Graduation Project

Enhancement of the process of reusing building products

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Connecting reusable products from the Construction Demolition Waste flows with construction sites to improve the process and stimulate the use of reusable building products.

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Preface

This master thesis is a result of my work of the past semester. Before my graduation project I wanted to contribute towards the circular economy and especially in the reuse of products and materials. To really add value to this transition towards a more circular economy and our climate challenge, it is important to focus on the upper circles of the circular economy. To really decrease the large impact the AECO sector has on the climate.

Reusing products is still not a common process. I think this research is a stepping stone towards more standardisation in the reuse process and I hope that the supply and demand will find each other better. This to stimulate the upper loops of the circular economy, prevent waste and let materials loop as long as possible in the circular economy.

Reflecting on my graduation period, as well as my career as a student at the Eindhoven University of Technology, I can say that I have grown as a person during these years. The opportunity at the University to choose a variety of courses, made it able to design my own personal path during the master. Combining the courses and my gathered knowledge evolved in the topic and methods used in this research.

This research would not be possible without my supervisors. Therefore I first want to thank my first supervisor Pieter Pauwels for his guidance and thorough feedback during this period, even though more than half of the meetings were online due to the corona pandemic, we still managed to get the most out of it. Next, I would like to thank my second supervisor and mentor Qi Han for her insights and the conversations we had during my thesis and master period. I would also like to thank my supervisors from Beelen Next, Axel Hendriks and Laura de Ridder for their support and viable input. Also special thanks to Sebastiaan Molenaar who showed me the deconstruction process on site and how a decision to reuse is conducted.

Finally, I would like to thank my family, girlfriend and friends, for always supporting me during this research and my entire study. Their support, advice and guidance really supported me in achieving the MSc title in the field of CME and I am very grateful for each and every one of you in my life.

I wish everyone enjoy reading my graduation project as much as I have enjoyed writing it.

F.H.R. (Fabian) Breteler

Eindhoven, April 2022

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Summary

The housing and infrastructure sector represents the largest resource footprint in the world with 42% of the 92 billion tonnes in 2017. Based on this growing material demand and associated increasing emissions from the production of these raw materials, the need for greater material efficiency and extended use has become indispensable. Nowadays, the Netherlands is already recycling most of its Construction Demolition Waste (CDW). However, recycling is the lowest form in the circular economy and a fully circular built environment aims to close the (biological and technical) loops to keep products and materials in the loops as long as possible and as valuable as possible, leaving no waste. Currently, the focus of architects and contractors on circularity is translated to future reuse. However, the focus on future reuse is insufficient to reach the goals of the Paris agreement of lowering the CO_2 footprint, therefore reusable products from the existing building stock should be implemented in current building designs to reach these goals. To know what products are available in the existing building stock, that does not contain a Building Information Modelling (BIM) model, it is important to know before the deconstruction and demolishing phase what products are in the existing stock. By inventorising what is in a building, the product value is captured and it will no longer be seen as CDW, but really as reusable products that contain a value. Therefore this research is focusing on enhancement of the process of reusing building products. With the main research question formulated as follows:

How can reusable building products from Construction Demolition Waste be connected with construction sites to improve the process and stimulate the use of reusable building products?

To answer the main research question, a literature review has been established and qualitative interviews were conducted; three applications have been developed based in this study. This resulted in an in-depth process chain analysis of the deconstruction process from the decision to demolish to the mechanical demolition of the building. It can be concluded that it is still very uncommon to use reusable building products in newly designed buildings. This also became clear in the found barriers to reuse, where the lack of information on current marketplaces and standardization was one of the main barriers. To reach a fully operating circular economy it is important to keep the material loops from the Ellen MacArthur Foundation as tight as possible. Where it is recommended to use the 10R's of the level of circularity of Cramer, which shows the order of priority from refuse (prevent raw material use) to recover (incinerate waste with energy recovery).

To be able to match reusable products, dismantled by the deconstruction companies with BIM models, first products needs to be inventoried. In the process chain analysis it was found that this current process was inefficient with many unnecessary, time-consuming steps. Therefore, the first developed application is an inventarisation application created for deconstruction companies, to collect data for reusable products on site in a specific data standard, which can be seen as a product passport. The inventarisation application is validation with a beta validation. Where the inventarisation application is tested with the end-user on a deconstruction site with a positive proof of concept. The inventarisation application results in a total time-saving of 150 minutes (38%) in comparison with the current process. Only minor improvements were found to add before implementation.

The second developed application is a matching application, created for architects and contractors, to match products from the stock of reusable products with JavaScript Object

Notation (JSON) data from BIM models by using similarity matching. This eases the search process of reusable products and the search scope can be tightened or broadened on each parameter. The matching application had a positive proof of concept during the alfa validation, however improvements are needed before implementation. In the proof of concept of the matching application, the JSON data must be handled manually by the user. The automatic connection of data between two environments, where the JSON data is passed back and forth in the back-end, without much intervention, is preferable and should be optimized before implementation.

The third application developed in this study is an interactive product management dashboard, created in PowerBI, to track the process of deconstruction projects. This application shows the possibilities of the inventoried data by the inventarisation application. The product management dashboard had a positive proof of concept in the face validity with the end-user.

This study contributes to improve the process of using reusable products, which leads to the valorisation of the market of reusable products. By inventorising products in an earlier stage in a standardised way before deconstruction or during a maintenance round, the value can be captured and this improves the chances to sell all reusable products before deconstruction to a new owner. Which in turn leads to more sales of reusable products and less transport costs and emissions. By increasing the supply of reusable products, the value of the applications increases.

Samenvatting

De bouw en infra sector vertegenwoordigt de grootste voetafdruk van grondstoffen ter wereld met 42% van de 92 miljard ton in 2017. Op basis van deze groeiende vraag naar materialen en de daarmee gepaard gaande toenemende emissies bij de productie van deze grondstoffen, is de behoefte aan een grotere materiaalefficiëntie en een langer gebruik van bestaande producten onvermijdelijk geworden. Tegenwoordig wordt in Nederland al het grootste deel van het bouw- en sloopafval gerecycled. Recycling is echter de laagste vorm in de circulaire economie en een volledig circulaire gebouwde omgeving is gericht op het sluiten van de (biologische en technische) kringlopen om producten en materialen zo lang mogelijk en zo waardevol mogelijk in de kringlopen te houden en zonder afval te creëren. Momenteel wordt de focus van architecten en aannemers op circulariteit vertaald naar toekomstig hergebruik. De focus op toekomstig hergebruik is echter onvoldoende om de doelen van het Parijs akkoord van het verlagen van de CO2 voetafdruk te bereiken, daarom moeten herbruikbare producten uit de bestaande gebouwenvoorraad worden geïmplementeerd in huidige gebouwontwerpen om deze doelen te bereiken. Om te weten welke producten beschikbaar zijn in de bestaande gebouwenvoorraad, die geen Building Information Modelling (BIM) model bevat, is het belangrijk om vóór de deconstructie- en sloopfase te weten welke producten zich in de bestaande voorraad bevinden. Door te inventariseren wat zich in een gebouw bevindt, wordt de productwaarde vastgelegd en zal het niet langer worden gezien als afval, maar echt als herbruikbare producten die een waarde bevatten. Daarom is dit onderzoek gericht op het verbeteren van het proces van hergebruik van bouwproducten. De hoofdvraag die dit onderzoek beantwoord luidt:

Hoe kunnen herbruikbare bouwproducten uit sloopafval van de bouw worden verbonden met bouwplaatsen om het proces te verbeteren en het gebruik van herbruikbare bouwproducten te stimuleren?

Om de hoofdvraag van het onderzoek te beantwoorden, is een literatuurstudie verricht, zijn kwalitatieve interviews afgenomen en zijn drie applicaties ontwikkeld. Dit resulteerde in een diepgaande procesketenanalyse van het deconstructieproces vanaf het besluit om te slopen tot de mechanische sloop van het gebouw. Geconcludeerd kan worden dat het nog steeds zeer ongebruikelijk is om herbruikbare bouwproducten toe te passen in nieuw ontworpen gebouwen. Dit werd ook duidelijk in de gevonden barrières voor hergebruik, waarbij het gebrek aan informatie over de huidige marktplaatsen en standaardisatie een van de belangrijkste barrières was. Om tot een volledig werkende circulaire economie te komen is het belangrijk om gebruik te maken van de binnenste cirkels van de materiaalkringlopen van de Ellen MacArthur Foundation. Waarbij wordt geadviseerd om de 10R's in de level van circulariteit van Cramer te hanteren, die de prioriteitsvolgorde weergeeft van weigeren (voorkomen grondstofgebruik) tot terugwinning (afval verbranden met energieterugwinning).

Om herbruikbare producten, die door de deconstructiebedrijven worden gedemonteerd, te kunnen matchen met BIM-modellen, moeten eerst de producten worden geïnventariseerd. In de analyse van de procesketen werd vastgesteld dat dit huidige proces inefficiënt was met veel onnodige, tijdrovende stappen. Daarom is de eerste ontwikkelde applicatie een inventarisatie applicatie, gemaakt voor deconstructiebedrijven, om gegevens te verzamelen

voor herbruikbare producten op de deconstructieplaats in een specifieke gegevensstandaard, die kan worden gezien als een productpaspoort. De inventarisatie applicatie wordt gevalideerd met een bèta validatie. Waarbij de inventarisatie applicatie wordt getest met de eindgebruiker op een deconstructieplaats met een positieve proof of concept. De inventarisatie applicatie resulteert in een totale tijdsbesparing van 150 minuten (38%) ten opzichte van het huidige proces. Er zijn slechts kleine verbeteringen gevonden die voor implementatie moeten worden toegevoegd.

De tweede ontwikkelde applicatie is een matching applicatie, gemaakt voor architecten en aannemers, om producten uit de voorraad van herbruikbare producten te matchen met JavaScript Object Notation (JSON) data van BIM modellen door middel van matchen van gelijkenissen tussen parameters. Dit vergemakkelijkt het zoekproces van herbruikbare producten en het zoekbereik kan voor elke parameter worden aangescherpt of verbreed. De matching applicatie had een positieve proof of concept tijdens de alfa validatie, maar verbeteringen zijn nodig voor de implementatie. In het proof of concept van de matching applicatie moet de JSON data handmatig door de gebruiker worden ingevoegd. De automatische verbinding van gegevens tussen twee omgevingen, waarbij de JSON data heen en weer wordt gesluisd in de back-end, zonder veel tussenkomst, verdient de voorkeur en moet worden geoptimaliseerd voor de implementatie.

De derde toepassing die in deze studie is ontwikkeld is een interactief dashboard voor productbeheer, gemaakt in PowerBI, om het proces van deconstructieprojecten te volgen. Deze toepassing toont de mogelijkheden van de geïnventariseerde data door de inventarisatie applicatie. Het product management dashboard had een positieve proof of concept tijdens de validatie met de eindgebruiker.

Deze studie draagt bij tot de verbetering van het proces van het gebruik van herbruikbare producten, wat leidt tot de valorisatie van de markt van herbruikbare producten. Door producten in een eerder stadium op een gestandaardiseerde manier te inventariseren vóór deconstructie of tijdens een onderhoudsronde, kan de waarde worden vastgelegd en dit verbetert de kansen om alle herbruikbare producten vóór de deconstructie te verkopen aan een nieuwe eigenaar. Dit leidt op zijn beurt tot meer verkoop van herbruikbare producten en minder transportkosten en emissies. Door het aanbod van herbruikbare producten te vergroten, neemt de waarde van de toepassingen toe.

Abstract

There is a growing awareness in the housing and infrastructure sector for their large resource footprint and its Construction Demolition Waste (CDW). The construction sector plays a crucial role in the transition towards a more sustainable and circular economy. In a circular economy, all loops are closed and products and materials cycle in the loops as long as possible and as valuable as possible, leaving no waste. The supply and demand for reusable building products in the construction sector is growing, however it was found that this process is still unstandardised and is lacking product information. Besides, finding a suitable reusable product for architects and contractors was found time consuming. To enhance this process of reusing building products, this study aims at valorising the reusable product market by standardising the inventarisation during the deconstruction process and match this data with information from the Building Information Modelling (BIM) model of the new building in JavaScript Object Notation (JSON) code. To solve this problem, in total three application that are working together were created. First, an inventarisation application is developed for inventorising reusable products in the existing building stock, that does not contain a BIM model. By using the inventarisation application, the value of the reusable products is captured in a standardised way and will no longer be seen as CDW, but really as a reusable product that contain a value. By using the inventarisation application a total time of 38% in comparison with the current inventarisation process is saved. The structured data can be seen as a product passport. Secondly, a matching application is created, for architects and contractors, which matches products from the stock of reusable products with JSON data from BIM models by using similarity matching. The search scope of the matching can be tightened or broadened on each parameter during matching. Thirdly, an interactive product management dashboard shows the possibilities of the inventoried data through the inventarisation application for the managers of the deconstruction company. Further development of the applications, as well as extensions and optimalizations are interesting topics for future research.

Keywords: Construction Demolition Waste management, reusable products, similarity matching, product passports, JSON.

List of abbreviations

Underneath a list of abbreviations used within the research project is provided for clarification. The abbreviations are sorted in alphabetical order.

Abbreviations	**Meaning**
AECO	Architecture, engineering, construction and operation
API	Application Programming Interface
AVG	Algemene Verordening Gegevensbescherming
BDS	Building Design System
BIM	Building Information Modelling
BMC	BIM-based Model Checking
BPMN	Business Process Model and Notation
CAD	Computer-Aided Design
CDW	Construction Demolition Waste
CO2	Carbon dioxide
DfD	Design for Disassembly
EoL	End of Life
ERB	Ethical Review Board
ERD	Entity Relationship Diagram
GDPR	General Data Protection Regulation
GUIs	Graphical User Interfaces
HOQ	House Of Quality
IFC	Industry Foundation Classes
ITO	Information TakeOff
JSON	JavaScript Object Notation
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LOD	Level Of Development
LOd	Level Of detail
LOI	Level Of Information
LOIN	Level Of Information Need
MDD	Material Driven Design
MS	Microsoft
MVC	Model View Controller
NL/SfB	Nederlandse Samarbetskommittén för Byggnadsfragor
NMD	National Milieu Database
QR	Quick Response
RAD	Rapid Application Development
SDLC	System Development Life `Cycle
SMC	Solibri Model Checker
SQL	Structured Query Language
URD	User Requirements Document
XML	Extensible Markup Language
YAML	Yet Another Markup Language

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CHAPTER 1.

Introduction

1. Introduction

1.1. Problem definition

The global use of raw materials has increased from 26.7 billion tonnes in 1970, to 92.0 billion tonnes in 2017. The International Resource Panel (IRP) forecasts that in 2050 the material use will even grow to between 170 and 184 billion tonnes (Circle Economy, 2020; IRP, 2017). The housing and infrastructure sector represents the largest resource footprint in the world with 42% of the 92 billion tonnes in 2017 (Circle Economy, 2020; European Commission, 2015a). Because of the growing material demand, the world will face scarcity of certain construction materials, such as steel and copper, in the future (Rios, Chong, & Grau, 2015). Based on this growing material demand and associated increasing emissions from the production of these raw materials, the need for greater material efficiency and extended use has become indispensable (Hertwich et al., 2019; Olivetti & Cullen, 2018). Eberhardt, Birkved, & Birgisdottir (2020) and Sanchez & Haas (2018) are suggesting that current buildings will become a major temporary material stock to supply future demand. Building on this suggestion, this research will focus on improving the process of reusing building materials, components and products by connecting the Construction Demolition Waste (CDW) flows with construction sites through a circular building hub. In this research, the term 'products' will be used to cover materials, components and products.

The Dutch government aims to have a fully operating circular economy by 2050, in which all materials are reusable, fossil energy sources are no longer used and no waste is generated (Rijksoverheid, 2018). Nowadays, the Netherlands is already recycling approximately 95% of the CDW, of which 85% is recycled to infrastructural projects like road foundations and aggregates for concrete whereas only a small percentage is recycled and returned in the building construction industry, see Figure 1 (E Schut, Crielaard, & Mesman, 2015).

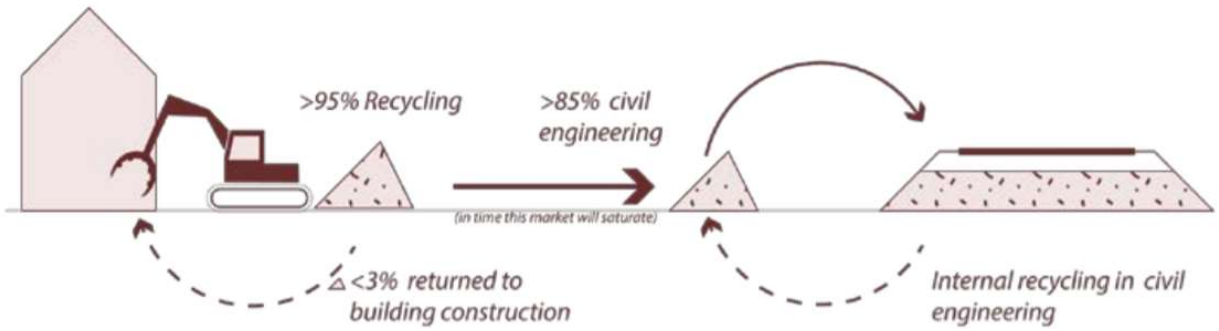

Figure 1 CDW in the Netherlands (E Schut et al., 2015)

In recent years, the construction sector has seen many developments. The construction sector wants to move from a linear 'take-make-waste' principle towards the circular economy to reach the goals of the government to have a fully operating circular economy with no waste flows in the year 2050 (Rijksoverheid, 2018). Recycling of building materials was the main purpose in the last years. However, going back to the raw material of the product is not always necessary. Currently, there is a shift towards reuse possibilities, which is the highest form in

the circular economy next to preventing the use of a product according to the Ladder of Lansink, explained in Section 2.1.3. However, the application of reusable products in newly constructed buildings is still quite limited, due to a set of different barriers on both the supply and demand side, throughout the entire construction process (Caldera, Ryley, & Zatyko, 2020; da Rocha & Sattler, 2009; Hart, Adams, Giesekam, Tingley, & Pomponi, 2019; Park & Tucker, 2017).

In 2018, the number of demolished and/or deconstructed buildings include 10,990 residential buildings and 2.4 million m2 of utility buildings (EIB, Metabolics, & SGS Search, 2020). The EIB expects an increase of 21,000 residential buildings and 3.3 million m2 utility buildings in demolishing and/or deconstruction towards 2030 (EIB et al., 2020). With this growing stock and an increasing material scarcity at the same time, keeping the materials cycling in the circular economy in the inner circle loops is crucial, this is further elaborated in Section 2.2. This stock contains a wealth of building materials that can be reused in other projects, however people must be aware that these are available. The focus in this research will be on large (publicly or privately owned) utility buildings, these are economically more feasible than a single residential building.

Most initiatives suggest BIM models as technological platform to store all data of reusable building materials in material passports. Among others, like 3XN Architects & GXN Innovation (2016 p.166) states that ”The huge amounts of data will make the BIM models extremely heavy and difficult to handle.” Therefore Scholten suggests linking the material passport to a reusable materials database in an intelligent material pool (Scholten, 2015).

In recent years, organisations like TNO (n.d.) researched the smart building logistics of building hubs with case studies and found that a building hub just outside the city is saving not only trips and kilometres but also lowers the CO2 emissions and time for the supplier. Deconstruction companies have extended this concept of a building hub towards a circular building hub. A permanent place where temporarily storing and repurposing of used building products is possible. According to Maria Karamanou (2019), the circular building hub is deemed as a solution to the Construction Demolition Waste management. Currently, reusable products in marketplaces are still demand-driven. This study focuses on the possibilities of changing the demand-driven process towards using a stock in a circular building hub. By using this stock, standardisation and upscaling of integrating reusable materials in the new construction projects is possible. Additionally, this study focuses on connecting the reusable building products in the stock of deconstruction companies with construction sites.

1.2. Research question(s)

Based on the problem definition and research objectives, the following main research question is formulated:

How can reusable building products from Construction Demolition Waste be connected with construction sites to improve the process and stimulate the use of reusable building products?

To answer the main research question, the following sub-questions are formulated:

1. What is a circular built environment and what is the importance of reusing building products?
2. What is the current process chain for reusable building products from a deconstructed building, through the circular building hub towards the new building?
3. How can the current process of reusing building products be optimized for maximum value and profit?
4. Which specifications of reusable building products are necessary for the management of the product?
5. How should the inventarisation of the necessary building products for current and upcoming construction sites from BIM models be stored, such that reusable products can be matched with the stock?
6. How to design a system (web application) that involves different stakeholders and end-users to match product information?
7. Can a proof of concept be developed to test the application, and what optimizations does it need after validation?

1.3. Relevance of the graduation project

The relevance of this graduation project can be divided into three levels. The first level is on the total construction sector, to contribute to the transition towards a more circular built environment. Improving the process of using reusable building products will boost the use of reusable products and this will lead to a growing market. This will create awareness of the possibilities of reusable products and will contribute to the goals of the Dutch government to reach the goals to have a fully circular economy with no waste flows in the year 2050 (Rijksoverheid, 2018). This graduation project is also contributing to improving the current product cycles of the circular economy in The Netherlands, to shift from recycling to reuse of products, which has the least negative impact.

The second level is the relevance for the deconstruction companies. A process analysis of the current situation is conducted to identify opportunities and optimizations within the supply chain of the graduation company. Based on this process chain analysis, it is suggested to create an application that will help to overview and manage data of the product passports of reusable products and these product passports can be matched with BIM models of new buildings. This application will boost the supply and demand of reusable products for deconstruction companies. This will save the architect and contractor time in searching for the right reusable product. Next to the application, also the current data is reviewed and compared to product passports to see what relevant information is missing for matching with the BIM models. Lastly, the application makes sure all data of inventoried products are stored in a database and can be managed by the application and overviewed in a PowerBI dashboard for management. Each product can be followed by its location status; on the deconstruction site, in the circular building hub or already on the new construction site. This graduation project takes the next step towards standardising the process and upscaling the use of reusable building products.

The third level of relevance is the awareness of the opportunities to connect non-graphical data from a database with data from a JSON model. Showing the connection of matching

between non-graphical data with BIM data gives the construction sector more insight into the possibilities of BIM data and using this in a web-based environment. This can unfold possibilities in urban mining and the process of stimulating reusable building products and being able to link the CDW with new construction plans.

1.4. Reading guide

Chapter 2 of this thesis provides a review of the current literature regarding the circular built environment, reusability of building products, construction demolition waste and the current process chain. Next, Chapter 3 provides a review of the current literature regarding the information management of product passports. In this literature review, product passports, Building Information Modelling (BIM) in the AECO sector, level of development and maturity levels of BIM and current initiatives are discussed. In Chapter 4 the methodology of this research and the research methods are described. This is followed by Chapter 5, which describes the results of the qualitative interviews to discuss and validate the literature review and create a more in-depth understanding of the process and barriers of reusing building products. During these qualitative interviews also user requirements for the application is found. In Chapter 6 a data analysis of current product passports and second-hand marketplaces is conducted, together with the explanation of the design and development of the application. Subsequently, the proof of concept and validation of the system is presented in Chapter 7. Lastly, Chapter 8 ends the thesis with a conclusion, contribution and recommendations for further improvement and research. A visual overview of the reading guide and structure of this research is presented in Figure 2.

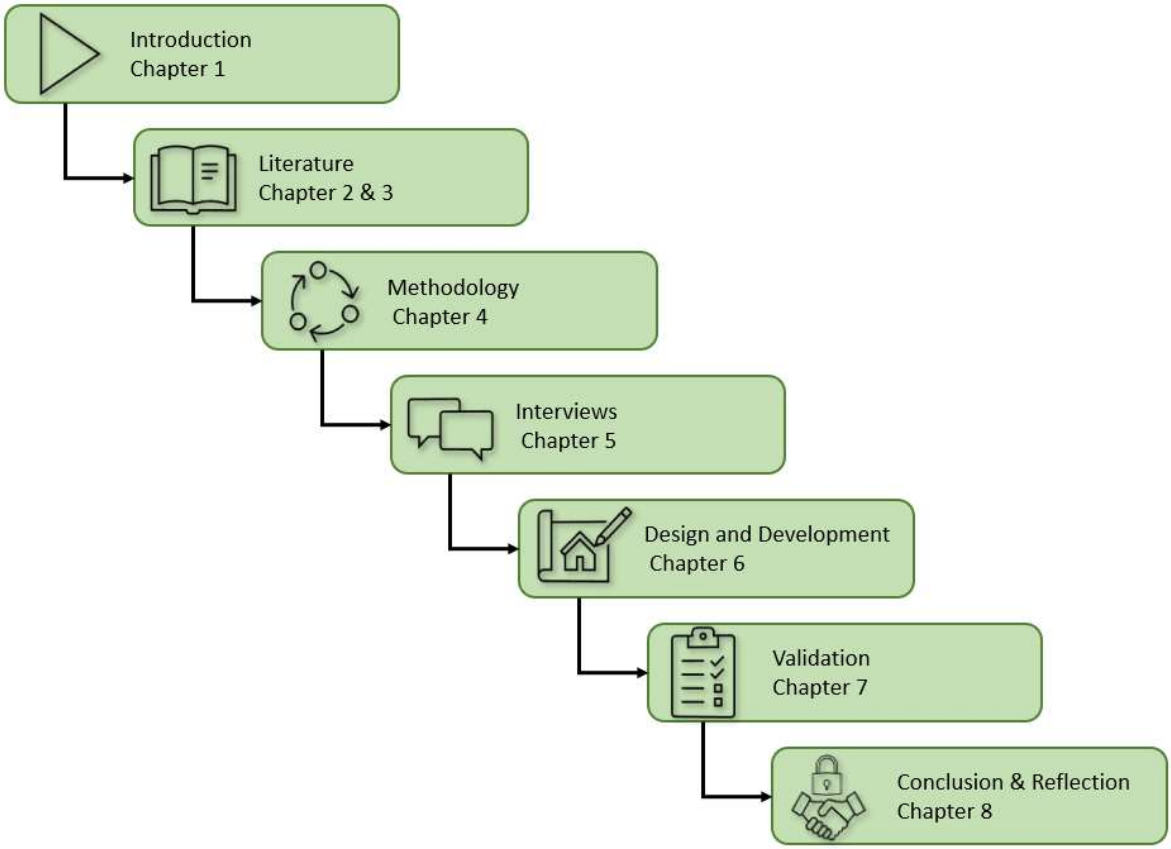

Figure 2 Reading guide and structure

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CHAPTER 2.

Circular built environment

2. Circular built environment

The literature review is divided into two parts. The first part, Chapter 2, is about the circular built environment and the second part, Chapter 3, is about the information management of product passports. This chapter provides insight into the circular built environment. Section 2.1 begins with the transformation to a circular economy. In Section 2.2, construction demolition waste is discussed and the possible end of life scenarios with in Section 2.3, the reusability of building products. Next, in Section 2.4, the hierarchy of a building is discussed. In Section 2.5, the current construction process is analysed as well as the deconstruction process. This chapter is concluded with a conclusion of the discussed topics in Section 2.6. In this literature review the following two sub-research questions are answered:

1: What is a circular built environment and what is the importance of reusing building products?

2: What is the current process chain for reusable building products from a deconstructed building, through the circular building hub towards the new building?

2.1. Towards a circular economy

The transformation towards a more circular built environment is crucial to reach the goals of a carbon-neutral economy in the year 2050, signed in the Paris agreement. However, understanding the concept of the circular economy is required for a successful implementation. This section starts by explaining the linear economy and explaining why another industrial economic model is necessary. Afterwards, the concept of the circular economy is explained with the definition, principles and advantages over the linear economy.

2.1.1. Linear economy

In the last 150 years, the construction industry was dominated by the linear economy, where products are manufactured from raw materials, sold, used and then disposed to landfilling or incinerated as waste (Wautelet, 2018). This linear economy, also known as the take – make – waste model, shown in Figure 3, is built on two assumptions. First, an exhaustible and available supply of resources of energy and raw materials, and second a limitless regenerative capacity of the Earth. Industrial and technological development in combination with global trade has led to enormous economic growth and has propelled human welfare. However, with this growth, the consumption of goods and services increased, which led to an increase in raw materials and waste (Sauvé, Bernard, & Sloan, 2016; Wautelet, 2018).

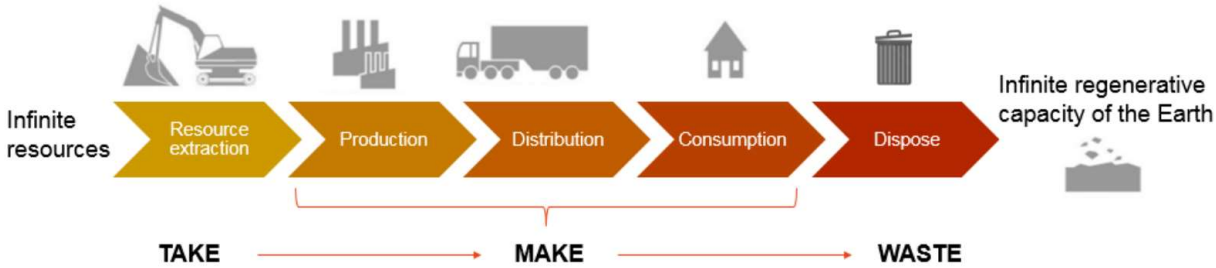

Figure 3 The Linear economy - take - make - waste approach (Wautelet, 2018)

In the current global context, the two assumptions of the linear economy are outdated, threatening the sustainability of our world, which creates the need for a new economic model. With the explosive increase in world population towards 9 billion people in 2050 and the increase rate in consumption, it will be increasingly difficult to sustain the quality of life on earth because of earth's limited resources (Durmisevic & Brouwer, 2002; Godfray et al., 2010). Virgin raw materials are running out, leading to substantial price increases in the past years. It is widely thought that the use of virgin materials is still cheaper than using reused or recycled materials. The commodity price index is shown in Figure 4 and the report by the McKinsey Global Institute (2013) shows a change in price trend in recent years that is expected to keep rising in the future.

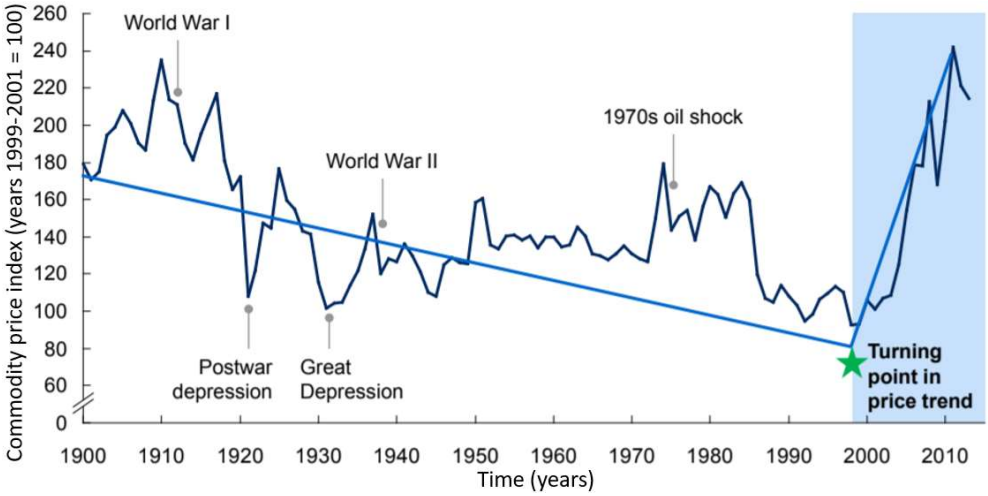

Figure 4 Commodity price index, based on the arithmetic average of four commodity sub-indices: food, non-food, agricultural items, metals and energy (adapted from McKinsey Global Institute (2013)

Since 2000, the commodity price index has risen steeply in the last decade and it seems to be the start of an irreversible process. These emerging numbers of raw material scarcity, growing consumption and growth in world population sorely need a new economy, wherein the limits of growth are in line with the maximum of what the planet can handle. A transition is necessary to replace the linear processes with cyclic processes with closed loops to create a sustainable development (Circle Economy, 2020; European Commission, 2015a; McKinsey Global Institute, 2013; Rijksoverheid, 2018).

Although many countries show great environmental improvements over the past decade, environmental and social pressure will further increase due to the growing population, still increasing CO2 footprints and resource consumption (Rios & Grau, 2020; Wautelet, 2018). All these factors lead to the debate to transform the current linear economy towards a circular economy.

2.1.2. Circular economy

The circular economy concept is trending and has gained momentum among scholars, politics and industries (Kirchherr, Reike, & Hekkert, 2017). Nevertheless, there is no commonly accepted definition of the circular economy. The most widely referred definition of the Circular economy concept is developed by the Ellen MacArthur Foundation, which corporates with businesses, governments and academia (Kirchherr et al., 2017; Leising, Quist, & Bocken,

2018). Therefore in this research, the Ellen MacArthur Foundation definition of the circular economy will be used:

"..One that is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles. This new economic model seeks to ultimately decouple global economic development from finite resource consumption" (Ellen MacArthur Foundation, 2015).

Within the circular economy diagram, also known as the butterfly diagram, two cycle loops can be distinguished as shown in Figure 5; namely the biological cycle and the technical cycle with their definitions (Ellen MacArthur Foundation, 2013):

- Biological cycle: where non-toxic materials are restored into the biosphere while rebuilding natural capital, after being cascaded into different applications.
- Technical cycle: where products, components and materials are restored into the market at the highest possible quality as long as possible, through repair and maintenance, reuse and redistribute, refurbishment and remanufacturing and ultimately recycling.

