ASSESSING DATA EXCHANGE OF MATERIAL PASSPORTS BETWEEN KEY STAKEHOLDERS

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“Technology is the answer, but what was the question?”

- Cedric Price

ABSTRACT

A material passport (MP) is a digital document which aims to track the circular potential of building materials. It is seen as a key enabler for a circular economy (CE) in the building sector. The construction industry is one of the most resource-intensive industries which produces massive amounts of construction and demolition waste (CDW). Shifting the construction sector from a linear to a circular model has been gaining increasing attention recently. Re-use of materials in existing building stock to prevent further depletion of natural resources is seen as one of the means to transition the sector towards a CE. Research in this area has been focused on the potential and opportunities of digital technologies in the reuse of materials, but there is a lack of research on the implementation of MPs by key stakeholders in practice.

This research aims to gain insight into key stakeholders' perspectives regarding current data exchange practices. The guiding research question for this thesis is "*How can the data accessibility and interoperability of Material Passports be optimised in order to improve the effectiveness of its implementation within practice?*" It is answered with the help of four sub-questions. The first sub-question aims to gain an understanding of the key concepts and characteristics of MP data exchange with the help of a literature review. This is followed by the second sub-question which explores the data exchange roles of key stakeholders per building lifecycle stage. The third sub-question seeks to gain an understanding of the main challenges faced by key stakeholders regarding MP data exchange through the use of semi-structured interviews. This is followed by a case study which seeks to examine the TU Delft's perspective as a public client and data owner regarding making data more accessible and interoperable for other stakeholders through the use of semi-structured interviews.

It is found that although ample data on materials and components exist, they are currently not accessible or interoperable for stakeholders across the sector. Stakeholders can be data providers or data extractors, however the responsibility for making data accessible and interoperable lies with the data owner who in most cases is the client. A lack of; standardised data, a government initiated centralised platform, data structure, and standards and norms are found to be the major challenges associated with data exchange of MPs. From a public client (TU Delft) perspective, it is found that although there is an understanding of improving data exchange, data privacy is a major hurdle that needs to be overcome before data can openly be shared with all stakeholders in the sector. In order to enforce a shift in the working methods of the building sector, more clients need to start demanding data from stakeholders.

KEYWORDS: material passport (MP), circular economy (CE), data exchange, reuse interoperability, accessibility, stakeholders

PREFACE

It has been an immense pleasure to write the following thesis for my Master in Architecture in the track Management in the Built Environment (MBE) at the Technische Universiteit Delft (TU Delft). I came to the Netherlands 5 years ago for the Bachelors in Architecture and it has truly been an exciting and at times challenging journey. I am proud to present this thesis on which I have been working for the past year and it is a remarkable opportunity to be able to contribute to the body of knowledge in my field.

Since my bachelor's, I have been passionate about contributing towards sustainability in the built environment and have always been curious about exploring the different ways technology can be utilised to develop the building sector. Through this research process, I have been able to develop my research skills further as well as learn a great deal from my mentors and the interviewees. I have learnt the increasing importance of data in our day-to-day lives and that it will only continue to grow in our sector. I hope to be able to pursue this field further in my professional career.

I must mention that this research would not have been possible without the encouragement, support and guidance of my mentors Ad Straub and Vincent Gruis. Their expertise and knowledge in this area has helped shape this research. I would like to thank them for their insightful feedback and constructive criticism giving me direction during the whole process. I couldn't have asked for better mentors to support me through this endeavour.

I am also thankful to the participants who contributed to this work. The research would not be complete without their willingness to devote time and their valuable insights. I am also grateful to my family and friends who have shown unwavering belief and support for me throughout this process. I hope this thesis sparks further curiosity and adds a valuable contribution to the building sector.

Kavya Pal
26th September, 2023

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1 INTRODUCTION

The building industry is one of the most resource-intensive industries in the world and produces more than 1/3rd of the total waste produced in the EU (Eurostat, 2020). Approximately 10 to 30% of the total waste delivered to landfills is construction and demolition waste (CDW) (Sönmez & Kalfa, 2023) from which only 20 to 30% is recycled or reused (World Economic Forum, 2016). Not only is the building industry a major user of natural resources but also a major producer of CDW (World Economic Forum, 2016). Furthermore, the construction industry is responsible for roughly 50% of annual global CO2 emissions of which 27% correspond to building operation activities and the rest 20% to embodied carbon or the building materials and construction (UNEP, 2021). The numbers above are alarming due to the environmental impact it has such as depleting natural resources, reaching landfill restrictions and large-scale pollution. This leads to urgency in decarbonising the building sector in order to reach the national and global goals set by the Dutch government to be climate neutral by 2050 as laid out in several national plans such as the Energieakkoord and the third National Energy Efficiency Action Plan (IEA, 2021) and the Paris Agreement goals (UNFCCC, 2016).

According to UNEP (2021), in order to reach these goals, a triple strategy needs to be implemented to reduce building emissions. The strategy would combine a reduction of energy demand, decarbonizing the power supply and addressing the footprint of embodied carbon (building materials) (UNEP, 2021). Material and construction emissions must be promptly addressed, especially for new construction as buildings tend to have a long life span. In order to drastically reduce the building sector's carbon emissions in the limited time frame, reducing CDW is not enough but must be reintroduced in the cycle. This would require a major shift in the sector's working methods from linear to circular processes, narrowing the loop by using fewer resources and improving efficiency in the production and design process.

The concept of urban mining seeks to reuse building materials from what is already available above ground rather than extracting natural resources and further depleting the earth's resources (Li, 2015). This strategy has a significant potential to reduce carbon emissions however, in current practices in the Netherlands, materials reclaimed from demolition sites or existing stock are downcycled and around 95% is recycled to be used as a road base layer (Mulder et al., 2007). It may seem that mainly waste is obtained once a

building reaches its end-of-life stage, however, this assumption dismisses the fact that buildings are in fact organised structures of building elements and components.

The challenge lies in coordinating the material flows of existing stock and new building stock and therefore making it more efficient. The Dutch building stock consists of 87.3% dwellings of which 86.2% fall under the energy label C, D, E, F and G in 2013 (CBS, 2013). Most of this existing stock is not built with deconstruction or disassembly in mind which can lead to considerable waste production when retrofitting or demolition takes place. Although recycling averts a percentage of waste from landing in landfills, its environmental impact is still considerably higher than that of reusing (Rakhshan et al., 2020). Lazarus (2002) claims that reusing reclaimed elements can reduce environmental impact by up to 96%.

According to stakeholders on the supply side, the envelope elements are considered to have the highest potential for improving energy performance (Van den Brom et al., 2018). In order to catch up on neglected retrofits from the past, it is estimated that activities in the technology-related market and building envelope will significantly increase in the short term (van den Brom et al., 2018). The focus of research on this topic has mainly concerned the potential of digital technologies such as BIM, AI, GIS and point cloud models for the reuse of building materials (Çetin et al., 2021; Rakhshan et al., 2020; Mêda et al., 2021). According to several studies, digitization is seen as the essential key for a transition to a circular economy (CE) (Chan et al., 2021; FCRBE, 2022; Lopes de Sousa Jabbour et al., 2018; Pagoropoulos et al., 2017; Okorie et al., 2018).

Material Passports (MPs) are a digital tool which supports the transition to a CE as they aim to facilitate material reuse (Platform CB'23, 2022). They are a representation of an object in a building and comprise qualitative and quantitative data which give value to it (Cirkelstad, 2021). Due to the involvement of various stakeholders during different phases and aspects of the building process, there are currently diverse types of MPs on the market as not only contractors or demolition companies but also parties such as architects begin to develop their own MPs. It is found in research that the diversity in nomenclature and formats of MP available are not consistent and therefore non-standardized (Kedir et al., 2021). Platform CB'23 is a public initiative from which the action team 'paspoorten voor de bouw' created a guideline that aims to standardise the information provided for an MP (Platform CB'23, 2022).

Much of the research on this topic focuses on the potential of MP for material reuse as a step towards a CE (Adisorn et al., 2021; Honic et al., 2019; Honic et al., 2021; Kedir et al., 2021), however, there is very little research carried out on the actual implementation of MPs in design practice. Within the scientific literature, there are little to no studies concerning the adequacy and sufficiency of the information provided by MP platforms to professionals (Adisorn et al., 2021). Material Passport platforms (MP platforms) are online databases for material and components in the form of MPs which facilitate the exchange of secondary resources. Although there are recent studies of projects and organisations where building materials are reused, these are not always implemented using MPs. The key stakeholders

which influence the use of MPs in the construction must therefore be further researched in order to understand methods by which MP data supply can be further developed.

1.1 Circular Economy in the Construction Industry

A Circular Economy (CE) is a concept that has been gaining popularity in the past years. CE in the construction industry advocates for better management of resources where the economy works in a closed-loop manner and resources are reused at their highest value (Benachio et al., 2020). The concept has been popularised largely by the Ellen MacArthur Foundation which states that a CE is based on three principles: elimination of waste and pollution; circulation of products and materials at their highest level of quality and a regenerative nature (Ellen MacArthur Foundation, 2019). It stresses that in a CE, dependency on finite resources is removed.

In the context of the construction industry, this means that CDW needs to be reintroduced in the process to close the loop. This implies a major shift from the current linear model in the construction industry to a circular model as seen in Figure 1. Currently, construction involves extracting raw materials which get transformed into building components and are assembled in a manner which does not fully support deconstruction (Li, 2015). The definition concluded by Fritz Benachio et al. (2020) after researching the term CE in the construction industry using a literature review is as follows:

'the use of practices, in all stages of the life cycle of a building to keep the materials as long as possible in a closed loop, to reduce the use of new natural resources in a construction project.'

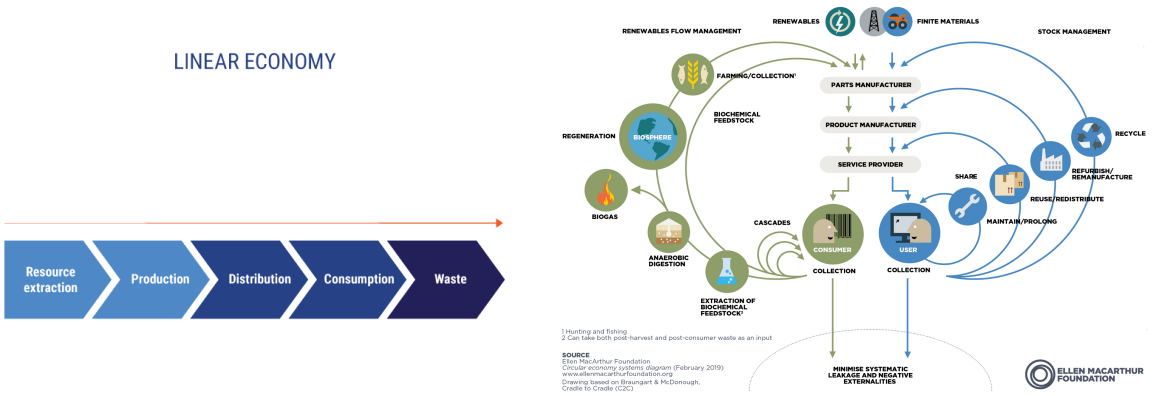

Figure 1. Linear Economy vs. Circular Economy (Daskalova, 2018; Ellen MacArthur Foundation, 2019)

The paper concludes that although there is widespread awareness of the need to transition from a linear model to a circular model, there is still a lack of study about standardisation practices to help practitioners implement reuse in their projects. The application of CE in the construction industry is still in its early phases as it is a relatively new concept. Although the potential of CE has been heavily researched, the potential of reusing building materials and

components has received less awareness. More attention has been focused on the reduction of construction waste and improving efficiency in recycling (Adams et al., 2017). Additionally, the application of CE on a wide scale in the built environment is lacking and occurs in an isolated manner either in a specific project or a particular sector (Adams et al., 2017). This is largely due to the highly complex nature of the construction industry. The involvement of multiple loosely linked actors with temporary contractual relationships (Heintz & Wamelink, 2015) along with the generally conservative nature of the construction industry (Vrijhoef & Koskela, 2005) can be regarded as the main barriers to the adoption of newer developments in the industry.

Hart et al. (2019) categorise the main barriers to CE in the construction industry into cultural (lack of interest; lack of collaboration between business and delivering CE in a linear model), regulatory (lack of consistent regulatory framework; lack of incentives and obstructing laws and regulations), financial (high front-end investment costs; low raw material prices; unconvincing business cases and limited funding) and sectoral (long product life cycle; technical challenges of material recovery; lack of standardisation and insufficient development of CE centric tools and the uncollaborative, adversarial and conservative nature of the sector) barriers.

In terms of stakeholders in the industry itself, contractors, researchers and consultants, and clients identify the following barriers to the adoption of CE in the built environment: the complexity of buildings; fragmented supply chain; the low value of materials; unclear financial case; lack of market mechanisms for recovery; lack of consideration for end-of-life issues; lack of the incentive to design for end-of-life; lack of CE knowledge; limited awareness across the supply chain and lack of interest (Adams et al., 2017).

1.1.1 Digital Technology as Enabler

Studies have increasingly identified digitization as a key enabler towards a CE (Çetin et al., 2021). It is seen as a major driver towards closing the circular loop by matching demand and supply. Digitization is considered to be essential in the transformation of the built environment to a CE. Studies show that a variety of digital technologies have been studied regarding the transition to a CE: Building Information Management (BIM) (Wang et al., 2019), Artificial Intelligence (AI) (Darko et al., 2020), Geographical Information System (GIS) (Wang et al., 2019) and Material Passports (MPs). Despite numerous studies concerning the opportunities provided by digitization, there is not enough study carried out on the implementation of DTs in practice by the key stakeholders and whether it meets their demands to be implemented into the construction process.

1.2 Problem Statement

The Dutch government has ambitions for the Netherlands to be completely circular and energy-neutral by 2050 (IEA, 2021; UNFCCC, 2016). The largely traditional nature of the construction sector along with it being a complex network of stakeholders leads to the sector lagging behind in the uptake of new technologies and business models (World Economic

Forum, 2016). As the CE is still a relatively new concept, its application in the construction industry is still quite limited. Although studies identify the advantages of transitioning to a CE, there is not enough research into its broad application in the industry.

As there is a limited supply of resources on the planet, there is an increasing urgency to reduce the demand for virgin materials. The existing building stock encompasses a large number of materials that have value and the potential to be reused. However, as a result of a lack of proper dynamic data regarding these materials, they end up as waste in landfill. The data on these materials need to be dynamic as their value and conditions are prone to change over the life cycle of a building. Currently, the implementation of MPs in the construction industry is fragmented over specific projects or certain clients and is still in the experimental phase where it is applied in pilot projects. In order to transition to a CE where secondary materials are reused into the loop, it is essential to study the key stakeholders that have an influence on the implementation of MP and their data exchange requirements. As the supply side is developing at a slow pace, it can be useful to research the adequacy of the data supplied and the extent to which it matches the needs of the stakeholders.

Data is currently still seen as a closed proprietary good by most stakeholders, however a shift is needed where data structured on open standards can be viewed as a common good. This would enable large-scale collaboration in the built environment and thereby facilitate the transition to a CE. Data exchange can help in making informed decisions for resource optimization and thus waste reduction in the entire value chain, provide insight into maintenance which can enhance a product's life cycle, facilitate traceability, and allow for continuous monitoring of various circular processes.

Integrating the use of MPs from existing building stock into the process of new construction can bridge the existing gap between the demand for materials and the supply of secondary materials in materials and building components. The reuse of materials would encourage collaboration and transparent information sharing in the construction industry, which is currently not the case. It would be one of many steps towards a CE. The research aims to contribute to existing studies by looking into the main data exchange challenges faced by key stakeholders in the implementation of MPs in practice and by getting insight into the main concerns of making data accessible and interoperable from a client perspective.

1.3 Research Objective

The main goal of this thesis is to give new insights from a stakeholders' perspectives on the main challenges associated with data accessibility and interoperability of MPs in the construction sector as it is currently lacking in existing research. Furthermore, it seeks to look into a public client's view on facilitating data exchange for stakeholders. As increasing efforts are made to transition the industry towards circularity, it is important to look at stakeholders' attitudes, needs and requirements for tools that are being created to ensure that these will in fact be used. The focus of the research is on data accessibility and interoperability as these factors are currently major barriers of MPs. Through the use of a literature review, interviews and a case study, the research aims to obtain insight into

stakeholders' data exchange challenges and needs from MPs followed by exploring a client's perspective on making their data accessible and interoperable for other stakeholders. This can potentially shed light on steps towards data standardisation for MPs from a stakeholder and client perspective. As MPs can be seen as a tool that facilitates the CE, the research additionally seeks to assist its further development. The research aims to contribute new knowledge in this area as well as provide recommendations for practice on the basis of empirical data in a bottom-up approach with the objective of improving data exchange of MPs in practice.

