 guideline.

6.1.4 Sub Research Question 4

What are the main discrepancies between state-of-the-art guidelines reflecting the learning experiences from the state of the art material passport implementation within the Netherlands?

The guideline of CB'23 presents the broadly accepted working agreements of public and private parties with respect to standardisation of the implementation of MP and road towards future development and harmonisation of MP's. The correct data and completeness was given as one of the critical success factors for MP implementation within practice. This is in line with vision CB'23 which adds that data should also be comparable and interchangeable to facilitate information flow between MP's in the future and between information tools used within practice. To maximise the circular value of MP's CB'23 envisions MP's to be used within an open and public data architecture. Within its guideline CB'23 describes how MP should be implemented and what preconditions for use should be pursued. Comparing guide 2.0 and the case study findings it may be concluded that the practical implementation experiences are much more unruly and experimental than described. However the policy and approach of applying and implementing a material passport as described in the guide are logical and understandable it appears that practice is much more challenging and ad hoc.

A material passport should be a tool to capture the information that is already used within practice with the addition of an information layer relevant from circular economic perspectives. This additional information requirement is new for all parties and therefore is not always available and subjective due to human guestimates (hence not always accurate). CB'23 envisions an incremental approach generating a MP to represent the as is situation over the life cycle, and as such during the four respective phases of design, construction,

use- and dismantling. Access is locked behind subscription based MP platforms. Not all parties had access to retrieve and fill data. Suppliers as such cannot deliver a product passport freely. Because the MP generation is not a simple and automated process (as wished for) the client and involved parties decided to generate and develop the passport as late as possible during the construction phase at as built phase in order to reduce multiple iterations and omissions due to differences in BIM models, design changes and delivery of data. As interoperability and comparability appeared limited parties had to make additional efforts to link, enrich and in some cases manipulate the relevant information. CB'23 describes that a MP has dynamic characteristics however due to interoperability issues with asset management tooling the current implementation runs the risk of becoming a static document and may imply double book keeping for parties.

Deviating from descriptions in the guideline MP and data are in practice not easily and freely accessible nor public therefore. Within practice a decentralised model is implemented. Information access is locked behind a subscription during implementation and locked behind an ownership structure after delivery. Therefore the contractor had to act as an intermediate between suppliers and the MP. The parties that generated and registered the data and incurred the associated costs are not the parties benefitting from the enriched data. Parties as such found it difficult to assess the added value of developing the passport from their respective social and economical perspectives as well the balance between associated costs and efforts and the potential generated additional value at the end of life. Information is not captured by the party that ensures the most added value but rather who is contractually specified to deliver the information. This is not in line with the guideline as it stipulates that the party that benefits most at the moment in question records the necessary data. The guideline does not clarify how efforts and added value is balanced in social, economical and financial perspective contributing to gain a broad support of parties and members as described. Other than describing an imminent mandatory use and governmental involvement the guideline does not clarify how parties are incentivised nor facilitating different interests and consequences for private and public clients without falling back in traditional contractual agreements.

The guideline envisions new roles and parties due to the application of passports. In practice innovative circular business models appeared more costly and risk increasing for client resulting in a traditional structure and approach. As such no new roles or parties did emerge except for the MP platform provider. The guideline does not describe the responsibility and role of the platform provider nor in the development phase nor in the exploitation phase. The guideline does not clarify how actualising data for MP due to non-interoperability and non-comparability of data will not imply potential additional bookkeeping for parties performing asset management for their assets over the lifecycle. It is not clarified who is responsible for standardising interoperability, the client, the passport provider, or the BIM and Asset Management software suppliers. Current development is led by market power however given the inherent business models of different platforms (subscriptions) it is not clear how they are incentivised to work towards standardisation. It can be argued that this could lead to a situation where parties rather diversify to gain a competitive advantage which is of course not in line with the intended goal of the guideline. How this discussion is placed in the road towards centralised data management is also not clear. Transiting towards centralised data architecture would mean that the business models of current initiatives could be harmed because data will no longer be stored on their servers. It should be made clear how owners, the party that registers the data (suppliers) and manages the data is incentivised to openly share his data. CB'23 explains that legislation should come about that would stipulate data delivery within the construction chain. However how soon such a regulation would come about is not verry clear and given the traditional CI contractual relations the materialisation of the intended MP development timeline can be questioned.

Currently there is no professional market place for substantial quantities of reusable or recyclable materials and products and availability in the (long term) future is unknown and uncertain. Total cost of ownership approach and balancing the efforts of MP implementation versus potential future circular net present value remains subjective. The guideline does not further clarify nor suggest possible solutions in order to entice new clients to implement a MP from a business model perspective.

The ID management system suggested by CB'23 is a valid and logical solution to reduce omissions between MP and BIM, and data transfer between MP's in the future. When applied in practice this could have mitigated omissions and problems with locating materials or products (e.g. door in Lelystad despite being applied in project in Driebergen) and add value for future data sharing. The long list as supposed by CB'23 is a good step towards defining the minimum requirements versus the possible desired information requirements for MP. This could aid the more standardised recording of data for circularity within the construction sector. However the guideline has not provided an intended timeline for when such a minimum requirement will come about. Parties within practice found it hard to assess the economic added value from their perspective balanced against the effort if implementing a material passport that contained as much as possible relevant information. The longlist seems valid to balance effort versus desired content however these considerations should also be expressed in for instance a cost benefit analysis. Without overview in the economic consequences of implementation versus additional added value for implementation and delivery of information. Material passport implementation is mainly based on goodwill of clients to initiate a passport in order to facilitate the governmental goal.

6.2 Conclusion of the Main Research Question

What does the implementation of a first of its kind material passport imply for guidelines and the development of material passports within the Netherlands?

When reflecting the findings of the first of its kind MP against the broadly accepted work agreements of the guideline, it can be concluded that implementation within practice is much more unruly and ad hoc than the suggested implementation guideline and road towards standardisation as described in the work agreements. Within this research multiple discrepancies have been found that could create a barrier for effective implementation with respect to ease of use and implementability and could impact the added value of the tool over the lifetime of the construction. Within a decentralised data architecture the parties that generated and registered the data and incurred the cost are not the parties that benefit from the enriched data. Therefore parties found it difficult to assess the additional efforts from their respective social and economic perspectives going forward. Within the guideline it does not become clear how respective social and economic perspectives are weighed against the possible added value of implementation. Not properly balancing these social and economic perspectives implies that a situation could arise where all parties will try to maximise their own CE project related social and economic values, while neglecting the data architecture as a whole.

Currently the guideline indicates that implementation of passports will become mandatory. The envisioned governmental involvement in order to facilitate the process towards standardisation must be addressed. The guide is written with in hind sight that governmental support will impose mandatory material passport in the near future suggesting 2025. When the implementation of the Triodos case is set against the maturity model of CB'23 it can be analysed that for this case it is located on level 1 (individual, ad hoc). The next step in the development will be to reach maturity level 2 which implies already registration according CB'23 principles. The guideline describes that the vision and principles including associated working agreements are supported and shared by all members of the platform. However the

evaluated discrepancies suggest support and sharing by market parties is lacking, which is also confirmed by the validation with one of the main public members of the platform. The guide does not make clear how governmental involvement leads to creating better shared views and how barriers such as interoperability are achieved nor whose responsibility it will be. Therefore governmental obligation implies that the architecture as a whole will be better managed but does not necessary align the social and economic values and perspectives of stakeholders or removes all discrepancies. This implies that stipulation versus market force should be more critically managed by the guideline. Where some measures such as a long list and ID management seem suitable to govern. Working together with all parties in the value chain and aligning values and perspectives driven by market forces would seem more suitable to achieve a dynamic and actual passport.

The guideline is not clear about the role and responsibility of material passport (platform) providers within the development and road towards standardisation. It is unclear how the obligation of a material passport is in line or is hindered by current development path and market force. The envisioned transition towards a centralised data architecture implies an impact on the business models of current initiatives whereby data will no longer be stored on their servers (e.g. subscription structure as business model). Also the guideline does not clarify how owners and parties registering and managing data are incentivised to openly share data in case passports become mandatory.

The private and incidental client objectives to apply a material passport in order to promote CE, capture circular value and score the circularity of constructions corresponded. Governmental professional and structured entities will have to follow and manage the circular strategy as envisioned by the Dutch government to act circular before 2030. Therefore it is interesting that within this research an incidental private client decided to implement an untested and first of its kind material passport. Decision to implement was mainly based on goodwill considerations to aid the transition towards CE within the construction industry rather than being based upon a proper cost benefit analysis. One may argue that not all private parties would decide accordingly without direct governmental involvement. RVB bases their decision upon other considerations that do not align with the case study nor the guideline of CB’23. RVB confirms the same barriers as found within this research and evaluated discrepancies based on current ad hoc implementations. As public clients own a substantial amounts of assets and is governances most of its asset management and data systems internally. RVB first intends to assess how to keep material passports and data up to date given the current organisation and use of data compatible with data in use. As such the organisation is quite reluctant to request material passports from the market or request should be for compatible data and preferably data originating and corresponding to their own data structure. Therefore it might be questioned if the broadly accepted working agreements are properly aligning the values and objectives of development of MP’s and road towards standardisation between incidental private clients and public clients. Sharing and supporting of the vision and principles described in the guideline may as such be lacking. And therefore imply that development and route towards standardisation could become more complex when MP for governmental entities are developed internally and MP development for private parties is left to the market power. As it does not become clear how the guideline currently balances the visions and perspectives of public and private clients with respect to the development and road towards standardisation. This implies that development of standardisation and development could be segregated between private and public clients both with different approaches.

As the guideline describes that the vision and principles including associated working agreements are supported and shared by all members of the platform. However the evaluated discrepancies suggest support and sharing by market parties and private and public clients is lacking. Cooperation, support and sharing of the CB’23 vision and ambitions from partners and members in the value chain is required.

Currently the material passport is far from an automated process and requires considerable efforts from parties to generate and enrich all the relevant circular value with respect to facilitating CE. Nevertheless parties recognise the need of data registration. It is noted that having a material passport does not necessarily make the design and construction of a building circular. Development and implementation is still quite experimental and recirculation of materials and products locked within constructions that have MP's will take quite some time. Therefor it is interesting to see how the tool will develop and take its function within a circular construction industry. As mentioned by one of the representatives "the proof of the pudding is in the eating".

6.3 LIMITATIONS OF RESEARCH

- Because this research focused on the learning experiences of a first-of-its-kind MP with the use of BIM, only one case study was assessed to fit the scope criteria for selection. This lack of cases could be due to the fact that implementation of innovations and the long lead time within the construction sector delaying applications. Or the fact that MP implementation within the construction industry is still very limited. The decision to continue this research with only one case could create a certain bias as implementation in the construction industry is ad hoc and may not represent potential findings when more implementations are evaluated.

- Circular Economy and Material Passports are broad subjects. When evaluating and analysing not all topics will have the same importance nor depth of analysis. As an example the data governance is not as well reflected by parties involved versus the importance of this topic as described in the CB'23 Guide.

- The implementation of MP within the construction industry is relatively new. A material passport only provides added value from a circular perspective when it is used to facilitate circular material flows. The impact of MP from a short-circular perspective (renovation) or long-circular perspective (demolition) cannot yet be assessed.

- The guideline is written to promote standardisation and act as a guide for implementation within the entire construction industry. Therefore, MP learning experiences and barriers of implementations that have undertaken maximum effort as within this research may differ from MP implementations with minimal efforts.

- MP application has been decided by Triodos Bank for registration purposes of "as built" status only rather than over all phases (design, construction, exploitation, dismantling). As such results may differ from implementations where other life cycles are integrated in the approach and development. It is noted that MP and implementations are rather new and long term experiences over lifecycle are lacking.