Within the circular economy diagram in Figure 5, the biological cycle on the left and the technical cycle on the right is visible. The vertical central axis shows the linear economy, where finite materials on top are mined, manufactured to new products and after use are leaked from the system. In the circular economy, the goal is to keep the materials as long as possible in a closed-loop and to minimise the leakage and negative externalities (Ellen MacArthur Foundation, 2013). As shown in the technical cycle in Figure 5, the closest loop is

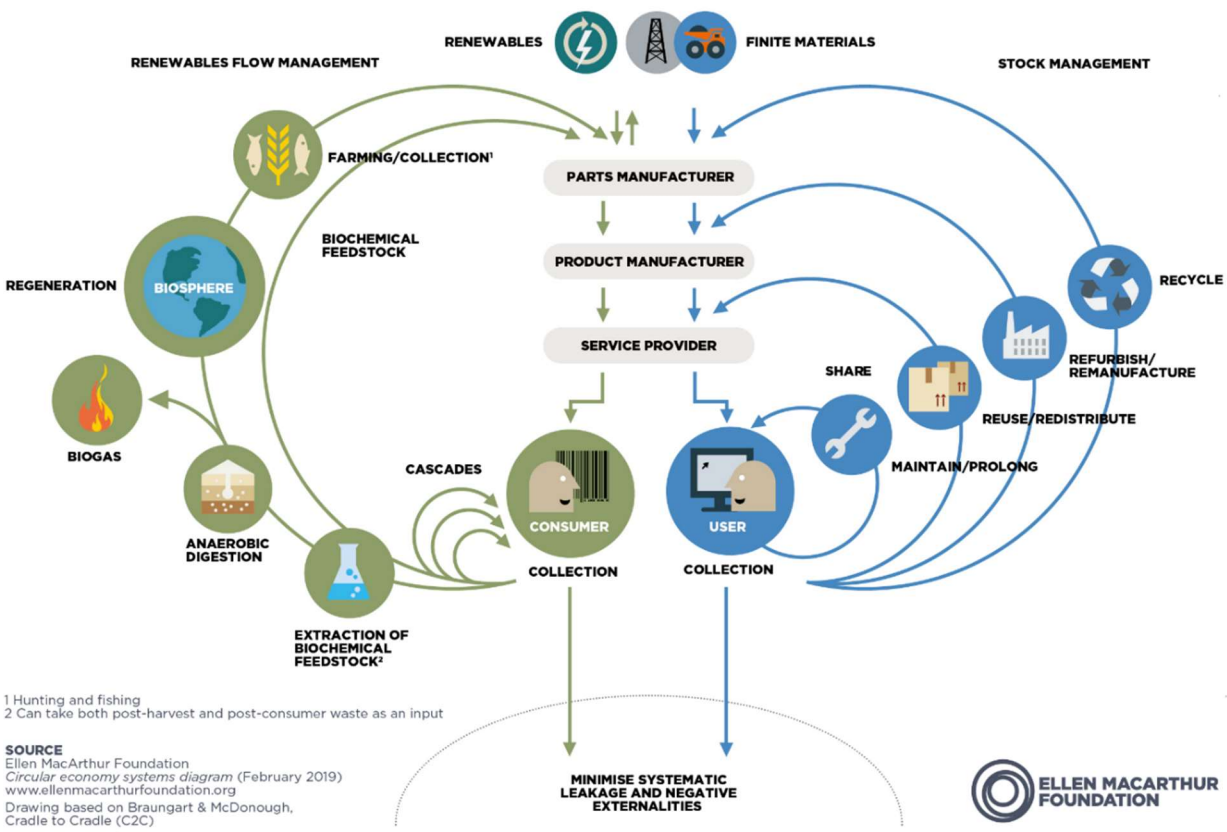

Figure 5 Circular economy diagram (Ellen MacArthur Foundation, 2019)

maintaining/prolonging products. However, if you want to make changes or build something new, the best loop according to the circular economy diagram is to reuse/redistribute the product.

Furthermore, the Ellen MacArthur Foundation established five simple principles that give a more detailed description of the circular economy (Ellen MacArthur Foundation, 2013):

1. **Design out waste.** Waste does not exist in the circular economy if products are designed with the intention to fit within the biological and/or technical cycle. Where the non-toxic biological products are easily composted and the technical products are designed to be used again with minimal energy and highest quality retention to keep the products as long as possible and within the smallest loops in the cycle.
2. **Build resilience through diversity.** Modularity, versatility and adaptivity are features that need to be prioritized in an uncertain and fast-evolving world.
3. **Rely on energy from renewable sources.** All systems should ultimately aim to run on renewable sources.
4. **Think in 'systems'.** In the circular economy it is crucial to have the ability to understand how parts influence one another within a whole and the relationship within a whole to the parts. The purpose is to have better management of the systems to avoid unexpected consequences.
5. **Waste is food.** For the biological cycle, this means the ability to reintroduce products and materials back into the biosphere through restorative loops. For the technical cycle this means for released materials, improvements in quality are also possible, this is called upcycling. In general, this principle means to close both loops.

These principles describe the concept of the circular economy, with its main objective to add value in social, environmental and economic aspects, in a way that it decreases the demand for resources, promote renewable energy sources and brings in diversity. The circular economy promotes a zero-waste supply chain and closed-loop material cycles in order to achieve a carbon-neutral and resource-efficient circular economy. In the last few years many governmental bodies, corporates and private companies did research towards searching for the value of the circular economy (Verberne, 2016). According to the Ellen MacArthur Foundation, the value of the circular economy can be divided into four core values which are shown in Figure 6 (Ellen MacArthur Foundation, 2013; Karamanou, 2019).

1. **Power of the inner circle.** If a product takes a tighter circle, the less a product has to be changed (in reuse, refurbishment or remanufacturing), the faster it returns to use and the higher the potential savings will be.
2. **Power of circling longer.** If a product takes a tighter circle, the product can maximise its cycles and last longer.
3. **Power of cascaded use.** Cascaded use refers to diversifying reuse across the value chain. This ensures reusing a material as long as possible by minimizing waste generation and energy consumption**.**
4. **Power of pure circles.** Uncontaminated pure material flows increase the ease of collection and redistribution efficiency while maintaining quality (for materials from the technical cycle) which extends product longevity and thus increases material productivity.

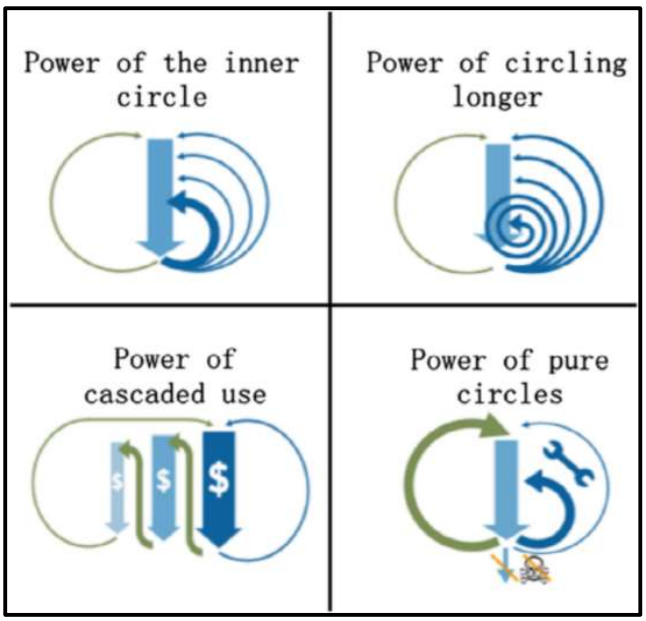

Figure 6 Four core values of value creation for the circular economy (Karamanou, 2019)

By assuring that the structures can be dismantled in a safe and easy manner, the powers of the circular economy can be fully optimized (Ellen MacArthur Foundation, 2013; Karamanou, 2019). The Design for Disassembly (DfD) method is a practice to do so. The DfD method has the goal to ease the deconstruction process at the end of the buildings life by taking it into account in the design and plan stage (Akbarieh, Jayasinghe, Waldmann, & Teferle, 2020; Akinade et al., 2015; Rios et al., 2015). With the DfD method products can be easier dismantled and reused. Durmisevic (2006) shows the design for disassembly throughout the total life cycle, as shown in Figure 7. The five key principles for DfD are (Durmisevic, 2006; Rios et al., 2015):

1. Proper documentation of the materials and methods used during the construction phase to ease the EoL deconstruction phase.
2. Design the connections and joints in an accessible way to be dismantled later in the deconstruction phase. This is done by using bolts, screws and nail connections.
3. Separate non-recyclable, non-reusable and non-disposable items.
4. Design structures and forms that allow standardization of products and dimensions. Because for standardized products there is a bigger reusable market and therefore, the chances for reuse increases.
5. Design that reflects labour practices, productivity and safety.

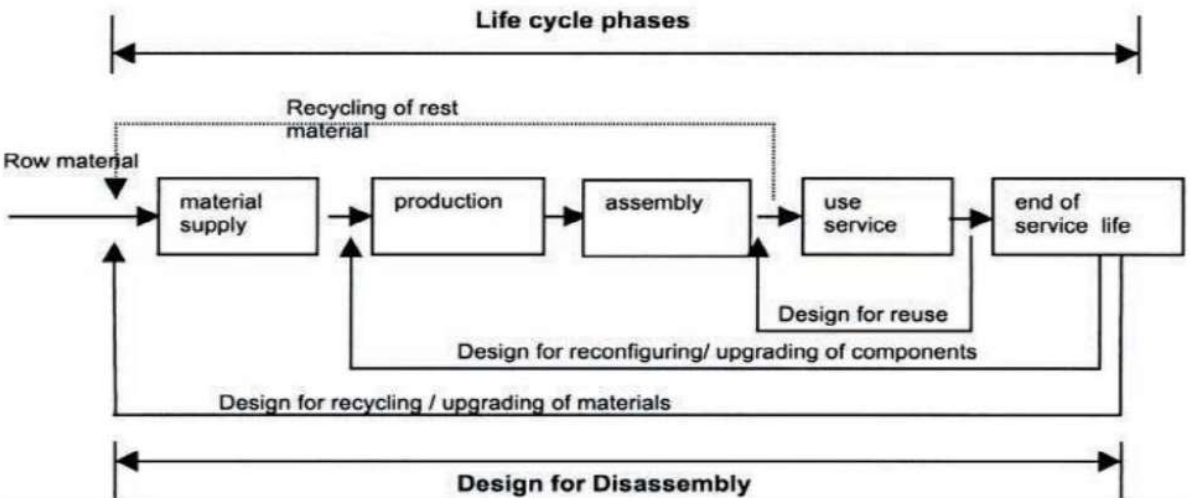

Figure 7 Design for Disassembly principle (Durmisevic, 2006)

Another concept similar to DfD is the reversible design concept, which also allows the building to be deconstructed and products to be used again, by keeping this in mind in the design and plan phase (BAMB & Durmisevic, 2018; Van Vliet, 2018; Verberne, 2016). These methods increase the reuse potential in the deconstruction phase when the building is dismantled. However, these innovations are useful when buildings that are currently being built will be dismantled, which could be over more than 75 years. To reach the goals of a fully circular economy by 2050, the reuse of products from the current building stock should become more common (BAMB & Durmisevic, 2018). The concept of Material Driven Design (MDD) can support architects to design with reusable products. In the MDD concept, the product is the point of departure of the design. This product can be a reusable product from the available stock to reach the goals of a fully circular economy. The goal of this concept is based on increasing knowledge, how an architect understands an unfamiliar situation when the process is completed and not about concrete results (Elvin Karana, Bahareh Barati, Valentina Rognoli, & Anouk Zeeuw van der Laan, 2015). In this concept, architects focus on what is available in the current reusable stock to design with reusable products. Currently, this is only executed on a small scale and experimental projects. Based on the circular economy, a framework for the levels of circularity can be defined which will be discussed in the next section.

2.1.3. Levels of circularity

On the contrary to the take – make – waste principle of the linear economy, the circular economy comes with the three R principle of Reduce, Reuse and Recycle. Cramer (2017) describes the raw materials transition in a case study and highlights the need to advance a 10R principle to create more value to materials shown in Figure 8. The higher the order of priority, the more circular a product is. According to Figure 1 by Schut et al. (2015), it can be concluded that most of the CDW in the Netherlands are happening on lower-ranked R – activities. To reach the goals of a fully circular economy by 2050, a larger focus on highly ranked R strategies is required, such as reduce, reuse and repair rather than recycling (Karamanou, 2019; Rijksoverheid, 2018).

Figure 8 Level of circularity: 10 R's (Cramer, 2017)

The 10R principle is the most comprehensive and extensive in comparison with other research where levels of circularity are discussed. However, other studies have proposed similar other levels of circularity, next to the 10R principle of Cramer (2017), as shown in Table 1. There are the levels of circularity for the circular economy from the Ellen MacArthur Foundation (2013), the ladder of Lansink, which is a waste hierarchy system already proposed in 1979 by Ad Lansink (Lansink, 2015) and lastly the general three R principle.

Next to maintaining the product, reusing the product has the lowest environmental impact according to all levels of circularity systems from Table 1. Therefore this research will focus on stimulation and standardisation of reusing building products in the construction sector.

Table 1 Levels of circularity from the literature

10R principle Cramer 2017	***Ellen MacArthur Foundation 2013***	***Ladder of Lansink Lansink 2015***	***Three R principle***
Refuse	Maintain/prolong	Prevention	Reduce
Reduce			
Renew			
Reuse	Reuse/redistribute	Reuse	Reuse
Repair			
Refurbish	Refurbish/ Remanufacture		
Remanufacture			
Repurpose			
Recycle	Recycle	Recycling	Recycle
Recover	Energy recovery	Energy recovery	
		Incineration	
	Landfill	Landfill	

2.2. Construction Demolition Waste

One of the most widespread definitions of Construction Demolition Waste (CDW) is defined by Tchobanoglous, Eliassen, & Theisen (1977), who emphasise demolition waste as waste arising from razed structures. Construction waste is defined as waste from construction, renovation and repairment of all types of buildings (Kabirifar, Mojtahedi, Wang, & Tam, 2020). This research focuses on CDW and enhancing the market for reusable building products. Inventorying valuable reusable products before demolition will prevent the loss of valuable products. This is consistent with the core values of the circular economy, as explained in Figure 6. By preventing mass recycling of valuable products, it uses the power of the inner circle and this supports the product to circulate longer.

The CDW sector is one of the major waste generators in the world (Osmani, 2015). The CDW activities are responsible for around 30% of the total annual waste generation worldwide (Akinade et al., 2018; European Commission, 2015b). In The Netherlands alone, the CDW contributes up to 7.270 metric tonnes every year (EIB et al., 2020). The EIB et al., (2020) forecasts that towards 2030, the amount of CDW will almost double itself. With this growing CDW stock and an increasing material scarcity at the same time, keeping the materials as high as possible in a “closed-loop” in the circular economy is crucial. This stock contains a wealth of building materials that can be reused in other projects, however people must be aware that these are available.

Almost 95% of all CDW is recycled in The Netherlands (Durmisevic, 2006; E Schut et al., 2015). This percentage suggests that the Netherlands is already almost circular. However, this is by far not the case as shown in Figure 1. Recycling is the least preferred end-of-life scenario, before landfilling, in the circular economy because a product is set back to the raw material of the product which is not always necessary (Rijksoverheid, 2018). A large portion, more than 85% of the CDW is downcycled to infrastructural projects and used like road foundations and aggregates for concrete. This is the least favourable way of recycling because of the degradation of materials and the loss of embodied energy. In the Netherlands, only a small percentage, less than 3%, is recycled and returned in the building construction industry (E Schut et al., 2015).

The amounts and types of CDW are dependent on the chosen End of Life (EoL) scenario for the building. The three EoL scenario’s that are possible for a building are known as demolition, selective demolition and deconstruction. Demolition is the most conventional practice where the complete building is demolished without any sorting between products, where the output is usually sent to landfills (Akbarieh et al., 2020). The disposal of materials is typically known for the linear take make waste economy. According to the European Waste Directive (2008), the conventional practice of disposal of demolition waste is the least sustainable action in the waste management hierarchy and should be avoided as much as possible.

The second EoL scenario of a building is selective demolition. With the selective demolition approach also mechanical demolition is used as a method to demolish the building. The big difference is that selective demolition encourages the separation and sorting of all materials. When the CDW is managed well, the materials are able to be recycled. Therefore selective

demolition is preferable over conventional demolition (European Comission, 2016; Zanni, Simion, Gavrilescu, & Bonoli, 2018).

The last EoL scenario is the deconstruction of the building. When deconstructing a building, valuable products are dismantled from the building and can be reused in other projects. When deconstructing, the valuable products remain in the market value chain for an extended period of time. Therefore the products can fulfil their full expected service life. In most cases, the expected lifetime of a product is longer than the building it is in (Akbarieh et al., 2020). The dismantling of a building requires more time and funds than traditional demolition. However, due to the dismantling of products, products are able to be reclaimed and reused in another building, which causes a financial benefit through the sale of the reusable products and a reduction in landfill or recycling costs (Heinrich & Lang, 2019).

2.3. Reusability in the built environment

Another term for deconstruction is "Urban mining", which is the process consisting of recovering resources from any kind of anthropogenic stocks, including buildings, infrastructures, industries and products as an alternative to using new resources and by that saving natural resources (Condotta & Zatta, 2021; Cossu & Williams, 2015; Koutamanis, van Reijn, & van Bueren, 2018). In this terminology, a building can be seen as a "mine", a large pot of materials and products (Cossu & Williams, 2015). The mining of products refers to dismantling products from a building.

To be able to reuse products, the concept of urban mining is increasingly used to reclaim compounds and elements from any kind of anthropogenic stocks, including buildings, infrastructure, industries and products (Cossu & Williams, 2015). The stocked materials may represent a meaningful source of resources, with concentrations of elements often comparable to or exceeding natural stocks (Cossu & Williams, 2015). The concept of urban mining is also known in the construction sector as harvesting building materials. However, the concept of harvesting building materials is from the latest years, reusing building products and recycling materials is of all times and has been done since the classical period (Addis, 2006). To harvest building products, the building needs to be deconstructed or dismantled. The disassembly of these reusable building products requires careful dismantling which must be carried out at the site (Addis, 2006). The extraction and processing of products during urban mining is strongly based on economic feasibility (Cossu & Williams, 2015). According to Waldmann (2017), the use of deconstructed reusable products in the design phase is gaining momentum in the total construction sector of the Architecture, Engineering, Construction and Operation (AECO) industry. However, using reusable building products is not yet the business-as-usual approach.

There are three ways to reuse previously used products in a project (Gorgolewski, 2008; nweurope.eu, 2020):

- **Adaptive reuse**: reuse of an existing structure on the site. This approach is now relatively common with heritage structures as they have cultural value. It is possible to strip the building to only its structure to improve the thermal performance. Lastly, it is common that there is a change of function due to building obsolescence.

- **Relocation**: Most or all of the existing building is moved to a new location. This type of reuse rarely occurs, it occurs sometimes for pre-engineered buildings such as industrial buildings, warehouses and temporarily buildings. The building is dismantled on the old location, transported to the new location and build again with most or all of the existing products.
- **Reuse individual products**: This form of reuse is also known as 'product reuse'. Individual products are extracted from a demolished building and reused in a new one. It is called direct reuse if a product can be directly reused where no remanufacturing or refurbishment is necessary. It is called indirect reuse if the product has to be repaired, remanufactured or refurbished to reuse the product again.

To improve the process of using reusable building products it is important to identify the current challenges within this process. Previous research has addressed multiple challenges when using a reused building product in a building which keeps it from a business-as-usual approach. Hart, Adams, Giesekam, Tingley, & Pomponi (2019) addressed 4 categories of barriers, through a literature review: cultural, regulatorily, financial, sectorial barriers. Caldera, Ryley, & Zatyko (2020) addressed 3 categories of barriers, through an evidence-based literature review, which are divided into governance, operational and market barriers. Icibaci (2019) addressed the influencing factors and barriers that occur in the process of reusing a building product in the Netherlands, by a literature review and qualitative interviews and divided these into 3 categories: technical, social and economical factors. Park & Tucker (2017) addressed the barriers through a systematic literature review and divided the barriers into 5 stakeholder categories, namely: end-users, architects, contractors, developers and governance. Lastly, the study of da Rocha & Sattler (2009) analysed the barriers through a literature review, 25 semi-structured interviews and 5 case studies. The challenges and their categorisation in the above studies are various, but the content is similar. After combining their findings, this research sorts out the challenges divided into 5 categories:

- **Process**: The period for demolition activities precludes deconstruction. The time for demolition is often tight due to strict deadlines, so the time for manual dismantling of valuable products is small (Caldera et al., 2020; da Rocha & Sattler, 2009; Icibaci, 2019). There is a lack of cooperation between companies. This means that not only those involved in a project need to work together, but also suppliers of dismantled reusable products. This is necessary in order to work together and pursue a common goal (Caldera et al., 2020; Hart et al., 2019; Icibaci, 2019). There is a lack of standardisation, so the cost and time invested is higher to use a reusable product (Caldera et al., 2020; Hart et al., 2019; Icibaci, 2019).
- **Social**: The client has a negative perception, a lack of information, awareness and motives regarding reused products (Caldera et al., 2020; da Rocha & Sattler, 2009; Hart et al., 2019). This is also a lack of culture for saving the resources and making optimal use of a product (Caldera et al., 2020; Park & Tucker, 2017). There is a lack of knowledge and information transfer concerning CDW management throughout the value chain, this can hinder the use of reusable products (da Rocha & Sattler, 2009; Hart et al., 2019; Park & Tucker, 2017). Some frame this challenge of delivering a circular project as a linear economy, which is based on a lack of circular products

business cases and supporting logistics (Hart et al., 2019). There are many incentives on the circular economy that can be confusing and make the supply chain and administrative work more complex (Hart et al., 2019). Leadership is seen as key to getting reusable products in a project, there is confusion about who should lead this process (e.g. contractors, architects, clients, deconstruction companies), this is crucial to deliver a project with reusable products (Hart et al., 2019; Park & Tucker, 2017). Reusable products do not contain guarantees, this led to risks for the investors and lower demand (Icibaci, 2019). There is a cultural barrier in the construction sector, which itself is conservative, uncollaborative and adversarial, which restrain innovation further (Hart et al., 2019; Park & Tucker, 2017).

- **Financial**: The deconstruction costs tend to be higher than demolition costs. However, deconstruction can be economically attractive if it can be easily deconstructed with low-cost manual labour and due to increasing demand for deconstructed products (da Rocha & Sattler, 2009). The price of reused products should be cost attractive compared to new products. Currently, the price for reused products is similar or higher than new products (da Rocha & Sattler, 2009; Hart et al., 2019; Icibaci, 2019). However, if products can be easily dismantled and few to no modifications are necessary reclaimed products can be sold cheaper than new products (da Rocha & Sattler, 2009; Icibaci, 2019). The low virgin material prices and even lower EoL values is a major barrier because of uncertainties about the product value in the distant future (Hart et al., 2019).
- **Regulatory**: There is a lack of a consistent regulatory framework, this includes an absence of policy support for the circular economy and a lack of targets beyond the basic landfill diversion (Caldera et al., 2020; da Rocha & Sattler, 2009; Park & Tucker, 2017). Also, laws and regulations can obstruct the use of reusable products (Caldera et al., 2020; Hart et al., 2019). Lastly, there is a lack of incentives to boost the circular economy in the built environment, authors do not always specify this type of incentive, but tax incentives and producer responsibilities are evident (Caldera et al., 2020; Hart et al., 2019; Park & Tucker, 2017).
- **Quality & Quantity**: Inconsistency of quality of products harden the use of reusable products, e.g. a scratch on a door (da Rocha & Sattler, 2009; Hart et al., 2019). Next da Rocha & Sattler (2009) identified that there is an inconsistency of quantities of products and a lack of dimensional coordination of reused products. Not all reusable products are extracted from the stock due to the lack of storage space and willingness to store reusable products, this can be increased if the supply and demand is stimulated (Icibaci, 2019).

2.4. Hierarchy of buildings

A building can be described in multiple levels of detail. Therefore this section shows the different building composition methods, the building hierarchy and the concept of level of development.

2.4.1. Building composition

The notion of seeing a building as a whole object is the dominant way of thinking about buildings (Beurskens & Bakx, 2015). A building is conceived, designed, constructed and used as an entity. However, in a building lifetime, a building is continuously changing, due to changes in user needs and environmental conditions (Verberne, 2016). Therefore, buildings should be seen as dynamic structures that are adapting to the needs of the present. Brand (1996), proposed a model of "shearing layers", the six S's, shown in Figure 9, that defines the composition of a building into layers. The building layers vary widely in their life span, which requires maintenance at different rates in the building lifetime. The building layers are separated as followed (Brand, 1996):

- Site: The geographical setting in which the building is positioned (eternal).
- Structure: All structural elements of the building like the foundation and load-bearing elements (30-300 years).
- Skin: The façade of the building, the exterior surfaces (20 years).
- Services: Contains services such as communication wiring, electrical wiring, plumbing, fire sprinkler systems, HVAC (heating, ventilating and air conditioning), elevators and escalators are part of the services (7-15 years).
- Space plan: the interior layout like; walls, ceilings, floors and doors (3-30 years).
- Stuff: furniture like; chairs, desks, lamps and pictures (< 1 year).

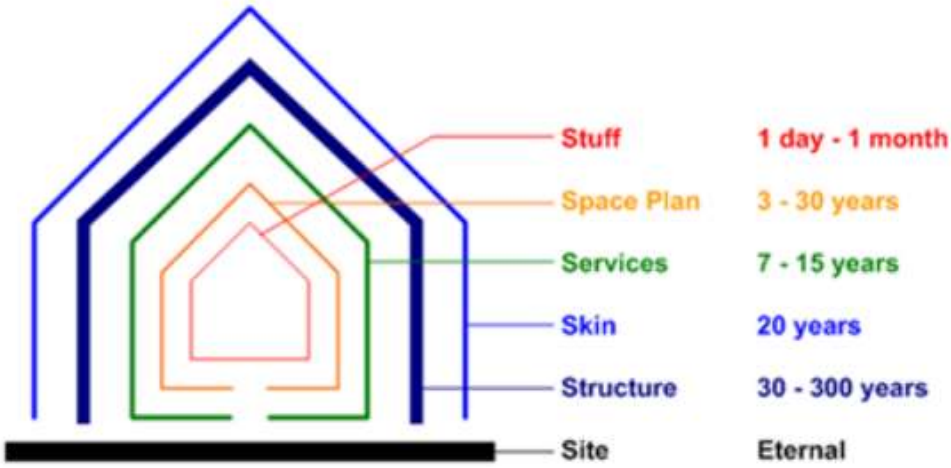

Figure 9 "Shearing layers" of Brand (PlatformCB'23, 2019)

There are similar other building decompositions proposed as shown in Table 2 (Schmidt, Deamer, & Austin, 2011). These mutations to Brand's model proposes modifications based on the time boundaries and nomenclature, but do not disprove the original Brand's model (Bernard Leupen, René Heijne, & Jasper van Zwol, 2005; Duffy, 1990; Richard D. Rush, 1986; Slaughter, 2001).

Table 2 Building decomposition systems (modified from Schmidt et al., 2011)

Brand 1994	***Slaughter 2001***	***Rush 1986***	***Duffy 1990***	***Leupen, 2005***
Site				
Structure	Structure		Shell	Structure
Skin	Exterior enclosure	Envelope		Skin
Services	Services	Mechanical	Services	Services
				Access
Space plan	Interior Finish	Interior	Scenery	Space plan
Stuff	Systems		Set	

The focus of this research is on building products. These products can be disassembled from the compositions of structure, skin, services, space plan and stuff of Brand's model. The site will be kept out of this research because the composition of 'site' is about the geographical location and not on building products itself. Although one could argue that gravel and sand are reused often on another location, however this is already a matured market and therefore kept out of this research.

2.4.2. Building hierarchy

The (technical) building structure is defined as a hierarchal arrangement of materials, which can be described at any level of abstraction. The higher level(s) will always dominate the lower level of technical composition. The hierarchy of material levels, as shown in figure 10, is inspired by the hierarchy of materials of Durmisevic & Brouwer (2002) and is used to avoid any misunderstanding in terms of methodology. Due to the broad definition of a component, an additional level 'product' is created, to clarify also products in the building hierarchy e.g. a door with a frame. This research will focus on product, component and material reuse. In urban mining, there is no clear distinction between recovering single materials from buildings or recovering components that consist of multiple materials (Lukkes & Max, 2018). Therefore, this research is referring to products, consisting of all products, components and elements available to reuse.

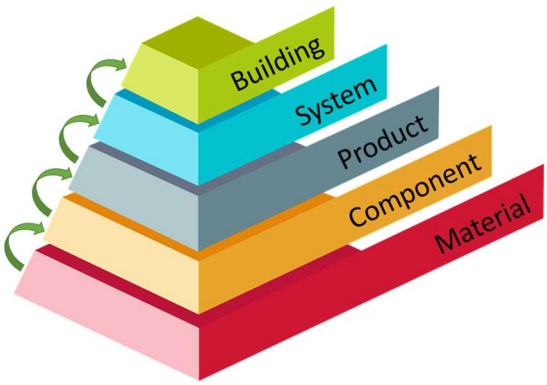

Figure 10 Hierarchy of material levels

2.5 Process chain analysis

In this section, the process chain of a building is discussed, including the repurposing phase where a building is deconstructed/demolished. Next to this, the circular building hub is discussed and the possible repurposing routes for deconstructed products are shown.

2.5.1. Process chain of a building

Many studies have been focussing on the process chain of a building. During the development of a building, there are four typical phases that every project development goes through independently of the collaboration method (Koppenjan, 2005; Priemus, Flyvbjerg, & Wee, 2008). The phases of a general project development of a new construction project are shown in Figure 11.

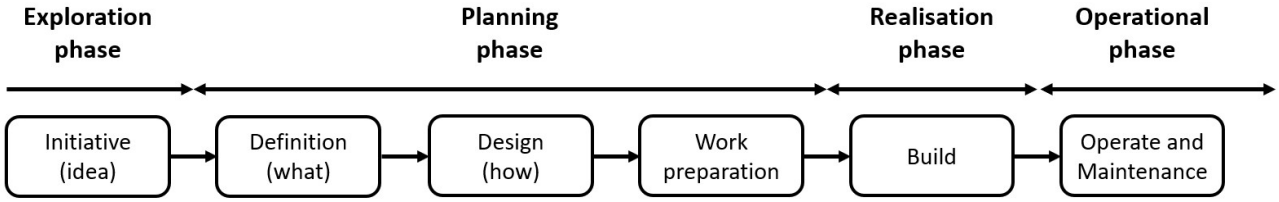

Figure 11 Phases of project development

The process chain of a building, also known as the life cycle of a building can be seen as a circle. In Figure 12 the life cycle of a building is shown according to PlatformCB'23 (2019). Platform CB'23 invented this life cycle for civil and non-residential construction projects, as well as for ground-, road- and hydraulic engineering. This life cycle connects the repurposing at the end of a building's use to the initiative phase of designing and planning a new building.

Platform CB'23, (2019) proposed a building passport that can be made during all phases in the life cycle. In this passport, all information of a product and/or material in the building can be documented. When a passport is made during the Design and Plan phase of a building, the information can be based on facts. However, when currently an old building is deconstructed, no information is available because in the past the data is not properly stored, therefore there is missing data in the system. It is possible to make a passport in the use and management phase or before demolishment. However, the passport is not made on facts, but on estimates, because only visual detectable information can be added (PlatformCB'23, 2019).

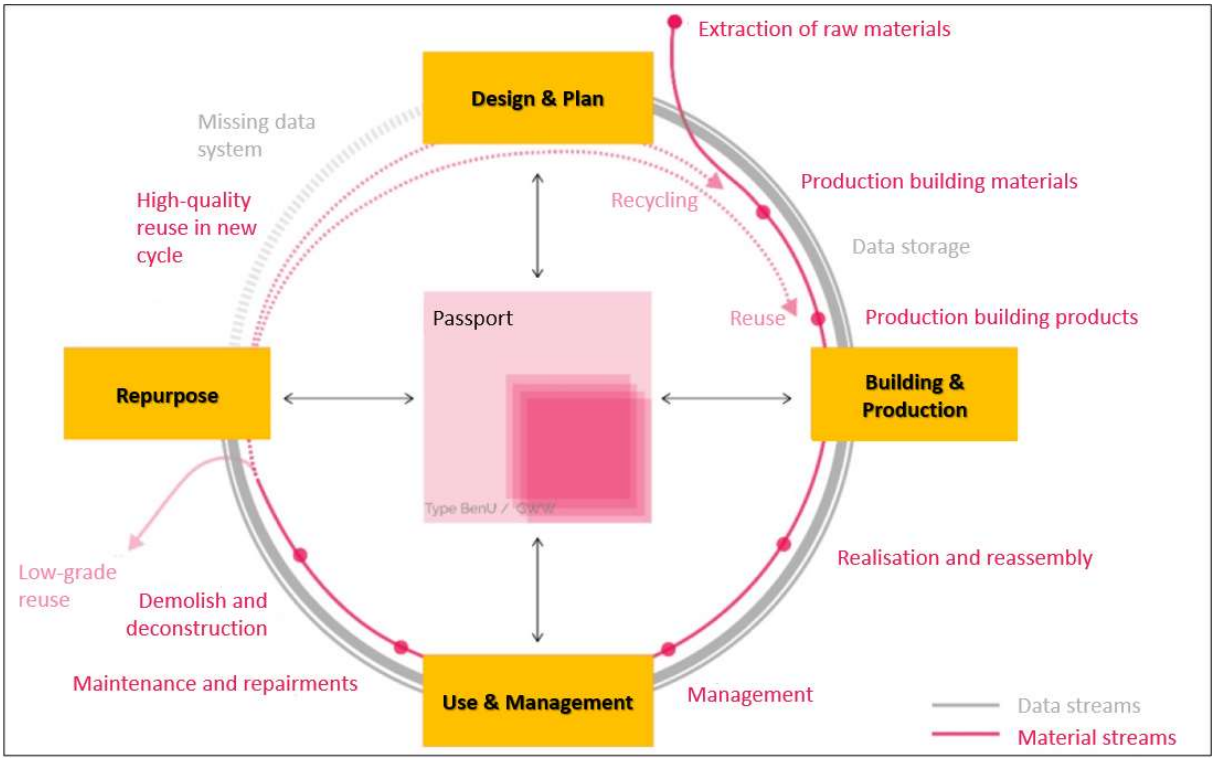

Figure 12 Lifecycle of a building, translated from Platform CB'23 (2019)

2.5.2. Deconstruction process

Looking more in-depth into the deconstruction process it is found that the traditional business as usual approach is identified by Arora, Raspall, Fearnley, & Silva, (2021) by conducting case studies, this business as usual process is shown in Figure 13A. In Figure 13B Arora et al., (2021) added additional steps for the dismantling of reusable products in cooperation with the involved demolishing company. A step with 'Inventory Development' is added where an analysis is conducted of the building of which products can be dismantled are reused. Followed by the next step 'Urban Mining and Recovery' which describes the process of dismantling the reusable products.