The research will therefore be guided by the following main research question:

1.4 Main Research Question:

How can the data exchange of Material Passports between key stakeholders be optimised in order to improve the effectiveness of its implementation within practice?

The main research question will be answered with the help of the following sub-questions:

1.5 Sub-questions

1. What are the key characteristics of material passport data exchange and data accessibility and interoperability?
2. What are the data exchange roles of key stakeholders regarding MPs per building life cycle stage?
3. What are the main challenges faced by key stakeholders regarding data accessibility and interoperability?
4. How do data owners, particularly public clients, perceive the idea of improving data accessibility and interoperability for other stakeholders?

The first sub-question aims to define the key characteristics of MP data exchange through the help of a literature review. This is followed by the second sub-question which aims to look at stakeholders' roles regarding the data exchange of MPs and seeks to map them per building lifecycle stage through the use of a literature review. This is followed by the third sub-question which explores stakeholders' concerns for their needs and requirements for data accessibility and interoperability of MP. The aim of this sub-question is to gain insight into what stakeholders require in terms of data accessibility and interoperability for the utilisation of MPs. This will be followed by the fourth sub-question which aims to explore the influence of data accessibility and interoperability on a public client's behaviour for re-use within practice.

1.6 Scientific Relevance

In the existing literature, there is a substantial amount of research carried out on the potentials and opportunities of MPs and their contribution towards a CE. However, there is very little existing knowledge on the implementation of MPs in the construction sector from stakeholder and client perspectives. A building's life cycle involves several stakeholders who can either provide input or extract output from MP, which adds to the complexity of using MPs in practice. It is essential to understand the main challenges associated with data by key stakeholders in order to improve data exchange and streamline the process in order to ensure that MPs can actually be used by key stakeholders in an effective manner. Additionally, there is insufficient research carried out on data owners's views on making data accessible and interoperable for stakeholders in the sector. Understanding their concerns is key in moving towards methods by which data can be shared safely and effectively with other stakeholders. These aspects of data exchange have currently not been researched in-depth and can potentially help in improving data exchange in the building sector.

1.7 Societal Relevance

There is an increasing concern to decarbonise the built sector and transitioning towards a CE (UNEP, 2021). The planet has a limited availability of natural resources and depleting them at the current rate for construction can have disastrous consequences (Li, 2015). According to Sönmez & Kalfa (2023), the building industry produces 30% of the total waste produced in the EU, from which 20-30% is downcycled or reused. Most of the CDW that end up in landfills still contains some amount of value but remains unknown because it is not properly documented and exchanged. As Thomas Rau says "waste is material without an identity". This is where MPs play a significant role in allocating value to materials so that they can be reused. As MPs are still an emerging concept, this research can contribute to gaining a better understanding of the stakeholder and client perspective on the implementation of MPs and their insights on how data exchange during a building's life cycle can be improved.

2 Research Methodology

In this section, the methodology used to answer the research question will be discussed. The main goal of this research is to gain insight into key stakeholders' main challenges with MP data exchange and explore a public client's view on making data accessible and interoperable for other stakeholders to understand how MP data exchange can be improved in practice.

The research makes use of a mixed methods approach as shown in Figure 2. Firstly, a literature review of the main concepts and theories is used to substantiate the problem statement. The literature review is further used to obtain a definition for key concepts used in the research for clarity and consistency. A review of existing literature also reveals the research gap that needs to be addressed in this research. The data is analysed with the help of a diagram which synthesises the existing literature on stakeholders' roles in data exchange for MPs.

Consequently, semi-structured interviews are used to obtain primary data for the third sub-question. For the fourth sub-question, a case study of a public client, CREFM is used. The case study is used to gain an in-depth understanding of their views and concerns with making their data accessible and interoperable for other stakeholders. The case study consists of two parts. The first part gives context to the organisation itself using secondary sources. This is followed by collecting primary data from experts in the organisation through the use of semi-structured interviews.

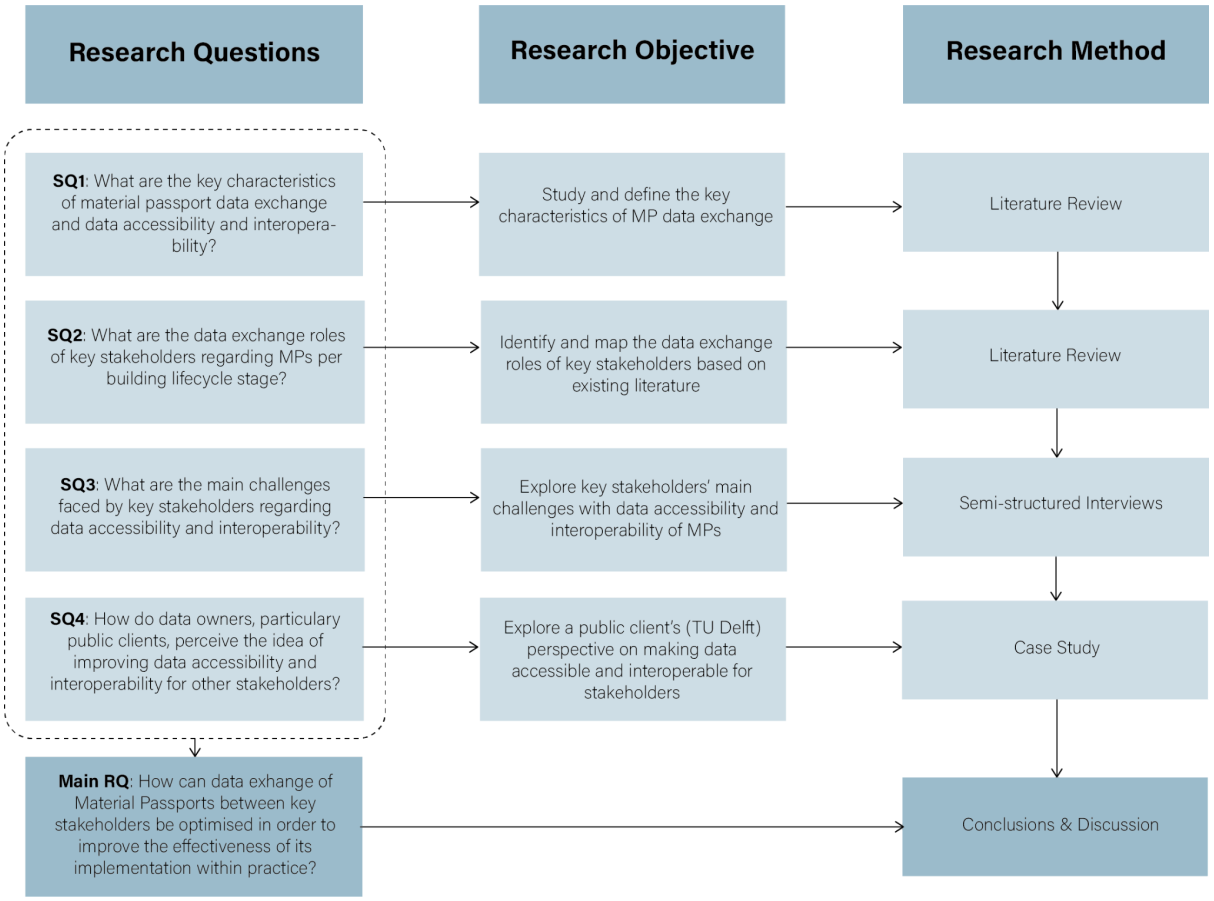

Figure 2. Research Design (source: author)

2.1 Data Collection

This research makes use of primary and secondary data sources. Within qualitative research, data collection methods typically involve the collection of a significant amount of data on the basis of purposive sampling through the use of techniques such as participant observation, in-depth interviews or focus groups (Hox & Boeije, 2005). Primary data can be defined as the new data collected for a specific research problem whereas secondary data refers to the data collected originally for another purpose that can be reused for another research problem (Hox & Boeije, 2005). In this research, secondary data is used for defining concepts in the literature review and for answering the first and second sub-questions. The secondary sources include mostly scientific papers and publications. The primary data is collected through the use of semi-structured interviews and a case study.

As the participants need to have the characteristic of being MP users, the purposive sampling method is used to select the participants for collecting primary data. Purposive sampling is a non-probability sampling technique where participants are selected on the basis of certain characteristics (Nikolopoulou, 2022). This technique however is at high risk of observer bias.

Additionally, secondary and primary data are collected for the case study to first establish and describe the case, followed by input from stakeholders via interviews. The case study is used to understand a large-scale public client and data owner's opinions and concerns regarding making data accessible and interoperable for stakeholders. A single case study is used to gain a deeper understanding of MP implementation in practice and to explore the influence of data accessibility and interoperability on reuse. The results from the research are used to formulate recommendations for improving data exchange in the building sector.

2.2 Semi-Structured Interviews

Semi-structured interviews are used to answer RQ2. An interview protocol is set up before the interviews are planned to give structure to the interviews and ensure that important topics are not missed. The interviews are semi-structured so that follow-up questions can be based on participants' responses (Kallio et al., 2016). The participants receive the interview protocol prior to the interview so that they can prepare the information they would like to share. While there is debate on how many interviews are adequate for qualitative research, Dworkin (2012) recommends anywhere between five to fifty as adequate. For the third sub-question, twelve interviews are carried out in total with various stakeholders. The preconditions for selecting participants are as follows:

1. Is based in an organisation in the Netherlands
2. Has experience using MPs, preferably from existing construction
3. Makes use of MP platforms
4. Falls under one of the stakeholder categories in Figure 8

2.3 Case Study Selection

According to Creswell et al. (2007) a case study research aims to build an in-depth, contextual understanding of a case through multiple data sources. They stress that the topic that the selected case study provides insight into is within a bounded system (i.e. a setting or context) as only then, it is relevant to the study. Case study research is a qualitative research approach where a case is studied through in-depth data collection using sources such as observations, interviews and documents, reporting a case description and case-based prevalent themes (Creswell et al., 2007). For this thesis, the public client Campus Real Estate & Facility Management (CREFM) is selected as the case study. They are a large-scale real estate owner and major forerunners in circularity. TU Delft has ambitions to be a pioneer in the circular transition by becoming carbon neutral and climate adaptive. On this basis, they are chosen as the case study for this research. The main aim of the interviews is to gain insight into a public client's views on making data more accessible and interoperable for other stakeholders. This is done by validating the results from the third sub-question with the interviewees.

2.4 Operationalization

To operationalise the primary data, a thematic analysis will be carried out for all the interviews. The transcripts are edited and read thoroughly by the author in order to identify discernible themes. For the interviews, these are used to establish the main challenges whereas for the case study, they are used to highlight the main concerns of CREFM regarding data accessibility and interoperability. Conclusions are supported with verbatim quotes from the transcripts. The findings from the client perspective are used to validate the findings from the stakeholder interviews. The transcripts are made from the video recordings from the online meetings. During editing of the transcripts, it is taken care to retain the needed information in its true nature on the basis of the verbal account. This is followed by writing down initial codes which are eventually used to develop themes on the basis of which the data is analysed.

3 Key Characteristics of Data Exchange

This section aims to explore the key characteristics of MP data exchange and the roles of key stakeholders involved to answer the first sub-question, *"What are the key characteristics of data exchange and data accessibility and interoperability?"*, key concepts are defined by consulting relevant scientific articles to gain a better understanding of the main characteristics of materials passports and data exchange.

3.1 MP Data Exchange Key Characteristics

3.1.1 Material Passport

Material Passports are seen as a key tool in the transition towards a CE (Kedir et al., 2021). There is a growing relevance for recording data in the construction industry as many materials, products and building components retain value for a long period of time (Kedir et al., 2021). Some of the advantages of MPs in literature are retaining or increasing the value of materials, products and components over time (Luscuere, 2017), facilitating reversed logistics and reclaiming of materials (BAMB, 2020) and making relevant data available for impact assessments (Honic et al., 2019). As MPs are still a relatively recent concept, there is a lack of a standardised definition of an MP and various initiatives/organisations give it their own definition. This section aims to define MPs within the context of this research.

One of the earliest studies on MPs was carried out by Luscuere in 2017. In the paper, he mentions that in order to comprehend the value potential of materials, a reliable set of information is required. MPs are referred to as 'nutrient certificates' based on the article 'Resource Repletion Role of Buildings'. In the article, 'nutrient certificates' are defined as sets of data describing characteristics of materials which give them value for recovery and reuse. Similarly, Luscuere (2017) defines an MP as an active tool for value tracking and bringing residual value to the market. MPs can be made for materials, systems and products. An MP as a tool can be used by various stakeholders throughout the value chain of a building with the goal to document and track the circular potential of materials by providing stakeholders with accurate information on various aspects including but not limited to its composition.

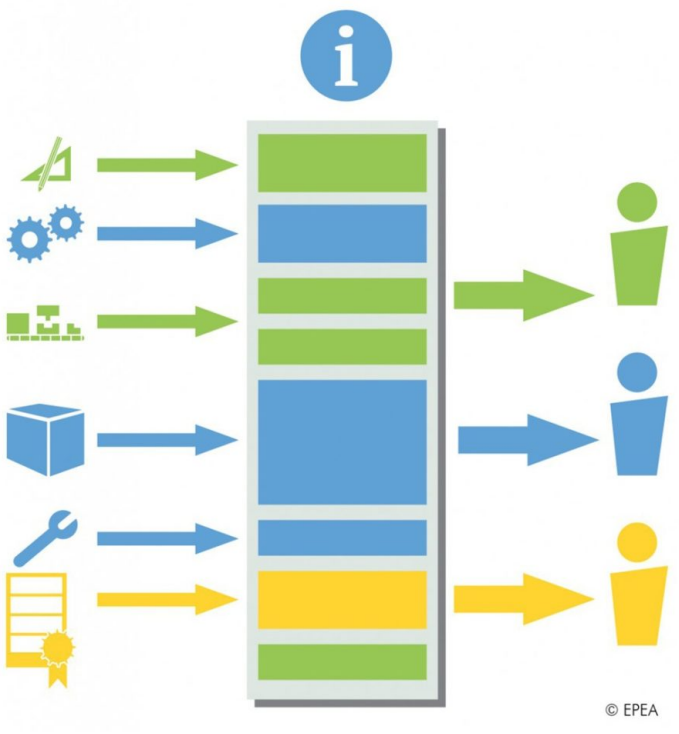

Figure 3. Information exchange of material passports (BAMB, 2020)

Platform CB'23 states the following definition: a material passport is a digital document that captures an object in the building industry. It documents the components out of which the object is made (qualitative and quantitative), its structure and its physical location (Platform CB '23, 2020). The documentation includes the ownership details of the whole object as well as its components (Cirkelstad, 2021). Buildings as Material Banks or BAMB defines MP as an electronic set of data which describes characteristics of materials in products which give them value for recovery or reuse (BAMB, 2020). See Figure 3. The online material platform, Madaster, defines MP as a digital document which records the identity of construction materials used in a building (Honic et al., 2021). A common concept across all these definitions mentioned above is the digital nature of MPs along with a supply of information regarding the material's components on various scales.

The information regarding a material or component can be categorised under levels of scale. These levels are Building, System, Product, Component and Material (Platform CB'23, 2020). This allows data to be structured in a way which prevents repetition. These levels of scale are determined by Platform CB'23 based on the modelling rules of NEN 2660, an Information system for the buffing field - Terminology, definition and general rules. As seen in Figure 4, the levels vary from physical objects to materials and finally down to raw materials.

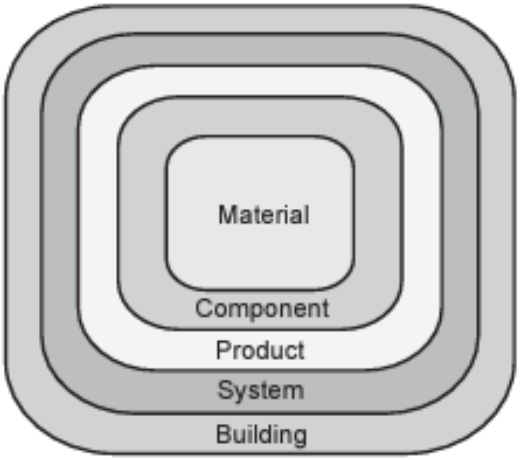

Figure 4. Information levels of scale of an MP (Luscuere & Mulhall, 2018)

MPs are not to be confused with material databases or material exchange platforms. These concepts, although similar, are distinctly different from the concept of MPs. Material database refers to a digital database of structured information on buildings and materials elements (FCRBE, 2022). It digitises information regarding existing building materials and shows the market the availability of reusable elements. It can also be used to map the material flows on a larger scale. Thus, it can be said that a material database consists of various MPs. Material exchanges, on the other hand, are online platforms which accumulate these secondary resources and aim to match the supplier of the material with the demand for it (Connecticut Department of Energy & Environmental Protection, 2020). Such exchange platforms aim to reduce the overall environmental impact and increase the financial value of these materials. MPs focus more on the recovering value of these materials and therefore maximising circular aspects (Luscuere, 2017).