- The project has decided not to apply innovative and new concepts like pay for use or take back guarantees and as such no innovative circular financing structures are applied. Therefore these possible new stakeholders are not taken account in depth within this research. No further interviews have been performed with possible other parties than the parties involved in the project. This may have an influence on the outcome of the research. This may cause a bias towards projects that have implemented alternative business models or evaluating the guideline descriptions.

- It is noted that some of the representatives answered more in depth due to actual involvement enriching data and communicating with colleagues in the operational scene, this made it difficult the reflect the findings on different abstract levels.

6.4 RECOMMENDATION FOR PRACTICE

All parties in the value chain of the construction sector understand and support the transition to a circular economy and the achievement of circular goals. Given the findings of this research, it is questionable whether the shared and supported work agreements and principles of the CB'23 guideline are truly shared by all parties within the construction value chain. For the development and road towards standardisation of MP's the support of all actors will be crucial. It is not clear how the guideline balances all the visions and social and economic perspectives of public and private parties. It is therefore recommended that Platform CB'23 shall convene with public and private parties physical in several brain storm sessions including openness and willingness to integrate creative alternatives or solutions in order to define the final strategy and policy. Including a shared working definition of CE. Minimum requirement versus nice to have, circular driven strategy, etc. An associated recommendation with respect to further process and actions Platform has to readdress its communication policy in order that all parties in the value chain are aware of ambitions, initiatives and consequences for individual parties with the focus that all parties need to become convinced in order to support and share CB'23 ambitions.

Standardisation is one of the goals of the CB'23 guideline. MP development and implementation in principle is still in its infancy and experimental phase. Nevertheless an ambitious timeline is indicated, whereby mandatory implementation could also be imminent. The main efforts and costs for parties in practice are due to data and architecture of BIM models used by partners being not interchangeable nor comparable nor standardised and as such not automatic linkable to MP's. The market offers many BIM tools not being equal in architecture and definitions. It is recommended that Platform CB'23 integrates this phenomenon and lessons learned into the discussions and in respect to the envisaged timeline. Due to its experimental phase and realising practice is more unruly and ad hoc as assumed by the platform it is recommended to do further pilots and implementations parallel to readdressing of vision and policy with full commitment from parties in the value chain and integrating lessons learned by private and public parties. Accordingly relaxation on the timeline is recommended.

Currently, parties involved in implementation in practice, both private and public, are having difficulty determining the tool's added value. The guideline describes the added value of MP implementation mainly from a social perspective. It is therefore recommended to make the added value clear from a financial perspective. As the financial qualification and quantification of costs and efforts versus potential additional rest value at end of life in combination with realism of achieving circular ambitions can be beneficial for parties in the value chain to become convinced and supporters.

Internationally also implementations of passports have been performed and evaluated. Where similarities can be drawn between developments within the discrepancies within other countries and the development in the Netherlands. Therefore it is recommended to integrate lessons learned and organise international cooperation and brainstorm sessions in order to define the policy forward.

6.5 RECOMMENDATIONS FOR FUTURE RESEARCH

Below multiple suggestions for future research are provided, which are based on the findings, limitations and evaluation of this research.

- The material passport represents an additional layer of information to other registration tools applied in the sector. This research and the CB'23 only asses the implementation of a MP as a means to act as a repository and tool to transfer information in order to facilitate a circular transition. It may be questioned if the MP is the right tool to apply versus the option of other registration tools allowing integration of these specific

circular characteristics of data and levels of scale. It is recommended to analyse what is the most effective and efficient registration tool serving the main purpose and functionality as envisaged for the MP.

- Currently not many MP applications have been performed. The experimental application for the private incidental client (Triodos) project is only limited to registration at “as built” status and subsequent to design decisions made at an earlier phase. Also the public client (RVB) confirms not many applications have been performed. As such lessons learned are very limited and current evaluation may as such be rather relative. As such it is recommended to analyse more case studies whereby it may be of additional value if both project applications in the public and private sector are evaluated.

- Validation of residual value and quantification appear vague and subjective. Total Cost of Ownership approach with many uncertainties such as not yet structured market place for reusable and recyclable products and materials not being available nor future professional availability is certain it is difficult to make choices for design and construction. Furthermore this may impact decisions regarding minimum requirement of information in relation to associated efforts and potential additional value at end of life. A further research is recommended to evaluate a more objective and financial sound base for deciding policies.

- Despite the fact that this study did not go into great depth on the information needs for the circular transition, there is minimal understanding within practice and the guideline in terms of the minimum versus desired information required to effectively enable the circular transition. The additional information with respect to the additional CE layer was not always easily available or known within the construction value chain. Future research should define the minimum and desired information requirements to best facilitate the circular potential of materials versus the availability and accessibility of this information within the value chain.

- Demountability is adopted as a principle for the design of the building as well as an applied feature in the implemented passport for the Triodos project. Due to construction processes, the realism and achievability of products and elements to be recovered for potential recirculation and reuse at the end of life are at stake. Because materials will be locked within the construction for a considerable time there is limited insight in the added value of MP’s. Future research should provide better insights into how CE construction strategies in combination with MP implementation can maximise the locked circular value potential within construction at the end of its lifetime.

- According to this study, the construction industry's lack of interoperability of tools and datasets is a barrier to MP adoption and maintenance throughout the lifecycle of the construction. It is envisioned that future MP implementation will become easier and automated. Therefore future research should provide insight into the current interoperability problems of datasets and tools and design an approach to automate MP application.

7. BIBLIOGRAPHY

Adams, K. T., Osmani, M., Thorpe, T., & Thornback, J. (2017). Circular economy in construction: Current awareness, challenges and enablers. *Proceedings of Institution of Civil Engineers: Waste and Resource Management*, *170*(1), 15–24. https://doi.org/10.1680/jwarm.16.00011

Adams, W. C. (2015). Conducting Semi-Structured Interviews. In *Handbook of Practical Program Evaluation* (4rd ed.). John Wiley & Sons, Inc. https://doi.org/10.1002/9781119171386.ch19

Aguiar, A., Vonk, R., & Kamp, F. (2019). BIM and Circular Design. *IOP Conference Series: Earth and Environmental Science*, *225*, Article 012068. https://doi.org/10.1088/1755-1315/225/1/012068

Alhosni, I. S., Amoudi, O., & Callaghan, N. (2022). Circular economy during project life cycle. In *Circular Economy and Sustainability* (Vol. 1, pp. 177–188). Elsevier. https://doi.org/10.1016/B978-0-12-819817-9.00012-0

Antikainen, M., Uusitalo, T., & Kivikytö-Reponen, P. (2018). Digitalisation as an Enabler of Circular Economy. *Procedia CIRP*, *73*, 45–49. https://doi.org/10.1016/j.procir.2018.04.027

Architectweb. (2019). *Triodos Bank bekroond als Kantoorgebouw van het Jaar 2019*. https://architectenweb.nl/nieuws/artikel.aspx?ID=46735

Aspers, P., & Corte, U. (2019). What is Qualitative in Qualitative Research. *Qualitative Sociology*, *42*(2), 139–160. https://doi.org/10.1007/s11133-019-9413-7

Atta, I., Bakhoum, E. S., & Marzouk, M. M. (2021). Digitizing material passport for sustainable construction projects using BIM. *Journal of Building Engineering*, *43*, Article 103233. https://doi.org/10.1016/j.jobe.2021.103233

Bastein, T., Roelofs, E., Rietveld, E., & Hoogendoorn, A. (2013). *Opportunities for a Circular Economy in the Netherlands.* TNO commissioned by the Netherlands Ministry of Infrastructure and the Environment. https://www.tno.nl/media/8551/tno-circular-economy-for-ienm.pdf

Baumgartner, R. J., & Zielowski, C. (2007). Analyzing zero emission strategies regarding impact on organizational culture and contribution to sustainable development. *Journal of Cleaner Production*, *15*(13–14), 1321–1327. https://doi.org/10.1016/j.jclepro.2006.07.016

Benyus, J. M. (1997). *Biomimicry: Innovation inspired by nature*. William Morrow.

Boulding, K. (1966). The economics of the coming spaceship earth. In *Environmental Quality in a Growing Economy* (pp. 3–14). Resources for the Future/Johns Hopkins University Press.

Bouwwereld. (2020). *Triodos Bank meest duurzame project*. 2020-02-10. https://www.bouwwereld.nl/duurzaamheid/triodos-bank-meest-duurzame-project/

Bowen, G. A. (2009). Document analysis as a qualitative research method. *Qualitative Research Journal*, *9*(2), 27–40. https://doi.org/10.3316/QRJ0902027

Bryman, A. (2008). *Social research methods* (3rd ed.). Oxford University Press.

Buur, A. P. (2008). De bouwnijverheid heeft veel gezichten. *ConcepTueel*, *17*(1), 6–9. https://research.utwente.nl/en/publications/de-bouwnijverheid-heeft-veel-gezichten

Carra, G., & Magdani, N. (2017). Circular Business Models for the Built Environment. *Arup, BAM & CE100*. http://www.duurzaam-ondernemen.nl/circular-business-models-for-the-built-environment-research-report-by-arup-bam/

CB'23. (2019). *Guide: Passports for the construction sector - Working agreements for circular construction* (1.0). Platform CB'23.

CB'23. (2020). *Guide: Passports for the construction sector - Working agreements for circular construction* (2.0). Platform CB'23. https://platformcb23.nl/images/downloads/Platform_CB23_Guide_Passports_for_the_construction_sector_2.0.pdf

Circle Economy. (2014). Circular construction - The foundation under a renewed sector.

Circle Economy & ABN.
Circle Economy. (2019). The Circularity Gap Report 2019. *Platform for Accelerating the Circular Economy (PACE)*. https://www.circle-economy.com/resources/the-circularity-gap-report-2019
CIRIAG. (2015). Circular Economy: A Critical Literature Review Of Concepts. In *Centre for the Life Cycle of Products Processes and Services*. Centre for the Life Cycle of Products Processes and Services. https://ciraig.org/wp-content/uploads/2020/05/CIRAIG_Circular_Economy_Literature_Review_Oct2015.pdf
Cobouw. (2020a). *Materialenpaspoort nog lang niet uniform in gww-sector*. 12-11-2020. https://www-cobouw-nl.tudelft.idm.oclc.org/duurzaamheid/nieuws/2020/11/materialenpaspoort-nog-lang-niet-uniform-in-gww-sector-101290065
Cobouw. (2020b). *Nieuw hoofdkantoor Triodos Bank 100 procent 'remontabel.'* 23-9-2020. https://www.cobouw.nl/duurzaamheid/nieuws/2019/09/nieuw-hoofdkantoor-triodos-bank-100-procent-remontabel-101276465
Corbin, J., & Strauss, A. (2008). *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory* (3rd ed.). Sage Publications, Inc.
Creswell, J. W. (2013). *Qualitative Inquiry & Research Design: Choosing Among five approaches.* (3rd ed.). Sage Publications.
Crowe, S., Cresswell, K., Robertson, A., Huby, G., Avery, A., & Sheikh, A. (2011). The case study approach. *BMC Medical Research Methodology*, *11*, Article 100. https://doi.org/10.1186/1471-2288-11-100
Damen, M. A. (2012). *A resources passport for a circular economy* [Universiteit Utrecht]. http://igitur-archive.library.uu.nl/student-theses/2012-1121-200521/UUindex.html
Denscombe, M. (2010). *The good research guide : for small-scale social research projects* (4rd ed.). McGraw-Hill/Open University Press.
Dyer, W. G., & Wilkins, A. L. (1991). Better Stories, Not Better Constructs, To Generate Better Theory: A Rejoinder to Eisenhardt. *Academy of Management Review*, *16*(3), 613–619. https://doi.org/10.5465/amr.1991.4279492
Eberhardt, L. C. M., Birgisdottir, H., & Birkved, M. (2019). Potential of Circular Economy in Sustainable Buildings. *IOP Conference Series: Materials Science and Engineering*, *471*(9), Article 092051. https://doi.org/10.1088/1757-899X/471/9/092051
EDGE. (2019). *EDGE delivers innovative and sustainable office building for Triodos Bank*. 11-09-2021. https://edge.tech/article/press/edge-delivers-innovative-and-sustainable-office-building-for-triodos-bank
Ellen MacArthur Foundation. (2013). *Towards the circular economy: Economic and business rationale for an accelerated transition*. *1*. https://ellenmacarthurfoundation.org/towards-the-circular-economy-vol-1-an-economic-and-business-rationale-for-an
Ellen MacArthur Foundation. (2015). *Towards a Circular Economy: Business Rationale for an Accelerated Transition*. https://ellenmacarthurfoundation.org/towards-a-circular-economy-business-rationale-for-an-accelerated-transition
Esa, M. R., Halog, A., & Rigamonti, L. (2017). Developing strategies for managing construction and demolition wastes in Malaysia based on the concept of circular economy. *Journal of Material Cycles and Waste Management*, *19*(3), 1144–1154. https://doi.org/10.1007/s10163-016-0516-x
European Commission. (2014). *Scoping study to identify potential circular economy actions, priority sectors, material flows and value chains: final report*. Publications Office of the European Union. https://op.europa.eu/en/publication-detail/-/publication/0619e465-581c-41dc-9807-2bb394f6bd07
European Commission. (2015). *Closing the loop - An EU action plan for the Circular Economy*. Publications Office of the European Union. https://op.europa.eu/en/publication-detail/-/publication/8a8ef5e8-99a0-11e5-b3b7-01aa75ed71a1/language-en/format-PDF/source-248342978
Frosch, R. A. (1992). Industrial ecology: a philosophical introduction. *Proceedings of the National Academy of Sciences*, *89*(3), 800–803. https://doi.org/10.1073/pnas.89.3.800