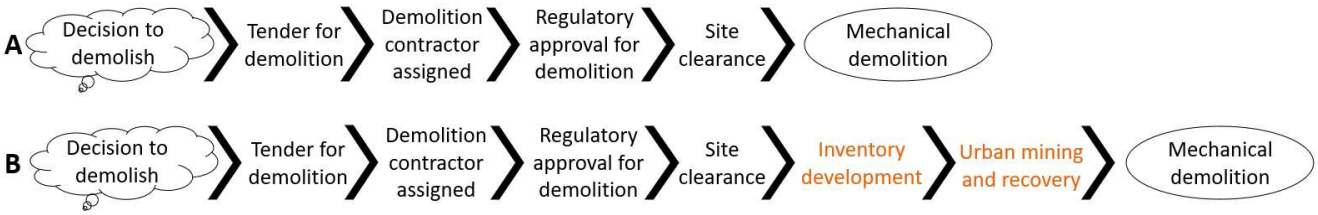

Figure 13 A: traditional demolishing process, B: process in study by Arora et al. (2021)

Regulatory approval for demolition is often a formality and from the point of time when a decision is made to demolish a building may take a few months in time. In these months, activities like disconnecting the water and electricity supply and identifying asbestos presence in the demolished building are conducted (Arora et al., 2021). Some literature suggests that the dismantling of a building is increasing the timelines of demolishing a building and subsequently building the new building on the plot (Densley Tingley, Cooper, & Cullen, 2017; Gorgolewski, 2008; Rios et al., 2015). On the contrary, Arora et al., (2021) suggest, by experimental case studies, that these months are sufficient to perform all steps of the

dismantling process, from planning till dismantling, before the mechanical demolition of the building starts, which lead to no effect on the project planning. Activities such as removing harmful substances such as asbestos, that need to be safely removed from the project, are also deconstructed in this time period to avoid occupational exposure (Akinade et al., 2015).

2.5.3. Material flows

There are many flows of materials at a buildings' end of life, these are shown in Figure 14. In general, there are two types of activities, the demolition activity of a building, which leads to landfilling or recycling and the deconstruction activity of a building, which is a gentle way to dismantle for reuse or dismantle toxic materials like asbestos to be safely disposed. According to Akinade et al. (2015), there are three types of building reuse after deconstruction: total building reuse (relocating or renovating), component reuse and material reuse. These are in line with the building hierarchy of Durmisevic & Brouwer (2002), however, Akinade et al. (2015) did not include the system level as described by Durmisevic & Brouwer (2002). This is probably because most products are deconstructed on the product, component or material level.

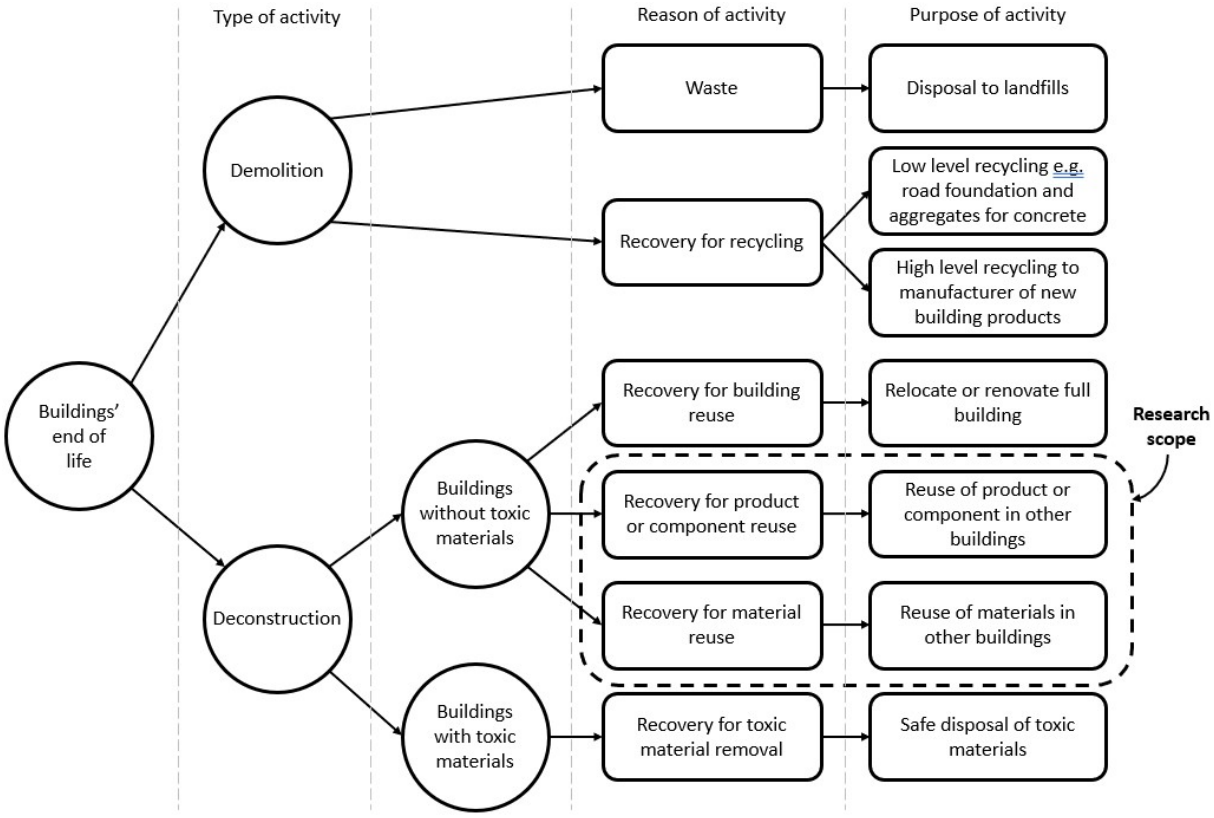

Figure 14 Types and purpose of buildings' end of life (Redrawn from Akinade et al. (2015)*)*

2.5.4. Circular building hub

In the Netherlands, there is a growing amount of places built in the inner city on a "stamp" location with limited place for storage and room for a full construction site. Therefore TNO (2018), researched the possibilities of a logistic building hub just outside the city through multiple case studies. With this building hub, producers of new building products now travel to the building hub instead of to the building site. In the building hub, the products can be stored and separated in a daily-fit package for the construction site, which saves storage on

the construction site. The results showed that such hubs increase productivity for specific processes on the construction site by 40% and can lead to an average of 65% of travel movements to the inner-city construction site. As less transport to the construction site is required, the CO2 emissions decrease extremely, up to 70% for some of the case studies (TNO, 2018).

Building on the promising results from building hubs, a next step found in the literature is a circular building hub. Where reusable products can be collected, refurbished and transported to the new location, with or without a combination with a logistical building hub. The dynamics in the supply and demand rate of reusable products within the time horizon suggest feasible storage opportunities, such as a circular building hub (Karamanou, 2019; Metabolics, 2021). Concerns are raised by municipality experts regarding the financial viability and contribution to the circularity of the materials (Karamanou, 2019).

2.6. Conclusion

The first part of this literature study gives a review of the importance of the shift from the linear to the circular economy with all its important factors and principles. However, not all loops are closed yet and won't be in the coming years, therefore there are still improvements to make. With the 10 R approach, it becomes clear what the best loops are to make to keep the products as long as possible in the circular economy. The improvement of loops of material processes is necessary because of the large number of recycled materials in the Netherlands and the low number of reused products. This is necessary to lower the environmental impact of the construction sector. Reusing a product is better for the environmental impact than pulling apart the materials of the product and recycle them. However multiple barriers are identified while reusing a product in this literature study. Currently, the focus of architects and contractors on circularity is translated to future reuse. However, the focus on future reuse is insufficient to reach the goals of the Paris agreement of lowering the CO2 footprint, therefore reuse in current designs is necessary to reach these goals.

From the three ways to reuse products from the existing stock, direct reuse of products have the most potential to lower the CO2 footprint of new buildings, after refuse, reduce and renew in the 10R principle. However, reuse of building products is not common practice yet and still many barriers were found in the literature. The main barriers are inventoried by qualitative interviews in this research and will validate the found barriers in the literature.

In reviewing the literature on the circular built environment, it became clear that the terminology for reuse in the literature is often also used for recycling. In this way, reuse and recycling are valued in the same way, which devalues (direct) reuse and is a barrier to achieving a higher standard in the 10Rs principle of the circular economy. Therefore, researchers need to be critical when searching for literature on reuse topics to avoid misunderstandings. It is recommended to separate the terms recycling and (direct) reuse in order to give more value to the reuse process and achieve a higher standard of the 10R principle.

While combining the deconstruction process with the process chain of a building, timing is crucial. The deconstruction work is responsibly for the supply and the process chain of a

building is responsible for the demand. Currently, architects and contractors are searching for reusable products early in the design & plan phase. On the demand side, the new building of the architects and contracts will take more than six months before construction work begins. On the supply side, the deconstruction company knows one month ahead what products will be deconstructed in the following month. Therefore there is a need for storage of the product. Which is one of the barriers identified in Section 2.3.1. The logistical building hub is proven successful and shows potential to grow even further in the future. However for the circular building hub only one source was found, where they discuss the advantages and disadvantages of a circular building hub. Only a few circular building hubs are known in the Netherlands and their practice is not researched in the literature yet. The deconstruction company has the role to inventory the products that are reusable from the to be deconstructed building and is responsible for the supply of reusable products with the correct product information. The current practice will be further elaborated in the interviews with the deconstruction companies about the current practice and analyse the process.

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CHAPTER 3.

Information management of product passports

3. Information management of product passports

In this second part of the literature review, the concept of product passports is first described in Section 3.1. Then, the concept of Building Information Modelling (BIM) in the AECO sector is explained in Section 3.2. Section 3.3 discusses the level of development and maturity levels of BIM. This is followed by Section 3.4 about the exchange standards. Next, in Section 3.5, the concept of similarity matching between data is discussed. This is followed by Section 3.6, which explains several current initiatives based on the literature. Finally, this chapter concludes with a conclusion on the second part of the literature review in Section 3.7.

3.1. Product passports

Material passports aim to increase or keep the value of materials over time (BAMB, 2019; Honic, Kovacic, & Rechberger, 2019; Madaster, 2020). Platform CB'23 defines a passport as:

"*A passport is a digital document that records an object in the construction- or civil engineering sector. It documents what an object consists of (both qualitatively and quantitatively), how it is built and where it is located. It documents ownership of the whole and/or parts*" (Platform CB'23, 2020).

Product information should be stored in the cloud and made accessible anywhere, anytime. Therefore, this definition has been slightly modified for this study and the definition is shown below by the inclusion of "over time and space", because the passport is not 'just' the property set and should travel with the product. This leads to the following adapted definition:

A passport is a digital document that records an object in the construction- or civil engineering sector. It documents what an object consists of (both qualitatively and quantitatively), how it is built and where it is located <u>over time and space</u>. It documents ownership of the whole and/or parts.

BAMB and Madaster are both companies that offer a platform and repository for storing, linking and providing relevant information on materials in buildings to the relevant actors along the value chain (Heinrich & Lang, 2019). By adding material passports an attempt is made to increase the value of building materials and enable the shift to a circular building sector by making the unknown specifications of the reusable materials accessible and therefore allowing for informed decision making (Spring & Araujo, 2017).

Platform CB'23 (2020), set up guidelines for variations of the passports within the construction sector. The scale levels are divided as follows:

- Building passport
- System passport
- Product passport
- Material passport
- Raw material passport

These scale levels are in line with the hierarchy of materials levels as explained in Section 2.4.2 in this research. A building passport should use the passports that are established at lower scale levels. It brings the lower-ranked passports together (or 'nest' these) at a higher scale level by the building (Platform CB'23, 2020). The terms building-, product- and material-passport are all used in current literature, the term defines the scale level of the passport.

Current material passports focus on single materials, which allows benefits for selective demolition because all quantities are known beforehand and do not have to be inventoried at the EoL stage based on estimates (Madaster, 2020). However for dismantling and reuse of products these passports are not sufficient. A reusable building product often consists of more than one material, which requires a shift from material passports to product passports. A product passport can include and describe multiple materials, such as a door with its hinges and locks or a glass inner wall in a metal frame. As a result, research now focuses on product passports and looks at products on product level which would allow dismantling products instead of knowing only the amounts of single materials (Madaster, 2020; Sauter, Lemmens, & Pauwels, 2019; Spring & Araujo, 2017). Also, reuse on the product level is environmentally better than reuse at the material level. The process of dismantling the product down to the material or raw material level is more intensive and therefore also knows a greater environmental impact (Evert Schut, Vorstman, Kreukniet, & Werk, 2021). Product passports support the DfD principles to give proper documentation of the materials and methods used during the construction phase to ease the EoL deconstruction phase.

Latest years, research is increasingly experimenting with product passports within newly constructed buildings and much information can be attached, stored and be categorised in physical, chemical, biological and process-related properties, however, this is not common practice (Heinrich & Lang, 2019). It is important to note that this data can be easily added to products in a BIM model for new buildings. However, most of the buildings that are deconstructed today do not have a BIM model. Therefore product passports need to be made before the dismantling of a building during a building analysis. Through product passports, relevant reusable products can be rated before deconstruction/selective demolishment. In this phase, relevant properties can be documented based on visual detectable information and product history. This allows time for the planning for the dismantling strategy and selling the reclaimed products (Heinrich & Lang, 2019; Platform CB'23, 2020).

For newly constructed buildings most initiatives suggest BIM models as a technological platform to store all data of product passports. Among others, like, 3XN Architects & GXN Innovation (2016 p.166) states that "The huge amounts of data will make the BIM models extremely heavy and difficult to handle." Therefore Scholten suggests linking the passports to a reusable database in an intelligent product pool (Scholten, 2015). This is more in line with current research in decentralisation and interchangeability of databases, web based compliant.

However, existing buildings that are decided to be deconstructed, have no BIM model. Therefore, to reuse products from the to be deconstructed building in a newly constructed building, the product information needs to be inventoried on location. This information can be collected in a product passport and saved in a database. This research focuses on matching

these product passports of reusable products with products from a BIM model to overcome several barriers from Section 2.3 and stimulate the use of reusable building products.

3.2. Building Information Modelling in the AECO sector

BIM is an abbreviation for Building Information Modelling and has improved the possibility to manage building data in the AECO sector. BIM is still a very broad concept and can be considered as a 3D model that stores all building data digitally (Aguiar, Vonk, & Kamp, 2019). On the other side, BIM can be considered as the process of creating digital building models within a team of different stakeholders and maintaining the models during the entire life span of the building (Borrmann, König, Koch, & Beetz, 2018). The concept of BIM originates within the Building Description System (BDS) proposed by Charles Eastman in 1975 (Eastman, Teicholz, Sacks, & Lee, 2018; Pauwels & Petrova, 2020). The work of Charles Eastman in 1975 still shows clear references to what BIM is today, namely a model that resembles the backbone of all information related to the building (Pauwels & Petrova, 2020). In this research, the US National Building Information Modelling Standard (NIBS) definition of BIM will be used:

"Building Information Modelling (BIM) is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition. A basic premise of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder" (Borrmann et al., 2018).

Currently, BIM models are ubiquitous in the AECO sector. Due to the use of BIM models, information is exchangeable between project partners and with clash detection conflicts can be identified and controlled early on in the process. The focus in the AECO sector shifted from the 3D Computer Aided Design (CAD) data towards the non-graphical information in a BIM model. A BIM model is no longer only a 3D representation of a building, but more like a database about the properties and relationships between objects. to gain more value from the BIM models and increase the quality and possibilities (McArthur, 2015). Therefore planning data and cost estimations can use BIM data due to the possibilities of quantity take-offs. Overall, the BIM process creates a higher design quality and a more effective collaboration between project partners due to easier communication through the BIM model (Farnsworth, Beveridge, Miller, & Christofferson, 2014).

3.3. Level of development and maturity levels of BIM

To make a match between the information of reusable building products and BIM models, the structure of non-graphical information of products within a BIM model needs to be analysed. Therefore, the level of development and BIM maturity levels are described hereafter.

3.3.1. Level Of Development

The amount, type and detail of information within a BIM model is considered to be dependent upon the level of development (LOD). The LOD is the most widely accepted concept in the construction sector to measure certainty and how seriously or definitive the information is. The LOD concept is published by the American Institute of Architects (AIA) in the AIA G202-

2013 (AIA, 2013; Bertin, Mesnil, Jaeger, Feraille, & Le Roy, 2020; BIM FORUM, 2020; Guillen et al., 2016; McPhee, 2013). LOD is often broken down into five levels as shown in Figure 15. For each LOD, only the data in red is usable on that level and indicates what to expect. The five levels in Figure 15 are the most commonly used definition of LOD. However, there is no exact guideline for the LOD (EV, 2014; PCSG, 2021).

Models that are indicated with LOD 100, contain only overall building massing which can be presented in a three dimensional way or by other data. However, all information derived at this level must be considered an approximation. At LOD 200, the model is graphically represented as a generic system or object for space reservation. Any information derived must be considered an approximation. At LOD 300 the model is graphically represented as a specific system or object in terms of quantity, size, shape, location and orientation. LOD 400 models are supplemented with complete information and sufficient detail and accuracy for the fabrication of the product. Models of LOD 400 can be referred to “as-planned” models, which can be suitable for project management in the construction phase. LOD 500 models can be referred to “as-built” models and all included data is field verified (Bertin et al., 2020; BIM FORUM, 2020; McPhee, 2013). The LOD 500 models are often used in the operational phase and are called a digital twin, which is a virtual, digital equivalent to a physical building (Grieves, 2014).

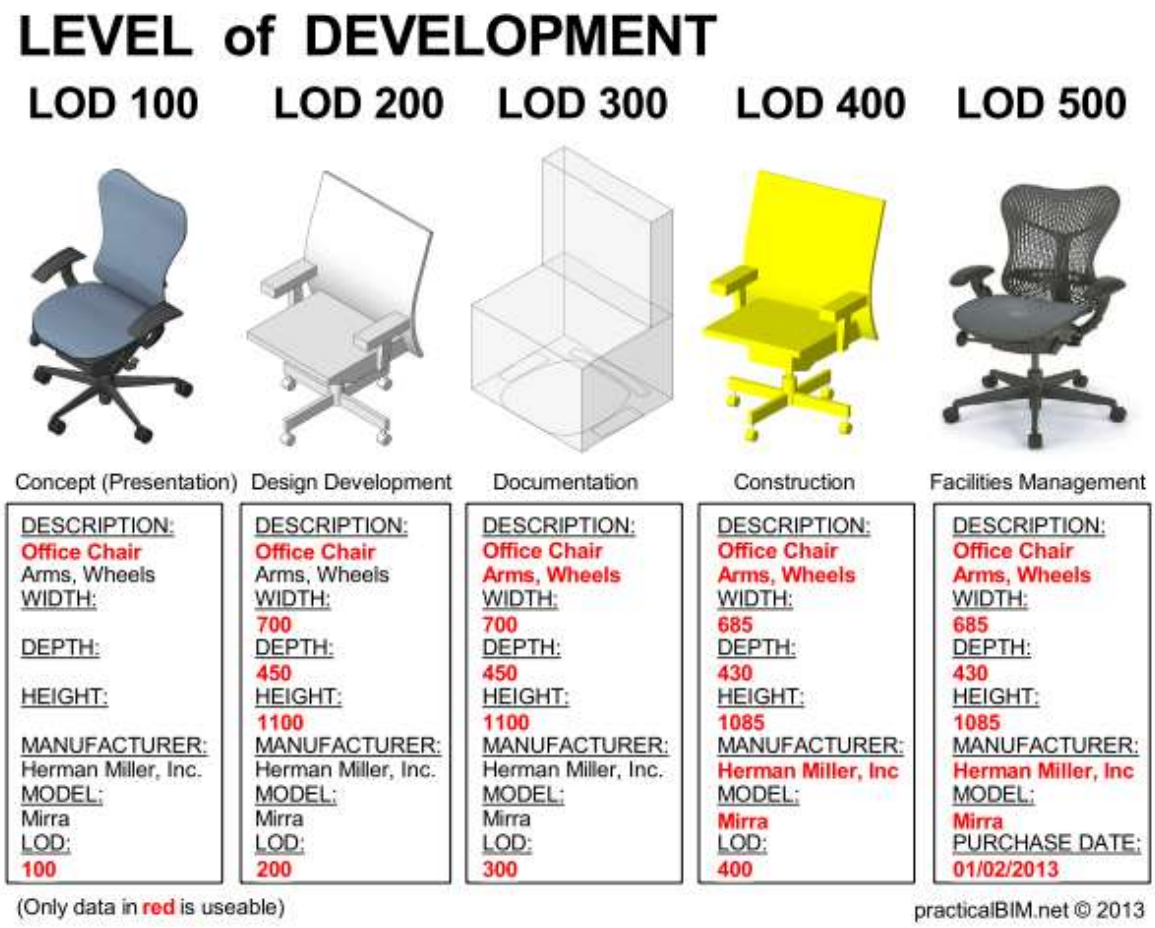

Figure 15 LOD levels example of a chair (McPhee, 2013)

Next to the LOD, there is the concept of level of detail (LOd) and level of information (LOI). The LOd is associated with the way the model looks, which relates to the graphical content of models. Therefore the model can have very detailed elements, but it might be generic and therefore have a low LOI. The LOI only relates to the non-graphical content of models and does not focus on the graphical content (Graham, Chow, & Fai, 2018; Machete et al., 2021; PCSG, 2021). The LOI is often determined by the data available. Unlike new-built buildings where all materials and assembly are known, a BIM model of an existing building relies on existing drawings, documents and on-site observations. In some cases no drawings or documentation is available and only on-site observations can be done (Graham et al., 2018). Therefore creating a BIM model for the deconstruction phase of the project is not valuable. The LOI levels are described in Table 3 on the following page.

LOI Level	***Description*** **(Graham et al., 2018)**
LOI 0	Information is not required. If information is present, it is limited to element classification e.g. “window”.
LOI 1	Some non-graphical data is included. However, it may be default settings and not derived specifically for the project.
LOI 2	More non-graphical data is specified and is partly project-specific. Overall materiality is labelled but may not include complete wall assembly details. The type is specified but not specific manufacturer information.
LOI 3	The non-graphical information includes specific requirements, e.g. wattage for lights. All material layers are labelled and classified with thermal, acoustic and structural values. The type of material is required, except the brand.
LOI 4	The specific manufacturer details are included and links to the manufacturer manual are present. All specifications included through the manufacturer are included and all materials are identified by brand. This LOI is often only reached for projects where the model is used in the operational phase.

Table 3 Description of LOI levels

In addition to the previous concepts, the Level Of Information Need (LOIN) is introduced in the ISO 19650. The international standard NEN-EN-ISO 19650 is regarded worldwide as the standard for the management of digital information in the life cycle of construction projects (BIM Loket, 2020). The LOIN is a broad concept, discussed in the NEN-EN-ISO 19650, that represents the framework for how the ‘richness’ of each information deliverable needs to be defined. It is used to provide the right level of information at each information exchange (Churcher, Davidson, & Kemp, 2019). There are many different ways to express the LOIN due to its general format. Therefore, guidelines will be developed in the near future with technical specifications alongside this standard (BIM Loket, 2020). During the writing of this thesis, the guidelines were not yet available.

BIM models are often not applied in existing buildings, due to the time-consuming data capturing, processing and modelling effort. In addition, often a high LOD level is required for maintenance or deconstruction, which is not compatible with the invested time and costs

(Volk, Stengel, & Schultmann, 2014). Therefore this research is focusing on capturing non-graphical data (LOI) of reusable products, from which data a product passport can be created.

Currently, the LOD is the most common and widely accepted concept in the construction sector because it defines a broader range of design quality than the LOd and LOI (AIA, 2013). How parties collaborate to operate a BIM model as an information system is dependent upon the level of maturity. This subject is explained in the next section.

3.3.2. BIM maturity levels

While discussing BIM, several stages of the adoption of BIM can be distinguished. These stages are commonly known as the BIM maturity levels. These four levels have been established to determine the type and level of collaboration through which BIM as an information system is used. These levels are digitally shown in Figure 16 – Wedge diagram of BIM maturity levels by Bew & Richards (2008) and are described hereafter (Dakhil, Alshawi, Underwood, & Dakhil et al., 2015; Pauwels & Petrova, 2020):

- Level 0: The use of unmanaged 2D computer-aided design (CAD).
- Level 1: The use of managed CAD in 2D or 3D software, with a fair level of information regarding materials, performance, and so forth. This form of BIM, where only one party manages and utilises the benefits of the BIM model, is often referred to “Lonely BIM”. Where the BIM model is not used for collaboration between the project team.
- Level 2: The use of 3D information models from all key project team members. There is model-based collaboration through separated discipline models, which are interchangeable between the project team. Currently, most AEC companies aim at implementing BIM up to level 2. This is not necessarily done on one shared central model. Because each stakeholder works in a different model, clear boundaries and rules must be set up so that models can be connected, interchanged and/or merged in a coordination model.
- Level 3: The use of a fully open interoperable process and data integration, also described by RIBA (2012) as the “holy grail”. This level abandons the file-based approach and instead all data and information are managed by a collaborative model server.

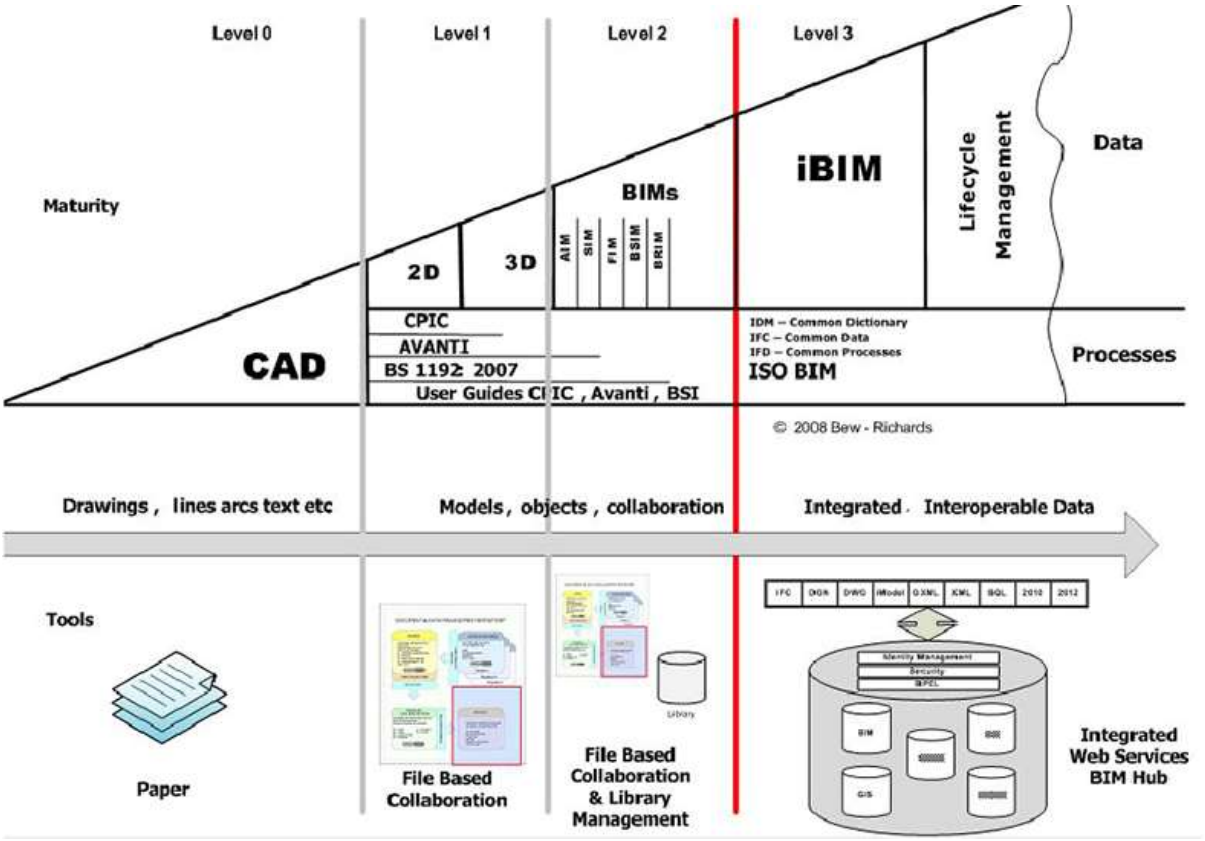

Figure 16 Wedge diagram of BIM maturity levels (Bew & Richards, 2008)

3.4. Exchange standards

As stated in the BIM maturity levels in the previous section, the exchange of BIM models and data becomes more and more important for collaboration. In the building industry, the Industry Foundation Classes (IFC) supports a neutral data format for BIM tools interoperability (Afsari, Eastman, & Castro-Lacouture, 2017; BuildingSMART, 2020). Due to the use of BIM-based Model Checking (BMC) software, the IFC files are able to be checked on clash detection and rulesets (Hjelseth, 2015). In the BMC software (e.g. Navisworks and Solibri Model Checker) requirements can be added to check the model, e.g. specific space requirements that are set at the start of the project and to check the model according to the Dutch building decree. Next to the requirements check, the IFC files are superimposed on each other and clashed on intersections. Quality assurance is the key aspect in BMC software and has higher reliability than visual inspection. Important intersections are communicated back to the responsible party of that model. The BMC software has as goal to improve the design quality of the model and avoid failures and extra costs on the construction site (Hjelseth, 2015).

Two of the most common BMC software tools, as mentioned before, are Navisworks and Solibri Model Checker (SMC) from Solibri. It depends on the project team's needs and goals which software tool is best for them. Navisworks is excellent for BIM coordination purposes, for clash detection and even for 4D modelling (time planning) (Hjelseth, 2015; Pauwels & Petrova, 2020). Navisworks also allows importing other file types next to IFC, which is an advantage for the interoperability. SMC software is in comparison with Navisworks easier in use but has less functionalities. Nevertheless, the SMC software is widely adopted in the

construction sector to check the quality of BIM models. With the SMC it is possible to check graphical intersections, non-graphical information and Information Take Offs (ITO) can be created for quantity take off and further calculation of material and works (Hjelseth, 2015).

To get the most out of BIM models and to increase its interoperability, building data needs to be available within cloud based formats. JavaScript Object Notation (JSON) and Extensible Markup Language (XML) are the most generic, scalable and highly adaptable cloud-based data exchange forms used in web applications (Afsari et al., 2017). JSON is most preferred in this research because compared with XML, JSON is a lightweight key-value style data exchange format with higher parsing efficiency than XML, therefore the JSON data exchange form is often used in web applications (Afsari et al., 2017; Peng, Cao, & Xu, 2011).

To reach the BIM level 3 of the wedge diagram of Figure 16 it is important to move towards this interchangeability of databases with open standards, where all kinds of databases that can be connected to each other with web services. JSON is also a commonly used standard in future developed web service technologies. It could be said that JSON is the successor of XML for web development technologies. Therefore JSON is chosen as preferred data exchange form in this study.

3.5. Similarity matching

For the matching of products between the stock of reusable products with BIM models, similarities between the data need to be matched. Therefore, similarity matching methods are analysed in this section. Similarity can be seen as distance within dimensions representing the properties of the product. If a distance is small, two products are very similar and if a distance is very large, the products have a low degree of similarity (Gupta, 2019). For the matching with reusable products it is important to filter on the properties with a small distance to the JSON data.

In literature, there are three common distance measuring methods as described below and visual shown in Figure 17 Phillips (2013):

- L0= The maximum of the absolute differences per dimension.

$$L0 = max(|x|, |y|)$$

- L1= The sum of the absolute values of the differences (Manhattan).

$$L1 = \sum_{i=1}^{n} |xi - yi|$$

- L2= The Euclidean distance (Pythagoras).

$$L2 = \sqrt{\sum_{i=1}^{n} (xi - yi)^2}$$

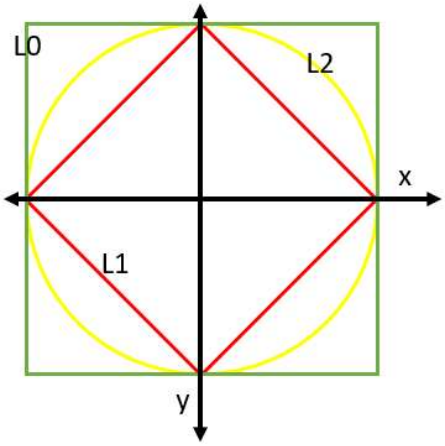

Figure 17 Distance measuring methods (Redrawn from Phillips (2013))

When comparing reusable products, one property does not have to be more important than another, this choice is based on project specific details and sentiment of the architect or contractor, e.g. architect 1 can be very flexible with a door height due to predefined high ceilings, but is not flexible in his width, due to narrow hallways. In contradiction architect 2 is restricted on the door height, but is flexible in the width of the door. Therefore, the L0 distance measuring method shows the best features for matching the stock of reusable products with JSON data. Due to the subjectivity of the end-user also no weights will be attached to the values.