3.1.2 Material Passport Data

According to Luscuere (2017), an MP contains a set of information regarding a particular material, product or component. Information from different sources makes up the data provided by MPs. Furthermore, the required information differs per stakeholder and the life cycle stage involved. For example, a subcontractor may require more detailed information as compared to an investor who requires simpler information for their decisions. According to BAMB (2020), CE in the built environment requires a large amount of data to be centralised rather than stored in different sources. It states that the main types of data required for MPs can be categorised as physical, chemical, biological and process-related properties. These properties can be explained as follows:

- Physical properties: Includes properties such as dimensions and weight, density, building physics, resistance and rigidity. The specification of this data further depends on the material/component in question.
- Chemical properties: This may include chemical composition, health and safety information, recycling and reuse potential, lifespan and durability. It is useful to

know chemical properties to find out the composition of the materials being used. For example, if there is asbestos in a material or component, the material can be discarded rather than reused.

- Biological properties: For the use of renewable materials such as timber, properties such as treated/untreated, decomposability and recycling or reusability potentials can be useful.

The data regarding an MP accumulates over time due to the dynamic nature of materials and components used in buildings and therefore needs to be stored in a safe and reliable manner. Data storage is a separate issue regarding MPs but is outside the scope of this research.

According to Adisorn et al. (2021), the main actors providing information regarding MPs are manufacturers and suppliers as other actors generally do not create new product data but rather forward the information making it a unidirectional data flow as seen in Figure 5. Relevant data is provided in various forms, for example, technical datasheets, online labels etc. Adisorn et al. (2021) state that acquiring information from a material currently in use phase can be particularly challenging and better product data can be delivered with the development of better business models. When manufacturers see a viable business case in providing product information, there will be intrinsic motivation for data compilation. If manufacturers decide to supply all the relevant data in a single form such as online (no physical form such as sheets), they also need to ensure that the users are able to acquire and process this form of data as it would otherwise be of not much use.

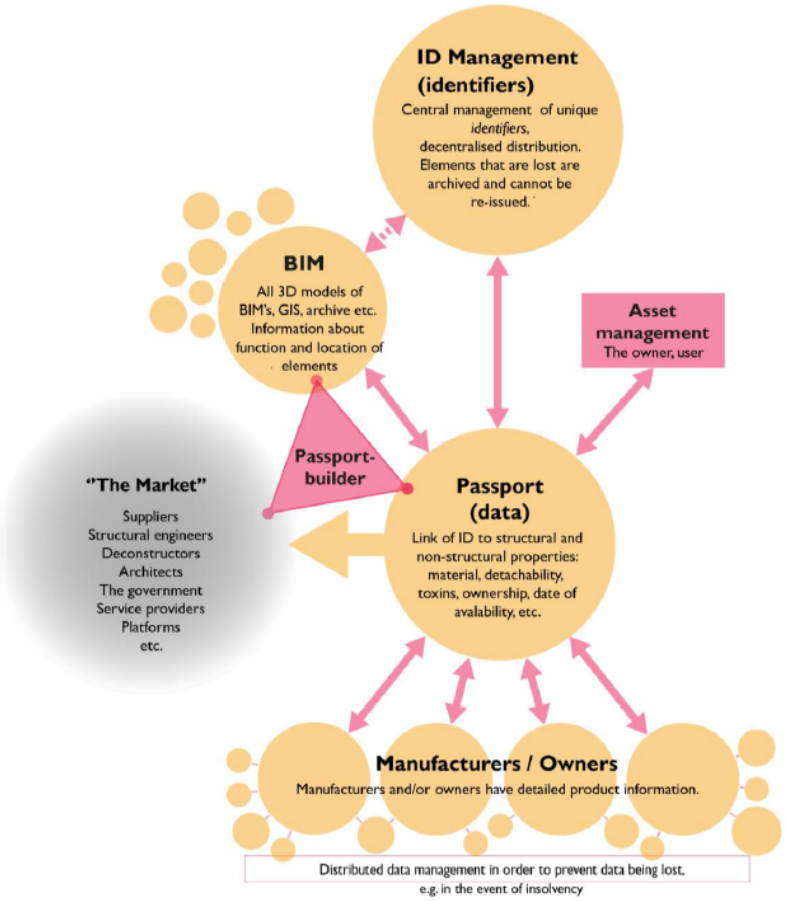

Figure 5. Stakeholders and their roles in recording and using data (Platform CB'23, 2022)

Recently BIM is gaining popularity as a tool used to acquire data from MPs (Honic et al., 2021). BIM-based MPs are created by acquiring data regarding material composition and geometry from a BIM model. Apart from BIM models, there are several auditing methods used to acquire various data regarding a building. For example, laser scanning technology can be used to acquire the geometry of materials and components in a building (Honic et al., 2021). Manual auditing of a building before it is demolished can also be used to get data about the materials that can still be reused, however, a limitation is accessing the internal composition of the products. This is where manufacturers and suppliers play a crucial role. For new construction on the other hand, ideally, MPs are created before the building is constructed.

Platform CB'23 (2022) states that there is a better chance of materials being reused if the quality of data from the source is better. The available data needs to be accurate, complete and up-to-date. If the data is of poor quality and does not accurately represent the real-life situation, an on-site survey should take place where calculations, measurements and condition assessment can be made (Platform CB'23, 2022). Platform CB'23 defines data quality as the 'accuracy of available data and the degree to which available data is suitable for its intended purpose'. In order for the data to be valuable to others, it must fulfil certain

data requirements. There is a current lack of data and thus data quality in the sector, which is gradually shifting as a result of increased legislation for collecting building data. Data quality is improved when it coincides with the actual situation of the material/component in reality (Platform CB'23, 2022).

'The better the data required for the reuse of materials has been recorded, the greater the probability that these materials will actually be reused.' - (Platform CB'23, 2022)

3.1.3 Life Cycle Phases

The data gathered in an MP relate to specific life cycle phases of the construction process. The life cycle stages of a building are mainly the production stage, construction stage, use stage and end-of-life stage (Çetin et al., 2021). The production and construction stages are concerned with the production of the materials required for the project and are the stages before the users can occupy the building. Here, activities such as extraction of raw materials, manufacturing components, transportation and construction take place. According to Çetin et al. (2021), it is during this stage that the most impact regarding the reduction of raw resources leading to lower carbon emissions can be made. The use phase is where the designated users make use of the building and is the longest phase of the life cycle. This is followed by the end-of-life phase where the building can either be renovated to fit a new function or the current building standards or demolished. In an ideal CE scenario, the end-of-life phase is eliminated as the newly available resources are reintroduced into the cycle through reuse, thereby reducing the need for primary resource inputs (Çetin et al., 2021).

3.1.4 Current Legislation Regarding Standardisation of MP Data

Standardised data refers to information that is structured and formatted using predefined standards and formats which help make the data easily understandable and reduce ambiguity in the definition of terms which is crucial for accurate data exchange and analysis. They can be open data formats such as public data portals, data exchange standards such as ISO 20022 for the financial sector which aims to create a common language for every kind of financial business transaction, and APIs which serve as an intermediary between 2 or more disconnected computer programs. Standardised data is crucial in any sector as it allows for a seamless exchange of information across stakeholders and organisations.

On the supply side of MPs, there are different parties that are developing their own MPs with different standards and types of data required. This lack of a unified approach increases the complexity of MPs (Block et al., 2020). Recently, there have been initiatives that aim to solve this issue of standardisation. Platform CB '23, an abbreviation for Circular Building in 2023 is an example of a public initiative initiated by the Rijksvastgoedbedrijf, Rijkswaterstaat, De Bouwcampus and NEN (Nederlandse Norm). The initiative aims to bring together stakeholders of the construction cycle and to establish working agreements which are eventually used as input for the national and European measurement methods and initiatives (Platform CB'23, 2022). As a result, one of the first guides for MPs has been

published: *Guide Passports for the Construction Sector 2.0*. The guide aims to establish a standardised passport for the sector which would ensure that relevant data is available in a reliable manner (Platform CB'23, 2022). The main focus of this guide is to indicate the preconditions which should be met by a passport as a minimum requirement (Platform CB'23, 2022).

The goal of their guide is to create a framework which can enable the structured collection of data and thus improve its suitability for use. MPs are currently developing as a result of market force and are thus fragmented and unaligned (Schols, 2022). This is opposite to the principles of CE where collaboration between stakeholders and sharing of information is essential. The framework, therefore, aims to provide insight into the requirements for the creation and use of MPs for its users and is intended for public and private parties.

According to Mulhall et al. (2022), there are several recent initiatives and regulations that aim to standardise Circularity Data in the construction sector. These are summarised in Figure 6:

Figure 6. Categories of diverse CE initiatives in the construction sector (Mulhall et al., 2022)

However, due to the lack of a common definition of CE, lack of a unified approach, and proliferation, there is still no widely accepted initiative across the construction sector (Mulhall et al., 2022).

3.1.5 Barriers to Adoption of MPs

Despite the researched opportunities and potentials of MPs, they are not yet common practice in the construction sector. There are various barriers present that prevent this from happening. An overarching reason is the complex and unique nature of the sector. As compared to other sectors, the construction sector is generally lagging behind in the implementation of digitisation (BAMB, 2017). The main barriers can be summarised as follows (Block et al., 2020; Cirkelstad, 2021; Hart et al., 2019):

- The complex and multifaceted nature of the supply chain makes it increasingly complicated to adopt radically new changes in the sector as there is an emphasis on

the traditional way of doing things. Therefore, new changes take a lot of time before they can become common practice in the industry

- As compared to products from other sectors, buildings have a considerably longer lifespan and change ownership over their life. As buildings can last multiple decades, the process to track materials and components becomes more challenging. Furthermore, this data needs to be stored securely which demands considerable storage for long periods of time.

- Lack of standardisation across the sector such as software/platform use or design and use contributes further to the complexities. Unlike other sectors, there is a lack of a unified approach in the construction sector as stakeholders make use of various types of contracting, tendering, design processes etc.

- Complexity of products which contain different types of materials in order to deliver the desired physical and chemical properties. This can make it more difficult to categorise and obtain certain materials from a product

- Information gap of material/product information as it is not communicated to relevant actors at the required time. Even if the appropriate information is present, it may not be reaching the right actors due to the fragmented and non-collaborative nature of the sector.

- Lack of a strong business case makes investors sceptical of the technology as they are not sure if financial returns can be guaranteed.

- Need for changes in culture and behaviour of stakeholders involved

The barriers mentioned above slow down the adoption of MPs into practice in the construction sector and must be turned into preconditions in order to lead to its successful implementation. This research will focus on two prominent barriers of MPs that are concerned with data exchange; accessibility and interoperability of data. These are further discussed in the sections below.

3.1.6 Data Accessibility

Accessibility is defined as “being able to be reached or obtained easily; the quality of being entered or used by everyone; the quality of being easy to understand” by the Cambridge Dictionary (n.d). In terms of MPs, accessibility refers to the ease with which key stakeholders can access stored MP data. A key factor of MPs is the data they hold. To ensure that secondary materials can be reused, access to this data is a key factor. According to CB '23 (2020), much of the required data already exists in existing software and only needs to be made cohesive and accessible. However, due to the competitive nature of the construction industry, hesitation from stakeholders to share information transparently is expected.

Additionally, according to Schols (2022), ownership can have further influence on the hesitation by parties to share data freely. Platform CB'23 (2020) states that data is not accessible when:

- It is unknown which data can be obtained and where;
- It is unclear how and under what conditions the data is available;
- The data is not made suitable for reuse.

3.1.7 Data Interoperability

Interoperability refers to the ability to share data between different computer systems, machines or software (Collins English Dictionary, n.d.). Data is interoperable when it is compatible with various software and machine types and can be interchanged. Interoperability of data is essential for MPs as data needs to be continually shared with different stakeholders during the project life cycle (Platform CB'23, 2020). According to Platform CB'23 (2020), good information modelling is required in order to be able to exchange data competently with key stakeholders and it must be possible to communicate data between different sectors.

Conclusion

In conclusion, MPs are a digital tool for the collection and storage of building data. They are intended to store various physical, chemical and biological data of all the materials in a building. Data is stored in an MP in various formats such as numerical or visual. CB'23 is a government initiated project which provides an extensive guideline for the data that should be provided by stakeholders. The guideline is on a local level as there are currently no international standards for MP data requirements. Based on the literature review, the definition of an MP for the context of this research is as follows:

'A material passport is a digital document which describes the characteristics of materials with the aim to track the circular potential of materials by providing stakeholders with accurate information which gives them value for recovery and reuse (Luscuere, 2017; Cirkelstad, 2021; BAMB, 2020; Honic et al., 2021).'

There are numerous barriers which make data exchange a considerable challenge currently such as complexity of the sector, lack of standardisation, information asymmetry, complexity of products and changing ownership. These factors contribute to the current challenges with MP data exchange. It is found that there are two main challenges concerned with the gap of information, namely data being inaccessible and non-interoperable for stakeholders. The research therefore aims to focus on examining the challenges associated with these characteristics of data exchange. The definition of data accessibility from from the literature review is as follows:

*Data is **accessible** when it is known what data can be obtained, where it can be obtained, the conditions under which the data is available is known and the data is made suitable for the purpose of reuse.*

The terms availability and accessibility are not used interchangeably in this thesis. The distinct difference between these terms is that data availability refers to data that is present and can be potentially used or obtained by someone whereas data accessibility refers to the actual locating and retrieving of the data. The definition of data interoperability for the context of this research is thus:

*Data is **interoperable** when it is possible to exchange data efficiently with key stakeholders in the public and private sector and community organisations across various technological aspects and different sectors without any restrictions.*

These definitions are used to determine whether the key stakeholders in section 4.1 view current data as accessible and interoperable and to determine the perspective of TU Delft as a public client on making their data accessible and interoperable for the building sector in an effort to facilitate the CE.

4 Data Exchange Roles

The following section seeks to identify and map the key stakeholders involved in the data exchange process of MPs per building lifecycle stage. With the help of a literature review, the following sub-question is answered: *"What are the data exchange roles of key stakeholders regarding MPs per building life cycle stage?"*

4.1 Key Stakeholders Involved in MP Data Exchange

MPs urge for collaboration between different stakeholders in order to obtain value from materials at the end-of-life stage. Platform CB'23 (2020) classifies the main users of MPs as the following: client, owner, architect, contractor, manufacturer/supplier, user and passport builder. BAMB (2017) identifies the following users of MPs: government, real estate developer, investor, architect, building permit authority, contractor, research institute, supplier, building valuator, owner, user, facility manager, product installer, maintenance contractor, insurer, deconstruction company, logistics manager, MP platform. The relevant stakeholders can be data providers or data extractors based on different life cycle stages of the construction process. Building an MP for an existing building is different from the process by which an MP is created for new construction. According to Block et al (2020), an MP is ideally created before a building is constructed, as this is not possible for existing buildings, techniques such as 3D scanning and augmented reality platforms can be used to evaluate the materials present in a building which can be used to extract data and create its MP.

One of the major challenges regarding data exchange of MPs is the fact that data is dynamic and changes over time. These changes need to be regularly updated in order to be an accurate representation of the building as buildings have long lifespans and can have multiple transfers of ownership. Additionally, in order to ensure interoperability across various software and platforms, the data needs to be standardised (BAMB, 2017). Furthermore, it is worth noting that not all the data available in the MP is relevant for all the stakeholders. For example, the data relevant to an investor might not be of interest to an architect. Thus, the option to have filters can make it more user-friendly.

A research carried out by Sultan Çetin et al. (2023) uses a mixed-methods research process to identify the potential users of MPs and their specific data needs in the context of European social housing organisations. The findings can help gain a better understanding of the stakeholders involved and validate the findings of Figure 7. The research involved interviewing 38 participants to create a data template for an MP. The findings show that many of the identified stakeholders take on an interchangeable role, both as data providers and extractors in all project phases (Sultan Çetin et al., 2023). Additionally, some stakeholders such as architects have a much more significant role in providing data whereas

others have less influence. Stakeholders such as tenants and municipalities play a minor role in data exchange and only need to be informed about decisions (Sultan Çetin et al., 2023).