Geisendorf, S., & Pietrulla, F. (2018). The circular economy and circular economic concepts-a literature analysis and redefinition. *Thunderbird International Business Review*, *60*(5), 771–782. https://doi.org/10.1002/tie.21924

Geng, Y., & Doberstein, B. (2008). Developing the circular economy in China: Challenges and opportunities for achieving “leapfrog development”. *International Journal of Sustainable Development & World Ecology*, *15*(3), 231–239. https://doi.org/10.3843/SusDev.15.3:6

Geraedts, R. P., & Prins, M. (2015). The CE Meter: An instrument to assess the circular economy capacity of buildings. In I. P. Ltd. (Ed.), *Proceedings of the CIB joint international symposium - Going north for sustainability: Leveraging knowledge and innovation for sustainable construction and development (Article A014)*. IBEA Publications Ltd. https://www.irbnet.de/daten/iconda/CIB_DC28849.pdf

Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner Production*, *114*, 11–32. https://doi.org/10.1016/j.jclepro.2015.09.007

Hansen, K., Baumgart, M., & Mulhall, D. (2012). “Resource Re-Pletion. Role Of Buildings. Introducing Nutrient Certificates A.K.A Materials Passports As A Counterpart To Emissions Trading Schemes.” In *The Springer Encyclopedia of Sustainability Science and Technology Meyers*. Springer-Verlag.

Hart, J., Adams, K., Giesekam, J., Tingley, D. D., & Pomponi, F. (2019). Barriers and drivers in a circular economy: the case of the built environment. *Procedia CIRP*, *80*, 619–624. https://doi.org/10.1016/j.procir.2018.12.015

Heinrich, M., & Lang, W. (2019). *Materials Passports - Best Practice Innovative Solutions for a Transition to a Circular Economy in the Built Environment*. Technical University of Munich, in association with BAMB. https://www.bamb2020.eu/wp-content/uploads/2019/02/BAMB_MaterialsPassports_BestPractice.pdf

Heintz, J. L., & Wamelink, J. W. F. (2015). Overcoming Barriers to Innovation in the Building Industry. *Boss Magazine*, *52*(March), 25–31. https://www.researchgate.net/publication/281578911_Overcoming_Barriers_to_Innovation_in_the_Building_Industry

Honic, M., Kovacic, I., & Rechberger, H. (2019). Concept for a BIM-based Material Passport for buildings. *IOP Conference Series: Earth and Environmental Science*, *225*, Article 012073. https://doi.org/10.1088/1755-1315/225/1/012073

Honic, Meliha, Kovacic, I., & Rechberger, H. (2019). BIM-Based Material Passport (MP) as an Optimization Tool for Increasing the Recyclability of Buildings. *Applied Mechanics and Materials*, *887*, 327–334. https://doi.org/10.4028/www.scientific.net/amm.887.327

Iacovidou, E., & Purnell, P. (2016). Mining the physical infrastructure: Opportunities, barriers and interventions in promoting structural components reuse. *Science of the Total Environment*, *557–558*, 791–807. https://doi.org/10.1016/j.scitotenv.2016.03.098

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Report of the World Commission on Environment and Development: Our Common Future*, *127*, 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005

Korhonen, J., Honkasalo, A., & Seppälä, J. (2018). Circular Economy: The Concept and its Limitations. *Ecological Economics*, *143*, 37–46. https://doi.org/10.1016/j.ecolecon.2017.06.041

Kovacic, I., Honic, M., & Rechberger, H. (2017). BIM based material passport as tool for enhancemet of circular economy in AEC industry. In *Working Paper Series, Proceedings of the EPOC-MW Conference*. http://epossociety.org/EPOC2017/papers/Kovacic_Honic_Rechberger.pdf

Luscuere, L. M. (2017). Materials Passports: Optimising value recovery from materials. *Proceedings of Institution of Civil Engineers: Waste and Resource Management*, *170*(1), 25–28. https://doi.org/10.1680/jwarm.16.00016

Luscuere, L., & Mulhall, D. (2018). Circularity information management for buildings - The example of materials passports. In *Designing for the Circular Economy* (pp. 369–381).

Routledge.
Lyle, J. T. (1994). *Regenerative design for sustainable development*. Wiley.
Mathers, N., & Nick Fox, A. H. (1998). *Trent Focus for Research and Development in Primary Health Care: Using Interviews in a Research Project*. Trent Focus.
McManus, J. (2004). *Managing Stakeholders in Software Development Projects*. Butterworth-Heinemann.
Meadows, D. H., Meadows, D. L., Randers, J., Behrens, W., & C. of R. (1972). *Limits to growth: A report for the Club of Rome's Project on the Predicament of Mankind*. Universe Books.
Mullhall, D., Hansen, K., Luscuere, L., Zanatta, R., & Willems, R. (2017). *Framework for Mate- rials Passports. Extract from an Internal BAMB Report.* BAMB Consortium, EPEA, SundaHus.
Munaro, M. R., & Tavares, S. F. (2021). Materials passport's review: challenges and opportunities toward a circular economy building sector. *Built Environment Project and Asset Management*, *11*(4), 767–782. https://doi.org/10.1108/BEPAM-02-2020-0027
Naderifar, M., Goli, H., & Ghaljaie, F. (2017). Snowball Sampling: A Purposeful Method of Sampling in Qualitative Research. *Strides in Development of Medical Education*, *14*(3), Article e67670. https://doi.org/10.5812/sdme.67670
Ness, D. (2008). Sustainable urban infrastructure in China: Towards a Factor 10 improvement in resource productivity through integrated infrastructure systems. *International Journal of Sustainable Development and World Ecology*, *15*, 228–301. https://doi.org/10.3843/SusDev.15.4:2a
OECD. (2018). *Global Material Resources Outlook to 2060: Economic Drivers and Environmental Consequences*. OECD Publishing. https://doi.org/https://doi.org/10.1787/9789264307452-en
Ollongren, K. H. (2020). *Voortgang circulair bouwen, beantwoording vragen, uitvoering moties*. Ministerie van Binnenlandse Zaken en Koninkrijksrelaties. https://www.lente-akkoord.nl/wp-content/uploads/2020/10/Brief-van-minister-Ollongren-september-2020-over-circulair-bouwen.pdf
Pauli, G. A. (2010). *The blue economy: 10 years, 100 innovations, 100 million jobs*. NM: Paradigm Publications.
Project Management Institute. (2016). Construction Extension to the PMBOK Guide. In *Project Management Institute*. Project Management Institute, Inc.
Rijkswaterstaat. (2015). *Beleidsverkenning Circulaire economie in de Bouw (RIVM rapportnummer 2015-0197)*. https://www.rivm.nl/bibliotheek/rapporten/2015-0197.pdf
Rudolphi, J. T. (2018). *Blockchain for a circular economy: Explorative research towards the possibilities for blockchain technology to enhance the implementation of material passports* [Eindhoven University of Technology]. https://research.tue.nl/en/studentTheses/blockchain-for-a-circular-economy
RVO. (2021). *Handreiking Circulaire Gebouwen op de Milieulijst van 2021*. Rijksdienst voor Ondernemend nederland. https://www.rvo.nl/sites/default/files/2021/06/Handreiking-CirculaireGebouwen-Milieulijst2021-def.pdf
Sariatli, F. (2017). Linear Economy Versus Circular Economy: A Comparative and Analyzer Study for Optimization of Economy for Sustainability. *Visegrad Journal on Bioeconomy and Sustainable Development*, *6*(1), 31–34. https://doi.org/10.1515/vjbsd-2017-0005
SBRCUR. (2016). *Kennispaper : Materialenpaspoort Hoogwaardig hergebruik van bouwelementen en -materialen*. SBRCURnet. https://issuu.com/burgersvanderwal/docs/kennispaper-materialenpaspoort
Stahel, W. (1994). The utilization-focused service economy: Resource efficiency and product-life extension. In *The greening of industrial ecosystems*. National Academies Press.
Stake, R. (1995). *The Art of Case Study Research: Data Gathering*. Sage.
Stewart Brand. (1995). *How buildings learn : what happens after they're built*. Penguin Books.
Taskforce Bouwagenda. (2016). *De bouw agenda - Bouwen aan de kwaliteit van leven*.

https://debouwagenda.h5mag.com/de_bouwagenda/
Transactionteam CBE. (2018). *Transitieagenda Circulaire Bouweconomie - Samen bouwen aan de circulaire economie voor Nederland in 2050*. Transitieteam Circulaire Bouweconomie. https://edepot.wur.nl/440495
Transactionteam CBE. (2020). *Advies Transitieteam voor het Rijk Wettelijke Verplichting Materialenpaspoort*. Transitieteam Circulaire Bouweconomie. https://edepot.wur.nl/440495
UNEP. (2014). *Decoupling 2: technologies, opportunities and policy options. A Report of the Working Group on Decoupling to the International Resource Panel. E.U. von Weizsäcker, J. de Larderel, K. Hargroves, C.Hudson, M. Smith and M. Rodrigues*. http://wedocs.unep.org/handle/20.500.11822/8892
United Nations. (2017). *World Population Prospects: The 2017 Revision, Key Findings and Advance (Working Paper No. ESA/P/WP/248)*. https://wedocs.unep.org/handle/20.500.11822/8892
van den Berg, M., & Castelijns, M. (2020). *Leeromgeving Madaster Infrastructuur, Rijkswaterstaat casus Beatrixsluis*. Rijkswaterstaat. https://puc.overheid.nl/rijkswaterstaat/doc/PUC_635191_31/
Vrijhoef, R., & Koskela, L. (2005). A critical review of construction as a project-based industry: identifying paths towards a project-independent approach to construction. In VTT (Ed.), *CIB Symposium, Combining Forces, advancing facilities mangement & construction through innovation series.* (pp. 13–24). VTT. https://www.irbnet.de/daten/iconda/CIB6804.pdf
Weisenfeld, U. (2003). Engagement in innovation management: Perceptions and interests in the GM debate1. *Creativity and Innovation Management*, *12*(4), 211–220. https://doi.org/10.1111/j.0963-1690.2003.00284.x
Wiebes, E., & van Veldhoven, S. (2018). *Totstandkoming van de transitieagenda's uit het Grondstoffenakkoord (IENM/BSK-2017/280995)*. Ministerie van Infrastructuur en Waterstaat.
World Commission on Environment and Development. (1987). *Our Common Future (The Brundtland Report)*. Oxford University Press. https://doi.org/10.9774/gleaf.978-1-907643-44-6_12
Yin, R. K. (2002). Case study research: Design and Methods. In *Applied Social Research Methods Series* (3rd ed., Vol. 5). Sage Publications.