3.6. Current initiatives

The latest years many studies have been conducted to increase the reuse potential of new buildings. The following concepts have been initiated based on passport information:

- Madaster is already a mature known company in The Netherlands that creates building passports based on BIM models to reduce the waste production in the AECO sector. Madaster identifies all materials used in a building from the BIM model and creates material passports, which shows a circular insight of the building, based on the quantity of materials (in tonnes and m^3) and there origin (e.g. from virgin material sources, recycled sources or if materials are reused). All material passports together are known as the building passport of Madaster (Madaster, 2020).
  In a latest article of Madaster (2021), the need for product passports was identified to make reuse possibilities better recognizable within the system. Because, the material passports are beneficial for the recycling company, however for direct reuse product passports have more value. During the writing of this research, the product passports were not yet implemented in the Madaster platform.
- Verhoeven (2020) created a cloud-based marketplace, using JSON file format as input and JavaScript for web development (cloud-based software). This marketplace includes the supply and demand of reusable building materials, driven by non-graphical information from the BIM models. The difference with the study of Verhoeven (2020) is that in this research no BIM model of the existing building is available, which is currently the case with most deconstructed buildings. Therefore there is no geometric data available of the to be deconstructed building, but only non-geometric data, which needs to be inventoried on site.
  Next to the cloud-based marketplace development, Verhoeven, (2020) created the Re Use Index – ILS. The Re Use – ILS is created to give guidelines on how to include the circular-based non-graphical information in BIM models for reusable products.
- Platform CB'23 is connecting parties across the entire width of the construction sector with circular ambitions. The aim of Platform CB'23 is to draw up national agreements on circular construction before 2023. With the vision of reducing the raw material use drastically, action teams are made to work on several topics with parties collaborating construction sector-wide. Finished topics are guidelines for a framework for circular construction, circular design and the circular purchasing process. Ongoing research is conducted for guidelines on the topics of future reuse, measuring circularity and passports for the construction sector. In the current research for passports for the construction industry, a longlist is created with passports from current practices. This

longlist includes information from various sectors at various scale levels from different perspectives and with different objectives. This longlist of passport items is developed to make the discussions about the content of passports as concrete and sharp as possible. From this longlist, filters are created for discussions on required content on measuring, maintenance and future (Platform CB'23, 2020).

It can be concluded that many companies and studies have inventoried passports for the construction sector. However, there is no standard yet for product passports to use in general projects, only pilot projects are until now conducted. The product passport standards for reusable second-hand products are even less inventoried and only Platform CB'23 published a passport for reusable products, which is during writing of this thesis ongoing research.

3.7. Conclusion

Based on the current literature study towards information management of product passports it can be concluded that passports for buildings, products and materials have lots of potential to store qualitative and quantitative data, as well as location and ownership. Most pilot projects were focusing on material passports which gains benefits for selective demolishment. However, when dismantling a product and reusing it, a material passport is not sufficient. Often a reusable product consists of more than one material, which requires a shift from material passports to product passports. Next, product passports support the DfD principles to give proper documentation of the materials and methods used during the construction phase to ease the EoL deconstruction phase.

The LOD, LOd and LOI are important concept to define the level of quality of the BIM model, including the graphical (LOD and LOd) and non-graphical information (LOD and LOI). The level of these concepts are defined before modelling to ensure the right level of detail and information in the BIM model. The level of information LOI has comparisons with the product passports. The LOI is focused on non-graphical information of BIM models. When dismantling an existing building, often no BIM model is available and a product passport can be made with visible detectable information. Therefore often information on maximum LOI 2 level is visible detectable, but also often the brand of the product is known, which is LOI level 4.

BIM models are often not applied in existing buildings, due to the time-consuming data capturing, processing and modelling effort. In addition, often a high LOD level is required for maintenance or deconstruction, which is not compatible with the invested time and costs (Volk et al., 2014). Therefore this research is focusing on capturing non-graphical data (LOI) of reusable products, from which data a product passport can be created.

It can be concluded that the use of BIM models has changed the way the AECO sector works and that there is still a lot of growth in the interchangeability and decentralisation of BIM data. The wedge diagram in Figure 16 with the BIM maturity levels clearly shows the current level of maturity and what still can be improved to reach BIM level 3. IFC supports a neutral data format for BIM tools interoperability. With BMC software tools like Solibri, models can be checked on graphical intersections and an ITO can be created for quantity take offs and further calculation of materials and works. To reach the BIM level 3 of the wedge diagram of Figure 16 it is important to move towards this interchangeability of databases with open standards,

where all kinds of databases that can be connected to each other with web services. Exchange format like JSON and XML are suitable for this interoperability due to their generic, scalable and highly adaptable cloud-based data exchange forms. JSON is the most commonly used standard in future developed web service technologies and is chosen in this research due to its lightweight key-value style data exchange format with higher parsing efficiency than XML (Afsari et al., 2017; Peng et al., 2011).

The literature review explained three commonly used distance measurement methods for similarity matching. Since each measure can be weighted completely differently by each end user, the maximum of the absolute differences per dimension (L0 method) is chosen for this study. The end user's choice in the matching application is based on project-specific details and sentiments.

From the current initiatives, it can be concluded that many companies and studies have done research on passports, but there is no standard yet and the AECO sector is still in the experimental phase, conducting pilot projects. Passport standards for direct reusable products are even less researched and only one study by Platform CB’23 published a passport for reusable products, which is being further researched during the writing of this thesis.

CHAPTER 4.

Methodology

4. Methodology

From the literature review about the circular built environment and the information management of product passports, it can be concluded that there are still major opportunities in the market of reusable products. Therefore an application is proposed in this research to match the reusable products of the deconstruction company with the used products by architects or contractors in a BIM model. The current stock of reusable products of the deconstruction company will be matched with a JSON file, containing non-graphical information of a product, from a BIM model of the architect or contractor. From the literature, it is found that finding the right reusable product is difficult and time-consuming, due to the splintered market of many small marketplaces and products that are lacking information. This research is focussing on overcoming this lack of information during the search for a reusable product. Next, this application could speed up and simplify the process of finding a matching reusable product for architects' and contractors' projects. In this methodology, firstly the research approach will be discussed in Section 4.1. Next, the research design in Section 4.2. explains all activities that are conducted during this research. Lastly, the research methods used in this research are explained in Section 4.3.

4.1. Research approach

As described in the introduction of this research and the literature review, the transformation towards a circular economy is necessary to reach the goals of the Paris agreements and to reach a carbon-neutral economy in the year 2050. The CDW around the world is a serious problem and waste production is still growing. With the recycling of materials, the first steps are taken towards a more circular built environment. However, recycling is at the bottom of the 10 R's ladder. To reach the goals of a fully circular economy by 2050, a larger focus on highly ranked R strategies is required, such as reduce, reuse and repair rather than recycling. Therefore in this research, the focus is on the direct reuse of products.

For this study, the engineering research cycle is used as chosen methodology and supporting framework. The engineering research cycle (Figure 18) embraces a mindset that emphasizes on open-ended problem solving (Wieringa, 2014).

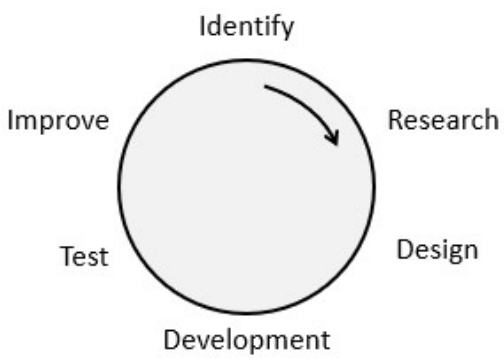

Figure 18 Engineering research cycle

The problem definition is defined in the introduction and the main research question is therefore as follows:

How can reusable building products from Construction Demolition Waste be connected with construction sites to improve the process and stimulate the use of reusable building products?

From the literature review, a research gap is identified, which includes the in depth process of deconstruction of a building until reusing a building product again. Also, a research gap is identified on the topic of product passports for existing buildings. This is due to the fact product passports are still rarely used in the construction sector and no clear format is given on what information is necessary for a product passport. Therefore the literature review is expanded with qualitative interviews, to form a good diagnosis. The literature review is hereby used to give guidance to the interview questions.

Based on the literature review and qualitative interviews a framework is proposed in Section 6.1. with a design of an application to stimulate the process of the use of reusable building products. This application will be implemented and validated at the graduation company.

4.2. Research design

The research design explains which steps are taken to answer the main research question of this research. The current research will be divided into four phases as shown in Figure 19. A theoretical part of 1 phase and a practical part of 3 phases. Firstly, the theoretical part, where sub-research questions 1 and 2 will be answered. In this part, the theoretical framework for this research will be established. Afterwards, the practical part is separated into three phases, a data analysis phase of the theoretical part to optimize the process of reusing building products for maximum value and profit, a data analysis, data gathering and development phase with corresponding sub-research questions 4, 5 and 6 and lastly a validation phase with corresponding sub-research question 7. Once all sub-research questions are answered, a conclusion is drawn up to answer the main research question.

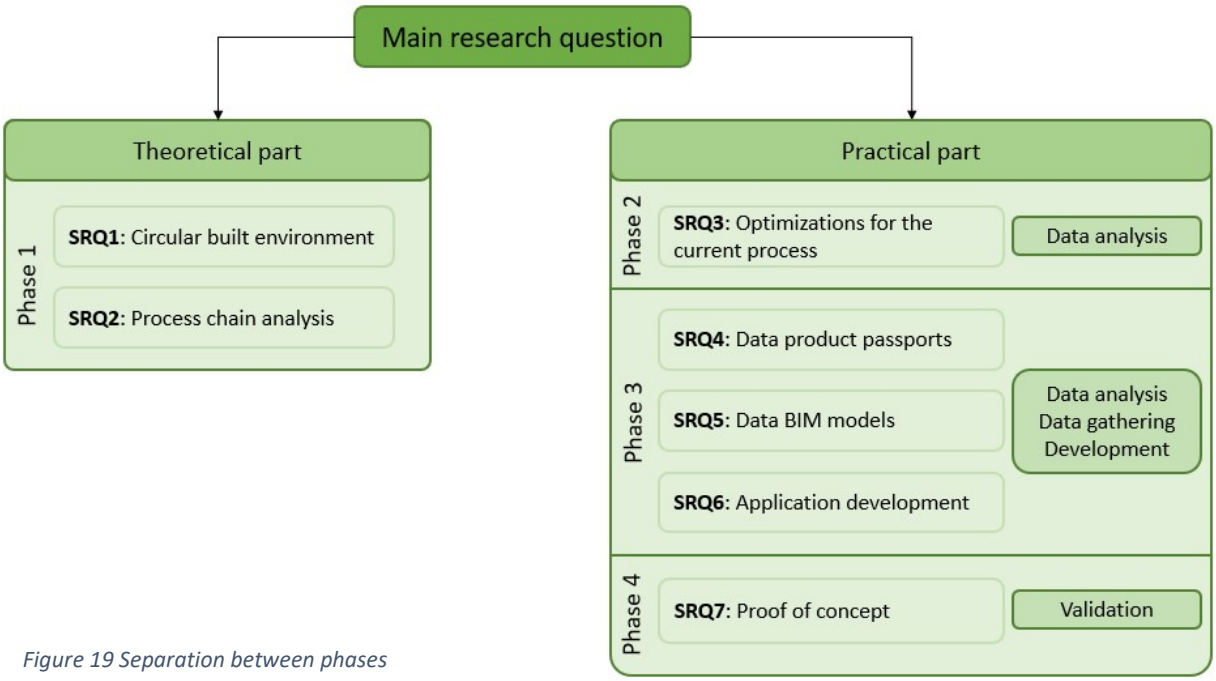

Figure 19 Separation between phases

The research framework for this graduation research is shown in Figure 20. In the first phase, a literature review of the circular built environment and the information management of product passports is conducted. Additionally, the current processes chain for reusable building products is analysed from a deconstructed building, through the circular building hub towards the new building in a Business Process Model and Notation (BPMN). The involved stakeholders are identified through the literature review and qualitative interviews with experts in the working field and a deconstruction company are held to form a good diagnosis of the current deconstruction process and barriers to reuse.

In phase 2, the current process from the interviews are analysed and optimization possibilities are suggested for maximum value and profit creation. Based on the results of this analysis, together with the other interview results presented in Chapter 5. The framework of the development of the application is proposed in Section 6.1 alongside with the system architecture.

In the third phase, firstly a data analysis is executed to examine which data is already available in the database of reusable building products by the graduation company and whether all required data is available to manage the data per product and if a product passport standard can be made. In the next step, the inventarisation of the non-graphical information of building products in BIM models of the current and upcoming construction sites will be investigated, so that the reusable products can be matched on their specification. In this phase, the ranges and overlap percentage in specifications between the data from the reusable products and the BIM model will be determined. The ranges and percentage of overlap in specifications are determined for only three products, as the focus of this study is on proof of concept rather than exhaustive implementation. The data from the database will also be searchable on the application. This allows the user to search for products without uploading a JSON file. After searching for the products or matching them with a JSON file, these products can then be reserved. A dashboard in Microsoft Power BI will be created which is linked with the developed application, this enables data and process analysis by the managers.

Lastly, in phase 4, a proof of concept is developed to test and validate the application by means of a case study. Lastly, the conclusion and discussion of this research are drawn up and recommendations for further research are given.

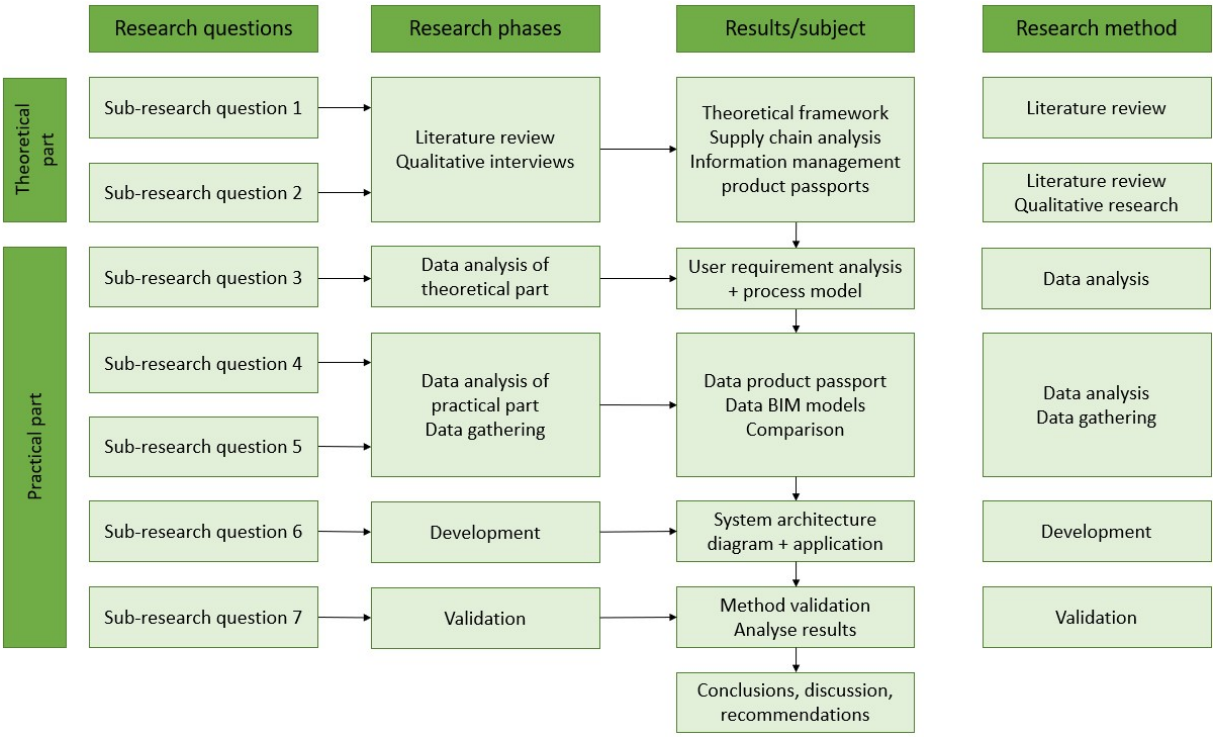

Figure 20 Research framework

4.3. Research methods

In this Section, the research methods used in this Master thesis are discussed. Firstly, in Section 4.3.1. the set-up and data analysis methods for the qualitative interviews are discussed. Afterwards, the methods used for the design and development of the application are discussed in Section 4.3.2.

4.3.1. Qualitative interviews

Next to the literature review, qualitative interviews are conducted to discuss and validate the literature and create a more in-depth understanding of the process of reusable building products. The interviews are conducted with the goal to:

- Get a good overview of the process from the decision to demolish until the use of reusable building products in a new building.
- Identify the barriers of reusing building products and validate these with the literature.
- Specifying user requirements for the application.

4.3.1.1. Interview design

A list of questions and topics that need to be covered during the interviews was determined and used as an 'interview guide' and additional questions are issued depending on the experts' answers. This allows for deviation from the standard questions, which can lead to broader follow-up questions and insights during the interview. The interview guide ensures that in each interview the same main subjects are covered and a reliable comparison during the data analysis is possible. The main advantages and disadvantages of semi-structured interviews are shown in Table 4 (Cohen & Crabtree, 2006; Galletta, 2013).

Table 4 Advantages and disadvantages of semi-structured interview

Advantages	**Disadvantages**
Allow for follow-up questions for more in depth information	Time-consuming
Provides qualitative data	Labour-intensive
Questions can be prepared beforehand to help guide the conversation	Get enough participants to draw up conclusions and comparisons

The experts have been carefully selected according to their position and the type of companies they work for as well as their expertise in reusing building products. To get a full impression of the process and barriers of reusing building products, a wide variety of companies are interviewed. In total 8 semi-structured interviews were conducted, of which 4 interviews on location and 4 interviews by Microsoft Teams due to stricter COVID-19 measures. Table 5 shows an overview of the participants with their company type, function, date of the interview and how the interviews were conducted (on location or online by MS Teams).

Table 5 Overview interviews

ID	Company type	Function	Date	Conducted method
1	Deconstruction company	account manager	20-09-2021	On location
2	Deconstruction company	General director	27-09-2021	On location
3	Architecture	Partner architect	06-10-2021	MS Teams
4	Contractor	Head of plan development / Innovation manager	07-10-2021	On location
5	Deconstruction company	Commercial director	22-10-2021	On location
6	Contractor	Project leader	09-11-2021	MS Teams
7	Project management	Project manager & superintendent	11-11-2021	MS Teams
8	Architectural design	Founder / Architectural designer / Senior consultant sustainability	26-11-2021	MS Teams

Participants were briefed about the main topics of the interview beforehand, to ensure preparation time and generate more insightful answers. At the start of an interview, the participant was obligated to read and sign an informed consent form to provide information about the TU/e ethical codes of conduct. A blank informed consent form is attached in Appendix 1.

A separate interview guideline was created for the deconstruction company and architects/contractors because of the different perspectives. However, the core of the questions remained unchanged to assure comparability in the analysis. The interview guidelines used in the semi-structured interviews are included in Appendix 2_Interview

guidelines in Dutch and English. The questions from the interview guide can be distinguished into four categories:

- Warmup questions, to get a better understanding of who the interviewee is and their experiences.
- Questions about the total process of reusing building products and found barriers.
- Questions about BIM and the potential connection with the application.
- Cool-off questions, to make sure if the interviewee has something to add to the interview or has any questions.

After transcription of each interview, the transcript was sent back to the interviewee for validation. This provided the interviewee with the opportunity to add additional information that they have missed mentioning during the interview, and is found to generate more in depth response from interviewees (Galletta, 2013). Extra notes of the interviewee based on the transcript are added at the bottom of the transcript. All transcripts, including the extra notes, are available upon request.

After transcription, the next step was to encode the expert interviews, in which relevant segments are labelled and categorised. Based on this categorisation, similarities and differences in the opinions of experts were identified. These relevant segments were coded by hands of an item analysis and categorised as followed:

- All sentences about the process of using reusable products are marked red.
- All sentences about the barriers of reuse are marked green.
- All sentences about user requirements for the applications are marked yellow.
- All sentences with other relevant information are marked blue.

4.3.1.2. Ethics and data management

Due to the AVG (Algemene Verordening Gegevensbescherming) and the GDPR (General Data Protection Regulation), a consent form is signed before every interview in which the participant gives his/her consent. To get approval from the Ethical Review Board (ERB), a Pre-Pia assessment and consent letter was made to secure the privacy and a safe and secure data handling approach. The Pre-Pia assessment and consent letter is discussed with data steward Sjef Öllers and approved by the ERB. The approval letter from the ERB is attached in Appendix 3 – Approval letter ERB interviews. All interviews are anonymised and pseudonyms are used. Only the job title of the person and the sector in which they are working was indicated in the research. All interviews are audio-recorded and transcribed soon after the interview had taken place. All data collected during the interviews was stored on the OneDrive account of TU/e, allowing for secured storage. After transcription of each audio recording, the audio recording was deleted.

4.3.1.3. Data analysis process chain

The current literature has limited depth concerning the process of reusing building products. One of the main goals of the interview was to gain a deeper insight into the current process chain from the decision to demolish until the use of reusable building products in a new building. After the interviews, there were discussions with all involved roles within the deconstruction company to validate the process chain analysis and get to know their role in

the process. The calculator, commercial worker, work preparator and recycler were spoken to. Next to this, multiple site visits with the account manager for a building analysis are conducted to validate this process. Also, a site visit to one of the recycling plants was organised to identify all steps during this process from the transport of the deconstruction site to the recycling plant. The process chain model is created in a Business Process Model Notation (BPMN) model. For the BPMN model the standards and notation from Owen & Raj, (2003) are taken into account.

4.3.1.4. Data analysis barriers

To analyse the barriers as identified in the qualitative interviews, they were categorized in the same five themes as in the literature, namely: process, social, financial, regulatory and quality & quantity. If the stakeholder identified a barrier, it is written down and an X-mark is noted in the column of that particular stakeholder, this is done for all identified barriers.

Next, to compare the interview barriers with the barriers from the literature, a simplified House Of Quality (HOQ) table lay-out is used as shown in Figure 21. The HOQ approach is often used for comparisons and finding relations (Clausing & Hauser, 1988). The roof contains the most critical information in the HOQ table and shows which interview barriers do have overlap with each other within a relation of a literature barrier.

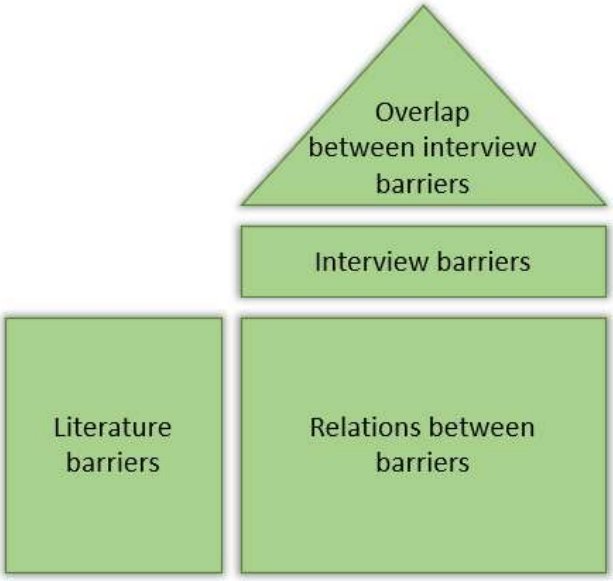

Figure 21 Description of the HOQ

4.3.1.5. Data analysis user requirements

For the user requirements, a User Requirements Document (URD) was created. In a URD a general description is given of the product and the specific requirements are described. An URD was created to make sure the application meets the users' needs, it needs to be understood, captured, and agreed upon. Creating an URD makes sure that all parties know what is required and communicating by such a document is critical for expectation management.

4.3.2. Design and development

This section describes the techniques and frameworks used for the design and development of the application. In Section 4.3.2.1. two software development techniques are examined for the development of the application. Secondly, the scripting framework architecture is discussed in Section 4.3.2.2. Lastly, in Section 4.3.2.3. the Application Programming Interface (API) for the application is explained.

4.3.2.1. Development techniques

For the development of the application, two software development techniques are examined. A traditional System Development Life cycle (SDLC) method (Biesemans, Horsten, & Deroose, 2010; Hassan, Qamar, & Idris, 2015), also known as the Waterfall Model approach, and the Rapid Application Development (RAD) method are both examined to find the most suitable method for the current project. In Figure 22 the traditional system development process is shown at the top and underneath it, the RAD process is shown (Biesemans et al., 2010). Based on the following arguments it was chosen to use the RAD method:

- The RAD method aims at fast application development, due to time restrictions of the graduation project this is important. A direct start of the application with RAD is possible, the method concentrates on the functionality and performances to enable faster outcomes. The design has not to be written down in detail before starting with the application.
- With the iterative prototype cycles, the developer is closer to the end-user, communication is improved, risks are reduced and higher user satisfaction is achieved.
- The RAD method is in line with the chosen engineering research cycle, which is on itself highly iterative.

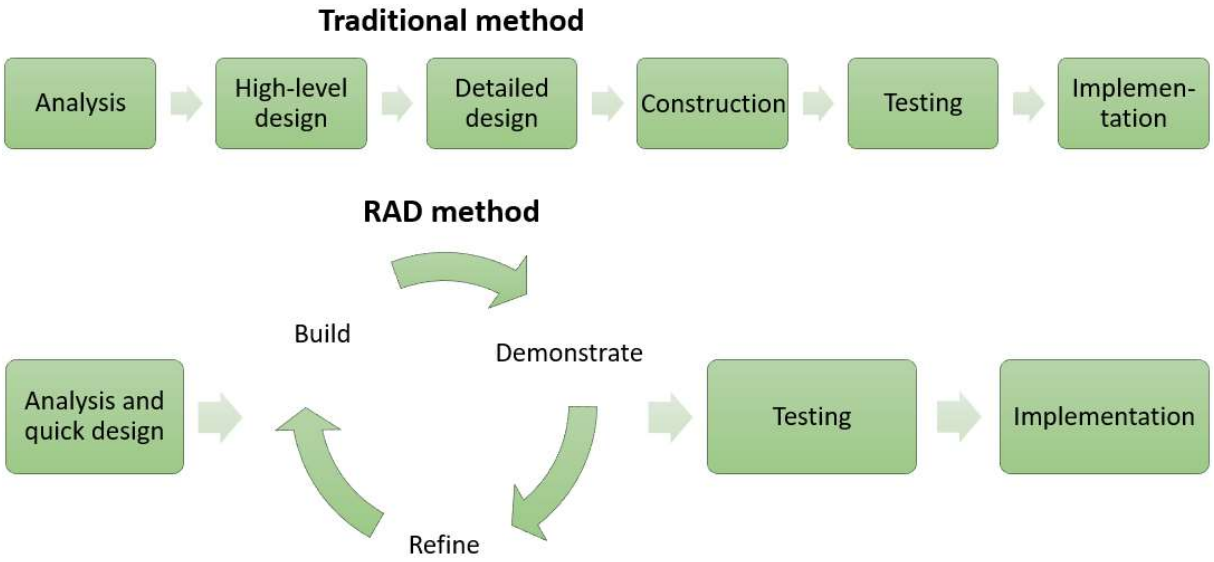

Figure 22 Traditional system development vs RAD method (Biesemans et al., 2010)

The RAD method has four typical phases: analysis and quick design phase (1), prototype cycles phase (2), testing phase (3) and the implementation phase (4) (Abd Ghadas et al., 2015).

In the first phase, the analysis and quick design phase, the requirements and goals of the application are collected, based on these requirements and goals the functions of the system

can be determined. This phase of the process includes deciding what programs and databases need to be used, which is then visualised in a system architecture diagram. In this phase also a quick design is made to determine the design of the interface and required data. It is important to understand the requirements of the system before beginning with the second phase of prototyping. The second phase is a repeated process of the prototype development phase, which includes building development, demonstrating and refining. The prototype will be developed in close contact with the end-user which will lead to multiple iterations of the circle. In this phase, the prototype will be developed and includes everything from programming the front-end and back-end, making a user-friendly interface and programming the script for the controller of the application. When the system is error free and the requirements are met, the proof of concept is complete and can be tested in phase 3, testing. In the test phase, the application is evaluated, validated and necessary adjustments are implemented in the system. The validation phase will increase the value of the prototype and therefore will increase the success rate of implementation. The last phase, phase 4, is the implementation phase, where the system will be implemented in the market when the validation gives a successful result. However, the implementation phase will be kept outside of this research.

4.3.2.2. Scripting framework architecture

Based on the requirements for the application a scripting framework is determined. The Model View Controller (MVC) architecture is a commonly used and powerful architecture approach for Graphical User Interfaces (GUIs). The MVC architecture paradigm is a way of breaking an applications interface into three parts, namely: the model, the view and the controller (Ceccaroni & Verdaguer, 2014). Figure 23 shows the relations between the three components and the user of the application. The user sees and uses the view of the application. If the user makes a request in the view, the controller is responsible to react to the request of the user. The controller then manipulates the model which includes the databases. Next, the model interacts back to the controller who updates the view and represents this to the user.

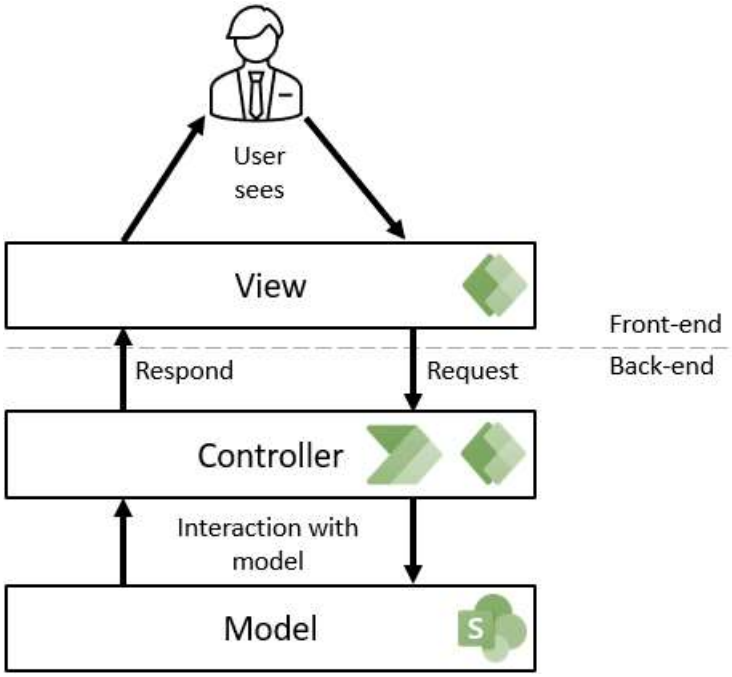

Figure 23 Model View Controller (MVC) Framework

The application script is structured using the MVC framework. The MVC framework provides the connection between the view (front-end) of the application, with the controller (to interact with the model) and the model (back-end). The model is responsible for storing the data and allows us to work with the data. The model consists of all non-graphical information in the database. The view consists of all user interfaces, which are operated and consulted by the user during the process of using the application. The controller is the middleware and the connector, based on the requests of the user in the view, the controller manipulates data in the model. Due to the controller, the view and the model can work together and interact with the data, as previously shown in Figure 23.

4.3.2.3. Application programming interface

The application programming interface (API) is a set of subroutine definitions, protocols and tools for building application software (Foster, Kesselman, & Tuecke, 2016). The API can be seen as a messenger, where the API receives a request, tells the system what activity to execute and sends back a response.

The application is developed by using low-code development platforms. Low-code environments were firstly composed by Rymer & Richardson (2014), who stated that firms prefer low-code alternatives to produce a flexible, cost-effective and rapid application in a model-driven way. Low-code platforms are ecosystems in which apps can be developed that are minimizing complex manual hand-coding because standard functions are already built and predefined. This benefits the rapidity and agility of the development of the application and can be created and maintained by someone without complex technological background. The low-code environment allows the developer to create applications for mobile or desktop devices that are multifunctional and with high information-management capabilities. Lastly, by using the low-code environment the proof of concept can be demonstrated without large

investments (Sanchis, García-Perales, Fraile, & Poler, 2020). After a positive proof of concept, the applications can be easily further elaborated and adapted to further enhancements.

The application will be developed in the Microsoft Power Platform, a so called low-code environment. PowerApps is chosen to develop the application because it is a low code development program, working in the secured Microsoft environment. The connection with Microsoft is necessary to get the system applicable for the graduation company. Power Automate is used to automate complex workflows that are not possible to script in PowerApps. Both platforms together are suitable for dynamic prototype creation. The language used in PowerApps and Power Automate is Microsoft Power FX. For the model, SharePoint lists are used to demonstrate the proof of concept. SharePoint lists can be easily linked within the Microsoft Power Platform.

PowerApps has the advantages of its low-code environment, where the main structure is set by adding components by drag and drop functionalities. After the main structure is set, adjustments can be made by using basic, Excel-style formulas. These formulas can be chosen from the property list; where functionalities like *'OnSelect'*, *'Colour'* of each specific item, *'visibility'*, but also *'width'*, *'height'* and positioning like the *'X-as'* value can be determined. PowerApps has an intuitive structure and due to the small pieces of code easy understandable.

Power Automate allows to automate (complex) processes which are harder to code in PowerApps. Power Automate is like PowerApps a low code environment, wherein step by step each item is coded with small pieces of code. A *'button'* in PowerApps can be used as trigger to start the flow process. Each action can be coded separately and if all actions are included, the output can respond in the PowerApps environment in a *'list'*, *'gallery'* or *'text input'*. Power Automate allows for debugging codes in the test menu.

Next to the positive sides of the Microsoft environment, there are also downsides. The Microsoft environment is not compatible with any other code yet and it is not accessible for others outside the Microsoft environment. Plus, SharePoint lists is a too rigid data storage environment.