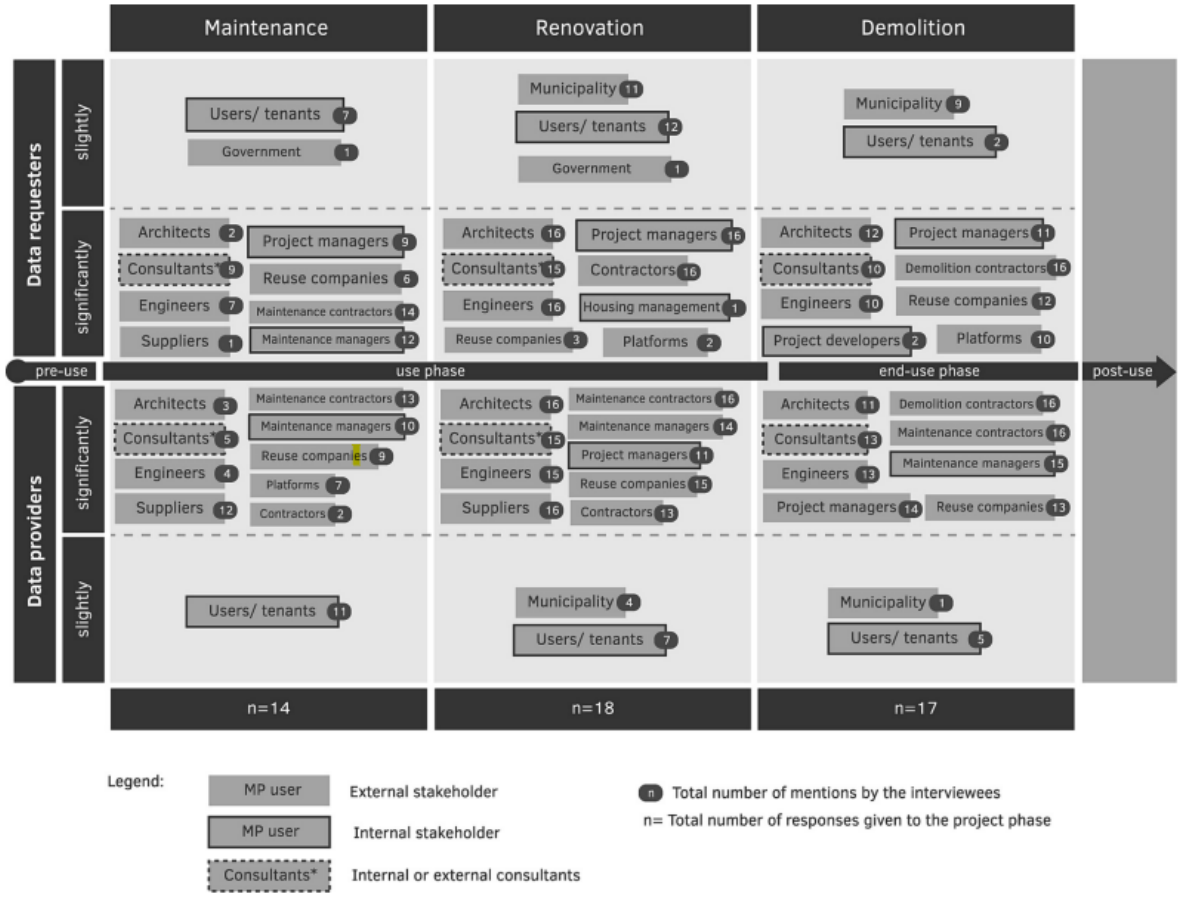

Figure 7. Users of MPs for existing housing stock (Sultan Çetin et al., 2023)

Sultan Çetin et al. (2023) distinguishes users of MPs into external users and internal users. External users are architects, engineers and consultants who have influence on the decision-making process. It is stated that demolition and reuse companies are seen as key actors in the EOL phase as they can provide valuable information regarding a material during harvesting (Sultan Çetin et al., 2023). Internal users on the other hand are developers, project managers and maintenance managers. At the centre of the data flow are the project managers who are coordinating projects and bridging their organisations with external stakeholders (Sultan Çetin et al., 2023).

4.1.1 Client as Data Owner

According to Schols (2020) and CB'23 (2020), in terms of the implementation of MPs, the decision and initiative should lie with the client. Specifically, when clients view circularity as an important aspect of their project, an MP can be used to describe their ambitions and circular strategies. As presenting a feasible business case for MPs is still a significant barrier, the intention to invest additional time and cost lies with the client (Cirkelstad, 2021). It is noted that clients require intrinsic motivation to implement MPs in the building lifecycle,

however, if it becomes just another "check the box" mandate, they do not see much-added value from using MPs (Schols, 2020).

Clients are also the stakeholders who are most likely to have ownership over the MP data and have the option to decide who can access it. The Platform CB'23 (2022) guideline views public clients as more organised and structured in managing their assets. When clients own a considerable number of projects, especially large-scale, it can be of interest to accumulate relevant data in order to facilitate reuse. This is especially relevant for public clients in the Netherlands as they own and manage a large portfolio of assets (Çetin, Gruis, et al., 2022). Chan et al. (2020) states that strong market power is held by these stakeholders as they are the forerunners in circularity in the construction sector. It is important to address the difference between professional clients and incidental clients based on their legal position. Public clients can be differentiated into two types; namely user and manager clients. User clients tend to fulfil a specific role such as providing education, making art accessible or caring for patients and thus both own and use their buildings (Hermans, 2014). On the other hand, manager clients tend to manage the real estate portfolio which is used by other parties, fulfilling the commissioning role for new construction, maintenance and improvement of the stock (Hermans, 2014). Private parties tend to focus largely on short term perspective as well as profitability. Unlike private parties, public parties are expected to comply with certain public values and principles of management such as social and cultural values.

It is therefore relevant to study a public client's perspective on making data accessible and interoperable for other stakeholders in practice.

Conclusion

To develop a comprehensive understanding of data exchange challenges related to Material Passports (MPs), it is essential to examine the roles of key stakeholders involved and their involvement in data access and interoperability. A literature review identified various stakeholders, including the client, owner, architect, contractor, supplier, user, government, real estate developer, investor, building permit authority, research institute, building valuator, facility manager, product installer, maintenance party, insurer, deconstruction company, logistics manager, and the MP platform (Platform CB'23, 2020; BAMB, 2017). Based on the information collected, the following diagram is made relating the concerned stakeholder to a life cycle stage where they either provide data for the MP or extract data from the MP for an existing building situation into a new build situation:

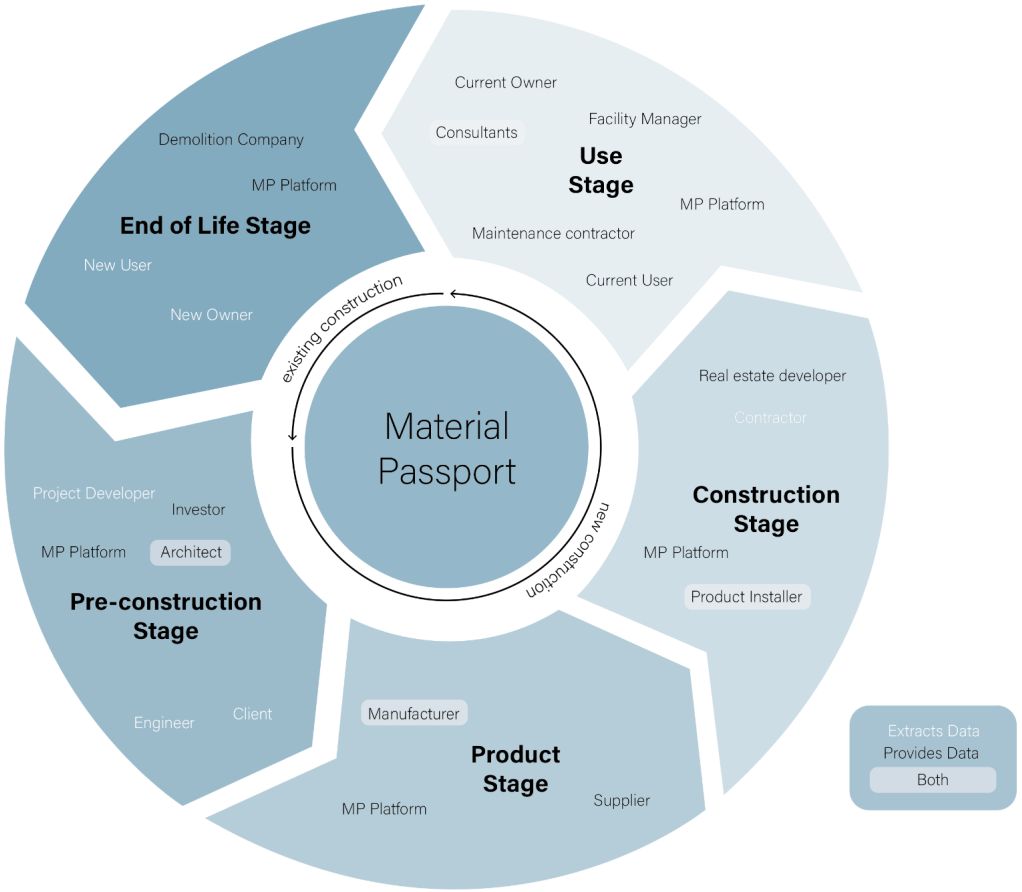

Figure 8. Stakeholders' roles in providing and extracting data from MP in the building lifecycle (source: author based on literature review)

As seen in Figure 8, the stage where an MP is created for an existing building is during its end-of-life (EOL) stage as the information was not accumulated earlier. The stakeholders are assigned to the stages based on the information available and some stakeholders mentioned by Platform CB '23 and BAMB above have been left out of the diagram as there is not enough information available to place them in a stage and would be based on assumptions. In the EOL stage, the demolition company can provide data to an MP platform which can turn this information into an MP. This information can be extracted by a new potential owner/user that would like to make use of secondary materials in their project. This is followed by the pre-construction stage of a new construction project where the architect, project developer, engineer and client need to extract data from the MP in order to evaluate the feasibility of the project and draw up the preliminary designs. Subsequently, is the product stage where the components are manufactured. In this stage, the manufacturers and suppliers need to both provide data to the MP regarding the characteristics of the new components as well as extract data regarding the reused materials. This is followed by construction where the contractors and product installers need to extract data about the installation and disassembly of the reused components and provide data regarding the installation and disassembly of new components. Finally, in the use phase, the MP needs to be continuously updated with data input provided by the current owners/users and investors and when the building is decommissioned, the cycle can repeat again.

Stakeholders can be categorised as either data providers or data extractors within the MP framework. The data registration process for existing constructions begins during the End-of-Life (EOL) stage, where a demolition company contributes data to establish an MP through an MP platform. In the pre-construction stage of new projects, architects, project developers, clients, and engineers extract data from the MP. During the product stage, suppliers are responsible for providing data on materials and components. Throughout the construction phase, contractors and product installers extract data on installation and disassembly, both for reused and new components. Ongoing data updates are necessary, involving input from current owners/users and investors, as well as during building decommissioning in the use phase. It is worth noting that limited research hampers the identification of roles for other stakeholders, leading to their exclusion from this analysis.

Furthermore, clients play a pivotal role in MP implementation, particularly when prioritising circularity and willingness to invest additional time and resources. Clients also typically assume the role of data owners for the MP, granting them primary decision-making authority regarding data sharing with other stakeholders. Implementing MPs proves particularly advantageous for clients with large portfolios, especially in the case of public clients who wield considerable market power and lead the way in circularity (Chan et al., 2020).

5 Interview Results

This chapter describes the interview results and data analysis in detail. The interview data is used to answer the third sub-question which is as follows: *"What are the main challenges faced by key stakeholders' regarding data accessibility and interoperability?"* The data is analysed using the grounded theory method as the themes are induced from the data.

5.1 Interview Participants

The interviewees are chosen based on the preconditions mentioned in section 2.1. It is therefore a purposive sampling method as the participants need to meet these preconditions in order for the data to be relevant for the research. The interviewees need to have background knowledge as well as experience with the concepts of CE, MPs and data exchange. The contacts are acquired through the help of the mentor's networks as well as by reaching out to persons from companies which have been associated with the use of MPs. Their names and personal details are anonymized for this research to protect their identities. It was important to get input from different stakeholders as data from MPs is acquired from multiple actors during the building lifecycle stages. The stakeholders were divided into the following categories: architects, contractors, suppliers, MP platform and consultants. Although a few demolition companies were contacted for the interview as it would be insightful to have their input for the research, no response was received. The answers from these interviewees are used to answer the third sub-question. The interview participants are summarised in Table 1.

Table 1: Interview Participants

	Profession	**Company**	**Stakeholder category**
Interviewee 1	Architect	Lister Buildings	Architect
Interviewee 2	International Product Manager	Madaster	MP Platform
Interviewee 3	Sustainability Advisor	Heijmans	Contractor
Interviewee 4	BIM Director	JP van Eesteren	Contractor
Interviewee 5	Consultant	ALBA Concepts	Consultant
Interviewee 6	Partner (Architect)	SuperUse	Architect
Interviewee 7	Specialist Circular Facades	Alkondor	Supplier
Interviewee 8	Senior Consultant	Demo	Consultant

Interviewee 9	Director	Madaster	MP Platform
Interviewee 10	Senior Researcher	Demo	Consultant
Interviewee 11	CFO	Block Materials	Consultant
Interviewee 12	Circularity Consultant	Insert	Consultant

The interviews range between 45-60 mins long and comprise roughly 15-20 questions which are also mentioned in the interview protocol, with the possibility to deviate from the questions. The interviews are held online via Teams on the basis of the participant's preference. The collected data is analysed using the software Atlas TI. After reading all transcripts thoroughly, codes are established using an inductive method on the basis of common relevant themes. The challenges regarding data accessibility and interoperability mentioned by the interviewees per stakeholder group are established.

5.1.1 Interview Topics

The interviews have been used to collect qualitative data regarding the main challenges that stakeholders face in terms of data accessibility and interoperability. In order to give the interviews sufficient structure, a few topics are established on the basis of the questions that are asked. The topics are as follows below:

- General Acknowledgement
- Data exchange role and needs
- Material Passport
- Data Accessibility and Interoperability
- Reflection

The topics aim to follow a logical order to give the interview structure. Each topic consists of open-ended questions which allows the interviewee to answer the question in depth from their experience and point of view. The open-ended nature of the questions provides the possibility to discuss some specifics in more detail including prompts to help the interviewee answer the questions (Burgess, 1984). The interview protocol is followed to an extent but may be strayed away from when the interviewer thinks it is appropriate and there is an opportunity to discuss a specific topic further.
The interviews begin by getting some background information on the interviewee's profession and the organisation where they work. This provides context into their position as a stakeholder. This is followed by questions regarding their data exchange role for an MP and is used to validate the findings of Fig 9. Consequently, the interviewees are asked about their experience regarding the current state of data exchange of MPs and what data they often miss to get clarity on the aspects of data exchange that need to be improved per stakeholder and the limitations that still need to be overcome. This is followed by questions regarding the main challenges concerned with data accessibility and interoperability and

finally with a reflection on their opinion about MPs as a tool for a CE. The questions are highlighted in Table 2 per topic.

Table 2: Interview Questions

Topic	Questions
General Acknowledgement	- What is your profession and what does the organisation where you work do?
Data exchange role and needs	- What is your/ your organisation's main role regarding data exchange? - What data do you need from a material passport, when and from whom?
Material Passport	- Who do you see as the main stakeholder regarding the data exchange of MPs? - What was your experience in terms of data exchange between different stakeholders, did you get access to what you needed? - What are some current limitations regarding data exchange that need to be overcome in your opinion?
Data Accessibility and Interoperability	- Is the data you need currently accessible? - Is the data you need currently interoperable? - How would making MP data more accessible and interoperable influence your work?
Reflection	- MPs are seen as a key enabler of a circular economy, what is your opinion on this? - What is your opinion on the fundamental differences between the theory and practice of using MPs - Who do you recommend I interview further on this topic?

5.1.2 Operationalization

To start analysing the data, transcripts of the recorded interviews are made. This is done by listening to the recording and making a written document of the interview. There are a total of 12 transcripts produced for this sub-question which form the data of the study. The transcripts are sent to the participants for confirmation so that they can make any changes that they do not agree with or add things that they may have missed during the interview. This is followed by thoroughly reading and re-reading the transcripts to get a first understanding of the data and eventually discern themes. The analysis process is depicted in Figure 9. The software Atlas TI is used for coding the qualitative data and will be further explained in section 7.2.