APPENDIX A: (ANALYSIS CB'23 VERSUS CASE STUDY)

A VALUATION PLATFORM CB'23 GUIDE VERSUS CASE STUDY

Parallel to the research the Platform CB'23 has been active and has developed guidelines for Passports for the Construction Sector. The guide version 2.0 has been released in July 2020 (CB'23, 2020). None of the parties except for Madaster have been member of the platform and did not refer to developments and actions of the platform. As such processes of CB'23 and the research have been conducted parallel, whereby lessons learned and feedback from the Triodos Bank project have not been communicated and integrated in development of the guide.

A.1 Background Platform CB'23

CB'23 is an abbreviation and stands for Circular Building in 2023, The platform was initiated by both public and private parties. Within the platform stakeholders within the construction value chain are represented, including market parties, policy representatives and scientists. The goal of CB'23 is to work towards commitment within the market for the circular transition and in doing so has multiple work groups (CB'23, 2020). For this research the guideline of the action team with respect to MP development and standardisation for the construction sector has been reviewed against the findings of the case study. Members of both public and private parties are represented within the action team.

"In the construction sector, passports are considered to be important means to achieving a more circular construction sector, as they promote reuse at the material, product, element and building levels" (CB'23, 2020, p. 6). In order to maximise the full circular potential against the effort of registering and sharing data captured within MP certain essential preconditions are not fully matured within the construction industry.

To optimise circularity within the value chain it is essential that passports must be comparable and interchangeable. At this moment the development and implementation is led by market force and not aligning the development could lead to a market where different tools are developed with different principles. This could result in a situation where MP's remain implemented ad hoc and where MP's cannot communicate with each other hence will have limited added value from a circular perspective (CB'23, 2020).

The guide has been created to give insight into how MP can be implemented within the market and is written up for all practitioners being either private or public parties within the construction value chain. Further goal of the guide as already described is the development towards standardisation within the market (CB'23, 2020).

"Three areas of attention are addressed in more detail in this updated 2.0 version of the guideline than in the previous version. They are: passport versions, preconditions and Data Governance" (CB'23, 2020, p. 6).

A.2 The main evaluation CB'23 Working Agreements for Circular Construction

A.2.1 Data easy and public accessible.

The guide states that data within and access to MP should be easily accessible and publicly available (CB'23, 2020, pp. 6, 28).

Triodos Bank has decided to apply the Material Passport for Registration purposes only. Accordingly contracted parties had to apply and implement the material passport using the

Madaster tool. Parties have developed and enriched data and commissioned the passport. After commissioning the parties do not really have access to the data and are not able to use the data developed for potential new projects where same materials and/or products and/or elements are used. This is not in line with Guide that data must be easy and publicly accessible. Within the project the data was thus locked behind subscription based access during implementation and after delivery it was locked behind ownership barriers.

A.2.2 Economic and/or Social Reflection for using the Material Passport

Within the CB'23 Guide nor Working Agreements it is argued if or when to use a material passport. However the guideline is written in such a way that it assumes that governmental involvement will lead to the mandatory implementation of MP, and that this will lead a better and more accurate MP implementation (CB'23, 2020, pp. 14, 41)*. No evaluation or reflection of associated costs and efforts for implementing a material passport is mentioned in relation to the potential added value of products / elements, nor at date of implementation, exploitation phase or at end of life cycle.*

For existing buildings CB'23 is described to apply ad hoc inspections and associated efforts for analysis of materials and/or elements and/or products in order to add value (CB'23, 2020, p. 25)*. No substantiation is given about the objective and quantified cost benefit balance nor of possible impact on structure by type of analysis is described to support the opinion of added value MP. In general it is noted that the guide does not balance costs and efforts associated to implement a material passport versus creation of additional value in perspective of time. It seems that the use of a material passport is not in question and is assumed to be applied despite possible financial negative evaluation. As such it may be questioned in how far circular and social perspectives overrule financial perspectives and the choice for applying a material passport has become an automatism in approach and thinking.*

The feedback of research is that associated costs and efforts for implementing and applying the passport were substantial for parties involved in the Triodos project. Additionally parties mentioned that no consideration is given to evaluate costs and efforts versus potential added value, whereby added value is questioned. This was mainly because the party that registered the data is not the one governing and owning the data after completion. Therefore the implementation only provided added value from a learning experience and possible distinctive character towards the market.

Some of the parties noted that they did not see much added value of using the material passport, whereas using BIM already may meet additional functionality sought by the material passport aiming to maximise circularity.

A.2.3 Passports should be comparable and interchangeable

As already discussed in the introduction section of this appendix A, material passport will need to be comparable and interactable to maximise the value that can be gained while implementing the material passport within practice (CB'23, 2020, p. 6, 25, 29).

It is noted that it appears CB'23 does not make a distinction between reuse uptake and reuse at the end of life time within their guideline (CB'23, 2020)*. Although this complicates the discussion, it is a valid one from a circular perspective promoting reuse over recycling. Is there for instance a different data requirement for re-use versus recycling within practice? This is also a question within practice: should we record all information or only the information of which we know that we can re-use and recycle. Within practice it can be seen that this discussion is also difficult to implement. Where the implemented circularity score did not promote reuse over recycling leading to a circularity score that is relative subjective in substance. With respect to the longlist of CB'23 that will be discussed later, it is also not clear*

information requirements are essential for different circular end of life strategies (CB'23, 2020, p. 21).

MP as implemented for the Triodos project is an ad hoc digital registration document, where assumptions or desired situation as described by CB'23 were no conditions. Furthermore unique or standardised coding was not always available and creative solutions were applied to enrich data in the passport. As such data in the passport may not prove to be comparable nor interchangeable with data from other projects respectively passports. As example it is noted that data of materials in database of Madaster only contain characteristics of virgin materials which differ from characteristics of material actually applied. Although the guideline is governed to work towards standardisation within the market, the current working agreements or guide of implementation might prove to be too far ahead of the market's position and therefore not easily achievable.

A.2.4 Use of same technical terms and definitions where data are concerned

"In order to ensure clarity and uniformity in the sector, it is important that everyone uses the same technical terms and uses the same definitions where data is concerned. Platform CB'23's Circular Construction Lexicon has been prepared with this in mind, i.e. to be compatible with the several different guides. The Circular Construction Lexicon is also intended to conform to CB-NL" (CB'23, 2020, p. 42).

The Lexicon and CB-NL were not mentioned nor referred to by parties involved in the Triodos project. Coding of data was not always straightforward. Sometimes parties had to be creative to define codes and enrich data. Process characterised as a process of trial and error, whereby not all terms and definitions were standard and/or universal. Parties did discuss that there is a lack of a generally applied definition of circular economy within the construction industry. This makes it hard to be on the same page and to easily compare different alternatives with respect to circular design and construction.

A.2.5 Passport Versions : Parties have different views and perspectives. Development of a Long List.

"The Long List of Passport Items tool has been developed to collect all the ideas, proposals and needs for passport items mentioned by stakeholders and structure them in a 'long list'. This long list lists all items that can be included in a passport, depending on their intended use" (CB'23, 2020, pp. 6, 20). This long list is not yet commonly accepted or fully developed within the guideline, mainly because different parties have different objectives (CB'23, 2020). The establishment of the longlist, on the other hand, would contribute in the development of standardisation by allowing for the uniformity of registered data throughout the value chain. Furthermore it could provide insight into minimum requirements versus desired requirements when implementing material passports .

Below a list of categories that are important to register are provided as stated within the guideline (CB'23, 2020, pp. 20, 21).

- general data;
- identification and location of the structure/object;
- physical composition of the structure/object;
- sustainability performance, certificates and performance declarations;
- safety, health and environmental hygiene;
- circularity;

- technical data;
- other.

Furthermore the longlist includes additional categories for of items to be registered that could be useful when clients decide to implement a material passport. These are presented below as stated within the guideline (CB'23, 2020, p. 21)

- industry;
- level of scale;
- life cycle phase;
- goal;
- target group;
- availability of data.

All parties in the Triodos project have their own interests, visions and perspectives in the application of the passport. The signal mentioned by CB'23 is in line with this perception however did not result in considerable disagreements. The development of the passport was a contractual requirement. As described parties do not have access or can use the data after completion except for the client. Parties jointly investigated the data to be registered and did this by logical reasoning and the idea that the client can use these data to facilitate circular value. This could be given as a reason why parties within this project did not object or had large differences of opinion with respect to information requirement of the MP. Because they cannot use the data in different projects or internally.

Stakeholders did not really refer to any different passport versions, although a passport is a subset of materials, products and components making up the construction. Although it was envisioned by some parties that a MP could be implemented as an iterative tool during the design stage leading towards the as-is delivery MP and a maintenance phase. Within practice it is unclear how such a MP would come about, and given the additional time and efforts that have to be invested as well as the fact that design changes or changes in BIM would then have to be altered within the MP throughout the process. It has been chosen to only register and make the MP shortly before the delivery of the tool.

Different interests and perspectives from parties involved were not really impacting the development and content of the passport. All parties involved in the Triodos project shared the goal and their efforts to achieve a passport aiming to optimise the possible reuse of materials at the end of the life cycle c.q. during the demolition phase and achieve circularity. The Madaster passport was prescribed to use for the project. Parties referred to their experience with other formats. Difference between potential formats were not further clarified during the research. CB'23 suggests to develop a Long List of Passport Items. Parties were not aware of the existence of this Long List. Parties noted that besides the Long List mentioned by CB'23 there should at least be a List of Minimum Requirements aiming to optimise circularity and reuse of materials (CB'23, 2020, pp. 25, 41)*. This is also indicated within practice as it would reduce the information burden, however within the project the focus was on registering as much as possible information. However as the longlist is not yet finished there is not yet a list of minimum requirements that have to registered. When and how such a list will come about and how is not entirely clear. Within this project the objectives to implement were aligned because of contractual agreements. However it is unclear how the objectives and perspective are so different as indicated within the guideline*

that it is so difficult to come up with a list of minimum requirements for data registration. It could be assumed that the CB'23 somewhat overcomplicates the objectives of all parties as the main goal of the MP should be to capture and facilitate the potential circular value.

A.2.6 Preconditions user requirements

"Action will have to be taken to make the use of passports more commonplace. However, this will not happen until users themselves indicate which information they would like to have in order to use the passport. Therefore, sufficient attention must be paid to the users (i.e. customers) and their information needs when making a passport" (CB'23, 2020, p. 22).