NOTE: The student also made a mobile application in MIT app Inventor, another low-code environment. However, due to security reasons and making the application applicable for the graduation company, the student moved on towards PowerApps, which has more functionalities than MIT app Inventor and can communicate with other Microsoft Apps. Another reason to switch to PowerApps is that the MIT app Inventor was only available on Android and not in an Apple environment.

CHAPTER 5.

Qualitative interviews

5. Qualitative interviews

In this chapter the results of the qualitative interviews are divided in three domains. Namely, the process from decision to demolish until the use of reusable building products in a new building (Section 5.1), identifying barriers in the current process of reusing a building product (Section 5.2) and lastly determining user requirements for the application to overcome the barriers (Section 5.3). Additionally, other relevant findings from the interviews that are not mapped in the three domains will be described as well in Section 5.4.

5.1. Process chain analysis

Based on all interviews, site visits and discussions with intern people from the deconstruction company a BPMN scheme is developed to show the process from decision to demolish until the use of reusable building products in a new building. For the BPMN model the standards and notation from Owen & Raj, (2003) are taken into account where all stakeholders have their own swimming lane. The entire process, as derived from the interviews, site visits and discussion is shown in A1 format in Appendix 4.

Two important phases are further described in detail from the BPMN scheme of Appendix 4, where the swimming lane of the graduation company, Beelen (NEXT), is divided into the relevant job functions with each their own swimming lane. In Figure 24, phase A is shown in detail with the tender process of the deconstruction company. In the tender process, the account manager of the deconstruction company is contacted by the calculator if there are reusable products in the building. If this is the case, the reusable products are inventoried by the account manager by a site visit, together with the calculator. The account manager makes photos and takes measurements of all products that they assume to be reusable, dismantlable and viable to reuse, based on their expertise. After the site visit, the account manager uploads all photos from their phone to the computer, where they are placed in a Word document and some details about the product are added. This process is shown in the orange box of Figure 24.

After phase A, shown in Appendix 4, the tender is won by the deconstruction company and the contract is signed. Next, the reusable products are further described in a Word document. Afterwards, all information is written in an Excel file which is then uploaded to the existing web-shop of the deconstruction company. Afterwards, the products can be sold online. The current process has clearly several redundant, time-intensive steps. During this process, the work preparation team is setting up a deconstruction safety plan for deconstruction and demolishment which needs to be approved by the contractor of the deconstruction project and the government. After approval and selling the product to the architect or contractor of the new building phase B starts, in which the deconstruction and demolition process and storage and transport on site of the reused product is shown.

In Figure 25, phase B is shown in detail, which includes the process from the granted permit by the government until the reuse of building products in a building. Before the mechanical demolition, reusable products are dismantled by the dismantling team.

When the reusable product is sold, it can be transported to the new location after dismantling from the deconstruction building where it is stored on location before the product is installed. The storage on location can be done by the client himself or a storage container by the deconstruction company. The client can also store the product temporary on one of the circular building hubs.

In case the reusable product is not sold, the account manager estimates whether the product will be sold in the next months. If the answer is no, the product will be sorted with the materials from the selective mechanical demolition and these are recycled, which is a low ranked R-strategy. If the answer is yes, the product will be transported to one of the circular building hubs and stored until it is sold.

Once all reusable products have been dismantled from the building, the selective demolition phase can begin. However, during this phase, non-inventoried reusable products may appear, such as reusable cable boxes from above the ceiling. In such a situation, the foreman contacts the account manager to visit the deconstruction site and to inventory the reusable products. These products are added to the project document and web-shop. This process is shown in the orange box in Figure 25.

It can be concluded that the full process of inventorising products is inefficient with many unnecessary, time-consuming steps.

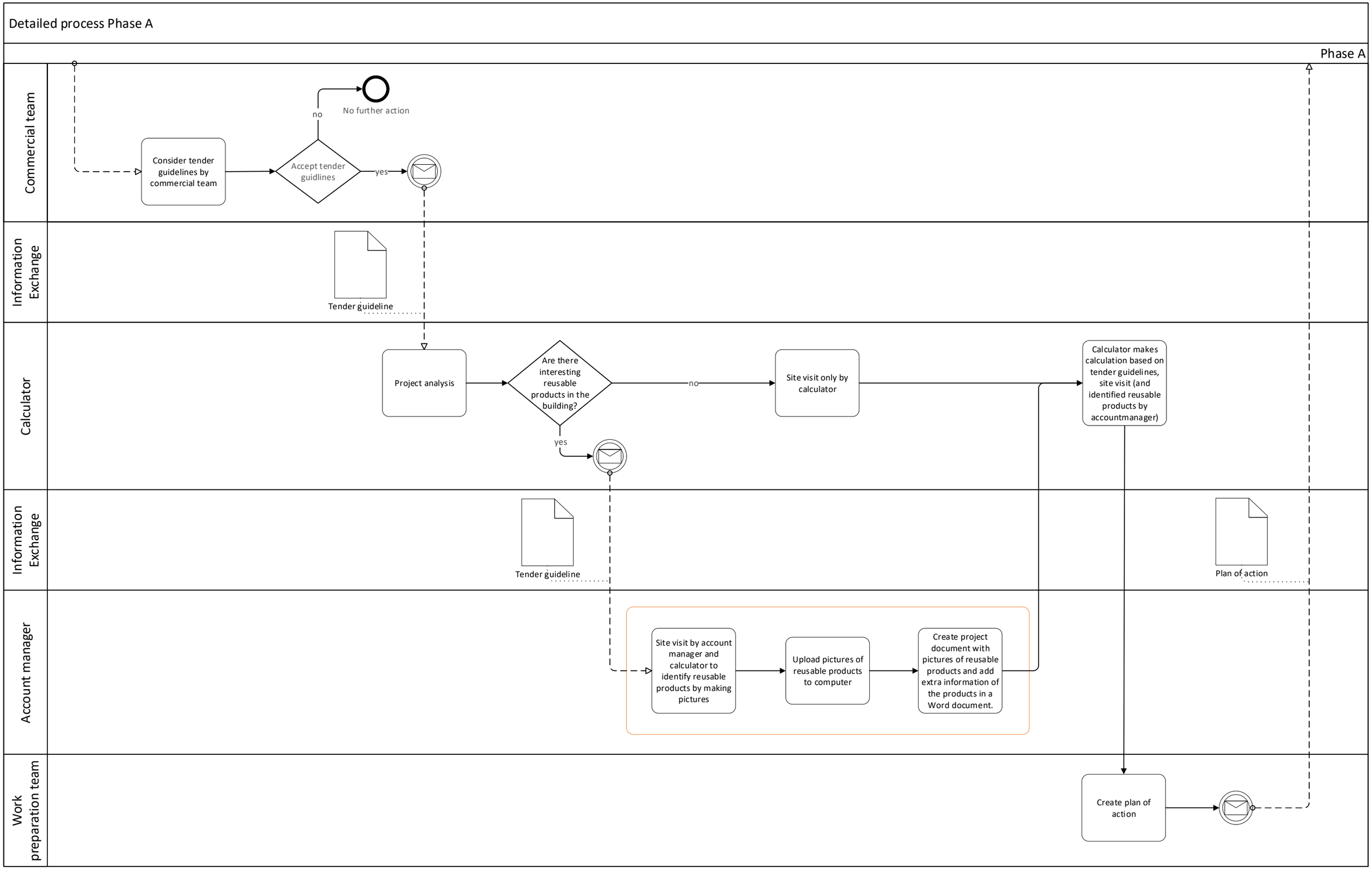

Figure 24 BPMN scheme phase A

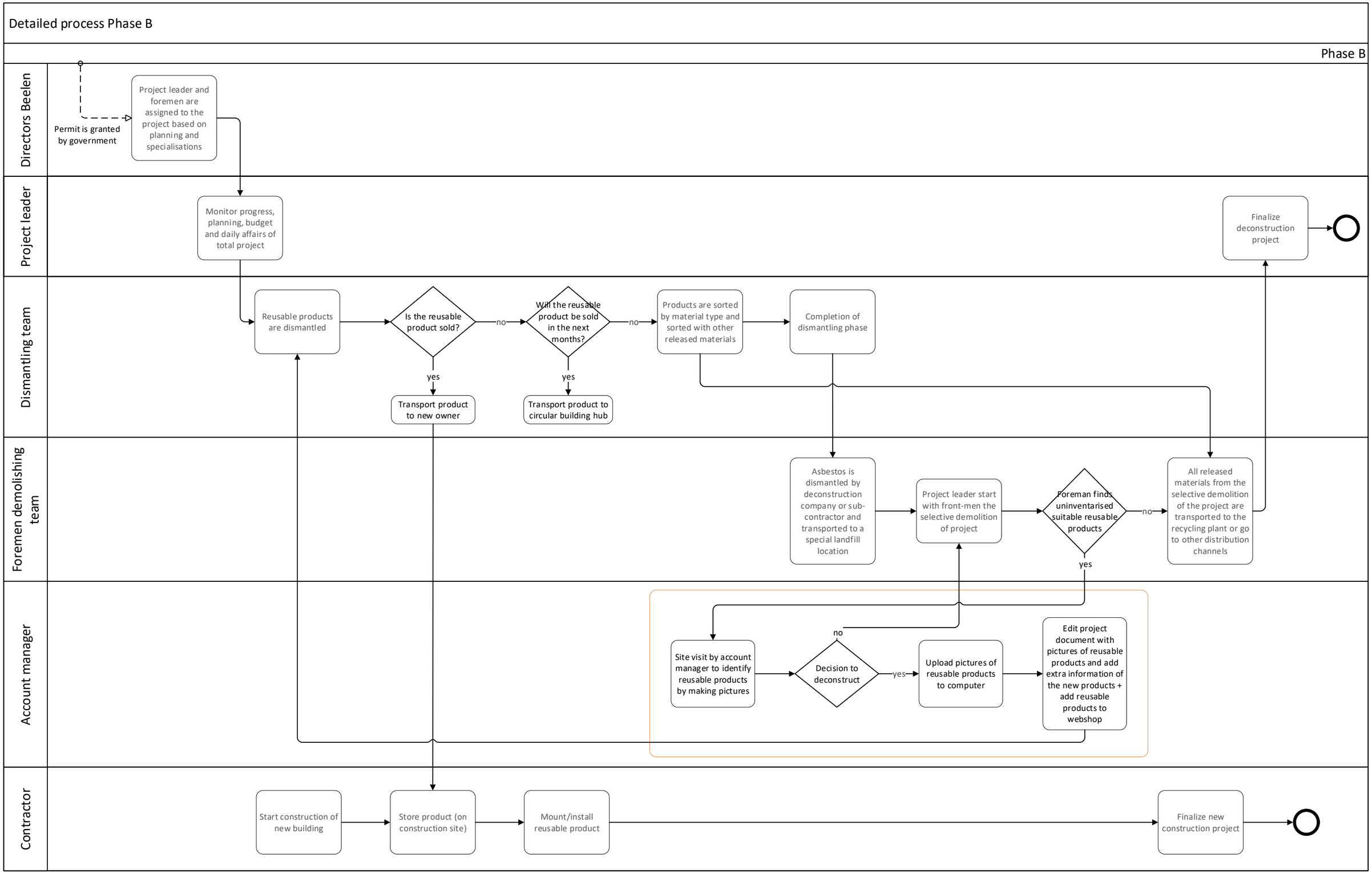

Figure 25 BPMN scheme phase B

5.2. Barriers of reuse

From the conducted interviews, barriers in the current process of reusing building products are identified. These barriers are divided in the same five themes as the barriers identified in the literature, namely: process, social, financial, regulatory and quality & quantity. The barriers identified during the interviews are shown in Table 5. An X-mark is written down if the stakeholder identified the problem during the interviews. In Table 6 the barriers from the interviews are compared with the barriers from the literature by a House Of Quality (HOQ) approach. An X-mark is written down in this table if the barrier from the literature matches a barrier from the interviews. Multiple X-marks per literature barrier indicate an overlap in interview barriers. Such an overlap indicates that there is a relationship between the barriers from the interviews and an X-mark is written down in the roof of the HOQ diagram. The interview barriers which have two interview barriers relating to them are further discussed below Table 5 and 6.

Table 6 Barriers of reusing building products from the interviews

Code	Barriers / Stakeholders	Architects & designers	Contractors	Project manager & superintendent	Deconstruction company
	Process				
P1	Buildings and products are not built with the design for disassembly techniques. This makes the disassembly sometimes a challenge in the process of dismantling the products.			X	X
P2	Architects and contractors are contacting the deconstruction company too late in the process.		X	X	X
P3	Lack of cooperation between deconstruction companies.	X	X	X	X
P4	Time schedules of deconstruction sites and construction sites often are not in sync with each other. Which often led to temporarily storage of a product by the deconstruction company or client.	X	X	X	X
	Social				
S1	The contractor and architect are not stimulated to build and design with reusable products. The desire to design and build with reusable products comes currently from enthusiastic clients. A government can play also a major role here.		X		X
S2	The flexibility of the architect and contractor. The architect and contractor need to be flexible if they want to reuse a product. A product is rarely an exact fit, if a door or window is slightly bigger or smaller than the architect and contractor need to be flexible in the design if they want to reuse the product.	X	X	X	X

S3	Decision making of clients/architects/contractors/ governments of reusing building products. Often approval and permit procedures are a barrier to take the risk of buying/reserving a reusable product.		X		X
	Financial				
F1	Valuable reusable products are often not dismantled because deconstruction is often more time-consuming than selective demolishment. Therefore clients of the deconstruction company sometimes don't give a timespan for deconstruction work. Clients/investors mainly focus on their sales rather than sustainability.		X		X
F2	Reusable products are not always of good quality, therefore direct reuse is not possible. Refurbishment or repairing is a good alternative. However, refurbishment or repairing can have high labour costs.	X		X	X
F3	Raw material prices are too cheap and not a fair price is paid.			X	X
	Regulatory				
R1	The regulatory increasing standards of products which makes direct reuse not possible for some products.	X	X		X
R2	There are many incentives in the built environment for the circular economy, however there are no norms from the government about reusable products. Therefore stakeholders can be hesitant and not informed of all developments.		X		
R3	There are no guarantees on reusable products. For new products there is a list of papers with all specification and requirements, for deconstructed building products this is not the case.		X	X	X
	Quality & quantity				
Q1	It is hard for an architect/contractor to find the right reusable product online, due to the high amount of webshops with low supply and lack of information on products. This process to find suitable reusable products costs a lot of time and energy.	X	X	X	X
Q2	Lack of information/specifications of products, only visible detectable information is identifiable. e.g. fire resistance or acoustic values are often not visible detectable.	X	X		X
Q3	The dismantling of products, selling them and transporting to the new construction site is not a common practice and therefore unstandardised and inefficient. Therefore more time is required for organisation, communication and checking the technical feasibility.	X	X	X	X

Table 7 Comparison barriers of reusing building products literature and interviews

	Barriers from interview Code / Barriers from literature	P1	P2	P3*	P4*	S1	S2*	S3	F1	F2	F3	R1	R2	R3	Q1*	Q2	Q3*
Process	Strict deadlines cause limitations to deconstruction of valuable products.									X							
	Lack of collaboration between deconstruction companies itself.			X											X		
	Lack of standardisation in the total process, causing higher costs and more time.														X		X
Social	The client has a negative perception, awareness and motives regarding reusable products.					X											
	Lack of culture for saving resources and making optimal use of a product.					X											
	Lack of knowledge and information concerning the possibilities of reuse among the value chain.												X				
	Lack of leadership to lead the process of using reusable products in a building.							X									
	Reusable products do not contain guarantees.													X			
	The construction sector itself has a conservative nature, uncollaborative and adversarial, which restrains innovation.																
Financial	Deconstruction costs tend to be higher than demolition costs.								X								
	The price of reused products should be cost attractive compared to new products, this is not always the case.	X								X							
	Low virgin material prices.										X						
Regulatory	Lack of a consistent regulatory framework for the circular economy.												X				
	Laws and regulations can obstruct the use of reusable products.											X					
	Lack of incentives to boost the circular economy in the built environment.												X				
Quality & Quantity	Inconsistency of quality of products.	X															
	Lack of dimensional coordinates of reused products.															X	
	Not all reusable products are extracted from the stock due to storage space and willingness to store the products.				X												X

* = Barrier is identified by all interviewed stakeholders.

In Table 5 a total of 16 barriers are identified by the stakeholders. Some barriers are identified by only one or two stakeholders, a barrier is then taken to be profession-specific. When all stakeholders identified a barrier, it probably signals a larger, commonly shared barrier in the construction sector. Solving these commonly shared key barriers will stimulate the process of reusing building products.

Since all interviewed stakeholders had some sort of experience with reusing building products not all barriers from the interviews could be directly referred back in the literature. Two barriers of the interviewees couldn't be linked back to the literature, these are barriers P2 and S2. Only one barrier from the literature did not come up in the interviews and that is about the conservative nature of the construction sector, which is probably because only stakeholders from the construction sector are interviewed.

From Table 5 and 6, four main barriers in the current process can be identified. These barriers were identified in the literature review and have two interview barriers relating to them, shown with the X-marks in the roof of Table 6. These four barriers are described in more detail below:

1. **Lack of collaboration between deconstruction companies (barriers P3 and Q1).**
   There is a lack of collaboration between deconstruction companies in the market for reusable building products. All deconstruction companies have their own web-shop with their own products. Therefore, it is difficult and time-consuming for an architect or contractor to find the most suitable reusable products online. This is because they have to search through a large number of web-shops with each a small range of products. This process of finding the right reusable product is both time and energy consuming. Both barriers, P3 and Q1, are identified by all interviewed stakeholders. Therefore, this is seen as one of the key barriers in the process of reusing building products.
2. **Lack of standardisation in the total process, causing higher costs and more time (barriers Q1 and Q3).**
   There is a lack of standardisation in the process of reusing building products. In the inventarisation there is a lack of information on products and a lack of consistency. Next, the dismantling of products, selling, storing and transporting to the new construction site is not a common practice. For each project or even product, a different method is used. Therefore the process is inefficient and requires a lot of communication between both parties. This lack of standardisation increases the price of reusable products and is time-consuming for both the deconstruction company and the architects and contractors. Both of the barriers, Q1 and Q3, are identified by all stakeholders in the interviewees. Therefore, this is seen as one of the key barriers in the process of reusing building products.
3. **The price of reused products should be cost attractive compared to new products, this is not always the case (barriers P1 and F2).**
   In the past, buildings and products were not built with the design for disassembly techniques. This makes the disassembly of some products a challenge because the reusable product should be prevented from getting damaged. The reusable building

products are not always of good quality, therefore direct reuse is not always possible. If this is the case, refurbishment or repairing is a good alternative. However, both options do increase the costs of the products due to high labour costs. Both of the barriers, P1 and F2, are not identified by all stakeholders in the interviewees. However, costs often play a major role in the process of choosing a product and therefore will be taken into account.

4. **Not all reusable products are extracted from the stock due to storage space and willingness to store the products (barriers P4 and Q3).**
   Lastly, not all reusable products are extracted from the deconstructed building. This is because the time schedules of deconstruction sites and construction sites are often not in sync with each other. This often results in temporary storage of a product by the deconstruction company or client. The willingness of clients to temporary store a reusable product is low, and the transport methods of the product from the deconstruction site to the new construction site are also not common practice and is therefore unstandardised and inefficient. Therefore, more time is needed to organize, communicate, and verify the technical feasibility of the reusable product. Both barriers, P4 and Q3, are identified by all interviewed stakeholders. Therefore, this is considered as one of the key barriers in the process of reusing building products.

It is not surprising that most of the barriers that are identified by all stakeholders do also have a relationship in the HOQ in Table 6 with another barrier. These are the best-known and most urgent barriers to solve. Therefore it is suggested to the construction sector and further researchers to focus on the four above barriers to solve. In this research the goal is to improve the process and stimulate the use of reusable building products. Due to the large scope of the barriers, not all barriers can be solved in this research. Therefore it is chosen to focus on main barrier two and in this barrier to focus on the deconstruction process and the matchmaking between the deconstruction company and architect/contractor.

With a positive proof of concept at the graduation company, the application can be further developed to make it usable for all deconstruction companies. This will lead to more collaboration between deconstruction companies, more harmonisation between product passports and solve main barrier one.

There is one barrier that is identified by all stakeholders and has no relationship with a barrier from the literature. This is barrier S2, which says: ”Flexibility of the architect and contractor. The architect and contractor need to be flexible if they want to reuse a product. A product is rarely an exact fit, if a door or window is slightly bigger or smaller than the architect and contractor need to be flexible in the design if they want to reuse the product”. For this barrier it is important to inform architects and contractors correctly and truthfully about the possibilities and advantages of reusing building products. This barrier could be solved through an awareness campaign, the success of Marktplaats.nl could be used for references. This barrier is kept outside the research due to the social context.

5.3. User requirements

It can be concluded from the qualitative interviews that the current data of reusable products is not structured, necessary product information is missing and the data is not manageable. Therefore there is a need to structure the data in a format and link these to product passports to get standardised data. Therefore, based on the process analysis and found barriers, it is chosen to develop two applications, instead of one. Besides the previous mentioned matching application, an inventarisation application is developed to generate data of projects and products in a standardized format. To describe the user requirements of the applications, a User Requirements Document (URD) is developed for both applications. The URD is intended to create a common ground between the parties involved in the project. The URD describes the exact requirements of the user with respect to the software. The document is for both, developer and client, within the project and becomes a mutual agreement between the parties. This is critical for expectation management.

The inventarisation application is designed to register and store project and product information in a structured manner to increase the amount of product information. Next, the inventarisation application is developed to improve and simplify the process of the inventarisation of reusable products. The inventarisation application will be a mobile application to make use on the deconstruction sites available.

The URD of the inventarisation application is shown in Appendix 5_URD inventarisation application.

The URD of the matching application is shown in Appendix 6_URD matching application.

The most important trade-offs to decide to create two applications were:

- The current database of reusable products is not structured, necessary product information is missing and the data is not manageable.
- The application should be available on a mobile application to use during a building inventarisation.
- The inventarisation of products should be simple and not too comprehensive.
- The matching of products should be in a range of measurements and not on exact measurements, to make the scope bigger to choose from for the architect and contractor.
- After a match, there are still questions and discussions about how to reuse the product and what is important to know, therefore only a marketplace is not enough. The deconstruction company is necessary for an advisory role.

5.4. Other findings

Next to the answers to the specific interview questions, also extra relevant information is retrieved due to the semi-structured way of conducting the interviews. In this section, other relevant findings are discussed.

According to the interviews with the deconstruction company, most of the reusable products are currently sold through their network, with phone calls and mailing. The online web-shop is not sufficient, not enough products are sold through there and it is lacking information.

Contractors and deconstruction companies mentioned that the government can play a major role in the promoting of reusable products by:

- Stop taxing reusable products, these are already taxed in the previous building.
- Make a law that the dismantling of a building is permitted. That gives deconstruction companies the time to get all valuable products out of the building and the products that are not good enough for reuse can be selective demolished. This gives more demand for reusable products.
- Paying a fair price for new products, if tax benefits are stopped for new products.
- Paying a fair price for new products, if the CO2 and other emissions will be taxed.

A nice example of the deconstruction company on barrier S2 in Table 5 is given by a general director of a deconstruction company and it is called the sofa example: *"if you want to buy a sofa from Marktplaats.nl. You will never find the exact sofa which fits all the specifications and has the right price. Eventually, we choose the sofa that fits the best on the specifications and price. If you do want the exact specifications you need to go to a sofa shop where you can choose all specifications separately yourself. However, you will pay more for that."*

Based on the above example, in construction, it is the same. You can wait for the exact right reusable product when it becomes available. However, the new construction site also has a timeline, which is seldom synchronic with the deconstruction site. Then you won't find the perfect match in reusable products. If the architects and designers are flexible in the design and if they search in between certain ranges, the demand becomes bigger. Therefore the matching application will not only show perfect matches but also matches within a close range.

If the architects and designers are searching for reusable products they do this from two sides which are both necessary. Firstly, search from what is in the newly designed building and search on similar reusable products for that product in the building. Secondly, look at the available stock and design with those products that become available. When designing from the available stock, the principles of MDD are used.

All interviewed stakeholders are advising that deconstruction companies need to work together and sell their products on one platform. Therefore architects and contractors can choose from a large stock of reusable products and more locally reusable products in circular building hubs can be bought to decrease transport costs and CO2.

Architects and contractors mentioned that it is a job in itself to find suitable reusable products through all the webshops and get all the necessary insights. Therefore the contractor sees the deconstruction company more as an advisory broker to give more information than only visible and also to discuss planning, storage and transport. Only a webshop is not sufficient for a contractor to use a reusable product, the advisory role is crucial to make it work. Often contractors want as much information as possible to make a good comparison. However, the deconstruction company wants to add as little information as possible, because extra information will take more time and costs to inventories and even some information is not detectable.

CHAPTER 6.

Design and development

6. Design and development

Based on the literature review and qualitative interviews, a framework is proposed in Section 6.1 with a design of three applications to improve the process and stimulate the use of reusable building products. In Section 6.2, the inventarisation application is designed and developed to increase the amount of product information and store this in a structured way. The inventarisation application improves and simplifies the workflow of the account manager through a mobile application, which can be used on the deconstruction site. Next, in Section 6.3, the matching application is designed and developed to match products from the database with JSON files of a product from the BIM model of architects and contractors. The matching application is using the data, generated by the account manager, from the inventarisation application. Afterwards, the Power BI dashboard for product management is explained in Section 6.4.

6.1. Proposed framework

Figure 26 shows the conceptual framework of this research with the three applications, with the blue rectangle highlighting the scope of this research. The non-reusable group is kept outside the applications because products from this group are recycled and not sold for reuse. All reusable products that can be dismantled by the deconstruction company for reuse are within the research scope. From the process chain analysis, in Section 5.1, it is concluded that the full process of inventorising products is inefficient with many redundant, time-intensive steps. Therefore the inventarisation application is developed to improve and simplify the workflow of the account manager, shown in the red rectangle in Figure 26. The information of reusable products is inventoried by the account manager on the deconstruction site and contains non-graphical information and photos. This information is stored in an online database. The account manager is inventorising the products on the location of the to be deconstructed building. Therefore the inventarisation application is developed as a mobile application that can be used on every site. From the product data added by the account manager in the database it is possible to create product passports.

The goal of this research is to stimulate and improve the use of reusable products. Therefore matching the reusable products with new buildings is necessary. The matching application has the goal to save the architect and contractor time in searching for the right reusable product. The matching with the stock of reusable products is done by matching non-graphical information retrieved by the account manager with a JSON file with non-graphical product information, generated from the BIM model by the architect or contractor. The matching application is shown in Figure 26 by the green rectangle. By using the product data from the inventarisation application, all product information is stored in the same standard. By importing the JSON file in the application, a similarity match is conducted and the closest matched products in the reusable stock are shown. It is rare to have a perfect match of a product, therefore nearly similar matches are also shown in the matching application. Finally, a Power BI dashboard for project and product management is created to overview and

manage the reusable stock with data from the online database. The PowerBI dashboard for product management is represented by the yellow rectangle in Figure 26.

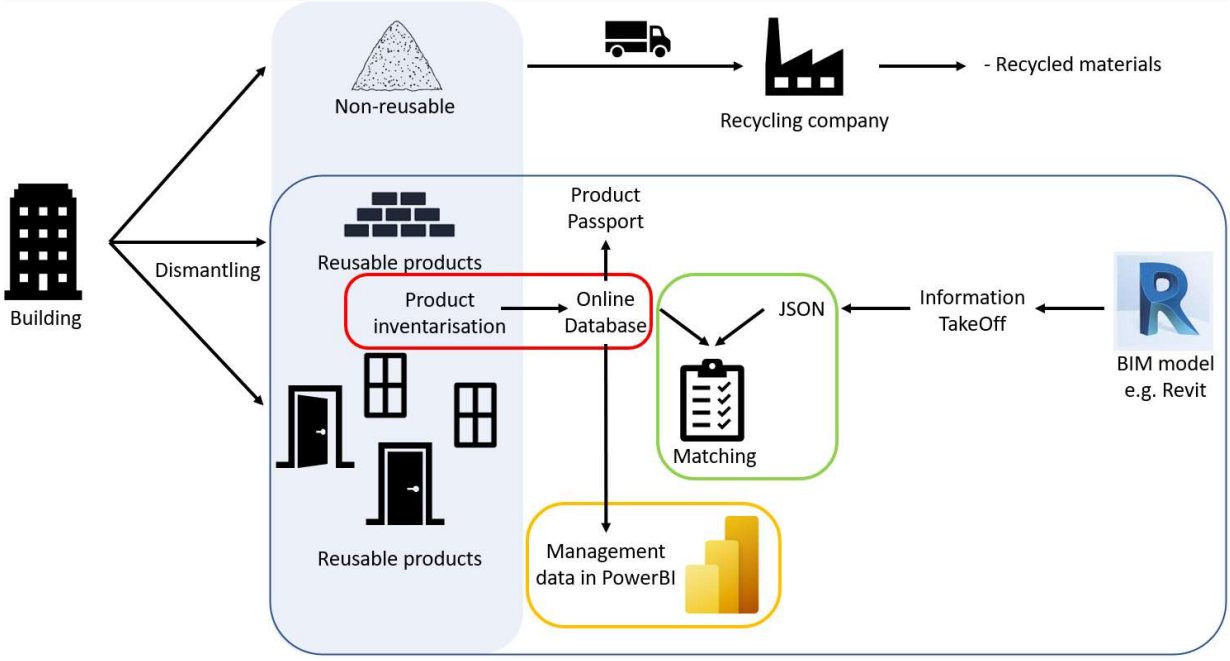

Figure 26 Conceptual framework

The system architecture of the inventarisation and matching application together are shown in Figure 27. All three applications consist of three components that are interrelated with each other:

1. View (front-end)
2. Controller (to interact with model)
3. Model (back-end)

The view for both applications is constructed in PowerApps and takes care of the graphical user interfaces. PowerApps provide a rapid development environment to build custom apps with graphical user interfaces (e.g., buttons, lists and images). This is in line with the chosen RAD method in Section 4.2.2 in the methodology. PowerApps is using a secured Microsoft network and can easily connect to other Microsoft Apps. The account manager and foremen are enabled to use the application and add, edit and remove non-graphical information and photos. After submitting the project or product information the data is passed to the controller.

The controller for the inventarisation application is scripted with functions in PowerApps. The controller is the link between the users view and the model, it interacts with the model and updates the users view after a request. When adding data to the model, the user is pressing a submit button in the view, which is a request to send the data to the model. Next, the controller sends the data to the model (back-end). When the data is sent and stored in the model, the controller responds on the users view with the next screen. All functionalities of the inventarisation application are explained in Section 6.2.3.

For the controller of the matching application also PowerApps is used to script functions. However, the function to parse the JSON file and convert values to interpretable variables to match with the model cannot be scripted in PowerApps. Therefore Power Automate is used to script and automate this workflow. So, the matching application is using PowerApps and Power Automate as controller.

The back-end for both applications was constructed in Microsoft SharePoint lists, which is fully integrated with other Microsoft Apps and contributes to the low code architecture to demonstrate the proof of concept. The controller interacts with the model to add or retrieve non-graphical data and photos. Lastly, the data from the model is showcased in an PowerBI Dashboard for product management.

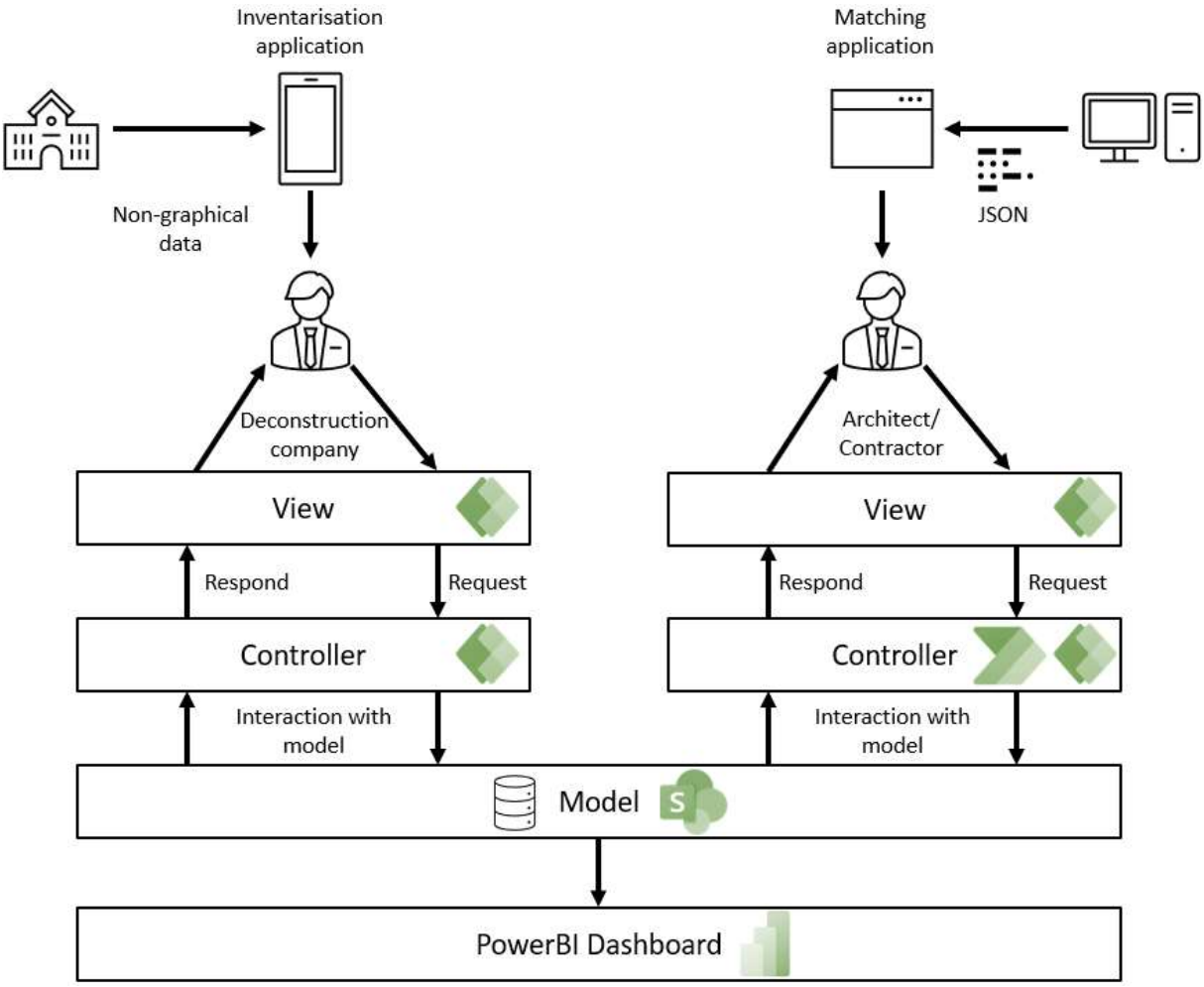

Figure 27 System architecture inventarisation and matching application

NOTE: All three applications are developed in the front-end for the Dutch language. The applications are developed with software in the Microsoft Environment of the graduation company. A barrier to the use of this software is that the main admin settings of the company are in Dutch and therefore all codes are written in the Dutch coding language of Microsoft Power FX, which was not changeable for this project.