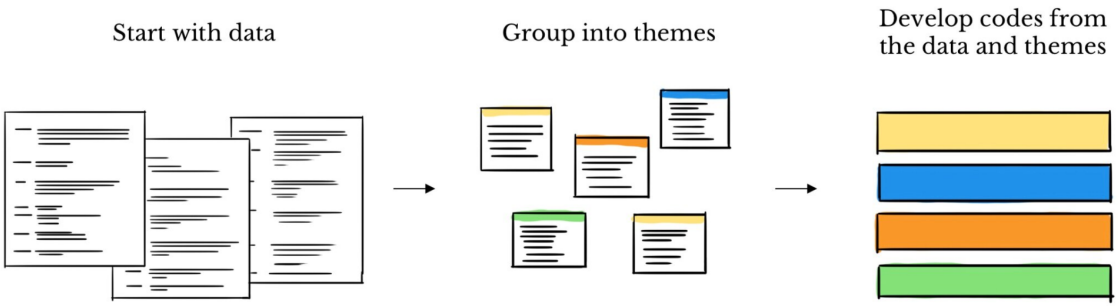

Figure 9. Data Analysis Process (Delve, 2022)

5.1.3 Coding

Based on the data, several codes could already be established. These codes are further grouped into categories which form the main themes under which the data is analysed. Using the software, codes are applied to various excerpts, sometimes resulting in multiple codes for one excerpt. This will further help determine the relationship between various codes.

The general information is used to group the interviewees into different stakeholder groups and therefore to compare the answers per stakeholder. Table 3 illustrates the codes applied for data analysis.

Table 3: Codes

Topic	Codes	Sub-code
Material Passports	Advantages	
	Challenges	
	Experience	
	Legislation	CB'23
		Regulations
	Limitations	
	Solution	Link with maintenance parties
		Central platform
		Arrange data structure
		Establish property rights & liabilities
Data Accessibility &	BIM model	

Interoperability	Data accessibility	
	Data exchange role	Data Provider
		Data User
	Data formats	
	Data interoperability	
	Data needs	
	Data ownership	
	Data source	
Financial Feasibility	Business Case	
Added Value	Use case	Certification programs
		Financial insight

5.2 Analysis

The interviewees are given the choice of location but all preferred to conduct it online via Teams due to convenience. All interviews were recorded for the purpose of making the interview transcripts with the permission of the interviewees. The transcripts were analysed using codes with the software Atlas TI.

This section will discuss the findings of the primary data in detail. In order to understand the challenges faced per stakeholder group, they are first asked about their opinion on MPs, followed by a discussion of their data exchange challenges in detail which refers to the main research question of this study. Finally, two important recurring themes that came across all interviews were the financial feasibility of using MPs and the added value it provides. The results are discussed based on the stakeholder groups to get a better understanding of the main data exchange challenges faced by each stakeholder group.

Architects

According to the two architects interviewed from different companies, material reuse is slowly gaining traction in the building industry but not always through the use of MPs. They mainly source materials to be reused through the help of third parties such as intermediates or material scouts. One of the main advantages of using reused materials according to interviewee 6 is that the materials are rich in history which gives added layers of character to a project. If the availability of materials is better known and can be matched with demand on time, it allows architects to have a wider range of options to choose from while at the same time reducing costs for storage and transportation. Although the architects put considerable effort into making projects detachable, the data regarding this is not

currently being documented by them. Therefore, the focus is primarily on designing in a way that the materials can be reused, for example, using screws instead of glue so that materials can be taken apart more easily. Finally, according to both interviewees, architects are both the user and providers of data of MPs. In the short term, they are users whereas in the long term, they are providers. The format of the data on the scouted materials can be images or text such as brief descriptions.

Main challenges

There are a number of challenges acknowledged by the architects. One of the main challenges is the influence of uncertainty on the whole process. As specific data regarding materials is not always known, this leads to uncertainty or question marks in drawings which are not familiar to other stakeholders such as contractors. This results in considerable constraints on the design options that can be made by architects because they are not designing on a blank canvas anymore. Such uncertainty makes the process more risky as well as time and cost-intensive. An example given by interviewee 1 is that even when a project with scouted materials is commissioned by a public party such as the municipality, they still find it a challenge to work with the uncertainty of not knowing specific details of materials that will be used in the project. Only once the building permits are there, can money be allocated to buy materials, however with rescued materials, in some cases, they need to be sourced and purchased before the building permit has been acquired. Thus, all stakeholders need to be aware of the differences in working with reused materials instead of new materials as it brings with it different challenges. Additionally, legislation should allow for more flexibility and uncertainty so that projects which make use of reused materials can be accommodated. Therefore, having specific data available would make the process more efficient as well as lead to a higher quality of the project. Currently the lack of specific data such as dimensions, acoustical quality, fire retardancy and toxicity results in lengthy discussions.

"We wanted to use big garage doors and when you source those, then you have to find basically a garage that's being demolished and then say, OK, we're going to use those, but then you don't know exactly how wide they're going to be. So you can say I want to look for garage doors that are between 3 and 4 metres wide. But it has a huge effect on your facade, and then you're talking to the municipality, they say. Why is this like a question mark here? I say well, we don't know yet. We only know when we when we bought them, maybe they're a bit higher, a bit shorter, we don't know, but we want to use them" ***- Interviewee 1***

Another challenge is matching supply and demand on time, as that can save potential costs on storage and transportation as it may occur that the material that was planned on being used is no longer available or something else that is better has become available. The interviewees find that the data they need is currently not always accessible and interoperable as different architecture firms tend to use different software. They are missing a central platform which combines information on all the available options. Additionally, they see building owners and demolition companies as the main provider of data, however, they think that building owners don't always know what is in their buildings material-wise.

"(...) let's say so on a window frame, the information on the size, the materials, the colours, the carbon footprint. Yeah, if you only get the rough shape, you can design. But if you get all the extra information as well, then you can get, well, much more quality in your project" ***- Interviewee 6***

Suppliers

For this stakeholder category, one participant was interviewed. Participant 7 mentions that as a supplier, they are obliged to collect and store data regarding their products from the government's side. QR codes are used to store data so that it can be traced back to a specific facade element. They make use of BIM 360 to store both 3D and non-3D data which can be accessed through QR codes. This data is viewed as the MP of an element. The data can be easily adjusted in their system and thus keeping the data up-to-date is not a major issue currently. As a supplier, they have the responsibility for managing and maintaining these elements which is facilitated by the collected data. They see themselves as producers of data as they determine the characteristics of the elements such as fire resistance, double glazing, sun protection etc. Additionally, the data on water and wind resistance, deflection etc are linked with the CE mark which has become mandatory for facade elements since 2014. According to Participant 7, the architect and the contractor are the most important stakeholders regarding data exchange.

Regarding ownership of data, when a client purchases a facade element, the data ownership is transferred to them as they purchase the BIM model along with it. After that it is up to the client to use this data further, some clients add it to the Madaster database while others give it to maintenance parties. It is suggested to use the collected data for management and maintenance because then there is a useful application for it along with providing an incentive to collect the data. According to the supplier, a material passport is purely a tool in order to reach the larger goal of circularity and the producer is mainly responsible for supplying this data.

<u>Main Challenges</u>
One of the main challenges mentioned is the use of different software by different manufacturing parties which makes it difficult to link similar data to a BIM model. A lot of information gets lost when working this way because everyone has their own system and their own software which is not always compatible with other systems.

Additionally it is mentioned that sometimes they do not get access to the data they need on time. An example is the location where the frames would be placed, or details of the floor edges. Additionally, as suppliers of window frames, they need data on the characteristics of the window frames such as the insulation value and the sound isolation that the element needs to provide. Furthermore, different stakeholders use different language and definitions regarding materials which can make it a considerable challenge. Therefore, efforts should be made to standardise the language and terminologies thereby preventing failure costs and making the process more efficient.

"Certainly, for example, when modelling in a contractor's model, when we model frames, we actually need the area in which the frame should sit. If we are engineering a facade completely, we want to know where the floor edges are located and at what height. So then we need data dimension, data of the floors of the construction (...) so that's very important data that we need in the design and construction process" ***- Interviewee 7***

Another challenge mentioned is that clients need to think long-term instead of only short -term. They should not be apprehensive of slightly higher initial investment costs and should look at the complete spectrum because saving data and reusing might actually turn out to be cheaper in the long term. Flexibility should also be incorporated into the process by clients to stimulate reuse in projects. Subsequently, there is also the issue of storage space and the costs incurred along with storing the data. If the data is stored for 20 years after which it might be used, but in the meanwhile, the client has to keep paying for storage then the use case is very weak.

The solution in Interviewee 7's perspective lies with the producers as they need to be responsible for storing information about these materials. Then there is a smaller chance of a client going bankrupt simply for storing collected data. Producers should be made responsible for plugging that data into an overarching model which is managed externally. They think that the system needs to be organised differently from a commercial institution where the focus is on profit which only makes it more expensive for clients.

"you pay for storage, while you don't do anything with it. But it's only stored to be used in 20 years, maybe because you're going to renovate that building. What is the use of it and is it worth investing there or could you do it in a different way? Well, I think the solution lies with giving the responsibility of keeping the information of products that are in buildings to producers and manufacturers" ***- Interviewee 7***

Contractors

Based on the 2 interviews conducted, there is currently more demand for MPs in utility and infrastructural projects as compared to residential projects. According to interviewee 3, this is because in utility construction they get a much more comprehensive assignment which includes the maintenance and management of the project. This provides them with an initiative to make and maintain an MP for such projects because they are also responsible for maintaining and managing it.

It is stated that an MP is very complicated to make because there are no agreements about circularity measurements and scores. Interviewee 4 states that there is a lot of different information that is required for making MPs such as their location, geometry, quantities, circular and material properties, detachability and disassembly. It is mentioned that the BIM model is mainly made by the architect, contractor and installation consultant. Through the various phases; preliminary, technical and final phases; the model gets more detailed. There is usually also a production model which is supplied by producers with unambiguous

information. Some components such as concrete floors where concrete is poured, do not have supplier models and then the design model remains leading. Interviewee 4 states that production models are better to use for making MPs because they are much more detailed than the design models.

"The supplier's models are more detailed and precise than the model of the designers so if you want to make a material passport, it is best to use those production models." ***- Interviewee 4***

According to interviewee 4, contractors are more users and collectors of data, meaning that they do not produce much data themselves. They find that data is currently not interoperable as there are no links with existing databases. Additionally, interoperability also has to do with data structures at a global level rather than only at the Dutch level. Furthermore, automating and linking data is challenging due to unstandardized terminology.

Main Challenges

Interviewee 3 states that they would mainly like to know when materials become available because matching supply and demand is still a major challenge currently. Additionally, they are missing a central platform where all the data comes together which is made easily accessible by the government. Data on energy and environmental performance of materials has become something that is stored via central public databases and it should be possible to link these databases with the making of MPs so that the process can become more efficient. The government can play an important role in making data accessible because they are not looking to make profits. If a building is sold to a different owner at some point, the data shouldn't need to be transferred to someone else but should rather be stored in a central platform which can be accessed by them which would result in lower transaction costs. Similarly, interviewee 4 mentions that currently, a large portion of information needs to be added manually which is time-consuming and cost-intensive. There needs to be a link to existing databases with public information in order to make the process more efficient. Furthermore, it is stated that the data needs to be shared in a way that sensitive data is not shared publicly.

A major challenge that is mentioned is keeping the data up-to-date. Interviewee 3 adds that as a building changes over 50-100 years, the MP needs to represent accurate data which can be solved by making the party responsible for managing and maintaining the project.

"And such a building will never be the same building in 50 or 100 years as it was then. Everything that changes in it must be kept up to date. And, sometimes we have what I just said in our hands, if we also receive a management and maintenance contract, then we can of course, together with the client, see how we can incorporate the material passport in the course of time in the project, so to speak. But if we only build the building and then we are out, then it is up to someone else to do it properly. Otherwise it makes no sense, because then we will have incorrect data in those passports in 50 years." - ***Interviewee 3***

The main issue mentioned interviewee 4 is that making MPs is currently time- and cost-intensive while the usefulness is not evident. It quickly spirals into a situation where if it's not used, it is not kept up to date and if it eventually does not accurately represent the situation, it is not useful anymore.

"The big problem is that it takes a lot of effort and time to make it, and it's not so clear yet what its usefulness is. And If you don't use it, it won't stay up to date. And then If at some point it doesn't add up, it's of no use to you anymore. If that data exchange gets better and you can make such a passport much easier than you do it more. They are not used because they are very difficult to make and because they are very difficult to make, they are not used." ***- Interviewee 4***

Consultants

A total of 5 consultants were interviewed for this role. The main role of consultants in MP data exchange is as a facilitator and appraiser for the building stock of a client as they support the making of MPs and ensure high quality of the data. This data is mainly used for maintenance plans, cost estimates and checking compliance. Obtaining data is much easier for new construction as compared to renovations of existing buildings because, for the latter, the drawings available are very old and inaccurate.

According to interviewee 8, information is collected from the buildings in various ways such as 3D scans using drones which are stored in the form of images and numerical data. Although the data is collected by the consultancy and stored in their asset management software, it is owned by the client. Therefore, the data can only be used with the permission of the client. The end user is usually the data owner in the end who is also the one who gets the most added value in the end according to interviewee 5.

Interviewee 10 mentions two projects, namely, BIM Speed and Reincarnate with the aim of facilitating data flows between various stakeholders and creating ontology for the lack of consensus on terminologies. BIM speed was developed as a tool to facilitate the data flow between different workflows through automatisation. Whereas the focus of the reincarnate project was to create machine-readable rules in order to structure the language so that eventually stakeholders can ask specific questions to the computer and find the answer that they are looking for without having to sift through irrelevant information for them. The conclusion of the project was that creating a large database with all the required information would be a challenge as the process is complex and entangled and therefore needs to be broken down into practical processes. The process needs to be simplified and untangled into smaller bits otherwise it becomes too complicated too fast.

Interviewee 11 introduces the concepts of property rights, transaction costs and liabilities. By organising property rights and liabilities, market failures can be dealt with because the owner is responsible in the case of future contracts. Making the owner liable for the products they own can lead to enforceable future contracts as they are also the owners of its data. An example of the car industry is given where car elements are being registered using blockchain technology. This has resulted in the value of second hand cars going up and

almost 99% car elements being reused in a high value way as compared to the building sector where it is around 3%. Furthermore, if there are high transaction costs associated with MPs, they will not be seen as a feasible alternative. They state that once property rights are established, the price of secondary materials can be compared to the price of primary materials. Recently, more parties are asking for a shadow price of carbon emissions. When compared to reusing materials, the cost of primary materials plus the shadow price of carbon emissions are much higher. In this case, reusing materials becomes more attractive because their carbon emission costs are much lower. A unified market for secondary materials which are transparent and comparable would help scale the process and therefore bring down the transaction costs of secondary materials. For this to take place, manufacturers need to be transparent about the data regarding their products and incentivized to share this with the buyer.

Main Challenges

Interviewee 5 states that currently MPs do not provide much added value in the short term as they will only be of use over a period of time. The data therefore needs to be linked with maintenance in order to provide some short term value and so that the data can be kept up to date. They find that current tools are not sufficient to facilitate this.

"If you look at a material passport now, I think it gives very little added value because it only helps you after 50, 75 years or maybe not at all, so it is important to think how can you link it to maintenance?" - ***Interviewee 5***

Another important challenge regarding interoperability is that currently it is complicated to exchange data across software and platforms as stakeholders often use their own or different software. Currently, an API or a conversion table is required, making the conversion process time-consuming. Similarly this also applies to the use of BIM as stated by interviewee 5. It still remains a challenge because every stakeholder does it in their own way. This makes it difficult to standardise the process and compare different BIM models. Furthermore, this is also the case with data structure. Since there is no uniformity in the data structure between similar kinds of data because stakeholders follow their own way, it makes them impossible to compare. If they could be compared, it would prove to be greatly useful for benchmarking purposes.

"The tricky part, of course, remains that each platform uses its own thing, so at least an agreement on what the most important things are and that it can be exchanged is very important. (...) I did indeed get a question the other day about whether it was possible to transfer it to another system. Well, that is currently not possible. - ***Interviewee 5***

"We are looking into connecting it with BIM but that remains a challenge because you see that the quality of such a BIM model is so different, one does it this way and the other in another way. I see a lot of opportunities of BIM." - ***Interviewee 5***

On the other hand, interviewee 8 states that they connect their data management to a BIM model as their software is able to store data in a 3D model.

"So our software is also able to use a 3D (BIM) model to store the data basically or to connect to the database." - ***Interviewee 8***

Finally other challenges such as privacy of data and financial incentive are mentioned. According to interviewees 8 & 10, privacy is mentioned as an important aspect that needs to be taken into consideration. The data should not trace back to any addresses or names as they classify as sensitive data. Additionally interviewee 10 mentions that in the short-term, everyone is generally thinking about maximising profit. Currently recycled materials are still more expensive than new materials so it is difficult to find a business case for using recycled materials as stated by interviewee 10 and 11. When reuse scales up in the future, the prices may reduce, however currently stakeholders need to have financial resources in order to implement reuse and may not immediately see it as a cost-effective alternative.