It is noted that the Dutch version of CB'23 translates "users" as the Client. Within Annex C "users" are the involved stakeholders and not only the Client (CB'23, 2020, pp. 7, 50)*. Within guide 2.0 CB'23 translates users both as the client and elsewhere as the several customers of the passport. Therefore it does not become entirely clear who the user of a passport is from the perspective of the guideline and if there are multiple users who is the most important one.*

Within the Triodos project a more directive approach of developing and implementing the MP is used. For the Triodos project the Client has decided to apply the passport for registration purposes only aiming to optimise the potential reuse at the end of the life cycle. The development of the passport was a contractual requirement, whereby possible added value for individual parties were disregarded and less important to address. It is noted that CB'23 reasons mainly from a public approach and policy whereby the private interest and policy seems not to be addressed in balance. The viewpoints of CB'23 are understandable however it must also be reflected that some clients are for instance incidental clients that do not possess the possible needed knowledge to indicate where their value proposition is with respect to circular value potential.

The figure below provides an overview of the interaction and possible value proposition of a MP within the construction value chain. CB'23 defines value proposition as " the composition of all the values a structure represents" (CB'23, 2020, p. 22). In relation to data it is not clear if value is regarded from an economic and financial perspective or is more intended to be regarded as the quality of the data resulting in a "value". To track materials between different MP's and reduce omissions within MP's an ID management identification system was introduced by CB'23. It is envisioned by CB'23 that a MP has interoperability with BIM information sets already available within the construction value chain. This should provide the MP with the necessary information to enclose the so called value proposition of a MP. Furthermore it can be seen that in order to keep up the MP over the lifecycle it is envisioned that a MP has a certain interoperability with asset management systems (CB'23, 2020).
It is worth noting that the guidelines indicate that for constructions that are already in use but lack relevant BIM information or updated BIM information, the implementation of a MP should be weighed first and foremost from an economic standpoint (CB'23, 2020, p. 23).

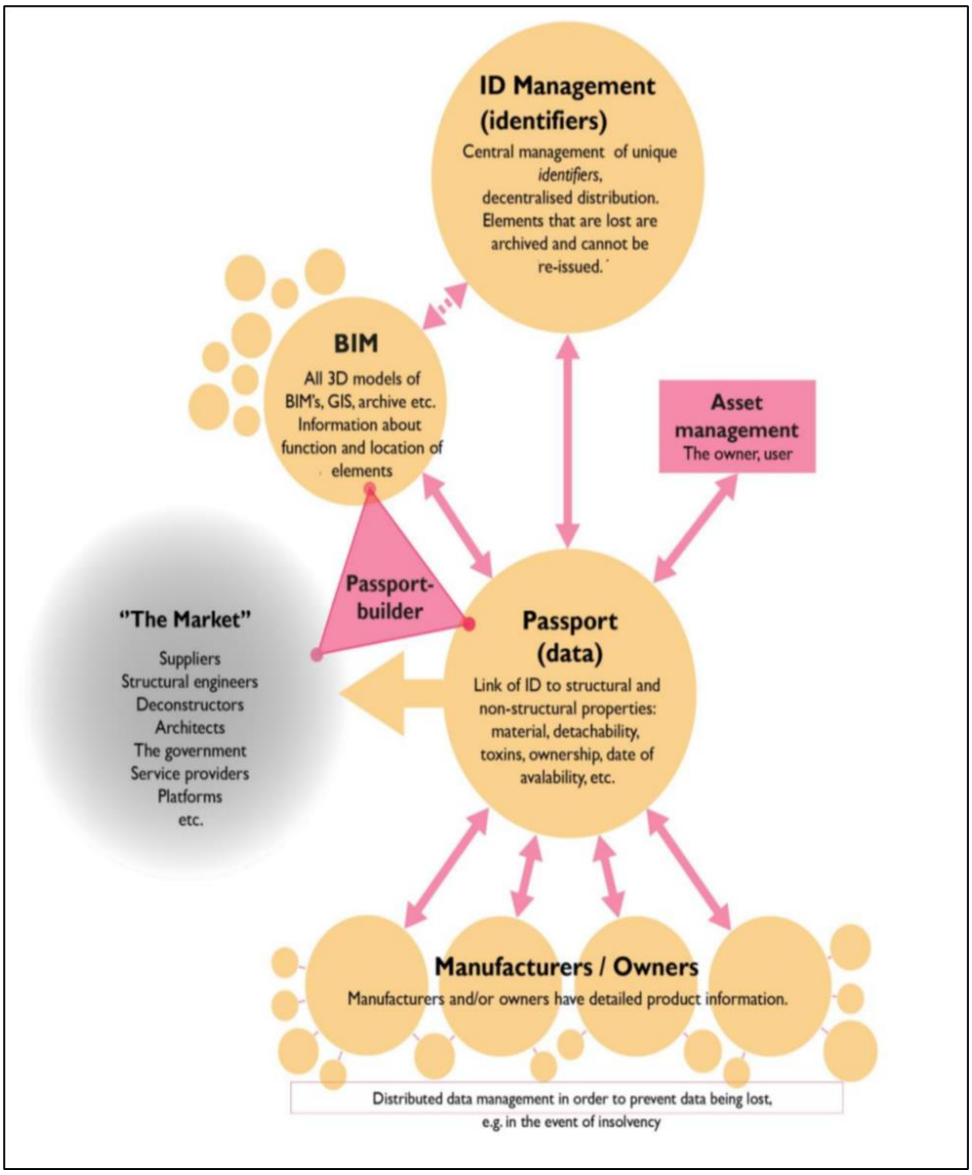

Figure 23 - Overview interaction stakeholders MP (CB'23, 2020, p. 23).

Parties involved within the Triodos project indicated that access to MP did not follow the same approach as indicated by the guideline. Not all parties had access to the MP, for instance suppliers did not have access to the MP and the contractor acted as an intermediate. CB'23 suggests that MP already has the necessary interoperability with BIM and Asset management systems (CB'23, 2020). Within practice it was indicated that this interoperability is not always in place. Where the high number of supplier BIM models and differences in object trees was seen as a barrier to easily generate a MP without omissions or without substantial human enrichment and alterations within BIM data. With respect to asset management (AM) systems all parties assessed that there is limited to no interoperability with AM software. Therefore it is unclear how the so called value proposition can be maintained throughout the life cycle within practice without relying on double book keeping. Madaster explained that it is not an asset management software developer. Therefore it is unclear whose responsibility it will be to ensure that such a interoperability will mature within the construction sector. From an economic perspective parties discussed that MP implementation is far from an automated process and comes at a considerable cost of implementing. It is also indicated within practice that closing circular value chains from an

economic perspective remains rather subjective as residual value is still hard to define. For instance residual value is taken up within the MP however only on material level. This thus does not facilitate insight in possible extra financial investments to incorporate products that have a higher chance to facilitate reuse compared to recycling. This leads to implementation that is mainly implemented because of goodwill given the fact that economic perspectives are not yet clear or fully matured. Also the market for circular materials and reuse are not yet common place.

Access can be said to be locked behind subscription base during implementation and behind ownership base after delivery. Therefore the suggested access and use case as indicated within the guideline seems missing within the construction sector. This means for instance that contractors cannot use the information enriched within a construction project within their company database as the client becomes the owner of the information. During implementation the subscription base access meant that not all parties had access to the material passport. For the Triodos project a passport builder (the contractor) as such is the intermediate between the client and manufacturers / suppliers and as such additional efforts from the contractor were required. The figure above suggests that the arrows between Passport (data) and Manufacturers / Owners are two-directional, while in practice this is one-directional only. The arrow between asset management and MP seems absent and if applicable highly doubted it will become a two directional arrow within the near future.

The addition of ID management for MP implementation seems relevant. Within the Triodos project parties had difficulties with linking the correct BIM files with the passport data. As a consequence materials from a different BIM file (read project) were taken up in the passport for Triodos. A door from a project in Lelystad as such was incorporated in the passport for Triodos.

Within the Triodos project parties had to do many extra efforts, whereby related value addition is questioned. The link / balance between efforts / costs and value creation / addition / loss is not clear. Also with relation to CB'23 for existing buildings to integrate economic arguments in relation to value created or loss as such is a sound principle, however specifying in practice may prove complex.

A.2.7 Timeline

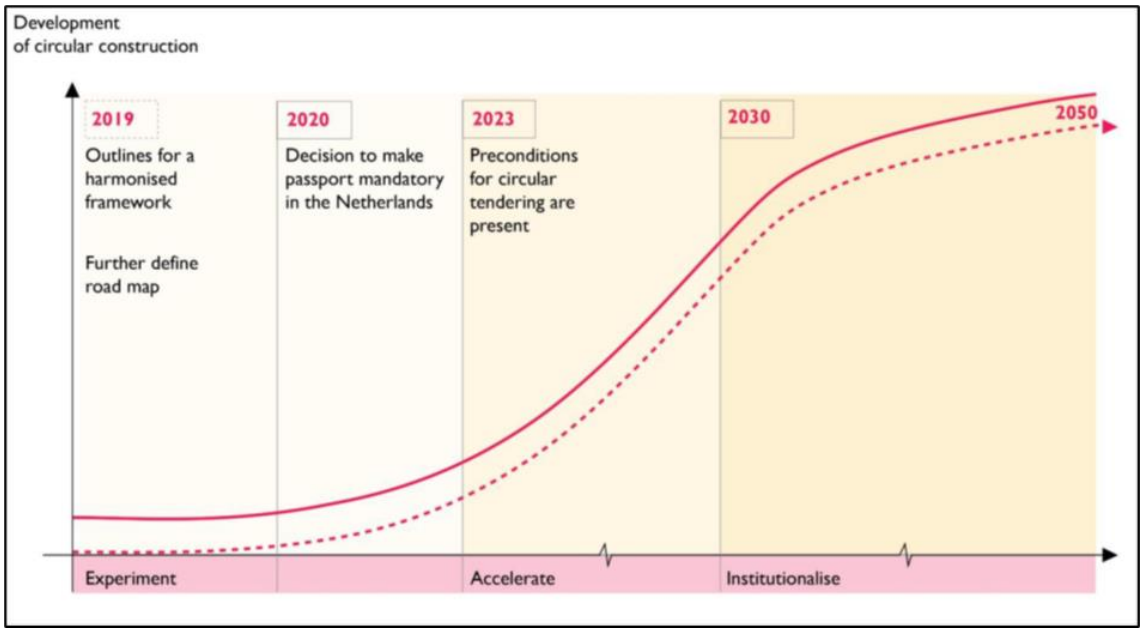

Figure 24 - Timeline MP development (CB'23, 2020, p.10).

In the CB'23 Guide it is noted that several actions need further clarification and definition including further working agreements (CB'23, 2020). Evaluating these outstanding actions it can be expected that indicated timeline is ambitious given the fact that it is unclear when these actions are finished within the timeline and the fact that case study found multiple discrepancies which could be a barrier towards the smooth implementation and ease of adoption of the guidelines principles. CB'23 envisions at least 5 actions and recommendations as follow up actions:

1. *"It is not clear to users why the NEN 2767 decompositions are constructed as they are, how they can be used, and how they can be related to other standards"*(CB'23, 2020, p. 56)*. To ensure this will become clear a committee will review the decomposition to ensure it clear and is aligned between all other existing special concepts in place within the Netherlands such as the IFC, NL/SfB, NEN 3610 and IMGEO/IMBOR*(CB'23, 2020, pp. 18, 42,56)*. Within practice this was also indicated as an obstacle although MP is aligned with BIM standards and generally follows the same approach as implemented within practice as it is not always clear when to define a building asset as a product or material within the decomposition of MP's*
2. *It is currently unclear how public access to MP goes hand in hand with privacy of information such as supplier information that should remain secret. Therefore a privacy impact assessment must provide additional insights. It is unclear when it impact assessment is finished. Within the Guideline a centralised data sharing and capturing is envisioned however within practice a decentralised implementation is taking place. It is not clear how this is incorporated within the assessment* (CB'23, 2020, p. 28)*.*
3. *"Defining a RACI matrix for data management of passports in the construction sector requires further scientific research"*(CB'23, 2020, p. 40)*.*
4. *With respect to transparency CB'23 suggests that investigations are intended "into how to assign information to market parties"* (CB'23, 2020, p. 29)*.*
5. *"CB'23 suggests its next step and responsibility will be to link the Circular Construction Lexicon to the CB-NL for the built environment"* (CB'23, 2020, p. 31)*.*

A.3 Passport Versions

A.3.1 Levels of Scale

CB'23 defines passport versions as passports for various scale levels, where the following scale levels may be implemented in practice: ranging from raw material, materials, construction product, construction part or component and constructions (CB'23, 2020, p. 14). During this process of compounding lower level passport versions into a higher level MP information of lower level MP's is inherited and supplemented with data from higher scale levels. According to CB'23, "this method of structuring ensures that data does not have to be entered repeatedly, whereas adding the relevant information enables value to be created at each level of scale – independently of the underlying levels of scale" (CB'23, 2020, p. 18).