6.2. Inventarisation application

The inventarisation application is developed to simplify the workflow of inventorising reusable products and to enrich the application to solve the lack of information to products. To do this, first an investigation is necessary to identify which specifications of reusable products are necessary for the management of the product in Section 6.2.1. Afterwards, the way of storing the data is explained in Section 6.2.2. In Section 6.2.3, the final inventarisation process is explained with a graphical storyboard for demonstration. The user for the inventarisation application is the account manager of a deconstruction company. The requirements of the inventarisation application are explained in Appendix 5_URD inventarisation application.

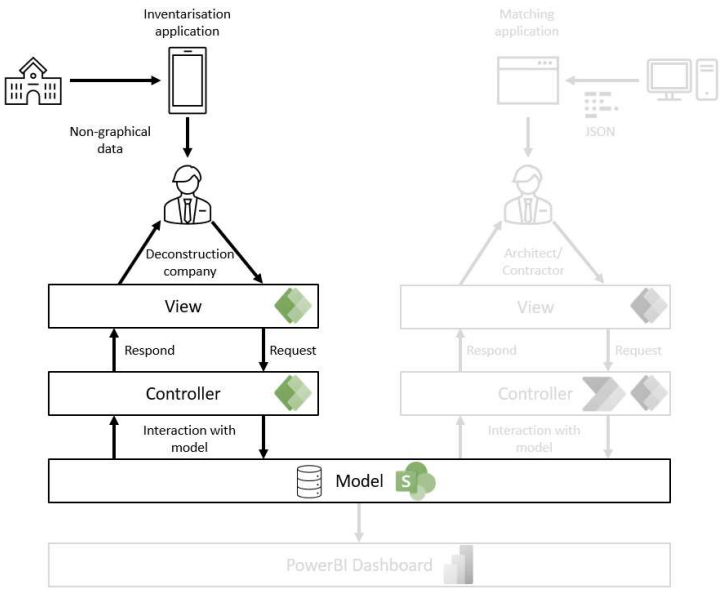

Figure 28 MVC Inventarisation application

6.2.1. Required input

To determine which information in a product passport is necessary, an analysis is conducted of the current initiatives. Adding too much information makes the inventarisation of the reusable product expensive and burdensome; adding too little information causes a lack of matches and uncertainties for the buyers. Therefore, the current passport standard of CB'23 is analysed on its filter 'future', which displays what information should be included with a reusable product for a product passport. Secondly, three current webshops for second-hand marketplaces' information on reusable products are compared to the CB'23 passport standards as well as to each other to gain understanding of the current common practice.

The information included in a product passport provided by CB'23 is shown in Appendix 8_ Product passport CB'23 Filter 'future'. A product only applies for reuse and a product passport if the product can be dismantled and has reusable value. A product has, in general, reusable value if the costs of the reusable product is lower than the new product. Products that are not valuable anymore, due to e.g. short remaining lifetime or hard to dismantle due to glued connections are recycled. The amount of information in a product passport provided by CB'23 is extensive in comparison with the second-hand marketplaces.

As some information is deemed more important than others, it was decided to take the platform CB'23 format as base, but remove or add information from the marketplaces. First, information contributing to selling the product is deemed more important than non-contributing information, so non-contributing information like a yes/no question if the product has standardized measurements and the archive number of the building permit of the deconstructed building were excluded. Second, during the inventarisation, only visibly detectable information is known when creating the product passport, so information like chemical composition and the performed emission tests from the passport of Platform CB'23

are excluded. Furthermore, additional information is necessary to facilitate offering the product to architects and contractors. To identify this information, three common webshops for second-hand marketplaces are analysed and compared to each other in Appendix 9_ Comparison second-hand marketplaces. This analysis showed that there is some common basis information on products, which is offered on all three marketplaces, however most information is not harmonised between the marketplaces. For example, the measurements of reusable products are displayed in cm's at two marketplaces and in mm's on the other. This finding is in line with the first main barrier in Section 5.2, that the webshops are not harmonised with each other.

The preferable process is to dismantle the product and directly transport the product to the new building without storage on a circular building hub to minimize transport emissions. Therefore general project information of the deconstructed building is included, next to the expected dismantling date to give an indication of the product release.

By not including all less contributing information, the ease of use of the application is increased. The included project and product information is shown in Table 8 and 9 underneath. Next to the list of specifications, the unit and an explanation of its importance is given.

Table 8 Project information deconstructed building

Parameter:	**Unit**	**Explanation**
Project_ID	Integer	Unique project ID.
Project_name	Text	Name of the project.
Client	Text	Building owner.
Address	Text 11	Address name and number of the project.
Postal_code	1111AA	Postal code of the project.
Location	Text	The place/location of the project.
Expected_dismantling_date	Date-format	The date the building will be dismantled, to give an indication on when the product becomes available (dd-mm-yyyy).
Description	Text	Description of project activities.
Building_function	Pre-defined list	From interviews this parameter came forward as handy.
Photos	JPEG	Photos are graphical information, however due to the functionalities in SharePoint lists, these images can be saved as text files.

Table 9 Product Information deconstructed product

Parameter:	**Unit**	**Unit, & explanation**
Product_ID	Integer	An automatic generated Product_ID during inventarisation.
Product_name	Text	Name of the product.
NLSfB_code	Integer	The first two digits of the NL SfB code of the product between 10 and 98.
Location	Pre-defined list	The location of the product can be chosen from a pre-defined list:

		- Dismantling site - One of the circular building hubs - Construction site
Material	Text	(Main) Material of the product.
Functional_unit	Pre-defined list	The functional unit of the product defined per piece, mm, m^2 , m^3 or kg.
Count	Integer	Amount of products available.
Length	mm	In mm's to make a match possible between BIM models.
Width	mm	In mm's to make a match possible between BIM models.
Height	mm	In mm's to make a match possible between BIM models.
Surface	m^2	In m^2 to make a match possible between BIM models.
Diameter	mm	In mm's to make a match possible between BIM models.
Cubic_meter	m^3	In m^3 to make a match possible between BIM models.
Brand	Text	The brand of the product.
Price	€/Functional _unit	The price of the product per functional unit.
Expected_lifetime	Integer	Expected lifetime in years.
Quality	Text	Quality of the product.
Description	Text	Used to give extra product specific information, e.g. if a door is cover (opdek) or stump (stomp) and if a door is a left-swing or right-swing door.
Type_of_connection(s)	Pre-defined list	A – Click B – Screw C – Bolt/Nut D – Glue E – Slide F – Weld G – Hook H – Clamp (notation based on CB'23 passport).
Amount_of_connection(s)	Integer	Amount of connections for dismantling.
Dismantling_instruction	Text	Instructions on how to dismantle the product on the dismantling site.
Photos	JPEG	Photos are graphical information, however due to the functionalities in SharePoint lists, these images can be saved as text files.

6.2.2. Model

The prototype version of the inventarisation application is available for the account manager and foremen on the deconstruction site. Both have the accessibility to all functions, no distinctions is made between the roles in the inventarisation application as was also anticipated in the URD.

The data from the inventarisation application is stored in SharePoint lists, which is used for all three applications. To give a good overview of the structure and datatypes in the SharePoint lists, an Entity Relationship Diagram (ERD) is created, shown in Figure 29. Every entity has its own list in SharePoint. If the SharePoint lists database is modified towards an SQL database, the structure would be similar as in Figure 29. The ERD is developed based upon the non-graphical analysis from Section 6.2.1, together with the data analysis of BIM models, discussed in Section 6.3.1. There is a many to many relationship between the entity 'Project' and 'Product', because a deconstruction project exist of multiple building products. After deconstruction the product is reused in another project and therefore a many to many relationship exists. This product passport can then be used for asset management.

A passport consists of dynamic elements and can be edited over time. Therefore the created date, created_by, edited date and edited_by are automatically included in the database on the product list. An example of a dynamic element is the Life Cycle Analysis (LCA)-score, which can be edited over time (Platform CB'23, 2020). For new products this LCA-score needs to be attached, for reusable products this is not included in the CB'23 passport filter 'future'. However, this data can be included by making a connection with other databases like the National Milieu Database (NMD). This can add value to reusable products if the CO2 savings are attached. The connection to external databases is kept outside the scope of this research.

By using SharePoint lists, photos are not an additional separate entity. Each photo can be stored as a separate line of text with a randomly created file name of the image. The maximum number of photos per product is set to eight in the URD, as this was one of the requirements of the account manager.

By using Project_ID as foreign key, this information only has to be inserted once and all products are connected to the building project.

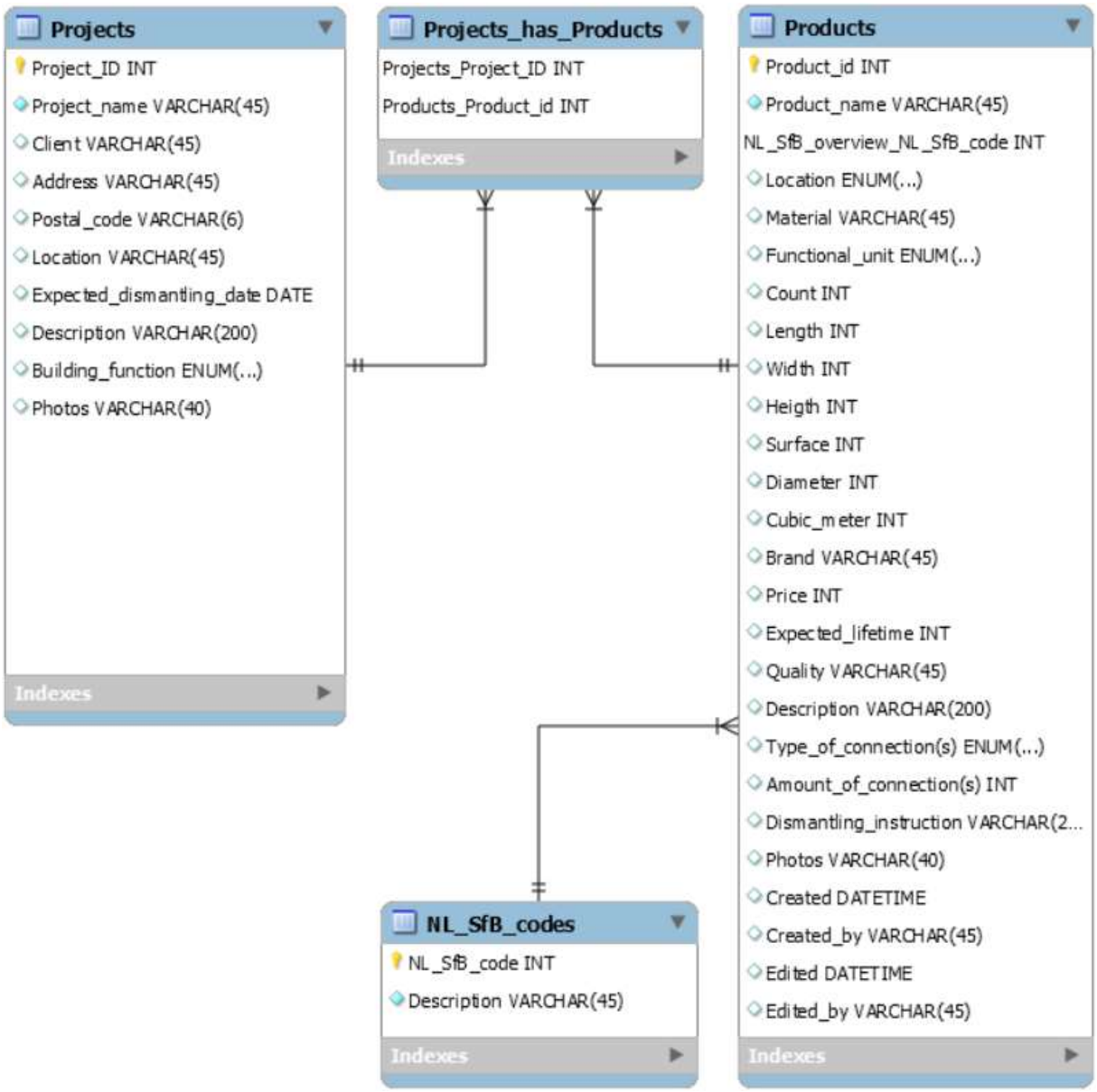

Figure 29 Database structure

The existing datatypes in the dataset of Figure 29 are:

- VARCHAR(xx): character strings, including Unicode of a variable length of xx.
- INT(xx): The integer datatype accepts only numeric values with a length of xx.
- DATE: This datatype stores the date in format ‘dd-mm-yyyy’.
- DATETIME: This datatype stores the data and time in format ‘dd-mm-yyyy hh-mm’.
- ENUM: This datatype has a predefined list of values of which can be chosen.

6.2.3. View & Controller

The process of inventorising and managing the project and product information in the inventarisation application is explained in this section. In Figure 30, the tree structure of the inventarisation application is shown. For clarification, a storyboard was created, representing the UI of the inventarisation application with which the user would interact (Figure 31). This storyboard allowed for evaluation sessions with supervisors and the account manager who is the end-user of the product. The arrows between the views in the application show the possible navigational steps a user can take from each view. View 4 has an iterative arrow because multiple products can be added after each other to the same project. Based on this storyboard the final inventarisation application is developed which is tested with a beta validation with the account manager on location. The beta validation of the inventarisation application is described in Section 7.1.

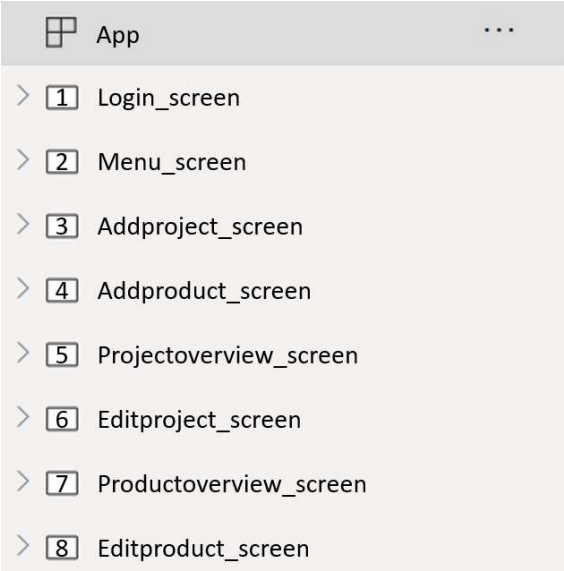

Figure 30 Tree structure inventarisation application

1 & 2 – Login & Menu screen

The mobile inventarisation application can be installed on Apple and Android devices and requires access to the phone's rear camera to use all features. After installing Power Apps, the application is available in the Power Apps environment. When the inventarisation application is opened, the *'login screen'* appears, verifying the employee's credentials. The application then navigates them to the *'Menu screen'*. The *'menu screen'* provide the employee with three options: First, navigation to the *'add project screen'* to add new projects. Second, navigation to the *'project overview screen'* of all existing projects. Lastly, there is a possibility to log out of the system.

3– Add project screen

In the *'add project screen'* a user can add all project details to a project as described in Section 6.2.2. There is also an opportunity to add project-related pictures on project level. The details of a project are attached to all added products. From this screen, the user is able to add products or save the project and go back to the menu.

4– Add product screen

In the *'add product screen'*, the user can add a new product to the project. On this screen all product information including photo's can be added to the product. After finishing adding all product information there is an option to add another product or finish and save the product inventarisation and go to the menu screen. A product inventarisation can be cancelled at any time, then the user is navigated to the menu screen.

5 & 6 – Project overview & Edit project screen

In the *'project overview screen',* all existing projects are shown that are added by the mobile application. In this project overview, a project can be edited, deleted and opened. By clicking on a project, all products of that project are loaded in the product overview screen. Also, there is an opportunity to go back to the main menu. In the edit project screen all information of the project can be edited and saved. After saving or cancelling the edit project screen, the user returns to the project overview screen.

7 & 8 – Product overview & Edit product screen

In the *'product overview screen'*, all existing products are shown that are added to a project. In this product overview, a product can be edited by clicking on the product information or deleted. There is also an opportunity to add new products to an existing project on this screen or go back to the project overview screen. In the *'edit project screen'*, all information of the product can be edited and saved. After saving or cancelling the product information, the user returns to the *'product overview screen'*.

The non-graphical information which can be added or edited in screen 3,4,6 and 8 are created with the form function in PowerApps. In contradictory with the non-graphical information of screen 5 and 7, which are created with galleries, as well as the attached photos of products or galleries. The form function is chosen for editable items that should be added or edited towards the database. The gallery is chosen for non-editable items. By adding a form or gallery, the data source is chosen first, where afterwards the displayed data fields are chosen. Other adjustments, like OnSelect, Visibility, Colour, as well as the edit and delete buttons are coded.

The mobile inventarisation application can also be used by the foremen on the deconstruction site, which will improve the process shown in the current process analysis in Figure 25. With the inventarisation application, the foremen can login in the application and add products to the project themselves. Next, the account manager can consider the product in the inventarisation application. This saves a site visit by the account manager.

The inventarisation application has the possibilities to be used also for other deconstruction companies and even contractors who have reusable building products. This will lead to more harmonisation between the web-shops of deconstruction companies. Which will help solve main barrier 1.

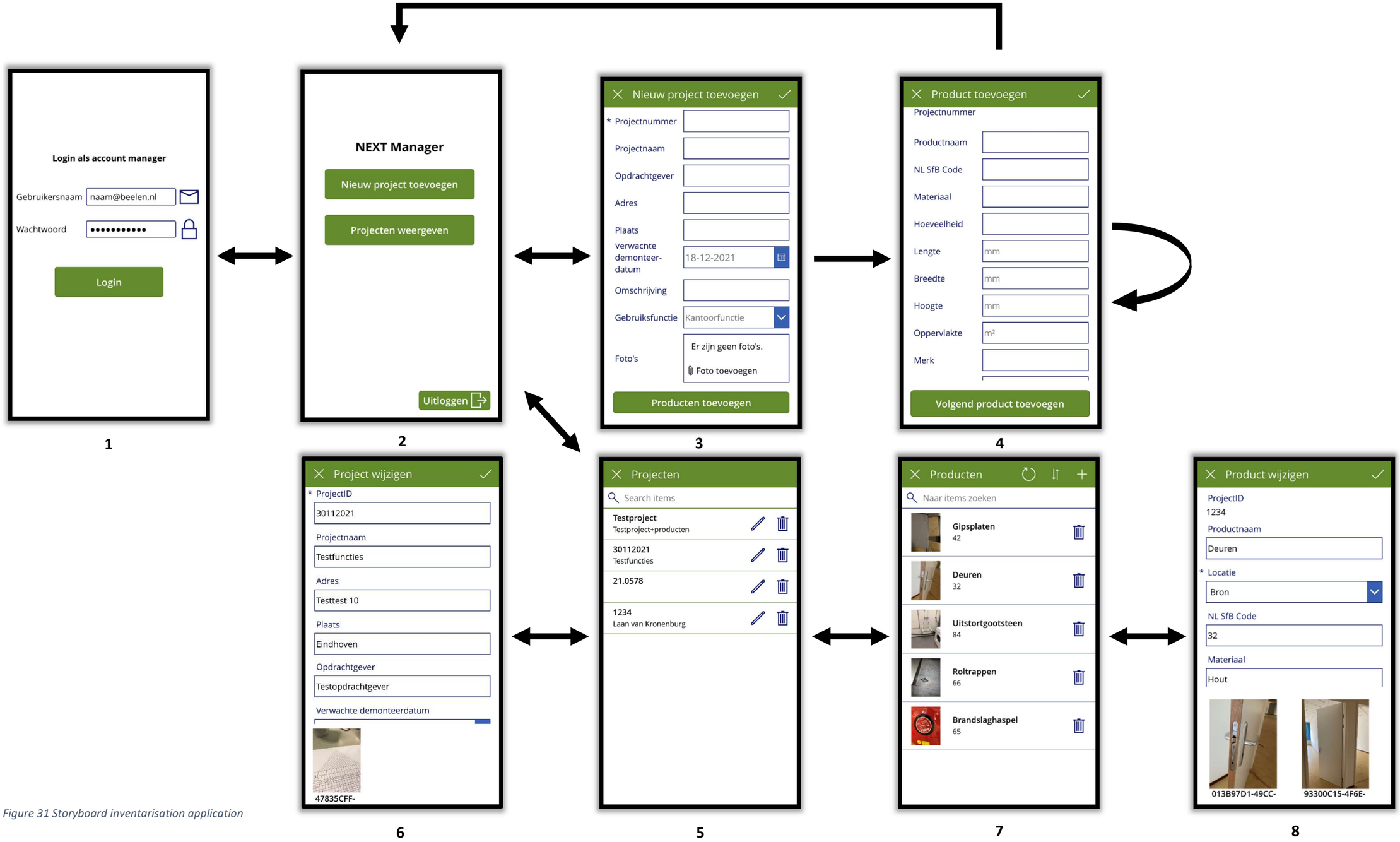

Figure 31 Storyboard inventarisation application

6.3. Matching application

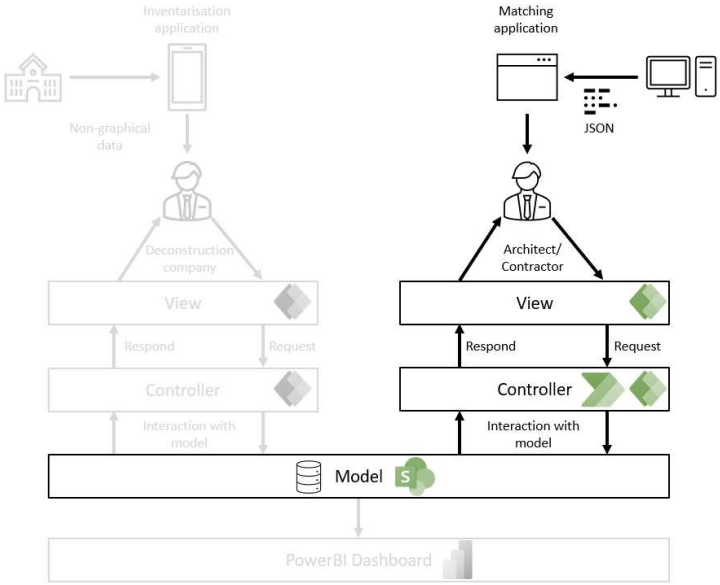

Figure 32 MVC Matching application

Thanks to the inventarisation application, the data of reusable products is now standardized and can be used in the Matching application. The matching application has as goal to match products in the reusable products database with JSON files of a product from the BIM model of architects and contractors. Matching the products in the matching application saves the architect and contractor time in the search for the right reusable product. In Section 6.3.1, a data analysis is conducted to find all usable product information that can be extracted from a BIM model. Next, in Section 6.3.2, the data throughput is explained, how to get the correct JSON file format from a BIM model. Afterwards, in Section 6.3.3, the product matching following the MVC framework is explained. The user requirements of the matching application are explained in Appendix 6_URD matching application.

6.3.1. Data analysis

First, a data analysis is performed to find out how the data in BIM models are structured and whether they are harmonized. For this purpose, three BIM models of architects and contractors were retrieved of partners of the graduation company. The format of these BIM models were retrieved in their exchange format, in an IFC file. Solibri is used as BMC for the analysis of the BIM models. Due to differences in modelling templates, the guidelines of the BIM basis ILS (Information Delivery Specification) were chosen for this study.

The BIM basis ILS consists of a few simple rules for a common base structure to achieve the goal of unambiguous exchange of information in a structured, efficient, and effective manner. Unfortunately, all three BIM models of the partners of the graduation company had different modelling standards and none of them conformed to the BIM basis ILS. Some of these BIM models included the NL SfB code in the 'Uniformat Classification', but none of these BIM models did this consistently and many products even lacked this property. Next, the NL SfB code is sometimes added in the 'Type', which can also be retrieved if done consistently. The NL SfB code is the most important filter. The other parameters such as the 'Bounding box' measurements and 'Type' can be retrieved in all BIM models. Ideally, the information is extracted directly from the BIM software such as Revit. However, the Revit should then by available and the data should be consistently structured according to the BIM basis ILS or another consistent standard. Since this is not the case, the backup model BIM from Schependomlaan is used, which is available in the IFC exchange format. The BIM model Schependomlaan was chosen because it uses the structure of the BIM basis ILS. In this BIM model, all NL SfB codes were clearly and consistently using the 'NL SfB (4 cijfers)'.

The following information is included in the BIM Basis ILS. By following the BIM Basis ILS standards, the following information is similar in all BIM models (which are further explained in Table 10):

1. 3.4. IfcEntity
2. 3.5. Name + IfcType
3. 3.6. NL/SfB
4. 3.7. Pset_EntityCommon
5. 4.5. FireRating
6. 4.7. IfcMaterial

In the interviews with architects and contractors, the fire rating and sound rating are mentioned several times. The 'FireRating' and 'AcousticRating' can be added from the BIM models using the column type property –'PSet_*Entity*Common', where the entity is the entity from the BIM base ILS 3.4. 'IfcEntity'. Where e.g. PSet_DoorCommon shows a common property set for all door occurrences, which all have a property type of 'IfcPropertySingleValue' and Data Type 'IfcLabel'[1]. The 'FireRating' and 'AcousticRating' can be added, however the regulations for reusable products do not specify yet whether they can be directly reused with the same fire resistance or sound insulation values that they had in the deconstructed building. This is a regulatory issue and beyond the scope of this research. Therefore, the 'FireRating' and the 'AcousticRating' are not included in the matching standard.

'IfcMaterial' is not added into the research, because most products consist of multiple materials which are nested into families and unique families in each project are hard to standardise in SMC. If a family is nested, the 'material' property is not included in the properties under the tab 'identification'. If the product consists of a single material, like a steel construction beam, the 'material' property is included. However, material names are often a name devised by the modeller of the BIM model and is not standardised, e.g. for steel construction beams there exists the following differences in naming: "033 – constructief staal", "05 Staal – RAL 7016" and "05 Staal_bordes_hoeklijnen". The BIM Basis ILS developed therefore NAA.K.T. (NAAm, Kenmerk, Toepassing), which means name, feature and application for creating a uniform material naming (BIM Loket, 2021). If NAA.K.T. is applied it is possible to connect the materials from the BIM models to other databases, e.g. LCA analyses, asset management and the matching application in this research.

The data from the BIM models need to be matched with the data from the product passports. Therefore, the analysis is conducted to find what data best can be matched. Next to the matching data, additional data is added in the information take-off set, so that an architect or contactor knows which products from the model can be matched. Therefore, the data from Table 10 are chosen as non-graphical information to retrieve from the BIM models. During the data analysis, multiple products from model Schependomlaan were tested to be sure all matching information is included when using the BIM Basis ILS as standard.

[1] https://standards.buildingsmart.org/IFC/RELEASE/IFC2x3/TC1/HTML/psd/IfcSharedBldgElements/Pset_DoorCommon.xml

Table 10 Non-graphical properties to export

Properties	**Explanation**
IfcEntity	The IFC predefined group, e.g. IfcDoor for doors.
Name	The combination between Name and Type represents what the product is.
Type	The combination between Name and Type represents what the product is.
Component	The component tells more about the product itself, e.g. if the product is a beam or column.
NL/SfB (4 cijfers)	A four-digit code that represents what product category a product is in.
Bounding Box Length (mm)	The length of a product.
Bounding Box Width (mm)	The width of a product.
Bounding Box Height (mm)	The height of a product.
Area (m^2)	The area of the surface, useful for ceilings or floor surfaces.
Volume (m^3)	The volume of a product, useful when reusing building installations like a buffer vessel.
Count	Amount of product occurrences in the model.

During data analysis, it turns out that there are several inconsistencies in the model Schependomlaan. For example, Figure 33 shows two steel beams. For both steel beams, the 'Type' is HEA balk (beam) 18. However, it can be seen from the measurements and the 'Name' that this is incorrect. Inconsistencies are human, so the system should be robust. Therefore, the 'Name' is kept in the properties to eliminate these inconsistencies and allow the user to choose the right element for themselves when matching. Also, some properties provide additional value when using the combination of 'Name' and 'Type'.

IFC Entity	Name	Type	Component	NL/SfB (4 cijfers)	Bounding Box Length	Bounding Box Width	Bounding Box Height	Height	Width	Length	Profile Width	Profile Height
IfcBeam	HEA180	HEA balk 18	Beam	28.11	6,173 mm	180 mm	171 mm			6,173 mm	180 mm	171 mm
IfcBeam	HEA220	HEA balk 18	Beam	28.11	11,000 mm	220 mm	210 mm			11,000 mm	220 mm	210 mm

Figure 33 Inconsistency in Type and measurements

Next, the 'Bounding box measurements' are chosen in this study because the data for the 'Height', 'Length', and 'Width' measurements are inconsistent. For example, in Figure 33, where the 'Height' and 'Width' measurements have not been added, only the 'Profile Width' and 'Profile Height', which are unique to the entity 'IfcBeam'. The next section describes the data throughput from how to go from the BIM model to the JSON file, to upload the product data.

6.3.2. Data Throughput

There is no BIM model exporter to JSON files yet. However, due to the increasing use of JSON files in construction a Revit exporter to JSON file format will be a matter of time. JSON is used throughout the world for exchanging and using data. Building data needs to be available in JSON. When this happens, connections can be created and the data can be used for all types of matching and data management applications. To transform the BIM data towards a JSON

file, several steps need to be taken by the architect and contractor, these are described in this section.

IFC is commonly used for the exchangeability of BIM data between separate models. However, to increase the interoperability of BIM data, the data needs to be available within cloud based formats. Therefore, JSON data is used in the application to match on. The Solibri Model Checker (SMC) is used as software tool for the data analysis of BIM models and generation of the Information TakeOff (ITO). The SMC can provide the architect and contractor with a clear insight of all products within the BIM model that can be selected to match on. The properties from the data analysis are set in an ITO and an example is shown in Figure 34. The ITO, created for this study, can be downloaded for users in the matching application and is available upon request. The ITO can be imported into Solibri and then the user can select the product for which they want to use reusable products.

IFC Entity	Name	Type	Component	NL/SfB (4 cijfers)	Bounding Box Length	Bounding Box Width	Bounding Box Height	Area	Volume	Count
IfcDoor	D1L, D1R, D2L, D2R	32_KD_berkvens_BA	Door	32.31	1,028 mm	173 mm	2,710 mm	2.78 m2	96 l	25
IfcDoor	D1L, D2R	32_KD_berkvens_BA	Door	32.31	1,010 mm	173 mm	2,620 mm	2.65 m2	89 l	6
IfcDoor	D1R	32_KD_berkvens_BA	Door	32.31	1,055 mm	173 mm	2,710 mm	2.86 m2	105 l	1

Figure 34 Solibri columns

The ITO can export the selected products to an .xls file. To convert this data to a .json file, it is required to first convert the .xls file to the comma separated values (.csv) file format. This .xls file can be saved directly in Excel as a .csv file. After generating the .csv file, the .csv file can be uploaded to a publicly available .csv to .json converter (https://csvjson.com/csv2json). Finally, the JSON file can be downloaded from the website. A direct export from the ITO to .csv would increase efficiency. A direct export from BIM software like Revit to a JSON file, would even further increase efficiency. Therefore, an export function in BIM software to the JSON file format should be developed in the near future. This can provide endless possibilities for web-based data transfer and improve the interoperability of BIM data.

After the CSV file is converted to a JSON file, the JSON file looks like the JSON example in Figure 35 when you open it in Visual Studio Code. This example shows two doors with different properties, based on the ITO from Figure 34.

Each JSON file will open and close with square brackets, with all products that are exported inside them. Each product is now written in JSON format within curly brackets. In the JSON format, values as text are written between “quotation marks” and

```
1   [
2     {
3       "IFC Entity": "IfcDoor",
4       "Name": "D1L, D1R, D2L, D2R",
5       "Type": "32_KD_berkvens_BA",
6       "Component": "Door",
7       "NL/SfB (4 cijfers)": 3231,
8       "Bounding Box Length": 1028,
9       "Bounding Box Width": 173,
10      "Bounding Box Height": 2310,
11      "Area": "2,78",
12      "Volume": "0,096",
13      "Count": 25
14    },
15    {
16      "IFC Entity": "IfcDoor",
17      "Name": "D1L, D2R",
18      "Type": "32_KD_berkvens_BA",
19      "Component": "Door",
20      "NL/SfB (4 cijfers)": 3231,
21      "Bounding Box Length": 1010,
22      "Bounding Box Width": 173,
23      "Bounding Box Height": 2420,
24      "Area": "2,65",
25      "Volume": "0,089",
26      "Count": 6
27    },
```

Figure 35 JSON example

values as numbers are written without. If another property or product is added, this is separated by adding a comma.