"Well, privacy is an important thing, so in my experience they're not unwilling to share the data, but it has to be in such a way that privacy is still secured right (...) as long as it's not connected to a certain address or a certain name." - ***Interviewee 8***

"(...) to give you an example of window recycling that I just showed you at the end, I had a question for them, OK, this is super interesting, so the recycled window should be less expensive, right? And they said no, it's more expensive. So I thought, "What is the benefit of a contractor buying these recycled windows (...) what can they do if it's more expensive?" - ***Interviewee 10***

"You need a large volume to organise your transaction systems (...) The supplier of the materials does not have any people who want to buy those things. Then they want to store it, but they go bankrupt on the transaction cost of warehouses and storage like is happening in the textiles industry in reusing textiles. In the textile sector, it's easy to collect textiles. Nobody knows the quality of the textiles. That immense warehouse is full with secondary material textiles and those who are providing this go bankrupt." - ***Interviewee 11***

MP Platform

According to both interviewees of the Madaster platform, Madaster is a tool which owners of data can use to register their data where the owner has the option to share the data with others as they please. When clients store their data in this platform, they automatically comply with guidelines such as the CB '23. In this way, the platform seeks to help facilitate the digital transition. There are 2 main groups of stakeholders who contribute the data to the platform; asset owners and manufacturers of products. They mention regarding data ownership that although the latter stakeholder contributes the most data, the previous stakeholders are the owners of this data. Interviewee 9 states that in their opinion, data exchange should always be initiated by the data owners. Additionally, they facilitate the transfer of data from one platform to another, ensure readability of data across different software and are working towards data being transferred at a high level across different

countries while complying with local regulations. In this way they ensure interoperability of data as an MP platform.

The platform is structured on the basis of accounts. The asset owner is the one in charge of giving access to different accounts. For example if an architect is working on a building commissioned by a client, they have access to the building information stored on Madaster as long as the client gives them the permission. It is mentioned that a large public owner of real estate such as the government often cannot share data due to security reasons. If the exact location of certain components or materials is made public, it could potentially be used for the wrong reasons. Therefore, the government cannot share all data publicly with other stakeholders. Currently, the main focus of the platform is collecting data which occurs mainly during new construction and renovation stages. Once enough data is collected on buildings, the focus can shift towards connecting demand with supply.

Data regarding detachability is received primarily from architects and contractors as they make final decisions regarding installation. It is more work for the architect or contractor to provide this information however, Madaster can receive in a more reliable manner rather than from a database as it goes on a project by project basis. Data regarding environmental information is obtained from Environmental Product Declarations (EPDs) which defines the environmental impact of a product.

Interviewee 2 mentions that currently the word 'Material Passport' is mostly only associated with reuse. However, they mention numerous other use cases for an MP which could provide value in the short term for stakeholders. For example, they mention third party certification programs such as BREEAM and LEED, calculating embodied carbon, LCA, detachability, financial information, reporting requirements such as Corporate Sustainability Reporting Directive CSRD etc. It is important to find the application of data because it can be used for much more than reuse.

According to interviewee 9, manufacturers must be urged legally to be transparent with data and share it with their clients. Also, in order to change this culturally within the sector, the client needs to ask for data transparency early on before contracts are signed and other parties are hired. It needs to become a part of the brief, otherwise parties will not bother to deliver it. Complete, correct and available data will help facilitate the transition to a CE.

Main Challenges

One of the main challenges outlined is the lack of data. If manufacturers and asset owners are not providing data in a machine readable, standardised way that can be entered into a database, then the required data is lacking at a large scale. This is especially relevant for data regarding toxicity as currently it is an estimation at best. In order to be certain, there would need to be an in person testing of the materials. Currently for new construction with potentially toxic materials, it is very difficult to say if there are toxic materials as the data is simply absent and has not been a requirement.

"The biggest issue is there's no content. But the format is not the problem." - ***Interviewee 9***

"So we face a lot of challenges like getting access to the right data." - ***Interviewee 2***

"Without an in-person testing of the materials, it's just a guess on our part because we're not going to the building. So it still would require basically someone going to the building, identifying exactly which materials are there, trying to find documents on the building to say when these materials were installed and which materials were they, and then doing tests regarding asbestos."- ***Interviewee 2***

An important challenge associated with obtaining data from EPDs is compatibility with previous versions. EPDs have to be updated every 5 years. Recently there is a new format for the 2019 version of EPD which is not compatible with the 2013 version. In terms of aggregating data, it means that there are two aggregations which contributes to complicating the process of collecting data as the formats are not compatible anymore.

Well, right now we're on the second version of an EPD. So there was a 2013 EPD, now there's a 2019 EPD, but the frustrating thing is that they're not compatible. All of the data from 2013 up to 2018 is one way, so we can report on that. And then as of 2019, there's a new format (...) and it gets complicated and messy. - ***Interviewee 2***

Another major challenge mentioned is the lack of standards postponing data registration. Since there are no widespread standards or rules on how to collect the data, stakeholders are less willing to register their data because they are waiting on standards and norms to be set. However, this is only resulting in a delay of action because data simply needs to be collected first so that better widespread norms and standards can be put in place.

"Standards and norms postpone the actual action that needs to be taken place which is registered as stuff that you have. So there are a lot of organisations that say we are not registering our product, materials, buildings yet because there is no standard yet or there is no method. It's not mandatory yet. And it is not mandatory yet because we say there is no standard yet. So, one of the blocking factors is that people postpone to take action."- ***Interviewee 9***

Furthermore the involvement of numerous stakeholders make the process much more complicated. This is especially relevant for large scale projects because there can be thousands of products supplied by thousands of different manufacturers who would all contribute data.

Conclusion

Based on the findings above, Figure 8 can be adjusted to illustrate the data exchange roles of the stakeholders from an empirical standpoint. As seen in Figure 10, the most important stakeholders in data exchange are written in bold text i.e architects, contractors, maintenance contractor and manufacturers. Furthermore, the asterisk (*) signifies the roles of data facilitators (MP Platform and consultants) who do not necessarily produce or extract data but rather facilitate and organise the data in a way which helps other stakeholders make use

of it. Additionally, the empirical data supports the hypothesis in Figure 8 that building owners, suppliers and demolition companies are providers of data and that contractors are mainly users (extractors) of data.

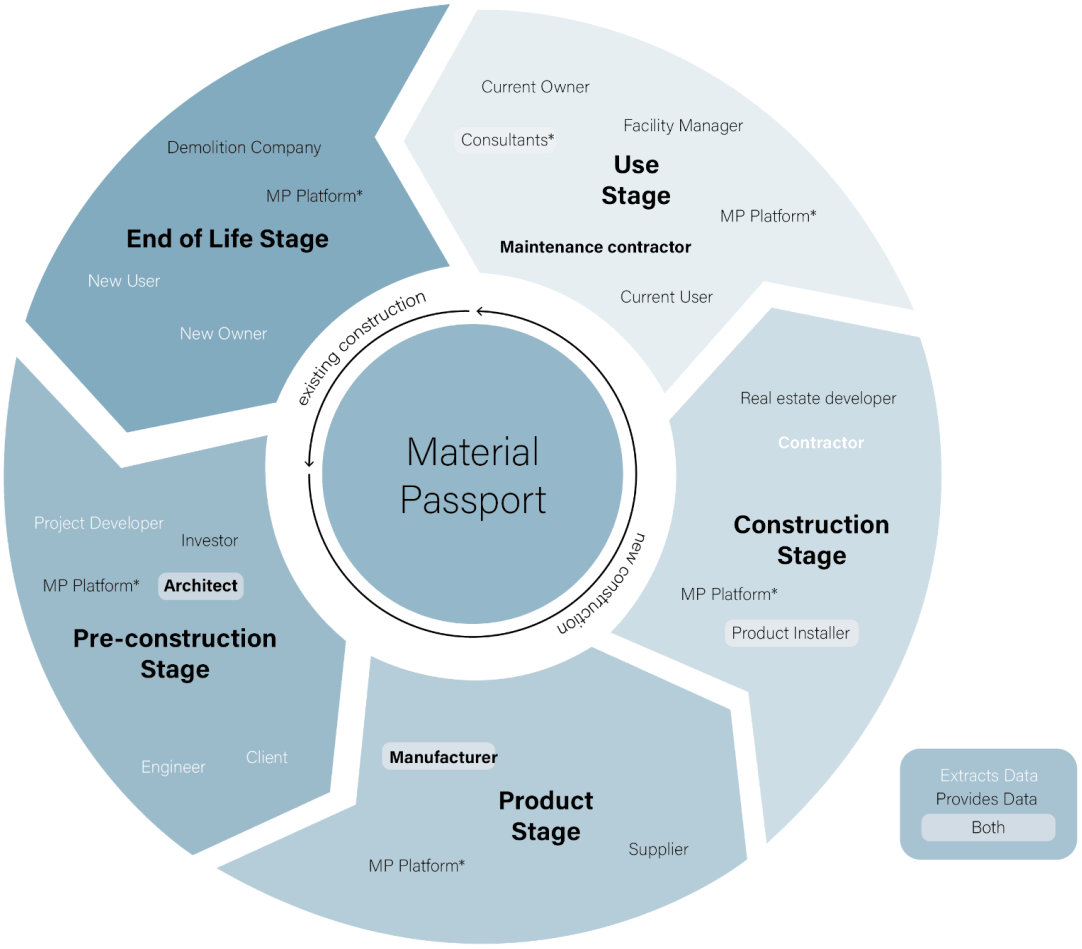

Figure 10. Adjusted Data Exchange Roles Diagram (source: author based on literature review and empirical data)

The stakeholders from the interviews highlight the main challenges regarding data accessibility and interoperability from their personal experiences. From the data analysis above, the following main challenges which are faced by key stakeholders regarding data exchange can be concluded as follows:

- There is a large-scale lack of machine-readable, standardised data which makes comparing cost of primary materials to the cost of secondary materials challenging and therefore, difficult to formulate a feasible business case. Data regarding toxicity, such as presence of asbestos and heavy metals which can have consequences on health, is largely absent and can be indicated as an estimate at best.
- Currently lack of specific data can lead to uncertainty in the design phase which most stakeholders are not accustomed to. This can result in lengthy discussions and delays in the process.
- Several stakeholders mention that they are missing a government initiated and non-commercial centralised platform where all the data regarding all available or

upcoming secondary materials is missing. It would make sourcing the materials much easier as currently there are numerous platforms.

- The use of different software and programs by stakeholders results in loss of information and makes exchanging data a challenge as a conversion system is usually required which can make it a time consuming process. Although registering data in a BIM model is seen as advantageous, it is still a considerable challenge.
- There is a lack of standardised language and definitions regarding building materials and components. Furthermore, a lack of uniform data structure makes it difficult to compare similar data.
- Storing data comes at a high cost which makes it unattractive especially if there is no short term use case for the data owner. Additionally, the data needs to be continuously updated in order to be of value however current tools and software do not enable this. The data needs to be linked with maintenance parties or software to facilitate updating and provide value such as maintaining, reporting and financial insights.
- Registering building data is significant manual work currently as there are missing links with existing public databases which could automate the process and make it cheaper and more efficient.
- Privacy of data owners needs to be taken into account so that sensitive data which can be traced back to them are not made accessible.
- Stakeholders postpone taking action due to a lack of standards and norms regarding data registration which further delays the establishment of standards.

Data Accessibility

Based on the definition in section 3.1.6, in terms of accessibility, data for MPs is inaccessible to a great extent. Efforts are not being made to register data properly which remains a barrier for stakeholders trying to get access. Although it is known what data can be obtained from which sources, the location where it can be obtained is not always known as stakeholders are not aware of all the platforms that exist. Furthermore, the conditions under which the data can be accessed is not always known as it can depend on the contract agreement between parties. Finally, from the analysis above, it can be concluded that data is not made suitable for the purpose of reuse due to a lack of a unified language and data structure.

Data Interoperability

Similarly, based on the definition of interoperability, it can be concluded that data is not interoperable due to the fact that insufficient data has been registered to make this step. It is currently a significant challenge to exchange data across software and platforms without conversion tools. Furthermore, there are major restrictions which prevent data exchange such as platform incompatibility, privacy concerns, manual effort. It is not an impossible task but it is a time-consuming process which is currently inefficient.

Data Ownership & Data Exchange

From the data analysis, it appears that the eventual asset owner is in most cases the data owner, as the data from the other stakeholders is transferred to them. When the data owners register their buildings on a platform, they also manage who else can access the data. According to interviewee 9, data exchange should be initiated by the data owner. However, interviewee 6 states that most building owners are not aware of what is in their buildings material-wise. The building owners own not only the materials but also the attributes and the data of the materials as stated by Interviewee 11.

"So often it is actually the end user who manages or already owns the passport." - ***Interviewee 5***

"It's the owner of the material who is the owner of the data. And he's also the owner of the other attributes of the stone, not only the stone, but also the information about the stone. And especially if it's the data infrastructure around the brick that will be an enabler for future transactions anyway, the circle of circularity can be organised." - ***Interviewee 11***

It can be concluded that according to other stakeholders, asset owners are responsible to initiate data exchange and to educate themselves on the composition of their buildings in order to initiate the CE, therefore it would be valuable to look at the perspective of a data owner regarding data accessibility and interoperability. The following section will be used to validate the findings of the third sub-question.

6 Case Study Results

The focus of this chapter is to gain insight into a client's perspective in order to answer the last sub-question *"What are data owners such as public clients' opinions regarding making data more accessible and interoperable for other stakeholders?"* The public client TU Delft has been chosen as the case study for this thesis as they are a large-scale public client who are forerunners in circularity and are in the initial stages of implementing MPs for their building stock. Campus Real Estate & Facility Management (CREFM) is involved in the development and management of real estate in public spaces of the TU Delft. Their objectives are to contribute to a healthy, comfortable and safe education and research environment. They are involved in the development of education buildings, infrastructure, offices, labs and parks.

Campus Real Estate & Facility Management (CREFM)

CREFM is an organisation under TU Delft (see Figure 11) which develops and manages the real estate and outdoor spaces as well as develops and manages the facility services on the campus. Their responsibilities range from developing the campus strategy to the urban area development of the campus. The campus is 160 hectares large containing 60 buildings with a total area of 600.000m2. They assist TU Delft in reaching their mission through real estate management and facility services. TU Delft's goal is to create an "Impact for a better society" and their mission is to create an environment where people can contribute their best to create an impact for a better society (CREFM, 2022). This goal and missions are to be reached through 4 strategic pillars:

- Creating an inspiring campus
- Managing the campus portfolio
- Contribute to the performance of the TU
- Reducing the negative impact on the environment

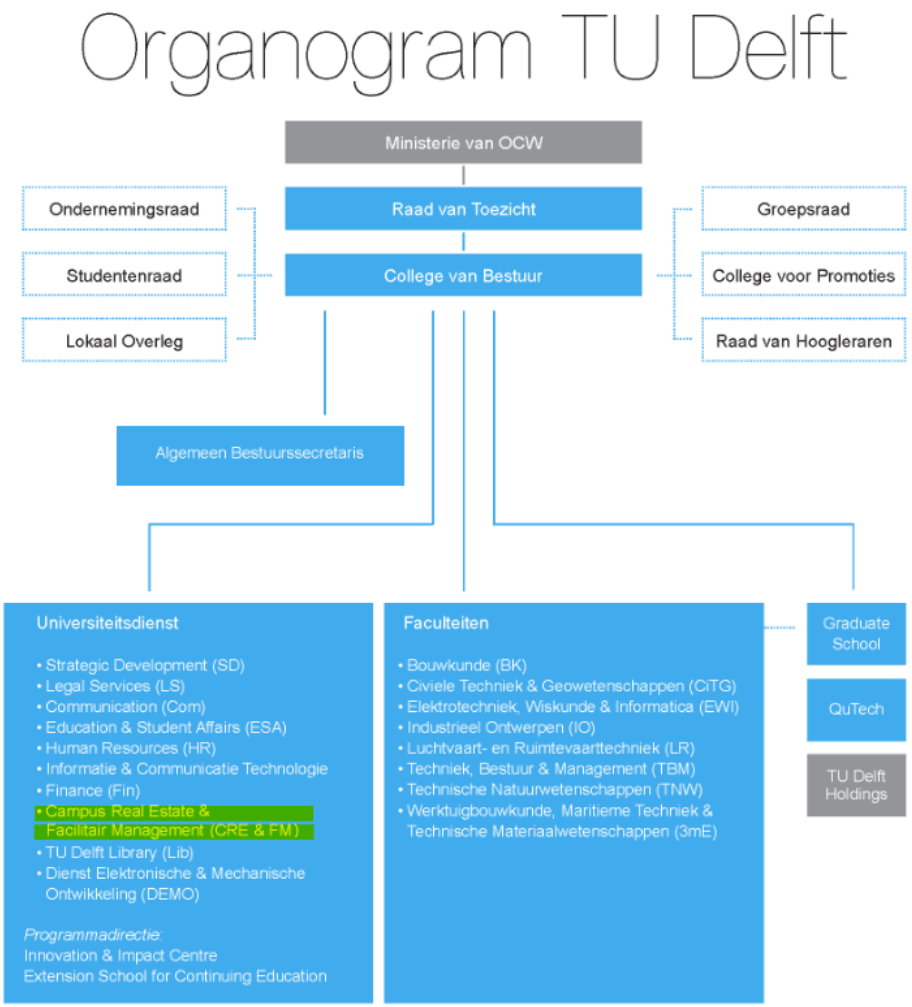

Figure 11. Organogram TU Delft (TU Delft, 2022)

In order to assist the TU Delft in reaching its goal of creating an impact for a better society as mentioned above, the focus of CREFM in the coming years will mainly be to modernise the campus, excel in the provision of services and to create a CO2 neutral and circular campus by 2030 (CREFM, 2022). The following section explains their sustainability goals in further detail.