For the Triodos project a similar approach has been implemented where different hierarchy levels of the construction have been distinguished within the finalised MP. According to parties the distinction of hierarchy level within MP's is in line with levels of scale used in construction and as applied within the BIM basis ILS.

With respect to hierarchy levels parties explained that is difficult to determine when something is a product or a material. And when is a product which deviates just a little bit a different product.(e.g. sewage pipes of PVC with different measurements). It must be noted that in practice suppliers do not facilitate uniform and standardised material passports for "raw materials" or at "product levels". For the development of the MP data had to be enriched by the contractor. When assumed necessary information requests were issued to the suppliers. Due to limited automation of the MP implementation a small deviation in product size or composition meant that a new iteration of MP enrichment was required. Therefore the decision was made to provide some products with a link to a material/product library code so that future MP development could link these codes to the elements and enrich them into the MP.

As an example a "granite tile" was mentioned. Granite is a material, but can also be regarded as a product. The only addition is that the material has 'measurements" (length, width and thickness)

CB'23 claims that value is added by supplementing data at respective levels whereby value is not further explained in view of associated costs and efforts and possible benefits to supplement data (CB'23, 2020)*. With respect to enabling tracing and locating of products it is noted that the option is achieved by linking the BIM format file to the MP. In practice using the 3D-viewer of the material passport is not sophisticated enough in order to easily and efficiently locate the products when one has not been involved with the development of the passport.*

Parties in research do not really address the shaping of levels of scale from perspective of passport. However they refer to using BIM as approach in order to link to material passport in development. In principle the use and structure of BIM has a similar approach.

A.3.2 Life Cycle Phases

Figure 25 - Life cycle phases in relation to MP implementation (CB'23, 2020, p. 19).

CB'23 describes that MP can be initiated during the different life cycle stages such as the design stage, implementation, use phase and before the demolition phase. Therefore CB'23 suggest that MP implementation can be seen as a process in which during every subsequent phase additional information is added and enriched, where for each phase an information requirement can act as a guide towards its development (CB'23, 2020, pp. 18, 19).

For the Triodos project the MP has been applied for registration purposes and to assess the level of circularity of the building. With the goal to optimise the circularity potential of the construction at the end of the life cycle. The choice was made to finalise and enrich the material passport at the end of the building phase in order to minimise the workload due to possible subsequent design or materialisation changes within the BIM format. At this stage the client will not actualise the passport over the use-phase and awaits further developments in the market. Stakeholders explained that the information requirements for asset management (use-phase) differ from the as built requirements and is therefore not included in the final MP. Furthermore information of MP's cannot yet be linked with asset management tools and as such the upkeep of data registration may require two separate data set management processes.

CB'23 distinguishes that minimum requirements for passports for indicated life cycle phases may be applicable, however the difference or specification for these minimum requirements are not described (CB'23, 2020, pp. 19, 21).

CB'23 indicates that the level of scale from a construction perspective is only relevant for the use phase. As during this phase the actual construction is in line with this level of scale. However it does not necessarily become clear what the added value of MP's is during the design phase and implementation phase. It is assumed that CB'23 sees the added value during the design and implementation phase with respect to optimising the design or the reduction of workload throughout the process of implementation (CB'23, 2020, p. 19). *However within practice the implementation was not an incremental process and it was chosen to compound all the information at the end of the construction phase.*

A.3.3 Completeness and Accuracy

The completeness of the MP and its accuracy is according to CB'23 directly influenced by the bullet points seen below as stated within the guideline (CB'23, 2020, p. 14).

- a structure's life cycle phase, in combination with the effort (and therefore financial investment) it takes to obtain and record the proper data;
- the value that can be created using this data, which depends on the quality and quantity of the data;
- the accuracy with which the passport is kept up to date during the use phase;
- the extent to which the government imposes an obligation;
- the level of scale at which the passport was drawn up.

The completeness and accuracy is not always directly related to only the several factors indicated. For instance the obligation by government does not guarantee completeness nor accuracy. Representatives in the research noted that obligating the material passport may imply only a 'check in the box" process. Furthermore efforts during use phase imply costs and efforts which may not be earned back in the end. As such the balance of efforts versus (added) value is not objective and may prove doubtful.

Completeness and accuracy is highly dependable of persons having the required knowledge, commitment and experience to work with passports and enriching data. The passport developed for the Triodos project has been developed and commissioned by several parties involved in the project, whereby the results have not been checked nor audited. As such completeness and accuracy is questionable.

A.3.4 Enabling access to passport data

CB'23 notes that "in order to enable access to passport data it is important that the party that benefits most at the moment of developing records the necessary data or organises recording by the person who produces or manages the object, with minimal effort and at the right time" (CB'23, 2020, p. 14).

For the Triodos project not all the parties involved had access to the digital passport. The client has decided to apply the passport mainly for registration purposes. The development and implementation of the passport has been a contractual requirement. To date the civil and installation contractor do not really benefit from the application. In line with description CB'23 the question to record data were relayed to other parties in the chain of cooperation. This however does not always result in envisaged delivery and enrichment of data by these parties. Not all parties within the construction sector work with (same) BIM models and cannot deliver data in the requested format or details. Also the requirement for standardised and unified data is relatively new. Therefore stakeholders have to go back into the value chain and try to gain the required data or information. This implies substantial additional efforts and costs for parties. Despite the feedback from a practical implementation of the passport both CB'23 as well as Madaster state that parties with the proper data and most information (mostly suppliers) have to register and supply. CB'23 mentions further that data should be publicly accessible (CB'23, 2020, p. 29)*. For the Triodos project the parties have developed and enriched the data and the passport and commissioned the passport to the client. After commissioning parties involved have no access to the data or the passport and access is restricted. Accordingly any other party will not have access to the same data or passport information. Access to data or platform is further limited to parties having a subscription of a platform provider. Parties involved having enriched data and commissioned were not able to use the same data for potential future applications.*

A.3.5 Structure of and relationship between passports

For optimum passport utilisation, a clear framework or structure is required. The guideline describes that material passports will have to be structured like a pyramid. Furthermore it has to be taken into account that a MP will contain a static element and will consist of a dynamic element (CB'23, 2020, p. 15).

The structure as described by CB'23 has been approached in a similar way for the Triodos project. However parties experienced difficulties to establish distinction between several levels of scale, for instance "construction product", 'material". Parties did not really address the shaping of levels of scale from perspective of the passport. They refer to using BIM as approach in order to link material passport in development. In principle the use and structure of BIM have a similar approach.

Material passport for Triodos was only aimed for registration purposes, whereby principles described by CB'23 are not really addressed. Goals as planning application, completion, mortgage and insurance were for goal of passport neglected. A lease option for the façade was considered, however appeared not economical and realistic and was furthermore evaluated by client as risky. As such data for mortgage and insurance were not applicable and necessary. Topics like planning application require parties to have a workable material passport at the start of the construction phase. For Triodos project the decision was made to generate the material passport at the end phase of the construction in order to minimise efforts due to iterative processes of changing and altering data information within as well BIM as in the material passport.

According to CB'23 a material passport consists of both static and dynamic elements. In practice updating and actualising of the dynamic elements appears difficult and unclear (CB'23, 2020, p. 15). *For Triodos the passport is commissioned to the Client, whereby the Client does not use the passport during use-phase of life. The Client does not have employees trained to work with the passport, whereby the market has no real parties assisting with MP upkeep. Furthermore the MP is not linked to asset management tools. If not linked this implies that minimal two systems have to be applied (MP, Asset Management). Every change or adjustment as such requires more effort than having one system in place.*

Evaluation of the Triodos initiative learns process of application and development is a directive and contractual requirement, where interests (public and private) are not specifically addressed accordingly. The private parties just had to generate the passport and its integrated information.

Data on circularity is for all parties a relatively new concept and therefore data or labels and certificates are not yet commonplace within the construction industry. Important aspect and insight into circularity is the demountability of the structure and its constituting elements. This information cannot be found in labels and/or certificates. Information on demountability has to be generated during the design and construction phase.

Principle of not repeating same information as noted by CB'23 is logical. However from research it is learned that substantial efforts by parties was required to enrich data and information, whereby also same information had to processed more than once.

A.3.6 Matrix of Passport Versions

CB'23 provides a matrix of potential passport variants in the table below, with distinct life cycle stages on the horizontal axis and various scale levels on the vertical axis (CB'23, 2020, p. 19). This gives an overview of the different lifecycle phases in which a MP can be generated in relation to the pyramid structure of MP's that can be implemented.

	Level of scale	Production Extraction etc.	Implementation Initiation etc.	Passport up to date	Use Maintenance etc.	Passport up to date	Demolition Dismantling etc.
Physical space	Level 1	O	O	X	X	X	O
	Level 2	O	O	X	X	X	O
		O	O	X	X	X	O
	Level n	O	O	X	X	X	O
Physical object	Level 1	O	O	X	X	X	O
	Level 2	O	O	X	O	X	O
		O	O	X	O	X	O
	Level n	O	O	X	X	X	X
	Material Raw material	X X	X X	X X	X X	X X	X X

Table 5 - Passport Matrix (CB'23, 2020, p.20).

CB'23 mainly focusses on the generation and timing / phasing of data for new constructions. Raw material passports are envisioned to be available and reliable from suppliers, whereby in practice this is not always the case. Circularity and uniformity of data is also a new development for suppliers.

Furthermore in the Life Cycle Analysis mentioned in CB'23 it is envisioned keeping the material passport up to date during the use phase, while in practice the use of time indications / stamps for the Triodos project are not executable in the tool of the passport (CB'23, 2020)*. The lag of the feature when objects / elements / materials are adjusted / replaced influences the accuracy, transparency and completeness of the passport over its life time.*

The Client noted that there is an information gap to generate a material passport for constructions already being in use (existing constructions).

A.4 Preconditions

A.4.1 Data Requirement Roles (Annex C of CB'23)

"Every user or stakeholder looks at the information in a passport from their own point of view. The information provided by a passport should therefore be in line with the user's requirements" (CB'23, 2020, p. 50).