In the matching application, the square brackets are not required because they are already included in the input file shown in the storyboard in Figure 37 and described in more detail in the next section. Only the product-specific information needs to be added within the curly brackets. Therefore, an architect or contractor can created an ITO, which then can be exported to a JSON file from all the products the user wants to match. However, a limitation in the matching application is that the user can match only one product at a time.

6.3.3. View & Controller

From the conducted interviews it is known that architects and contractors like to search for products in two ways. Firstly, they like to look at the reusable stock and design with those products that become available. Secondly, they like to search from what is designed in the new to construct building and search for similar reusable products for that project. The second search option is the main focus of this research. Within the matching application both search options are created. In this section, the process of matching a product with the reusable product stock is explained. In Figure 36, the tree structure of the matching application is shown. For clarification, a storyboard was created, representing the UI of the matching application with which the user would interact (Figure 37). This storyboard allowed for evaluation sessions with supervisors to optimize the product. The arrows between the views in the application show the possible navigational steps a user can take from each view. Based on this storyboard the final matching application is developed which is tested with an alpha validation in Section 7.2.

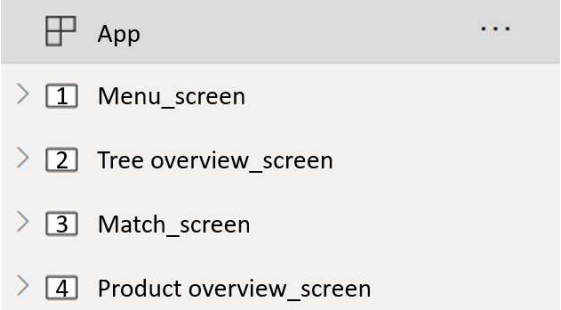

Figure 36 Tree structure matching application

1 – Menu screen

The *'menu screen'* is the first view of the user and the start screen. From here, the user can directly go to the *'tree structure screen'* or to the *'matching screen'*.

2 – Tree overview screen

The available products are all sorted on the NL SfB code in the *'tree overview screen'*. The user can select one of the NL SfB codes with a description from the list on the left side. After selecting a category, all reusable products are shown with their name, NL SfB code for checking and the amounts. When the user selects one of the products, the user is redirected to the product overview screen (screen 5).

3 – matching screen before match

When the user goes to the *'matching screen'*, the user sees a text format where he or she can insert the JSON file. As can be seen, the brackets are already inserted in the text file, so only the product information of one product category between the curly brackets should be added.

This is explained in the information button next to the input screen. Next, after the JSON text is imported, the match button can be pressed.

3 – Matching screen after match

After pressing the match button, the JSON file is send to Power Automate where it is parsed and additional modifications are conducted. Such as the transformation of the four digit NL SfB code towards a two digit NL SfB code. In the inventarisation tool the NL SfB code is manual added to the inventorised product. To make the tool accessible for the end user it is determined to only add the first two digits. Therefore, the matching application only uses the first two digits of the NL SfB code.

After the parsing process in Power Automate, it is send back to PowerApps where it is automatically searching the stock of reusable products within a range of 10% of the product measurements and corresponding NL SfB code. All reusable products with all properties within the range are presented for the user in a horizontal slide show. Every reusable product on the slide show presents the first photo of the product, the name, measurements and amounts that are available. The range of 10% is chosen, together with the supervisor and account manager of the graduation company, to get enough product matches on every inserted product and because the preferred range differs for every product and user. For example, one architect was willing to adjust the ceiling height from the interviews, to fit reusable steel door framing in the project. Another contractor wants the exact door height and is variable in width. Therefore, an *'edit matchings criteria button'* is added, where the user can change the range of each property him or herself after the first match is done, to broaden or narrow the scope. The possibilities of matching are also explained for the user in the information button next to the *'download ITO'* button and *'Match'* button. If a reusable product is selected, the user is directed to the *'product overview screen'* of the selected product.

4 – Product overview screen

On the *'product overview screen'*, all project and product information is retrieved from the model including photos of the reusable product. The project information of the deconstructed project is attached so that the location and deconstruction date is available for the user. With this additional information, the user can determine if the deconstruction and building date are in the same range and if the location is viable to transport the reusable product to the new construction site. When the user selects to go back button in the product overview screen, the user is redirected to the matchings overview screen or the tree structure screen, depending on the taken route to the product overview screen, the previously inserted JSON file or search option is saved for the user. The home button will redirect the user to the home screen and the search screen is refreshed.

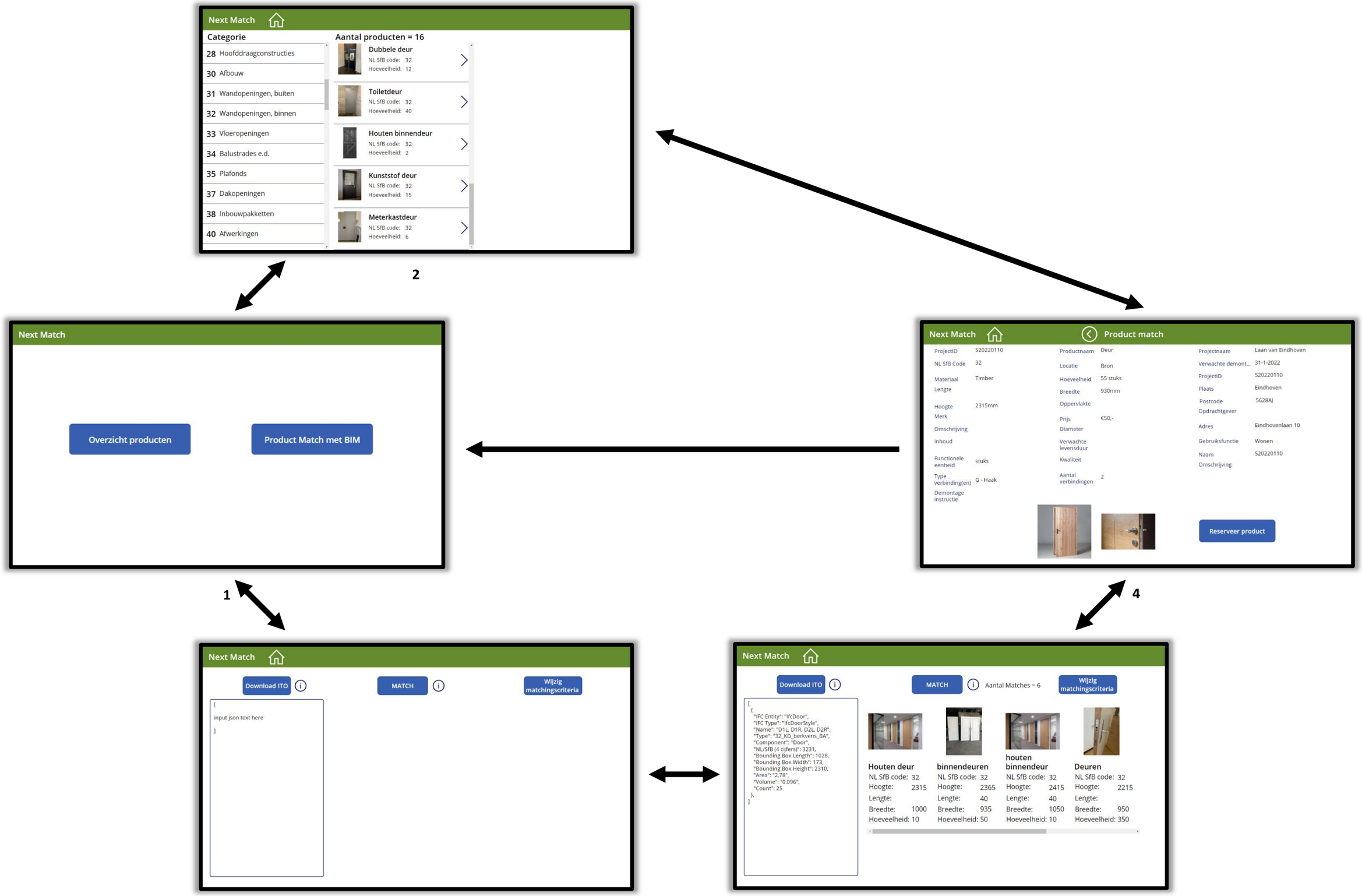

Figure 37 Storyboard Matching application

Export options of PowerApps:

There are possibilities to export the PowerApps code to other PowerApps accounts in a .msapp file format. However this can be only opened in the PowerApps environment. Lately, Microsoft came with a PowerApps source code tool[2], which can export the .msapp file from a PowerApps canvas into a Yet Another Markup Language YAML file. To do this first, the source code tool needs to be downloaded and the GitHub repository needs to be cloned to your desktop to use the PowerApps source code tool. Using this tool let you unpack the .msapp files in the command prompt to editable source files of YAML. These source files can be easily uploaded into GitHub. After editing (in Visual Studio Code or GitHub), the YAML files can be packed in the command prompt towards a .msapp file which can be uploaded into PowerApps. Dunnam (2021), created a detailed step by step video of this method.

YAML is a human-readable data serialization standard that uses the style of Python indentation to indicate nesting and because YAML is a superset of JSON, JSON files are valid in YAML (RedHat, 2021).

This functionality is still in the experimentation phase of Microsoft PowerApps. However, this creates the opportunity to use code editors like Visual Studio Code and use the power of GitHub to search and edit the code. All (YAML) source files are available upon request on GitHub.

6.4. Dashboard product management

The inventarisation application was developed for the account manager. However, to keep track of the inventory of reusable products, the manager should be able to keep track of the process. Therefore, a dashboard is created in Microsoft PowerBI with a connection to the online SharePoint lists. The PowerBI dashboard is a single page canvas which structures and shows the data through visualisations. The PowerBI dashboard helps the manager to monitor the business. For the dashboard for product management all three SharePoint lists (projects, products and NL_SfB_codes) are used to create combinations between data sets. The SharePoint lists form the model for the dashboard. The data is not editable in the PowerBI dashboard. Therefore, in the MVC of the product management dashboard in Figure 38, there is only a single arrow from the model to the PowerBI dashboard. The view and controller are both integrated into the PowerBI dashboard in Figure 38. The user sees the dashboard via the view and can interact with the data by requests, and the controller updates the view after a request.

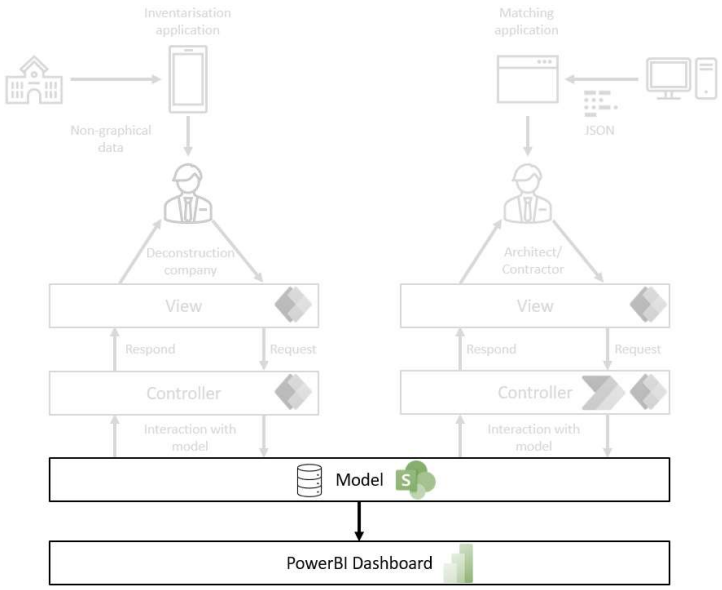

Figure 38 MVC dashboard product management

[2] https://powerapps.microsoft.com/en-us/blog/source-code-files-for-canvas-apps/

The dashboard should provide the manager of the graduation company with information about when to take action. It should show the manager information of all products that are or will be dismantled in the future by the company and show the current statistics. The PowerBI dashboard is not only a visualised picture, but is highly interactive, the figures, tables and maps updates if the underlying model changes and if a data source is selected by the end user.

The dashboard for product management is shown in Figure 39 and displays the following information:

- **Top left:** *The total number of reusable products per location*, which shows how many and what percentage of the total products still need to be dismantled, are at which circular building hub and are already sold and transported to the new construction site.
- **Bottom left:** *The location of products within a project*, showing what percentage of reusable products still need to be dismantled, are stored on which circular building hub and have already been sold and transported to the new construction site.
- **Middle:** *The location of the products per NL SfB code*, showing the number of reusable products per category and their location status if the products still need to be dismantled, are stored on which circular building hub or have already been sold and transported to the new construction site.
- **Right:** *Location of each project with the amount of products,* showing the location of each project on a geographical map. The larger the circle, the more inventoried products are location in that area.

PowerBI's interactive features allow the end user to generate additional information by, for example, selecting the products to be dismantled for a particular project. Selecting this data adjusts the data from the other figures, so can, for example, be determined what products are still to be dismantled in the figure in the middle of the location of products per NL SfB code.

Based on the current data sets, the manager can even discuss the opening of another circular building hub in the south of the Netherlands around Tilburg. This is because the geographic map on the right side of the dashboard in Figure 39 shows that most of the inventoried products are located near these cities.

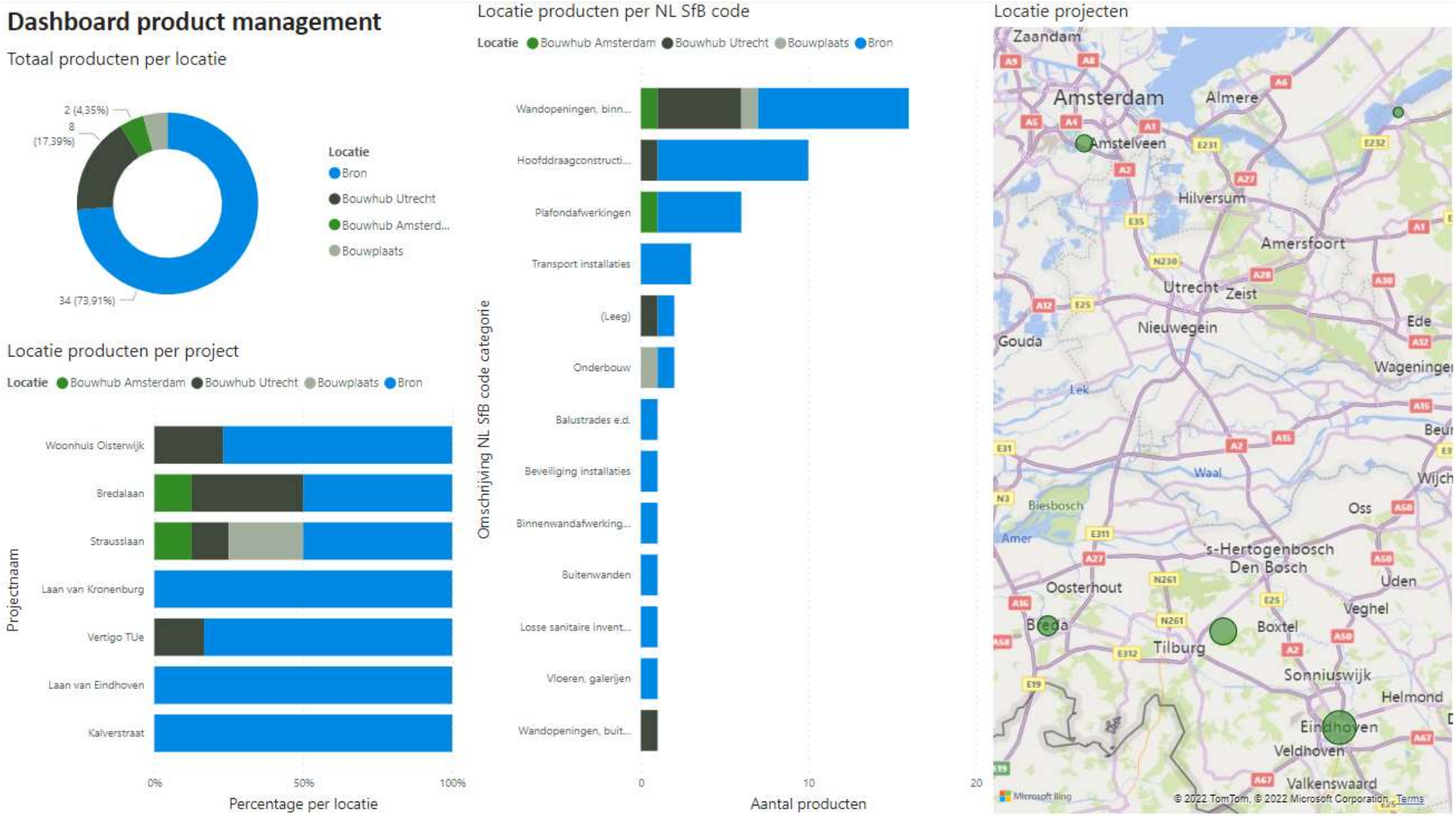

Figure 39 Dashboard product management

CHAPTER 7.

Validation

7. Validation

In Chapter 6, the design and development of the inventarisation application, matching application and dashboard for product management were described. Both applications are validated in this chapter to quantify how the proposed solutions improve the process and stimulate the use of reusable building products. In Section 7.1, the inventarisation application is validated using a Beta validation. The Beta validation is performed on-site by the end-user and provides a complete overview of the true experience gained while experiencing the product. The goal is to get customer feedback on the product and make software changes accordingly. Secondly, in Section 7.2, the matching application is tested using an alpha validation. Lastly, the validation of the dashboard for product management is validated with the end-user based on a face validity method and is discussed in Section 7.3.

7.1. Validation inventarisation application

For the inventarisation application, a beta validation is conducted. Multiple products from multiple projects are inventorised using the inventarisation application by the account manager (Figure 40).

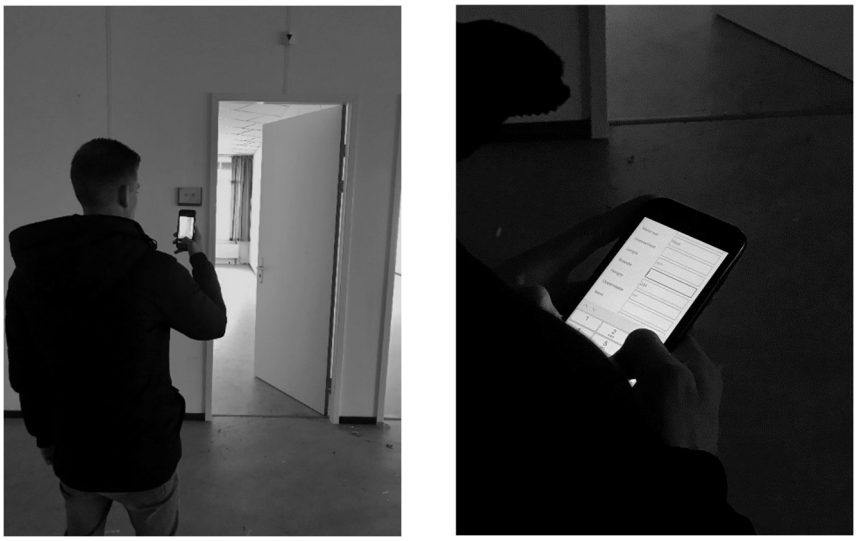

Figure 40 Beta-validation on site, use of inventarisation application

In Appendix 10, a validation report for the inventarisation application is created based on the URD in Appendix 5. In the validation report, each requirement is checked by the account manager if it is accomplished in the inventarisation application or not. Additionally, feedback is given on the inventarisation application for future improvements.

A comparison of the time spent on all steps in the inventarisation process with and without the inventarisation application is shown in Table 12. The time of the current process in minutes is calculated based on a project with 30 inventorised reusable products. The proposed process is the expected time in minutes, determined by the account manager for a similar project. As shown in Table 12, the use of the inventarisation application requires more time on-site during the inventarisation, however it saves additional steps and time in the office. Another advantage is that the account manager can add all data directly in the application, instead of

after the site visit, which reduces the amount of forgotten measured data during the inventarisation. In total, the use of the inventarisation application results in a time-saving of 120 minutes (36%). By making the application available for the foremen, an extra 30 minutes and transport time and costs can be saved when an extra inventarisation during deconstruction is necessary, excluding the extra transport time and costs of the account manager. This results in the total inventarisation process including one extra inventarisation in a total time-saving of 150 minutes (38%) in comparison with the current process, with a potentially higher percentage in time saving when accounting for the account managers' transport. Figure 41 shows an overview of the total time saving with and without the requirement of an additional inventarisation during deconstruction.

Table 11 Comparison process time

Activity	Current process (minutes)	Proposed process (Minutes)
Drive to location.	Variable	Variable
Inventarisation on site.	120	180
Upload pictures to the computer, and make a project document.	150	-
Add extra relevant data to products and preparation for sale. E.g. adding the price to the reusable product and add relevant data which is not added during the inventarisation on site.	-	30
Add products to an Excel format to upload products to the webshop.	60	-
Extra inventarisation if foremen find extra reusable products during deconstruction.		
Drive to location if foremen found extra reusable products that are not inventoried yet.	Variable	-
Inventarisation by account manager + additional steps for project document & uploading to the webshop.	60	-
Inventarisation by foremen and check by the account manager.		30
Total time:	330 minutes	210 minutes
Total time including one extra inventarisation:	390 + additional driving costs + time	240 minutes

Furthermore, the account manager describes his experience with the inventarisation application as very user-friendly and easy in use. An improvement is if the inventarisation application can be linked to an existing webshop of the graduation company. This is possible by creating a link from the SharePoint lists database to the existing website. However, is kept outside the scope of the research. Appendix 10 contains the complete feedback of the account manager on the inventarisation application.

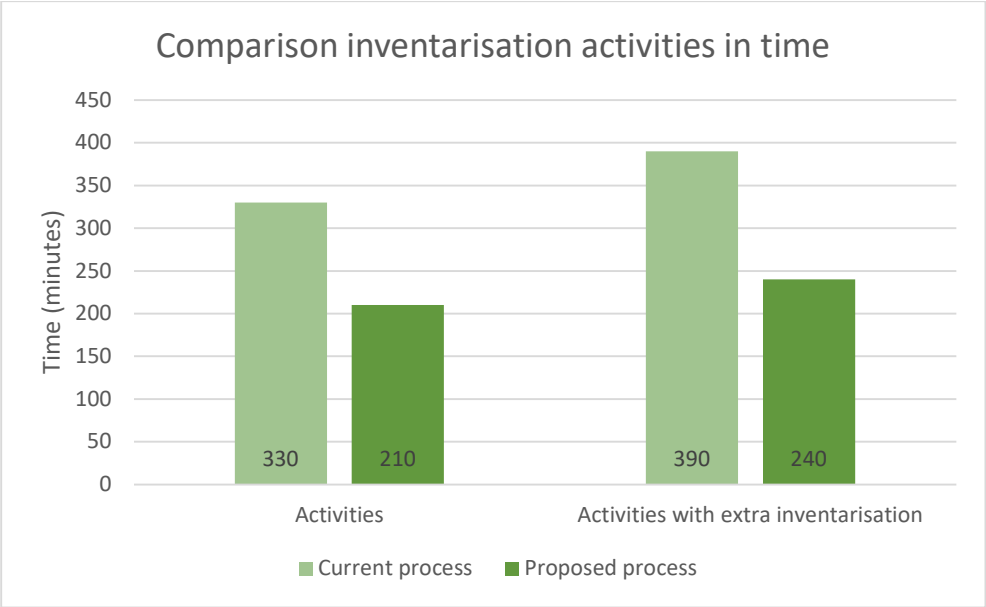

Figure 41 Comparison inventarisation activities in time

To conclude, the inventarisation application can be further improved by automatically adding the four NL SfB code digits instead of manually adding two digits. This could be done by creating a product category or linking the NL SfB code to the name of the product. This saves the account manager time and more in depth information is included.

7.2. Validation matching application

For the matching application, an alpha validation is conducted. During this alpha validation, three products from the BIM model Schependomlaan are chosen to match with the stock of reusable products. The JSON files of the products will be matched with the reusable product stock by using the matching application and the tree structure is used to find the same products. These results will be compared to see if the matching has additional value over the tree structure. Firstly, in Section 7.2.1, the functionalities of downloading the ITO is described. Afterwards, three products are matched and looked up in the tree structure. First, 25 interior doors are matched in Section 7.2.2. Second, in Section 7.2.3, 3 construction beams are matched. Next, in Section 7.2.4, a ceiling finish of 112 m^2 is matched. Finally, in Section 7.2.5, the optimizations for the matching application are discussed.

7.2.1. Downloading ITO

For new users of the matching application who wish to use the matching features, an ITO must first be downloaded to add in the SMC. The 'Download ITO' button is depicted on the matching screen in Figure 42. An information icon is shown next to the 'Download ITO' button. After clicking on the information icon, a pop-up window appears underneath the button with information about the steps the user needs to take to create the JSON file. Another information icon is located next to the 'Match' button. Clicking on this information icon opens a pop-up window with information on how the matching is conducted between the JSON file and stock of reusable products.

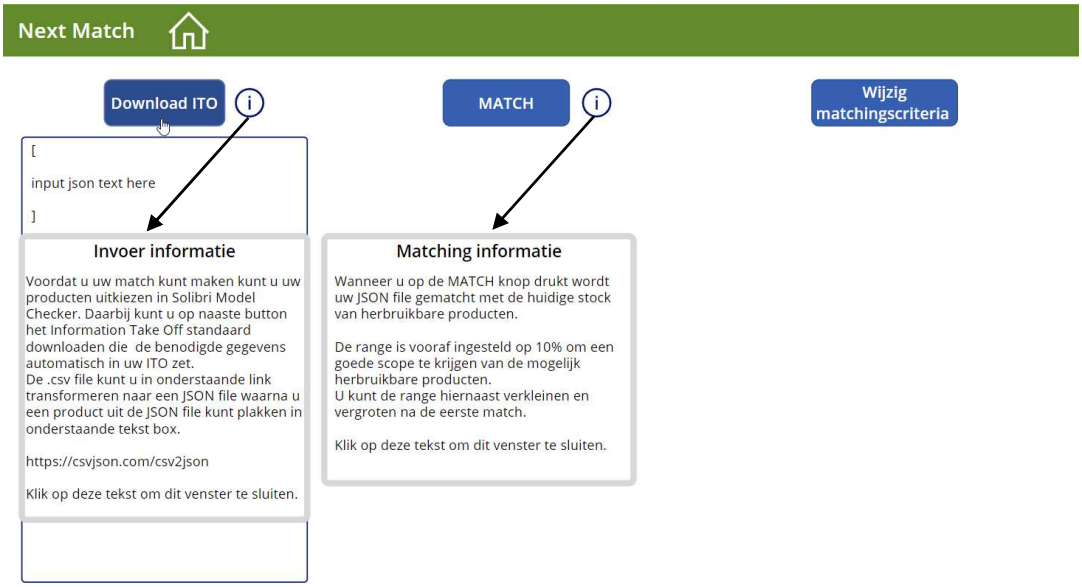

Figure 42 Downloading ITO button and additional information

After clicking on the 'Download ITO' button in Figure 42, an additional tab will open, as shown in Figure 43. Here the ITO for this study can be downloaded to the user's personal computer.

Figure 43 Downloading ITO format

After downloading the ITO, SMC can be opened and when selecting the *'information TakeOff definitions'*, additional ITO definitions can be added. After opening the downloaded ITO, the column structure will appear in the schedule. Now the architect can edit the scope of products for which a reused product can potentially be applied by editing the scope in the *'Edit Information TakeOff definition'*. Figure 44 shows an example with interior doors after performing the ITO.

IFC Entity	Name	Type	Component	NL/SfB (4 cijfers)	Bounding Box Length	Bounding Box Width	Bounding Box Height	Area	Volume	Count
IfcDoor	D1L, D1R, D2L, D2R	32_KD_berkvens_BA	Door	32.31	1,028 mm	173 mm	2,710 mm	2.78 m2	96 l	25
IfcDoor	D1L, D2R	32_KD_berkvens_BA	Door	32.31	1,010 mm	173 mm	2,620 mm	2.65 m2	89 l	6
IfcDoor	D1R	32_KD_berkvens_BA	Door	32.31	1,055 mm	173 mm	2,710 mm	2.86 m2	105 l	1

Figure 44 Example ITO of doors

Now, the architect or contractor can export their ITO to a .xls format. This .xls file can be saved directly in Excel as a .csv file. After generating the .csv file, it can be uploaded to a publicly available .csv to .json converter (https://csvjson.com/csv2json). Finally, the JSON file can be downloaded from the website. Now the information from the ITO report is transformed towards the JSON file structure. The data input of the ITO in Figure 44 is exactly the same as the data output of the JSON file in Figure 45, only the file structure is different. Now the architect or contractor is ready to match the JSON files in Section 7.2.2, 7.2.3 and 7.2.4.


```
[{"IFC Entity":"IfcDoor","Name":"D1L, D1R, D2L, D2R","Type":"32_KD_berkvens_BA","Component":"Door","NL/SfB (4
{"IFC Entity":"IfcDoor","Name":"D1L, D2R","Type":"32_KD_berkvens_BA","Component":"Door","NL/SfB (4 cijfers)":
{"IFC Entity":"IfcDoor","Name":"D1R","Type":"32_KD_berkvens_BA","Component":"Door","NL/SfB (4 cijfers)":3231,
```


Figure 45 Transformed ITO to JSON standard

7.2.2. Interior doors

In Figure 46 the properties of the interior doors in a JSON file are shown in a structured way, including an image of the interior door from SMC. The JSON file in Figure 46 is the same standard as shown in Figure 45, however in Figure 45 each data is presented in a single line. Therefore the data structure does not differ from each other. In this first example, an architect or contractor has selected 25 interior doors for which reused interior doors can be applied.


```
{
  "IFC Entity": "IfcDoor",
  "Name": "D1L, D1R, D2L, D2R",
  "Type": "32_KD_berkvens_BA",
  "Component": "Door",
  "NL/SfB (4 cijfers)": 3231,
  "Bounding Box Length": 1028,
  "Bounding Box Width": 173,
  "Bounding Box Height": 2250,
  "Area": "2,78",
  "Volume": "0,096",
  "Count": 25
},
```


Figure 46 Interior doors properties in JSON format and image from SMC

The user can copy the JSON code and paste it into the text box on the left side of the matching screen in Figure 47. The JSON code will remain in the text box until the user returns to the main menu. This gives the user the opportunity to review the details from the JSON file while finding a match. In Figure 47, the 'Match' button is already pressed and six possible matches in the range of 10% have been found. For each reusable product, a limited amount of information and an image is added, so that the user can quickly distinguish between products.

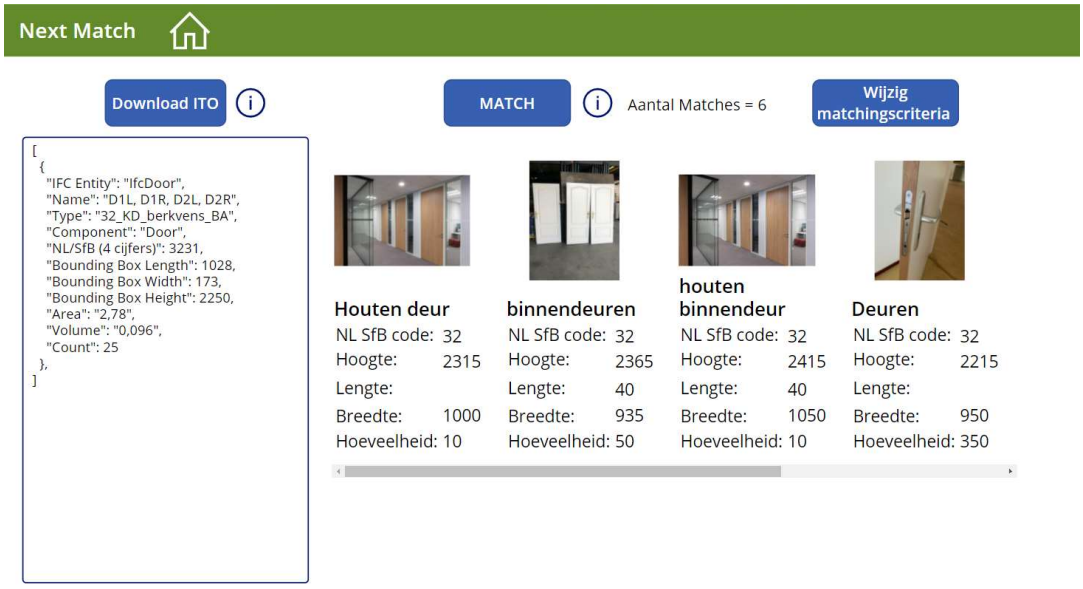

Figure 47 JSON data matched with stock of reusable products

In case the user would like to further narrow the search, for example because the height is limited in the specific project the architect or contractor is working on, the user can edit the

matching criteria under the ‘edit matching criteria’ button. The user sets the maximum height to 2255mm. The user is more flexible with the length, so the maximum length is extended to 1300 mm. Finally, the user wants to order all interior doors from one location. Therefore, the user sets the ‘Minimum number from source location’ to 25. These adjustments in the edit matchings criteria are shown in Figure 48. The properties in grey were not included during matching because they are less important for this NL SfB category and can even lead to mismatches. Logically, for each NL SfB category different properties are deemed important. Therefore, the criteria which are grey depend on the type of product which is matched.