CREFM Sustainability Ambitions

CREFM has ambitions for the TU Delft campus to be carbon-neutral, circular and climate-adaptive by 2030. Furthermore, the aim is to be a recognizable climate university of the world which can inspire others and set an example by demonstrating what TU Delft preaches about sustainability (CREFM, 2022). According to CREFM, a circular campus can be defined as follows:

"A circular economy is one where the material loop is closed in efforts to move away from a linear economy. New materials or products will only be contracted through sustainable procurement. Thereafter, the lifespan of the materials will be maximally utilised without

releasing damaging emissions into the environment. By building projects as well as during procurement, there will be a demand to make the constructions adjustable and detachable. In addition, a circular campus offers a liveable working- and learning environment in which health and well-being are central and circular initiatives are stimulated" (Campus and Real Estate, 2019).

CREFM aims to achieve a net zero carbon campus by including carbon price in decisions, carrying out an energy retrofit of existing buildings, creating super sustainable new buildings and by following circular methods for contracting and procurement. Figure 12. shows the carbon footprint of TU Delft in 2019 and the forest area that would be required to offset the emissions.

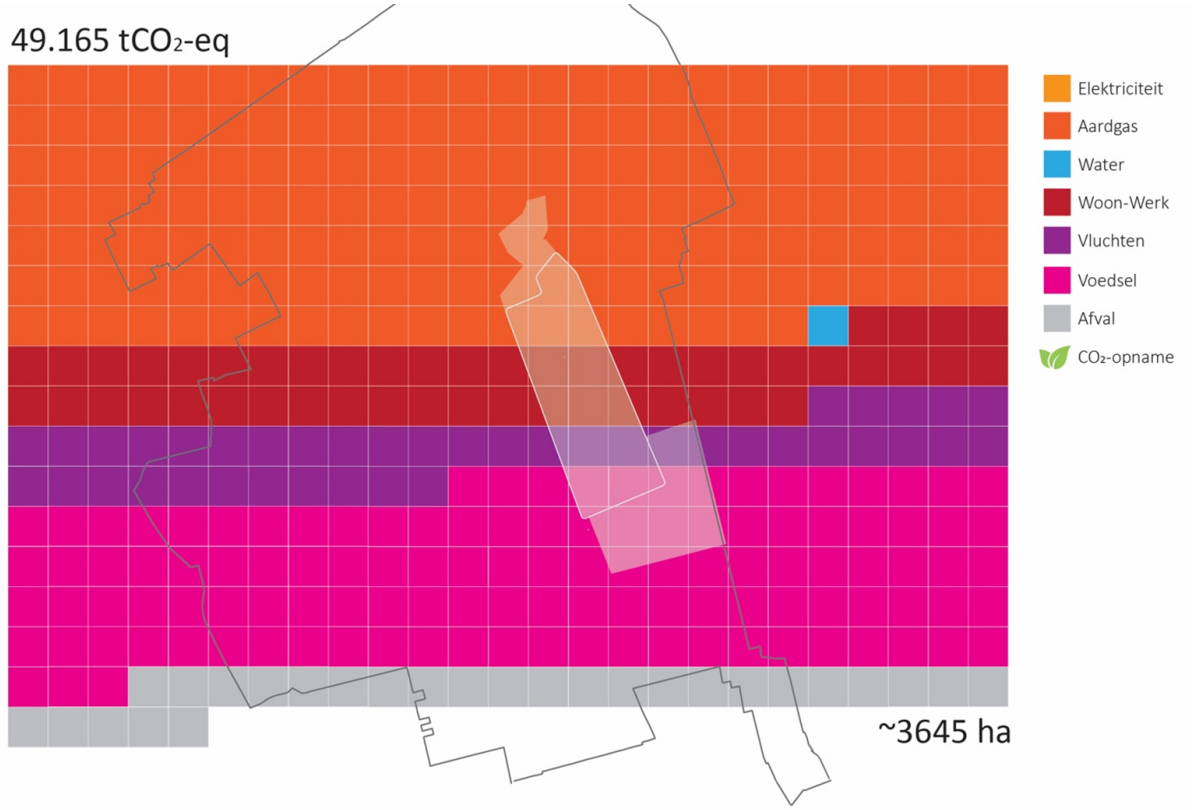

Figure 12. Carbon Roadmap (TU Delft, n.d)

One of the strategies outlined to reach the sustainability goals is to develop an MP policy. Their goal is to develop the use of MPs as a tool to get insight into material flows of their buildings. The MP policy should adhere to the CB'23 guidelines as well as connect to a BIM protocol with other parties. Their data governance strategy would follow connecting with a public material marketplace.

6.1 Interview Participants

The participants for the case study interviews are chosen from the CREFM organisation as seen in Table 4. Similarly, for these interviews, the participants are selected using purposive

sampling as they must be part of the Campus Real Estate & Facility Management at TU Delft.

Table 4: Interview Participants

	Profession within CREFM TU Delft
Interviewee 1	Policy Officer Sustainable Campus & Real Estate
Interviewee 2	Circularity Project Manager

The interviewees are given the choice of location but both preferred to conduct it online via Teams due to convenience. All interviews are conducted in the English language and are recorded for the purpose of making the interview transcripts with the permission of the interviewees. The transcripts are analysed based on a thematic analysis.

6.1.1 Interview Topics

The interview methodology is similar to the one mentioned in section 2.1.2. The questions are mainly formulated based on the input from the interviewees from section 2.1. The questions are formulated to get CREFM's perspective on the concerns addressed by the stakeholder. The topics are as shown in Table 5:

Table 5: Interview Questions

Topic	**Questions**
General acknowledgement	- Can you tell me the main motivation for making material passports for TU Delft's portfolio? - What value does it offer you in the short term? - Are there any current or upcoming projects where data on existing materials is being collected?
Data accessibility and interoperability	- As the owner of building data, would CRE FM be willing to make this data available to other stakeholders? - How do you think data can be made more interoperable? - Is privacy a concern? - Is BIM currently being used to store data? - What factors would enable you to make data accessible and interoperable to other stakeholders? - What is your view on linking the data with a maintenance party/software for keeping it up to date? - How do you deal with missing data such as toxicity? - How will the data on these materials influence the decision to be reused or sold?

	- Who is the most important stakeholder for MP data in your opinion? - Are manufacturers currently asked to provide data about the products that they supply? - What are the main challenges of making data accessible and interoperable for all stakeholders?

6.2 Analysis

CREFM is working on establishing a policy for the use of MPs in the TU Delft campus. According to both interviewees the main purpose for implementing MPs is to get insight into the building portfolio for the purpose of reusing building materials and components with the ambition of circularity in the end. As mentioned in the previous section, MPs can be used for various use cases and it is important for the client to know the exact use case for registering the data as that can help with determining the exact data that is required. In an ideal situation, all the building data would be made accessible to all stakeholders in the sector to be used in other projects, however they raise a few concerns that need to be addressed first before this ideal scenario can be achieved.

"The main purpose is to let's say for current buildings when there isn't renovation and it is important that we have insights into what kind of materials there are within the building portfolio so that it can be reused again in the project or on the campus or outside the campus. (...) The purpose of the material passport is to capture information about materials to make future reuse possible, but also to stimulate disassembly, management and maintenance, so that they have information about materials which can be used to improve the maintenance as well as future reuse." - ***Interviewee 2***

Currently, CREFM is busy with elaborating policies on incorporating MPs into their regular process as in present conditions, stakeholders such as contractors are not asked to share data with the client and therefore they do not deliver any information. The main data required as stated by Interviewee 1 is a material/component's age, condition, detachability, maintenance and an estimation of financial value. Interviewee 2 states that a great deal of information has already been captured whereas specific data regarding detachability and materials still has the potential to be captured as parties are not being asked to deliver this data. Interviewee 2 mentioned that during a conversation with a contractor while going over the list of information that they required from them, the contractor stated that they have the information that is being asked such as detachability but they are not delivering it simply because they are not used to it and it is not asked for. According to Interviewee 1, it is a challenging process to adjust to because the whole sector is used to working with new materials and starting with a blank canvas. An example is given of the Echo building on campus where furniture has been reused however, the ambition is to reuse materials and components such as the load-bearing structure as only then there will be a considerable impact for the CE. Therefore, the change that needs to be initiated by the client side, is to demand this information from other parties early on in the process. Interviewee 1 states that there are not many advantages in the short term due to data registration being a

time-intensive process and thinks that numerous advantages will come to light once they are used by more parties in the sector.

"Well, the most important thing is that the public client has to ask parties to capture information in the right way. So they really have to think about how and what are we going to capture." - ***Interviewee 2***

Both interviewees mention suppliers, architects, contractors and maintenance parties as important stakeholders that can help contribute to the making of MPs. Interviewee 2 states that they have different strategies for new construction and renovation. For new construction, the focus is on documenting data in BIM for which the architect and contractor are essential stakeholders whereas for renovation the focus is on making data accessible on a material marketplace in order to reuse materials. In terms of choosing an online platform for registering their data, interviewee 2 states that the most important characteristic is to have a low entry barrier where reuse is stimulated. After comparing the various platforms available based on their needs and use case as a client, the choice was made for Insert.

"So the most important stakeholder for new construction is the architect and the construction party, because they have to capture this information during construction. For renovation I think there are a lot of stakeholders because it's important to make a good inventory of materials before you start with your renovation, to have insights into what is becoming available." - ***Interviewee 2***

Data Exchange

One of the interviewees from sub-question 3 mentioned that building owners are not aware of what is in their building materials-wise. When asked about this statement, interviewee 2 agreed stating that building and facility managers tend to know about the materials they see such as furniture, but do not know enough regarding construction. Furthermore, they state that significant data about their buildings do exist such as floor plans and data from maintenance parties but it is not registered centrally and is scattered which makes it challenging to get a clear picture of the available data. Furthermore, they are stored in different systems which makes data interoperability more challenging. Interviewee 2 compared data list requirements from the BIM Basis information delivery specification, CB '23 guideline and Het Nieuwe Normaal (HNN) from Cirkelstad to get an idea of the data formats that are required to store this data. It was found that different information would be needed in different formats, for example, data regarding maintenance would be in a PDF format whereas data regarding detachability would be in a BIM model. Toxicity is one of the important data required in assessing whether a material can be reused or not as presence of a toxic chemical mentioned in the Banned List of Chemicals Cradle to Cradle can greatly hinder its ability to be reused. In the toolbox for HNN, it states that this information can be obtained from product suppliers by requesting EPD or C2C certificates. In the current state, most materials do not have a certification which indicates toxicity, which is why it is an indication rather than a standard in the HNN.

"There are a lot of new materials which do not have a certain certification status right now, (...) not all materials have the certification code and that results in not being able to clarify for every material whether it's toxic or not." - ***Interviewee 2***

Interviewee 1 mentions that implementing MPs in their regular processes might be a bit easier as CREFM owns the buildings on campus and therefore the ownership makes it easier to experiment with different processes and improve for the next time. On the other hand as buildings are used for the services provided, CREFM is also looking into leasing a facade from a supplier instead of buying it. In this case the supplier remains responsible for the maintenance and can take back the facade when it is not needed anymore, make adjustments and lease it out to a different party. Although it has potential in terms of ownership and circularity, it brings along with it financial challenges such as getting a mortgage for the facade since the client does not own it and raises the question of how to finance it.

They state that they are looking to create a digital twin of their buildings, which in ideal case, would be a self-learning model which can potentially indicate steps to making maintenance more efficient. Such a BIM model, however, is complicated to set up despite there being numerous advantages. There are financial and time related restrictions as employees need training to use the software. This combined with keeping the data up-to-date poses a significant challenge as the model would lose value quickly if not maintained to represent the actual situation. Interviewee 1 suggests the establishment of a standardised way of working with tools such as BIM and MPs because currently there are multiple platforms to choose from which makes data exchange considerably difficult.

"I think we need to get a more standardised way of using things like a BIM model or material passports." -***Interviewee 1***

"Now, if you're going to add all this material information to the BIM model, it's also important to maintain the BIM model when we are doing maintenance in the building, we have to capture that information and update the model as well. And currently the organisation is not ready for that. So that's why in the first stage, we will focus on adding information which is more about monitoring how circular the construction is." - ***Interviewee 2***

One of the main concerns raised regarding data exchange by both the interviewees is privacy of data. Interviewee 1 states that as certain materials become more and more scarce, making the location or value known publicly of these materials can pose a risk if it is used for bad intentions. Additionally, there is the legal issue that CREFM is a public client and thus cannot sell materials to other private parties. Therefore, it is important to consider which data is safe to be shared with other stakeholders. Furthermore, as CREFM is a public client, it could be useful to first test sharing of data between university campuses as they have similar portfolios with similar products and can later potentially be opened to all parties.

*"When people have bad intentions, they could go into the buildings as they are all open and get these materials, so that was the reason to start with our own internal marketplace." -**Interviewee 2***

*"For example, if you have some copper wiring, you don't want to tell everybody where that is located in your buildings because that's a scarce material and everyone wants to have that. So if you tell them it's in that building, then it can potentially become a dangerous situation if it reaches people who do not have good intentions."-**Interviewee 1***

*"So maybe we can exchange materials with other public parties. So that would be the first thing we want we want to explore and want to want to look on but in the end it must be a system in which all materials can be exchanged with private and public parties."-**Interviewee 2***

Conclusion

In conclusion, for a public client such as CREFM which is also a forerunner in circularity it is clear that in an ideal situation, data needs to be openly available for all stakeholders to reach the goal of circularity. There are, however, concerns regarding privacy of data which need to first be tackled in order to ensure that data can be shared in a safe and reliable manner. It would be logical to start with making data accessible to other universities or public clients, and eventually scale up to the whole sector. The main purpose for collecting data and making MPs is to have insights into their building materials and circular performance, and stimulate reuse within their portfolio. In their experience, other stakeholders are not used to being asked to deliver data even though they may already have this data stored somewhere. This is largely due to the traditional working methods of the sector. From the client side, it is their responsibility to demand data from suppliers, contractors and architects in order to shift away from the traditional way of working with primary materials.

Additionally, it is found that although there already exists considerable data regarding these buildings, there is a lack of both centralised and integrated data structure. The data needs to be accumulated on one platform in a standardised manner which supports different data formats such as PDFs and BIM models.

Implementing circular principles in the procurement process is of utmost importance as it creates a legal obligation for other parties to fulfil. Thus, clients need to ask stakeholders to deliver data early on in the process and hold them accountable for it. Otherwise essential data such as toxicity and detachability, which determine a material's adequacy to be reused cannot be properly registered.

*"But when you really think about circularity, you must make it more accessible to the whole community in order to get the highest results of reusing materials." **-Interviewee 2***

7 CONCLUSION

This section will elaborate on the conclusions drawn from the research. The conclusions are made on the basis of the literature study and primary research. First the conclusion for each sub-question is explained and later the conclusion for the main research question is established. Subsequently, recommendations for practice are discussed, followed by recommendations for further research, limitations of the study and a personal reflection from the author.

7.1 Research Conclusion

The main research question of the research is broken down into four sub questions which will help answer the main question step-by-step. The conclusion per sub-question is summarised below.