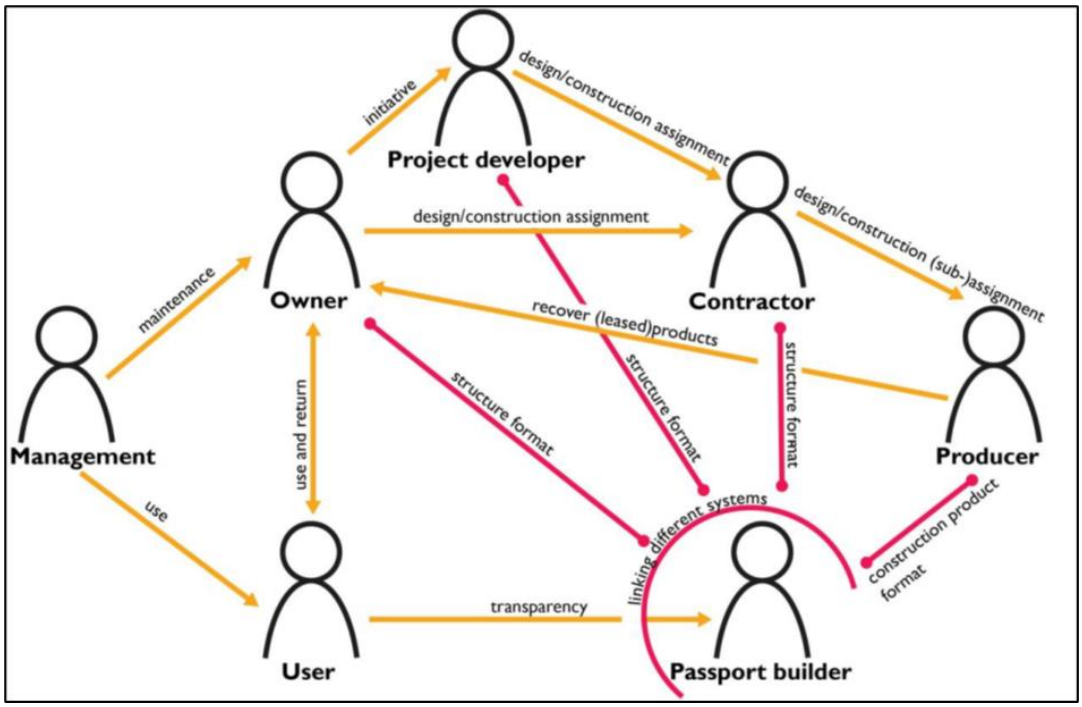

Figure 26 – roles and relationships between parties (CB'23, 2020, p. 50).

It is noted that the Dutch version of CB'23 translates "users" as the Client. Within Annex C "users" are the involved stakeholders and not only the Client (CB'23, 2020, p. 50). *CB'23 states that "information provided by a passport should be in line with user's requirements"* (CB'23, 2020, p. 50). *Stakeholders/users involved in Triodos had their own interests and view on possible added value from the passport. This however has not been really addressed nor incorporated, whereby the purpose of the implementation was for registration only and to optimise value at the end of life with potential of reuse. As such decided by the Client, a private party, also in his role as owner of the building. Parties had a contractual obligation to deliver the passport, and process as such was more directive of nature. Parties mention that the passport as developed did not have added value from their point of view and interests, whereby they noted that BIM tool was more suitable and open for incorporation of circularity data. According to CB'23 the Client / Owner takes the initiative for MP implementation* (CB'23, 2020, p. 51). *Parties referred that initiative may also be undertaken by other stakeholders in the process, such as the contractor. The described roles assume that a material passport is already available during the start of the construction phase in order to optimise the circularity of the design. For the Triodos project this was not applicable.*

Described roles and focus appear logical and realistic. However parties did not have unlimited access to the passport. Stating that the manufacturer "wants to trace their own parts" is not in line with feedback suppliers Triodos (CB'23, 2020, p. 51). *The supplier is interested in supply only. In case that supplier remains owner of their supplied materials then the supplier may be interested to trace their own parts. At present manufacturers are not always aware of availability of third-party materials and/or raw materials and do not always have the associated certificates or related passports, which hinders the process of*

developing a material passport for the several levels of scale. Within the figure above it can be seen that "passport builder" is seen as a new role. For the Triodos project the contractor had the contractual obligation to build the passport. CB'23 assesses that the passport builder is "responsible for the availability and legibility of this data" (CB'23, 2020, p. 52)*. Legibility is highly dependable of availability, correctness and completeness of data of suppliers and the knowledge and competences of the person enriching and developing the material passport. Within practice the contractor is dependable from other parties whereby information supplied cannot be really audited or confirmed by contractor himself. It is noted that CB'23 does not describe the role of the platform facilitator. CB'23 indicates that new roles will arise when MP implementation will become common place within the construction industry. However does not indicate the MP facilitator as a new role* (CB'23, 2020, pp. 54, 55)*. Within the development and implementation these facilitators play a critical role in standardising and unifying the envisaged passports. Madaster is the platform supplier for Triodos project and coordinates the access to the passport and the development and implementation of potential additional tools or characteristics of the passport. Madaster mentioned however that they do not see a special role for themselves, rather than facilitating the platform.*

A.4.2 New Roles

As described in previous section CB'23 sees the development of new roles when MP will mature within the market, such as a central management organisation, cloud service, marketplace, data mining (CB'23, 2020, pp. 54, 55)*.*

For the Triodos project lease concepts have been considered for the façade, however after economic evaluations and the assessment by client of riskiness (in case of bankruptcy of the supplier) not further pursued. Subsequently no real new roles were encountered or seemed necessary. The passport development has been mainly become an activity as part of the function of the engineer, mainly the engineer for BIM application. Parties referred to other examples (van Wijnen, temporary houses), where material passports are part of documents for new parties, like insurers, financers, notaries, etc. Parties realise that new roles and/or competences may evolve from implementing material passports and ambition for circularity, like new roles for storage of secondary materials. New roles imply that information and data will become publicly accessible and available. With current ownership of information at the Triodos project (limited to Client only) this implies a hinderance for further development and new roles. Client noted that public availability of its data and passport information will only be required and provided at the end of the lifecycle in order to explore opportunities to reuse materials and/or elements of the building.

A.4.3 Access (Accessibility and Interchangeability)

An important precondition towards use of MP is that they should be easily accessible and interchangeable with tools and formats already in place within the market (CB'23, 2020, p. 24).

Not all parties involved in the Triodos project had access to the passport. Due to absence of standard codes contractors had to be creative to enrich data whereby comparability with other tools and passports may be questioned. Compatibility with other tools appeared limited. To date parties cannot yet access libraries of other parties or data do not have the same definitions and/or characteristics. The same hinderance is experienced with parties using their own BIM software, where parties are also present who do not use BIM yet. Interoperability as such is hindered when these barriers are not overcome.

A.4.5 Standards Committee 351225 "Rules for Information Modelling of the built environment"

"CB'23 mentions that the effective and efficient registration and records of information of the built environment have become increasingly important" (CB'23, 2020, p. 55). However within practice this development seems to be ad hoc leading to differences in structured data of assets. This could lead to a situation where data cannot easily become transferable between data sets and MP's. Therefore the standards committee 351225 was brought to life in order to harmonise the way in which stakeholders can structure and decompose this information. With the goal to also incorporate the requirements of the material passport into the equation (CB'23, 2020, p. 55).

The vision and explanation by CB'23 appears logical and rational. It is noted however that further clarification and policy development and integral approach of respective decompositions and standards may take a substantial period to complete and formalise. This may influence the ambition for the timeline of the material passport implementation. According to CB'23 the obligation to apply the MP is in 2020. This may delay the process, whereby meanwhile the individual initiatives on current and future prospects may increase hesitation of parties in the value chain to apply the passport and object to obligations to apply the passport.

A.4.5 Access

A.4.5.1 Open Standards

"According CB'23 it is left to users' discretion how to store information as long as it is compatible with multiple platforms, data formats, resource management software and other means of storing and accessing information" (CB'23, 2020, p. 24). Furthermore it is mentioned that it is important to also keep in mind that construction materials could also be used within different other sectors and therefore should also be interoperable with other sectors.

The approach appears logical and rational. During the research this topic has not been addressed nor mentioned by parties involved. It is noted that data and the passport were not accessible for all parties involved and relation with way of communication differs from the vision by CB'23. Some parties within the sector do not use digital tools like BIM nor passports and may hinder the general approach and accessibility.

A.4.5.2 Traceable

CB'23 envisions a hybrid model of managing data (CB'23, 2020, pp. 38, 39). "If the recording of passports (i.e. not the actual data) is managed centrally, central management will in all cases continue to be responsible for keeping the passports traceable as long as it owns them" (CB'23, 2020, p. 24).

The vision is logical, however the period of responsibility may be subject to phases of respective constructions. In case the building is demolished, one may assume the sense of managing related passports becomes doubtful. Central management for the Triodos project was not mentioned by parties. The ultimate passport has been commissioned by involved parties to the Client. The client has not decided how to use or manage the passport during the use period and awaits further developments in the market. Also parties have no access to the commissioned passport and its data enriched, whereby it is for parties not possible to use their enriched data for other future projects and passports. This was regarded as negative by parties in the research. Therefore the MP followed a decentralised approach in which information ultimately is owned by the client.

A.4.5.3 Reducing the Information Burden

"In order to reduce the information burden, it is advisable to retain references to the product information and to capture them at source in standards" (CB'23, 2020, p. 24). The logic reasoning for CB'23 is that high-quality data at the source will be more valuable since it is more probable that this information will facilitate the circular potential of materials and products.

Practice is that not all producers in the construction sector deliver proper data in requested formats and standards, whereby the ambition for circularity and sustainability is a rather new development. Parties involved in Triodos project mentioned that efforts for generating and enriching data were substantial and costly. Parties are not really reimbursed for the associated costs, whereby when having delivered the information, they do not have access anymore and as such no feedback. Contractor was partly reimbursed, however parties delegated or required to deliver information towards the contractor were not reimbursed. The economic balance of value of materials versus possible additional costs and efforts are not really evaluated with respect to value and value at the end of lifecycle. Defining what is minimum required and what is desired should incorporate this balancing and evaluation. CB'23 is not really clear how costs and efforts for developing a proper material passport are evaluated to decide requirements. Parties confirm that it is most effective to register information at the start of the value chain (e.g. producer). Furthermore to define and agree at the beginning of the process what information has to be registered and associated process. The basic principle is to separate the minimum information necessary from the desired set of information seems logical and has been noted by Madaster as well. Nevertheless practice appears not as simple as suggested. Reference also to what is minimum required in relation to indicated categories by CB'23, whereby the proper balance is at stake. It is questioned if all the categories identified in the long list need to be already addressed as of the beginning. As a minimum one could start with the general data, identification and location of the structure/object and its demountability, whereby the other categories can be addressed at a later more detailed phase.

A.4.5.4 Interchangeability

CB'23 states that "interchangeability of data is guaranteed by firstly standardising the ID and product codes used, and secondly by proper management. There should be an obligation to exchange data. If this hinders a business interest, the possibility of arbitration must be set up" (CB'23, 2020, p. 25).

The stated vision is logical. That is based upon the use of a material passport and incorporating respectively enriching data. For the Triodos project parties pursue interchangeability by using BIM protocols. Some parties do hesitate or decline to exchange data freely, in particular when intellectual property and competition considerations are involved. Arbitration as suggested by CB'23 may be a manner to convince parties to exchange data, however every situation where intellectual property and competitive edge are at stake may differ and as such also the outcome of any arbitration may differ and involve substantial costs and time. As such practice may prove harsh to assume free exchange of data.

A.4.6 Application to Existing Structures

In reaction to section 4.6 of the guideline "Application to existing structures", as can be found on page 25 of the publicly available document (CB'23, 2020, p. 25).

The vision of CB'23 appears to be logical. It is questionable if the assumption of the action team that most of the existing structures not having been built circular have reached the end of their design phase or functional service life. Triodos has acted on another existing building evaluating the building and its elements accordingly, but were not really successful and

satisfied with the results. The ambition is to maximise circularity and optimise the reusability of materials and elements. However efforts and costs to develop passports for existing elements and/or products in an existing building is quite substantial, whereby also analysis may have detrimental effects to the construction and its elements. The associated costs and efforts have to be balanced versus the realistic value creation when reusing the materials / elements.