SQ1: *What are the key characteristics of material passport data exchange and data accessibility and interoperability?*

On the basis of the literature review, it can be concluded that MPs are a digital tool which are used to store diverse data about building materials in various formats. It is a relatively new concept which is the reason why there is a lack of standardisation and fragmented types of MPs. The definition of an MP for this research is therefore as follows *'A material passport is a digital document which describes the characteristics of materials with the aim to track the circular potential of materials by providing stakeholders with accurate information which gives them value for recovery and reuse (Luscuere, 2017; Cirkelstad, 2021; BAMB, 2020; Honic et al., 2021).'*

Although there is currently a lack of regulations for data structure of an MP on a global scale, CB '23 in the Netherlands is a national guideline regarding the type of information that should be stored in an MP. Within literature, it is seen that MPs have numerous advantages for a CE, however there are still many barriers which stagnate the implementation of MPs. Complexity of the sector, lack of standardisation, information asymmetry, complexity of products and changing ownership are some factors that contribute to the current challenges with MP data exchange. The barrier of information asymmetry is still a considerable challenge especially in terms of data being accessible and interoperable for the various stakeholders (Block et al., 2020; Cirkelstad, 2021; Hart et al., 2019). The definition for these terms for this research on the basis of a literature review is as follows: data is defined as being accessible when it is known what data can be obtained and under which conditions. It is interoperable when data can be efficiently exchanged between sectors and software without restrictions. These characteristics of data exchange are currently making the implementation of MPs difficult. Gaining insight into the main challenges faced by stakeholders regarding these aspects can be valuable to improve its use in practice.

SQ2: *What are the data exchange roles of key stakeholders regarding MPs per building life cycle stage?*

In order to gain a better understanding of data exchange issues faced by key stakeholders involved in the use and making of an MP, it is first important to get an understanding of the stakeholders and their respective data exchange roles as this can shed light on their responsibilities regarding data access and interoperability. Through the use of a literature review, it is established that the key stakeholders are the client, owner, architect, contractor, supplier, user, government, real estate developer, investor, building permit authority, research institute, building valuator, facility manager, product installer, maintenance party, insurer, deconstruction company, logistics manager and MP platform (Platform CB'23, 2020; BAMB, 2017).

Stakeholders can be categorised as data providers or extractors of an MP. For existing construction, the process of registering data begins at the EOL stage where a demolition company can provide the data to an MP platform which can set up an MP for the building. This is followed by architects, project developer, client and engineer extracting data from the MP during pre-construction stage of a new construction. Subsequently, during the product stage the suppliers need to provide data for the materials and components During the construction stage, contractors and product installers extract installation and disassembly data of the reused components and provide data This is followed by construction where the contractors and product installers need to extract data about the installation and disassembly of the reused components and provide data regarding the installation and disassembly of new components. Finally the MP needs to be continuously updated with data input provided by the current owners/users and investors and when the building is decommissioned in the use phase. The data exchange roles are based on conclusions from the literature review. The roles of the rest of the stakeholders could not be established as there was not enough study carried out and therefore they have been left out.

Additionally, the conclusion can be made that clients play an important role in the implementation of MPs. This is especially the case when circularity is an important ambition for the client and they are ready to invest additional time and cost. Furthermore, clients are most often the data owner of the MP, therefore the choice to share the data with other stakeholders lies primarily with them. It can be useful to implement MPs when a client owns a large portfolio, especially in the case of public clients as they hold strong market power being forerunners in circularity (Chan et al, 2020).

SQ3: *What are the main challenges faced by key stakeholders' regarding data accessibility and interoperability?*

Based on the primary research conducted with 12 interviewees, it can be concluded that there are numerous challenges concerning data exchange currently. These are summarised as follows:

- One major issue is the lack of standardised, machine-readable data, which makes it difficult to compare the costs of primary and secondary materials and create viable business cases. Toxicity data, such as information on asbestos and heavy metals, is also largely absent or estimated at best. The absence of specific data leads to uncertainty in the design phase, resulting in lengthy discussions and project delays.
- Stakeholders express a need for a government-initiated, non-commercial centralised platform that provides comprehensive data on available and upcoming secondary materials. Currently, there are multiple platforms, which complicates material sourcing. The use of different software and programs by stakeholders leads to information loss and data exchange challenges, often requiring time-consuming conversion processes. Although integrating data into a Building Information Modeling (BIM) model is seen as advantageous, it remains a significant challenge.
- The lack of standardised language and definitions for building materials and components, along with a lack of uniform data structures, makes it difficult to compare similar data. Storing data is costly and unattractive, especially if there is no immediate use for it. Continuous data updates are necessary for the data to be valuable, but current tools and software do not adequately support this. Linking the data with maintenance parties or software is crucial for updating and providing insights, such as maintenance, reporting, and financial analysis.
- Registering building data is currently a manual process, lacking connections to existing public databases that could automate and streamline it, reducing costs and improving efficiency. Data privacy is also a concern, as sensitive information that can be traced back to owners should not be accessible.
- The absence of standards and norms for data registration leads stakeholders to postpone taking action, further delaying the establishment of standards in the industry.

It can further be concluded on the basis of the interviews and the research definition of data accessibility and interoperability that data is largely inaccessible due to improper registration practices, creating a barrier for stakeholders seeking access. While the potential sources of data are known, the specific locations and conditions for accessing the data are often unknown. Additionally, the lack of a unified language and data structure hinders the suitability of the data for reuse. Overall, there is a need for improved data accessibility and standardisation in MP efforts. As for interoperability, data is not interoperable in the context of insufficiently registered data. The exchange of data across different software and platforms is challenging without the use of conversion tools. Major restrictions, including platform incompatibility, privacy concerns, and manual effort, hinder data exchange. Although not impossible, the current process is time-consuming and inefficient.

Lastly, stakeholders assert that asset owners have a crucial role in initiating data exchange and understanding their building composition to drive the CE. Therefore, considering the perspective of a data owner on data accessibility and interoperability is valuable. To contextualise and validate the findings, interviews are carried out with the public client TU

Delft. The case study is from a public client perspective and will be discussed in the following paragraph.

SQ4: *How do data owners, particularly public clients, perceive the idea of improving data accessibility and interoperability for other stakeholders?*

In conclusion, a public client like TU Delft who is a pioneer in circularity, recognizes the need for open data accessibility to achieve circular goals. However, privacy concerns must be addressed to ensure safe and reliable data sharing. A logical approach would be to initially make data accessible amongst universities or public clients and gradually extend it to the entire sector. Their primary purpose for collecting data and creating MPs is to gain insights into the building materials and circular performance of their portfolio, thereby promoting reuse. The interviewees state that currently stakeholders are not accustomed to providing data, largely due to traditional working methods in the sector. Hence, it is the responsibility of clients to demand data from suppliers, contractors, and architects, shifting away from the conventional approach of working with primary materials.

Furthermore, although substantial data already exists for their buildings, a centralised data structure is lacking. It is necessary to accumulate the data on a standardised platform that supports various formats such as PDFs and BIM models. Implementing circular principles in the procurement process holds significant importance as it creates a legal obligation for other parties to comply. Thus, clients should request data from stakeholders early in the process and hold them accountable for its provision. Otherwise, crucial data such as toxicity and detachability, which determine the suitability of materials for reuse, cannot be adequately registered.

Conclusion Main Research Question

How can data exchange of Material Passports between key stakeholders be optimised in order to improve the effectiveness of its implementation within practice?

The answers to the four sub-questions sets a foundation based on which the main research question can be answered. The research aimed to explore the main challenges faced by key stakeholders regarding data exchange of MPs and gain practical insights into methods for improving this in order to learn how MPs can be better implemented in practice. Based on a mixed-methods analysis including primary and secondary research, it can be concluded that data exchange in current day and age is largely inaccessible and non-interoperable mainly due to two factors. Firstly, stakeholders are not used to delivering data unless they are obligated to. They are used to working in a traditional manner where material data is not asked for. It is ascertained that although this data is collected and stored by stakeholders, they are simply not used to sharing it with the building owners. Consequently, this results in the second factor which is a lack of machine readable, standardised data on a large scale. Despite significant data existing on buildings and their materials, they are not registered in a standardised central manner. This makes the data inaccessible because even though it exists, its location and the conditions under which it can be accessed are not always known.

Therefore, the language and data structure need to be standardised which would further make the data suitable for the purpose of reuse. Subsequently, the issue of data interoperability is seen as a problem down the road because standards and regulations to make data interoperable simply cannot be established until sufficient data has been registered which can act as a guideline. Thus, the first step towards improving data exchange is for all stakeholders to start registering and collecting their data. Even though there are no strict standards or norms in place, ample data collected can fuel the need for establishing eventual norms and systems in place to facilitate data exchange.

From the client perspective based on the case study on TU Delft's CREFM, as asset owners are mostly data owners, data registration and reuse needs to be initiated by them. In order to get the most use out of creating MPs, data owners need to have a clear use case for them which need not always be reused, as it is noted above that MPs can have multiple short and long-term uses. Clients need to evaluate how they can make data accessible to other stakeholders in a safe manner. The key takeaway from the case study is that clients need to start demanding data from other stakeholders and hold them accountable for it. This will urge stakeholders to shift from a traditional way of working and move towards circular working principles. Although literature states that manufacturers/suppliers are the most important data providers, according to CREFM, architects, contractors and maintenance parties are also key stakeholders in providing data. However, implementing MPs might be easier for a public party than for a private party and therefore requires further research. A first step to improving data exchange would therefore be to have a platform for public parties such as universities, hospitals etc. to share and exchange materials to test it out first and gradually expand to the rest of the sector.

The research contributes empirical knowledge for a transition to a CE by addressing data exchange problems and delving into the user perspective of MPs which is currently lacking in existing literature. It gives first hand insights from the people who are involved in the making and utilisation of MPs. It addresses the gap in knowledge by exploring the challenges that need to be overcome from user perspective and the steps that are needed to shift from a CE to a linear economy which can help reduce the sector's dependence on primary materials and reduce the percentage of construction and demolition waste that end up in landfills.

7.2 Discussion & Limitations

This section will discuss the methods chosen to answer the main research question and its limitations. The aim of the research was to understand the main challenges of MPs regarding data exchange from the user and client perspective. The results indicate that the traditional working nature of the building sector is a considerable barrier regarding data exchange and can be changed if all stakeholders start to register, structure and demand data from one another. TU Delft, a public client and forerunner in circularity, is willing to and aims to make data accessible and interoperable for all stakeholders in an ideal situation but there are some concerns that would need to be addressed first such as privacy. Therefore, an initial step

would be to have centralised platforms for similar clients who can exchange data and materials with one another and eventually scale up to the entire sector.

It was interesting to learn that even though public parties such as the municipality would commission projects with reused materials, the process would still be difficult because it would be a challenge to get a building permit without all the complete information about a reused material or component. This shows that there is a need for more flexibility in the legislation surrounding reused materials as well as financial incentives. Furthermore, it was also mentioned by one of the interviewees that they are designing and building with detachability in mind but without storing this information anywhere. For example they don't use glue but screws which can be later removed. However, they didn't feel the need to register this information in a specific document. So essentially the data exists but it is not being registered. It may be in the future that there is another party trying to disassemble the construction but the information regarding how would simply be missing.

Additionally, it can be seen that the competitive nature in the sector hinders reuse because parties are not easily trusting each other and are hesitant to share their data openly with others. This unfortunately comes at the cost of progress for the entire sector. Stakeholders are more likely to register and share their data if there are some sort of financial incentives in place as circularity alone is not enough to push for change. There needs to be a combination of top-down and bottom-up approaches from the government as well as from every individual stakeholder shifting their mindset.

The interviewees of CREFM are concerned about the privacy of sensitive data, but this issue can be addressed as they have control over which data is shared. For example, if they are hesitant to share data about materials because they fear anyone can walk into a building and steal something, they can choose to not specify its location. In this way, it is still possible to know what materials are available without the issue that they may get stolen.

The initial goal of the research was to explore the use of MPs in practice, ideally in a large-scale project. However, after initial research, it was concluded that there are very few such projects where the full life cycle case of MPs could be researched. This further reveals the state-of-the-art nature of MPs as they are a very recent tool in the building sector. Therefore, it was decided to shift the focus of the case study on getting insights from a client perspective on challenges with making their data accessible and interoperable for other stakeholders. This research adds the user and client perspective to the existing literature as there was previously little to no research on this aspect. Most of the existing literature focused on the potentials, opportunities and barriers of MPs, but the practical challenges were just scratched at the surface. The aim of this study was to highlight challenges related to data exchange from the stakeholder and client perspective so that these can be overcome in order to stimulate the use of MPs. Furthermore, the research was conducted with time and resource constraints and on the basis of the experiences of the interviewees and therefore cannot be generalised. Further research should be conducted with more stakeholders in order to validate the findings of this research. It is possible that there is a positivity bias to a

certain extent from the stakeholders' side as the interviewees were mostly enthusiastic about MPs and the research and were optimistic about the use of MPs in the sector. However, it would also be interesting to explore the perspective of stakeholders that are apprehensive and reluctant of MPs to gain a broader understanding from the whole sector.

One of the main limitations of this research is that it is carried out on relatively new concepts such as CE and MPs. There is still a lack of a unified understanding of these concepts across the building sector and that results in diverse answers and suggestions. Once a CE and MP are better defined and stakeholders have more experience with these concepts, it can be valuable to conduct a similar research. This is especially the case for MPs as it is still in a stage where they are created but not used for renovation or new construction. It would be interesting to research these later stages in a few years where the data from an MP would be used to explore the challenges of data exchange such as keeping it up to date.

The qualitative data is analysed using a thematic coding process. This process has certain limitations. The process requires certain creativity, objectivity and critical thinking from the researcher. The conclusions therefore are based on the interpretations of the data by the researcher.

In terms of the interview participants, 12 stakeholders were interviewed due to time constraints under the categories of architects, contractors, suppliers, consultants and MP platform. For the case study, 2 participants were interviewed from CREFM. These are small sample sizes and cannot be used to generalise the outcome for the entire building sector. Efforts were made to get in touch with demolition companies, as there is little research on their perspectives and could be a valuable contribution for the study, however, no response was received. Further research should include demotion companies as they play an important role in the creation of MPs. Additionally, other stakeholder groups need to be interviewed to provide a comprehensive picture such as product installers, investors, building users, engineers and project developers. From the client's perspective, a public client is studied. More public clients need to be researched to gain a better understanding as well as clients from the private sector as their priorities and challenges are also different. Studying the private sector would further enrich the research. The research has been conducted meticulously and lays a foundation for further research in this topic despite the limitations.

7.3 Recommendations for Practice

Based on the suggestions from the interviewees and analysis of the qualitative data, a few recommendations for practice are discussed in this section.

- One of the major challenges found is the lack of data from all kinds of stakeholders, therefore it is recommended to start with registering data even if there are no standards or norms currently present. In order to establish an effective data structure, sufficient data needs to be collected first.

- Keeping data up-to-date is not possible with current tools and software. Clients are recommended to link their data to a maintenance party which can regularly carry out maintenance as well as update the state of materials and components.
- Various formats of data are required to get a comprehensive insight into building material information. However, these are often spread around and not stored collectively. In order to make data collection more centralised, the use of BIM is urged as it can facilitate data collection and storage.
- In the current traditional working methods of the building sector, parties are not used to being asked to provide data. Clients can help change this by demanding stakeholders to provide data and asking for MPs early on in the building lifecycle stage.
- It is recommended that MPs are created for the purpose of reusing materials and not simply just having them. They fulfil their potential as a tool when the information stored in them becomes relevant at the end of life stage and makes it possible to reuse materials and components.
- From the empirical data it can be concluded that making MPs involve significant effort, it is important for stakeholders and clients to weigh the efforts against the benefits it provides and consider is in the end it is actually worth it.
- Standardisation is often mentioned, it is interesting to reflect on a future where standardised elements, software and processes are used in the building industry. This would bring about new challenges such as creating unique designs for architects.

7.4 Recommendations for Further Research

A few recommendations for further research are discussed below based on the limitations, findings and conclusions of this research:

- MPs and CE are new concepts in the building sector and are yet to be applied on a wide-scale. Its experimental and fragmented nature of implementation limits the possibilities for learning. It is recommended to carry out case studies of MP application in new construction and renovation projects throughout the building life cycle to analyse the data exchange efficiency.
- Interoperability of data was challenging to evaluate in this research as sufficient data has not yet been collected by stakeholders in the sector to implement interoperability principles. Therefore, researching interoperability of data should be conducted for future research.
- Due to time and resource constraints, only one case study was carried out on a public client. To enrich the findings of the research it would be valuable to research the perspective of more different public clients such as other universities, hospitals etc. as well as explore the perspective of private clients.
- The research of the stakeholders perspective involved 12 interviewees from 5 stakeholder categories. The data is from a small sample size and thus cannot be generalised for the entire building sector. It is recommended to conduct interviews with larger sample sizes for all stakeholder categories. This can provide a better

insight into each stakeholders perspectives and can be used to compare similarities and differences.

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