A.4.7 Current Circular KPI's (Key Performance Indicators)

CB'23 mentions that "to be able to use passports effectively in order to make circularity measurable, they will have to be able to provide input for the KPIs" (CB'23, 2020, p. 26).

Statement of CB'23 is clear. For the Triodos project the material passport was also used in order to define the circularity of the building. However the tool used in the Madaster platform to measure circularity is currently not sophisticated and reliable enough to assess the circularity. For example the reuse is scored on the same level as recycling, thus not taking into account the additional costs and efforts to reuse materials. The lack of a standardised and objective circular indicator also makes it difficult to compare different projects and performances.

A.4.8 Basis for Standardisation

A.4.8.1 Semi-Decentralised

In reaction to section 4.8.1 of the guideline "Semi-decentralised", as can be found on page 26 and 27 of the publicly available document (CB'23, 2020, pp. 26, 27).

The described vision by CB'23 appears logical and rational. However obligating parties to use existing materials, raw materials and construction products may be contrary to goal of an optimal new building where these have to be applied to. If the quality and/or life expectancy of existing materials appear less than for new materials a Client may resist the obligation. It is noted further that CB'23 mainly mentions public entities, whereby vision, responsibility and approach of private parties including private clients may differ from parties within the public sector. During the research this topic has not really been addressed or commented on.

A.4.8.2 Ownership

According to CB'23 the owner of the building products is the owner of the data within the MP. Therefore a split ownership model could be assumed when for instance leasing options are pursued. Because a MP is built like a pyramid the situation could arise where a MP is governed by multiple owners (CB'23, 2020, p. 28).

The explanation about ownership by CB'23 is theoretical and logical. Practice may prove more challenging. What in case of a supplier going bankrupt. What if a material passport is not updated and actualised during its use phase. The Client in the Triodos project has decided to apply a material passport for registration purposes in order to optimise potential reuse of elements, products and materials. Also the lifetime of a structure may be substantially longer than the contractual relation between parties at date of contracting. A longer involvement or guarantee from suppliers will increase associated costs for the client, whereby added value may be doubtful. The innovative concept of product as a service has been evaluated for the façade, but the client has evaluated this option as too risky, what in case the supplier goes bankrupt and possible creditors claim their rights by claiming the façade. The wooden structure supplier in the Triodos project has been involved in a contract with a take back guarantee. And evaluation was not positive and generated additional risks and costs. For the Triodos project this was proposed by Client as a feasible option, however from perspective of costs and risks not pursued. Also a take back option for the facade was not pursued by the subcontractor. Take back involves for manufacturers and suppliers

additional risks and costs, including financing costs, which in traditional models are not applicable. Balance in risks and benefits need to be clear, objective and transparent. Reference also to reflection on exchange of data, where parties may object due to intellectual property and competitive edge considerations, where any arrangement and/or arbitration and outcome is project specific and involves associated costs and time.

A.4.8.3 Privacy

CB'23 notes that "once it had been established that a circular economy was needed, the issue of ensuring sufficient legal protection against people's right to privacy being breached also emerged" (CB'23, 2020, p. 28).

People's right to privacy is already for several years a topic of concern, both for public as well as private entities including citizens. The phenomenon of hacking and personal data having become public, despite all digital and ict actions to prevent access to private data, is commonplace and it may be expected this will take still a substantial period before systems become privacy proof. During the research the topic of intellectual property and associated ownership of data has been addressed, whereby the topic of privacy was not really seen or noted as a problem for the development of the passport for the Triodos project. Privacy Impact Assessment has become a social issue and concern. Development of this assessment may take several years, if concluded anyhow (CB'23, 2020, p. 28)*. The impact on the timeline for MP implementation may become evident.*

A.4.9 Transparency

In reaction to section 4.9 of the guideline "Transparency", as can be found on page 28 of the publicly available document (CB'23, 2020, p. 28).

CB'23 explanation is theoretical and logical. Parties involved in the research mentioned that for intellectual property or competitive edge considerations they are reluctant to exchange data freely. Supplier noted that intellectual property is important for him, having invested in distinguishing its product from the competition and remaining its edge. As an option to overcome having to exchange sensitive data the supplier proposed the introduction or implementation of a certificate. Furthermore it is noted that intended investigations how to assign information to market parties may take substantial time and may hinder the envisaged time line for implementation of material passport as mentioned in the guide.

A.5 Data Governance

A.5.1 Legislation and Regulations

A.5.1.1 The Dutch Library of Concepts

In reaction to section 5.2.1 of the guideline "The Dutch library of concepts", as can be found on page 31 of the publicly available document (CB'23, 2020, p. 31).

The policy mentioned by CB'23 is logical and rational. Parties involved in the Triodos project mentioned they had to be creative to qualify and enrich data. Sometimes new codes have been introduced autonomously, whereby national codes or standards did not suffice. Parties have developed the material passport and enriched with data. When the passport was commissioned to the Client the Triodos parties did not have access to their data and cannot use them for new projects. This is in principle a hinderance for the process of standardisation and legislation. CB'23 suggests that the process has to be managed by BIM Loket. Experience with the Triodos project indicates that not all unique nor standard codes were in used BIM software available. Additionally it is noted that some parties in the construction sector do not apply BIM or use similar levels or detailed data as assumed and suggested. Parties needed to translate hard copy information into digital data as a consequence. In order to proceed it is advised to gain access and evaluate lessons learned from processes

where initiatives for application of a material passport have been gained and integrate these lessons in further policy development. Further it is noted that the proposed CB-NL expansion will take an unknown period and may impact the ambitious timeline for the implementation of the material passport as suggested in guide 2.0.

A.5.1.2 About IMBOR (Annex D of CB'23)

In reaction to section 5.2.2 of the guideline "IMBOR", as can be found on page 31 of the publicly available document (CB'23, 2020, p. 31).

Reasoning by CB'23 is logical. However this has not been a real issue in the research. Parties involved in the Triodos project mentioned that data developed and enriched in the material passport do not properly suit data used in the respective asset management tools. When applying besides a passport also an asset management tool this may require double activities for registering data.

A.5.1.3 Information Delivery Specifications

According CB'23 "good data management requires the ability to consolidate data according to specific guidelines and make it easily retrievable" (CB'23, 2020, p. 31). Furthermore the data that should be shared given a standardised format for this the construction industry often implements data within an IDS or Information Delivery Specification. As a result, the MP information requirements will be required to join the IDS, according to the guidelines (CB'23, 2020, p. 31).

For the Triodos project the development and implementation of the material passport was a contractual requirement. Client and project developer incurred problems to specify what the requirements should be of the content and structure of the material passport. The incorporation of an IDS for material passports can partially overcome this barrier. However there should also be flexibility to experiment as the material passport is far from standardised and complete. For this project a BIM protocol was made up where the IDS was part of this information requirement. However it is clear that not all suppliers yet have the knowledge or capacity to deliver the required information specification.

A.5.1.4 Association between Standards

In reaction to section 5.2.7 of the guideline "Association between Standards", as can be found on page 32 of the publicly available document (CB'23, 2020, p. 32).

Explanation CB'23 is theoretical and logical. However parties involved in Triodos project mentioned that enriching data and development / implementation of passport required substantial efforts, costs and creativity. Administrative costs as such appear considerable. CB'23 refers in the guide not to respective lessons learned of initiatives of applying passports including the Triodos project. What the impact of lessons learned is regarding this topic is as such not clear.

A.5.1.5 Mapping and Recording Data

In reaction to section 5.3.3 of the guideline "Mapping and Recording Data", as can be found on page 35 of the publicly available document (CB'23, 2020, p. 35).

For the Triodos project several items are not incorporated in the passport. An example mentioned are pipes. The same applies for bolts and nuts. Parties involved envision that aiming for a circular building is based on designing and constructing maximising the demountability. Nevertheless the effectiveness and realism are doubted, since holes etc. have been poured in with grout and/or PUR foam. It is noted that despite the building should be regarded as demountable, it may prove at demolition and/or end of life that demountability and securing elements / products for reuse is not so simple as envisaged / assumed. The client has decided to apply the passport for registration purposes only and optimising the potential reuse of elements and materials at the end of the life cycle. In the use phase the

client has not yet decided to actualise the data in the passport and awaits developments in the market. This may impact the quality of data at the end of life, since no data are enriched and/or changed during the use phase.

A.5.1.6 Interoperability of Data - Metadata

In reaction to section 5.3.4 of the guideline “Metadata”, as can be found on page 36 of the publicly available document (CB’23, 2020, p. 36).

Research learns that at present incorporating a time stamp in the passport is not straightforward and not developed within the Triodos MP.

A.5.1.7 Interoperability of Data - Data Aggregation

In reaction to section 5.3.4 of the guideline “Data Aggregation”, as can be found on page 37 of the publicly available document (CB’23, 2020, p. 37).

From 3D-viewer in passport it is quite difficult to assess where certain elements are located. Some parties do not work with BIM whereby suppliers may just deliver a product sheet. Not all data from this product sheet are enriched in the passport. Instead the product sheet is referred to in the passport. The consequence may be that interoperability is hindered. CB’23 in its guide does not specify how economic value is addressed (financial value when reusing versus associated costs to add and create value)) nor is the feedback from research that residual value has been quantified respectively specified. The Client has not yet decided how to apply and actualise data during the use phase. As such correctness and actual status of data during both the use phase as well at end of life may be at stake. The recording of the passport and associated data at Kadaster of some other key register as suggested in CB’23 is not further addressed nor commented upon during research.

A.5.1.8 Data Management Roles

In reaction to section 5.4.4 of the guideline “Data Management Roles”, as can be found on page 39 of the publicly available document (CB’23, 2020, p. 39).

Research indicates roles, functions and responsibilities as well as what data are required in passport and process of development process has to be discussed and agreed as early as possible in the process. Development of RACI matrix according description CB’23 is still under process. Timing may conflict with timeline indicated for implementation material passport.

A.5.1.9 About the Roles within Data Management (Annex D of CB’23)

In reaction to section 8 of Annex D of the guideline “About the Roles within Data Management”, as can be found on page 61 of the publicly available document (CB’23, 2020, p. 61).

Description CB’23 is mainly addressing roles for public parties. Reference and practice with private parties is not addressed or reflected. For the Triodos project parties had to use the Madaster platform. From research Madaster sees for itself not an additional role or responsibility yet, such as training users, updating and integrating from lessons learned. Parties see the activity of applying and using a material passport as an extension of traditional functions. Such as an addition of the activities of a BIM engineer or engineer. CB’23 does not clarify if new roles do have an impact in hierarchy of functions. Lessons learned of development and experiences with adoption of BIM may be beneficial to integrate in further development of implementation of material passport.

A.6 Results and recommendations CB'23

A.6.1 Results

In reaction to section 6.1 of the guideline "Results", as can be found on page 41 of the publicly available document (CB'23, 2020, p. 41).

Essential that the ambition and the implementation of material passports are shared by all parties involved in the construction sector. Furthermore an objective evaluation of value and required efforts and costs to generate additional (economic, social) value seems lacking and does not contribute for parties to share principles and support the ambitions. It is questioned if managing and extending the long list is the crucial next step forward to achieve standardisation in the long term. Parties in the research did not evaluate the passport as implemented in its current status and approach as having much added value from their social and economic perspective, whereby it is noted that future MP's need to be much simpler, transparent and less time consuming. As such results, including associated Follow-up Steps and Recommendations described by CB'23 may be not conclusive and subject to revisiting.

APPENDIX B: INTERVIEW TRANSCRIPTS (SEPARATE DOCUMENT)

Appendix B, Interview Transcripts, has been disclosed as a separate non-public document to avoid disclosing potentially sensitive information and to protect the privacy of the interviewees.