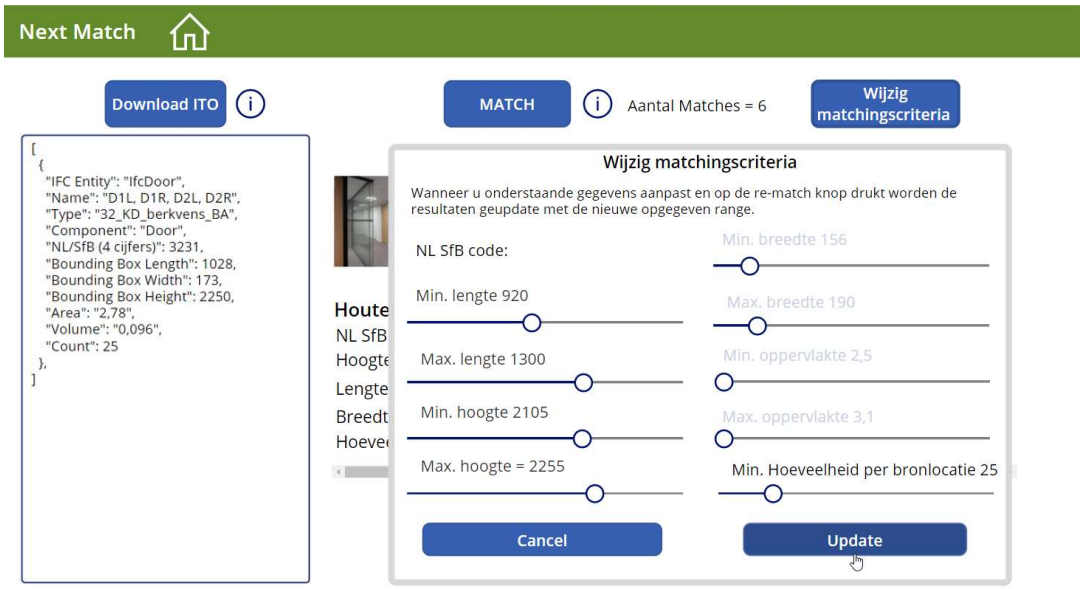

Figure 48 Adjusting matching criteria

After clicking the ‘update’ button in Figure 48, the range is tightened and the number of matches has further decreased to one, as shown in Figure 49. The architect or contractor is interested in this interior door and clicks on the product to go to the ‘product overview screen’.

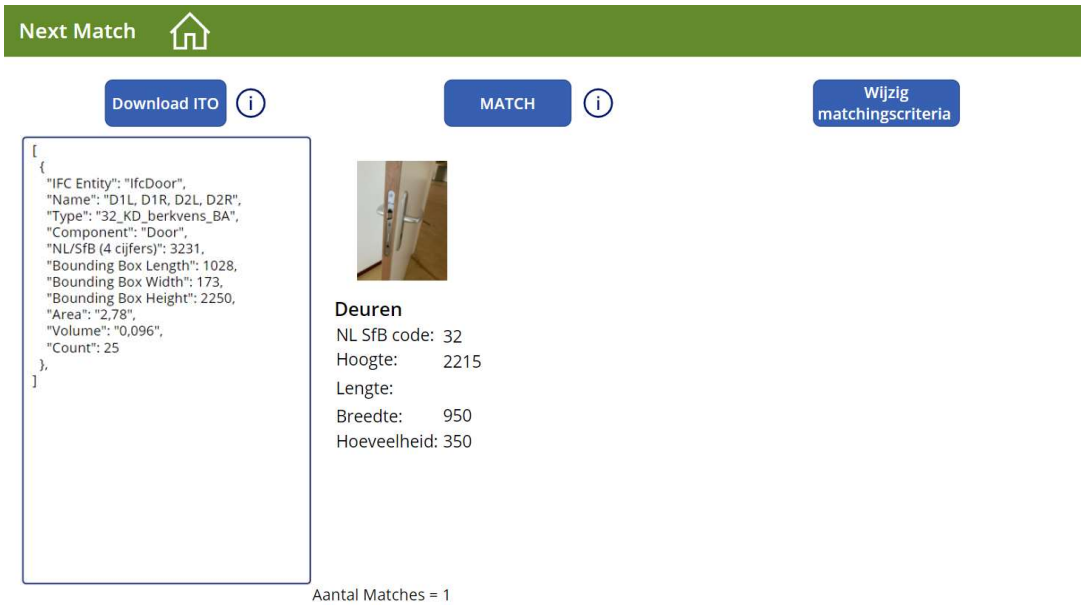

Figure 49 Matches after adjusting matching criteria

In Figure 50, the product overview screen is shown with all product- and project-specific information of the selected interior door. This overview also shows the location and the expected deconstruction date. The selected reusable product consists of 350 interior doors, of which the user needs only 25. Thus, for the implementation phase, the deconstruction company must determine what the minimum quantity of the reusable product to be sold is.

Next, a search function based on location is deemed interesting, especially when more data is available the location, transport costs, time and CO_2 emissions can be a deciding factor for the user. Choosing products that are close to the construction site saves additional transport costs, time and CO2 emissions. The expected deconstruction date is also an important property and can help to link the deconstruction dates with the construction planning.

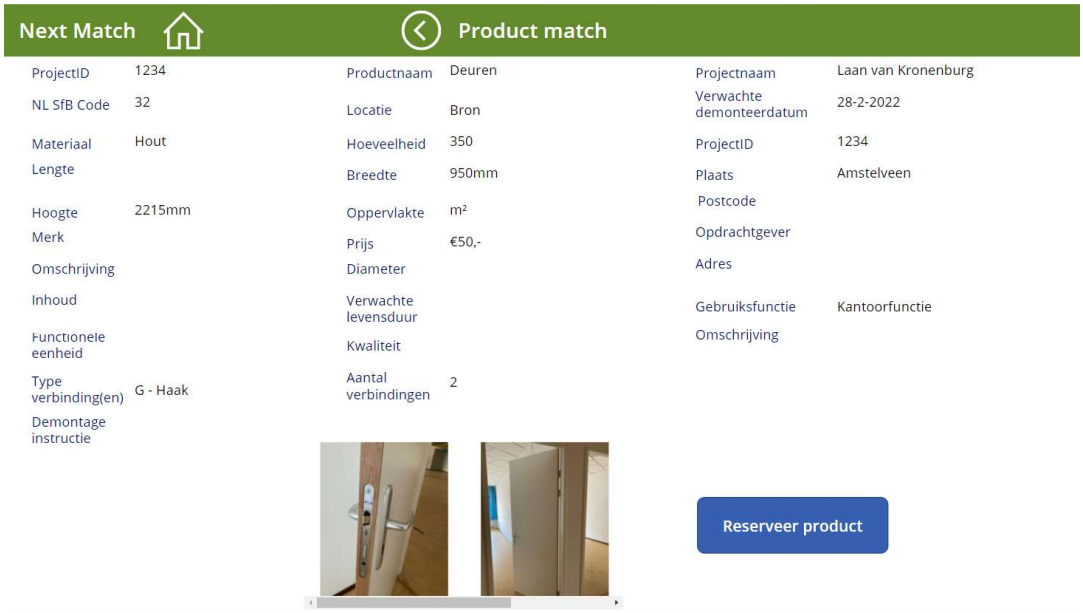

Figure 50 Properties of reusable interior door in stock

Searching for the interior doors using the tree structure shows all interior openings with NL SfB code 32. Figure 51 shows that this results in sixteen options. This method does not require

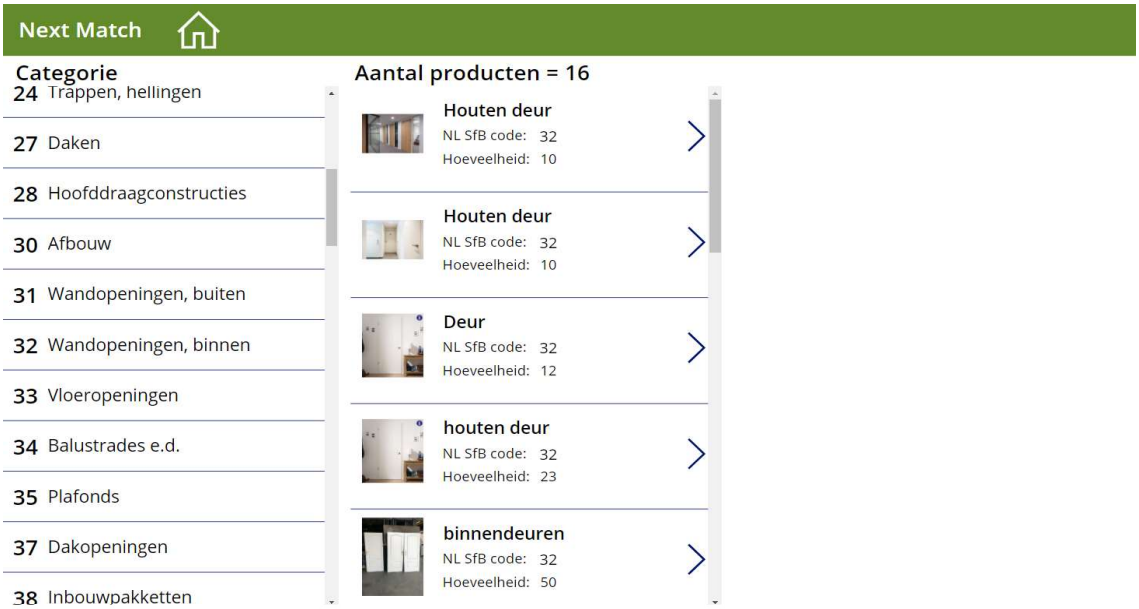

Figure 51 Tree structure interior openings

a BIM model and is a comparable method used by current marketplaces to search for reusable products. To obtain additional data, each product must be selected and examined. It is therefore a more time consuming method compared to searching with the matching option.

7.2.3. Construction beams

In this second example, an architect or contractor has selected three steel construction beams for which reused steel construction beams can be used. The properties of this steel construction beam, including an image from SMC are shown in Figure 52.


```
{
  "IFC Entity": "IfcBeam",
  "Name": "HEA200",
  "Type": "HEA balk 20",
  "Component": "Beam",
  "NL/SfB (4 cijfers)": 2811,
  "Area": "",
  "Volume": "0,003",
  "Bounding Box Length": 1640,
  "Bounding Box Width": 180,
  "Bounding Box Height": 191,
  "Count": 3
},
```


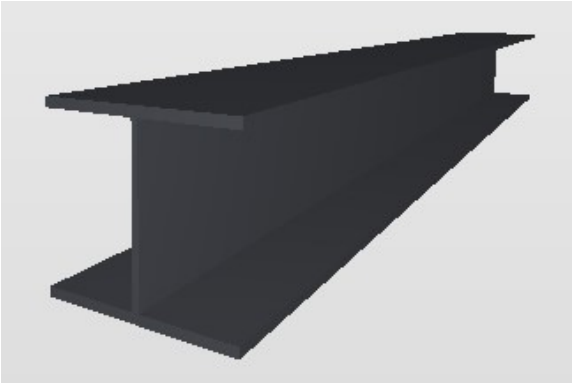

Figure 52 Construction beam properties in JSON format and image from SMC

The user can copy the JSON code and paste it into the text box on the left side of the matching screen in Figure 53. The 'Match' button is already pressed and only three possible matches were found. The range of 10% of each property is determined together with the supervisor and the account manager of the graduation company. However, the maximum length of steel construction beams is extended to 30% to broaden the scope. This is because reusable steel construction beams can easily be cut to the right size.

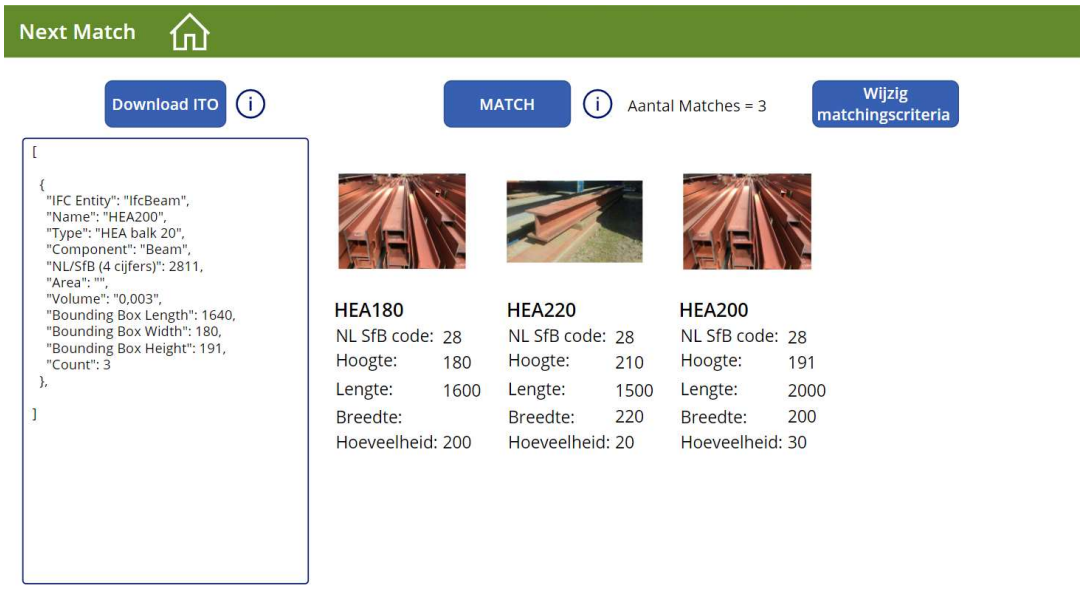

Figure 53 JSON data matched with stock of reusable products

The architect or contractor is looking if there is a longer construction beam available to possibly cut two needed lengths from a reusable steel construction beam. Therefore the 'edit matching criteria button' is pressed and the maximum length is set to 2640mm as shown in Figure 54. Unfortunately, no new products show up and only the three first matches are shown. A critical remark must be made that the maximum editable length of a product is now set to a fixed number. Before implementation, setting the maximum length of an input category to the maximum length present in the stock is recommended. This will lead to less no-new-result searches from the user, eventually saving the user time and energy.

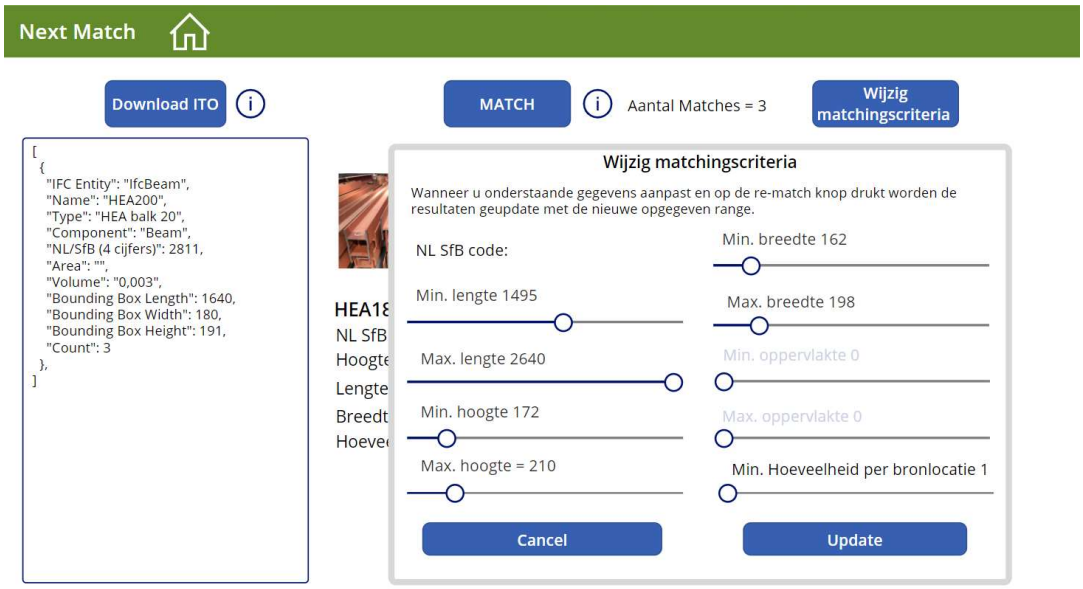

Figure 54 Adjusting maximum length of a product

The architect or contractor has chosen to go for the HEA 200, based on the minimum structural quality requirement. Although the HEA 220 also met this requirement, however this beam was considered too short. The properties of the HEA 200 are shown in Figure 55.

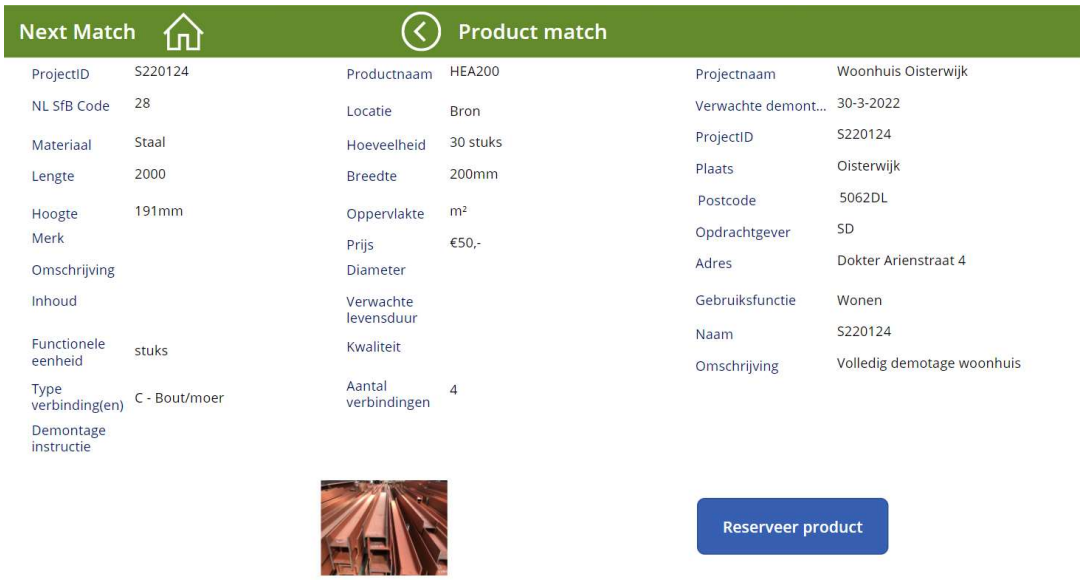

Figure 55 Properties of reusable construction beam in stock

Searching for the steel construction beams using the tree structure shows all reusable load bearing structures with NL SfB code 28. Figure 56 shows that this results in ten options. It is recommended to add more product specific information in the tree structure during the implementation phase, such as length, width and height, to facilitate the search in the tree structure. Lastly a second column can be created on the right side in Figure 56 to display more products at first sight.

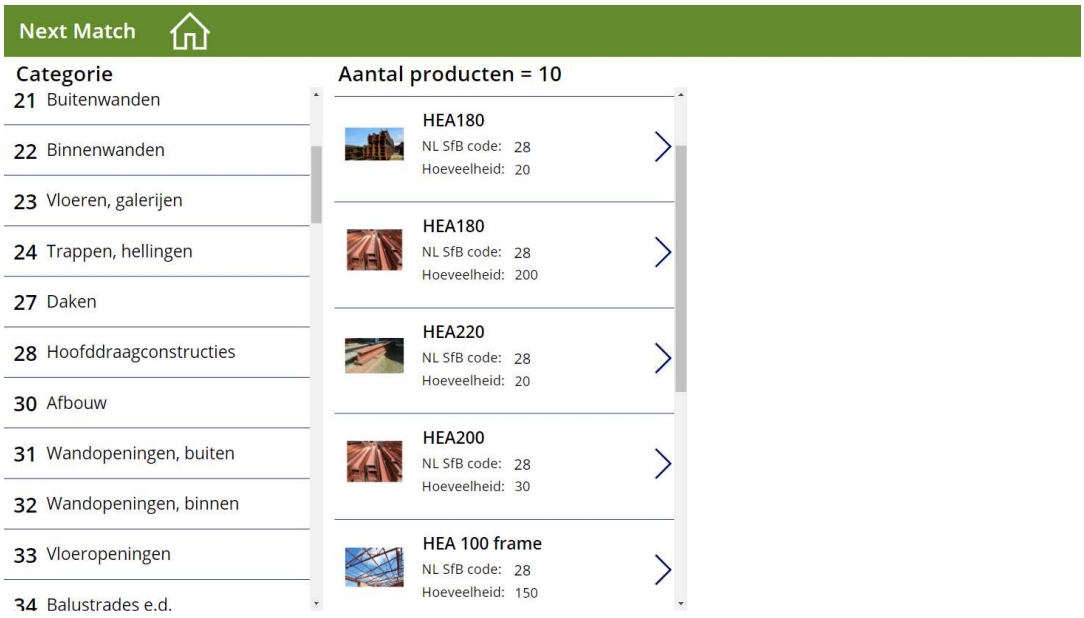

Figure 56 Tree structure construction beams

7.2.4. Ceiling finish

In this last example, an architect or contractor has selected a ceiling finish of 111.27m^2 for which a reused ceiling finish can be used. The properties of this gypsum ceiling finish, including an image from SMC are shown in Figure 57.


```
{
  "IFC Entity": "IfcCovering",
  "Name": "gipsplafond",
  "Type": "IFC_gipsplafond_2*12,5 25",
  "Component": "Covering",
  "NL/SfB (4 cijfers)": 4511,
  "Bounding Box Length": 13940,
  "Bounding Box Width": 7982,
  "Bounding Box Height": 25,
  "Area": "111,27",
  "Volume": "2,15",
  "Count": 1
},
```


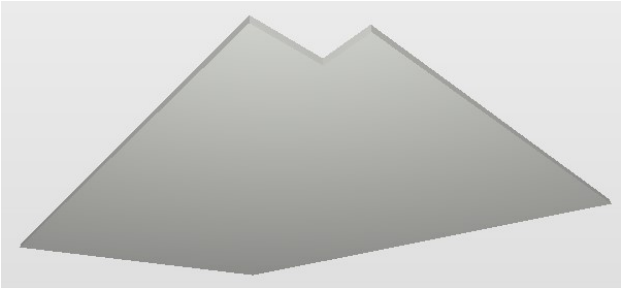

Figure 57 Ceiling finish properties in JSON format and image from SMC

The user can copy the JSON code and paste it into the text box on the left side of the matching screen in Figure 58. The 'Match' button is already pressed and two possible matches were found. For the ceiling finish, a filter is only performed on the NL SfB code and the surface area with a range of 10%, as this product category cannot be matched on length and width. The

surface area is not included in the matching screen, so both products need to be opened to determine the surface area of these products. For future development, it is recommended to link the last property 'quantity' to the functional unit of each product. This will ensure that the correct functional unit is displayed on the matching screen for all products.

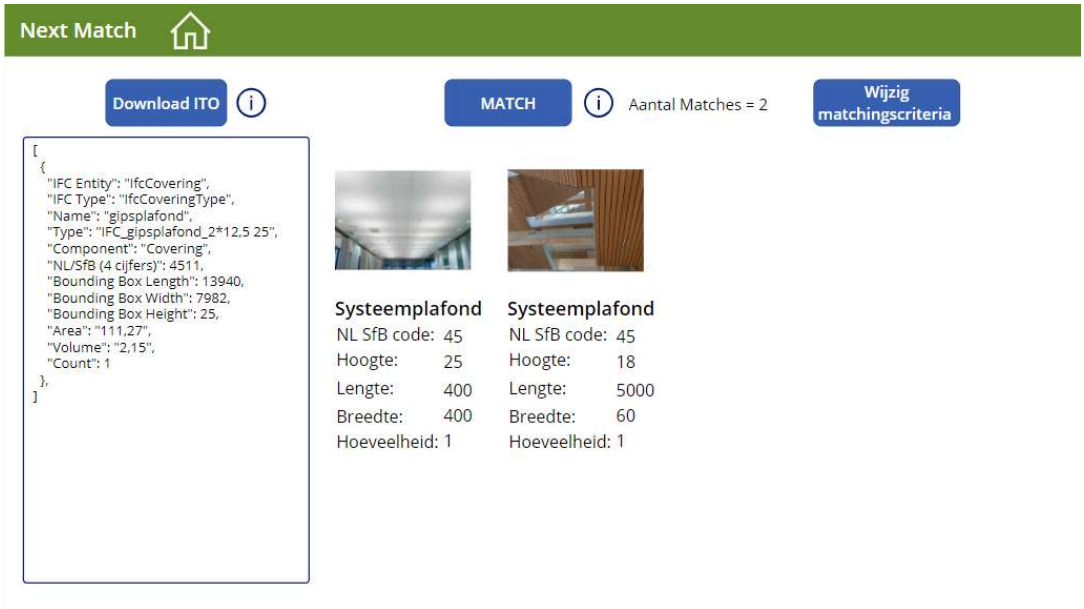

Figure 58 JSON data matched with stock of reusable products

In Figures 59 and 60, the product overview screen is shown with all the product- and project-specific information for the two ceiling finishes. The ceiling finish in Figure 59 is made from the correct material, however the surface area is not sufficient for the current project (111.27m^2). Therefore, the user has to combine this product with another product or choose the ceiling finish in Figure 60.

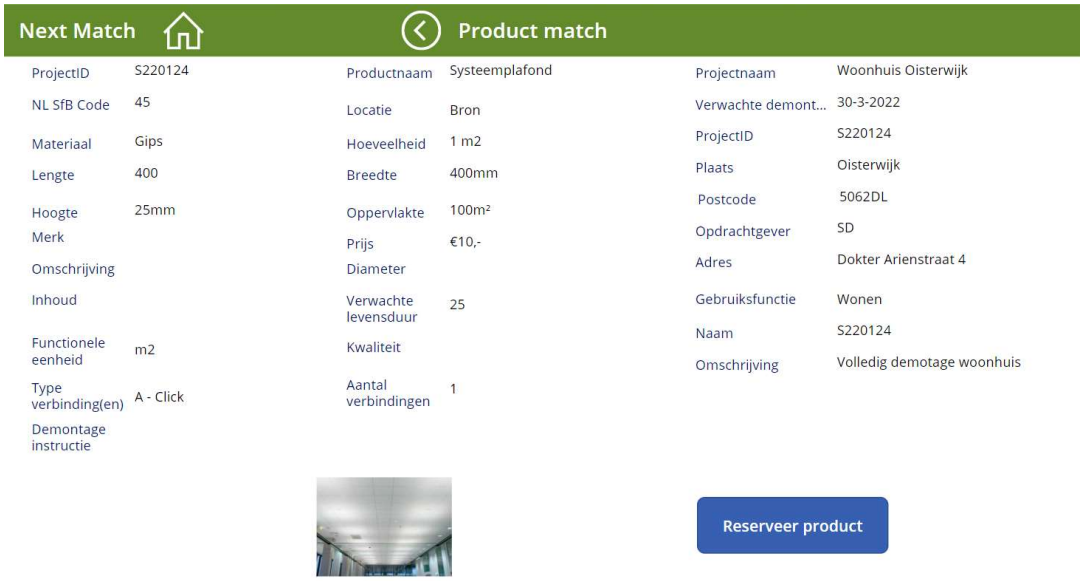

Figure 59 Properties of reusable ceiling finish in stock 1

The ceiling finish in Figure 60 has a sufficient ceiling area. However, it is made of a different material. The architect or contractor can decide if the product fits into the new project and whether the product is selected may depend on several factors. In addition to dimensions, several aspects may play a role next to measurements, such as the quality, location, expected delivery date, storage possibilities and price. A stated choice experiment among architects and contractors can provide an answer to the priority regarding the importance of these properties. Finally, for further development, it can be discussed whether the project information such as the client of the deconstruction company and the address details should be hidden from the end user.

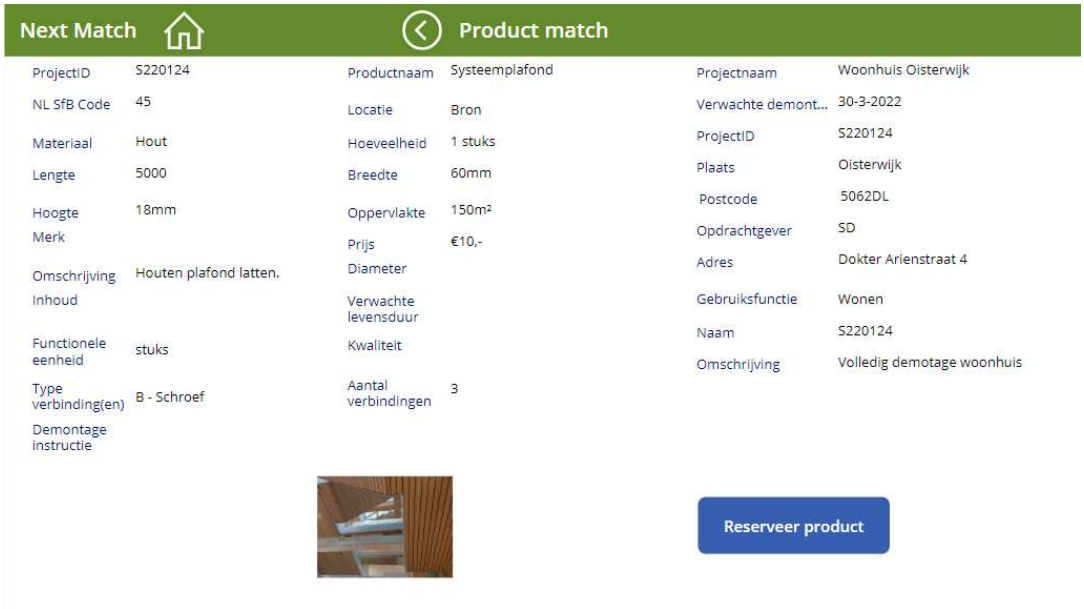

Figure 60 Properties of reusable ceiling finish in stock 2

Searching for ceiling surfaces using the tree structure shows all ceiling surfaces with NL SfB code 45. Figure 61 shows that this results in six options. Additional product specific information such as the surface area would be beneficial. Therefore it is recommended to add the surface area for the tree structure and the matching screen.

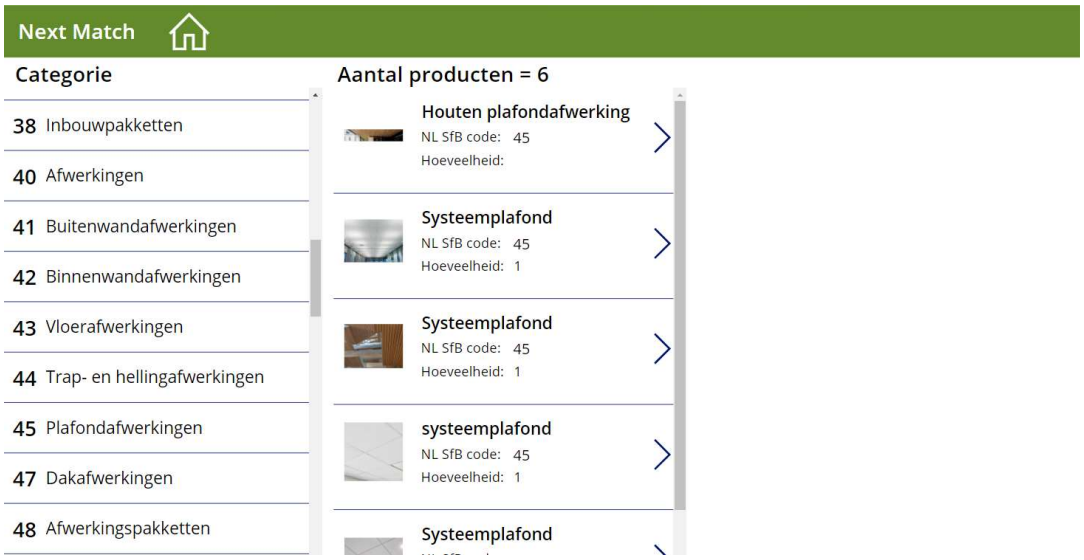

Figure 61 Tree structure ceiling finishes

7.2.5. Optimizations and opportunities

From the validation it was concluded that the design of the matching application as described in the previous sections should be further developed before implementation. In this Section optimizations and opportunities are discussed that were not discussed in the previous sections. From the URD of the matching application in Appendix 6, all requirements with status 'Must have' and 'Should have' are accomplished.

It may happen that two products from different projects are identical to each other. In this case, the products will still be displayed separately because they are from a different dismantling location. In this case, the user can still make a decision based on other factors, like the distance from the dismantling site to the new site, dismantling date or visual quality.

As shown in Section 7.2.4, sometimes a product may have a quantity that is too small. If larger quantities are not an option, the user can combine two (semi-)identical products. The location, deconstruction date and transportation must then be taken into account. If the reusable stock becomes bigger, the range of the matching criteria should become smaller, to limit the amount of matches in the similarity matching.

Next to these standard products, there exists also more exclusive products that are not matchable e.g. giant timber curved rafters from a farm shed. These are special items which are not easy measurable. For these items, the search function as tree structure is useful.

It can be concluded that the matching application has shown its advantages over the tree structure in search time. This advantage becomes even greater if the stock of reusable products grows over time due to an expected increase in demand and collaboration between deconstruction companies. However, due to manual data conversion, the process will still be time consuming. Due to the chosen Microsoft environment, the architects and contractors must manually import the JSON file themselves. This should be done automatically to achieve BIM Level 3, as depicted in the wedge diagram in Figure 16. So the databases are connected with each other and the JSON data is passed back and forth in the back-end. To achieve this, an automatic connection from the modelling software like Revit towards a JSON file should be created.

This even creates the interchangeability to add data from the reserved reusable products database to the properties of a product in the BIM models. So properties with the information of the reusable product can be added and exact metric data can be changed. This is also possible with the creation of a Revit plugin, however then its only available in a restricted software environment.

Lastly, a link with the national environmental database could be established to use this data to convince clients of architects and contractors to use the reusable products. Further research on decentralization of data is recommended by linking databases from different sources with linked data.

7.3. Validation dashboard product management

The dashboard for product management is validated by means of a face validity with the end-user, the commercial manager of the graduation company. Below, in Figure 62, an example of the capabilities of the dashboard for product management is shown based on the project called 'Woonhuis Oisterwijk'. The dashboard shows that 10 inventoried products (76.92% of the total project) still need to be dismantled. The column in the middle shows the location of the products. It can be seen that the products to be dismantled are mainly products from the supporting structure with some interior openings and ceiling finishes.

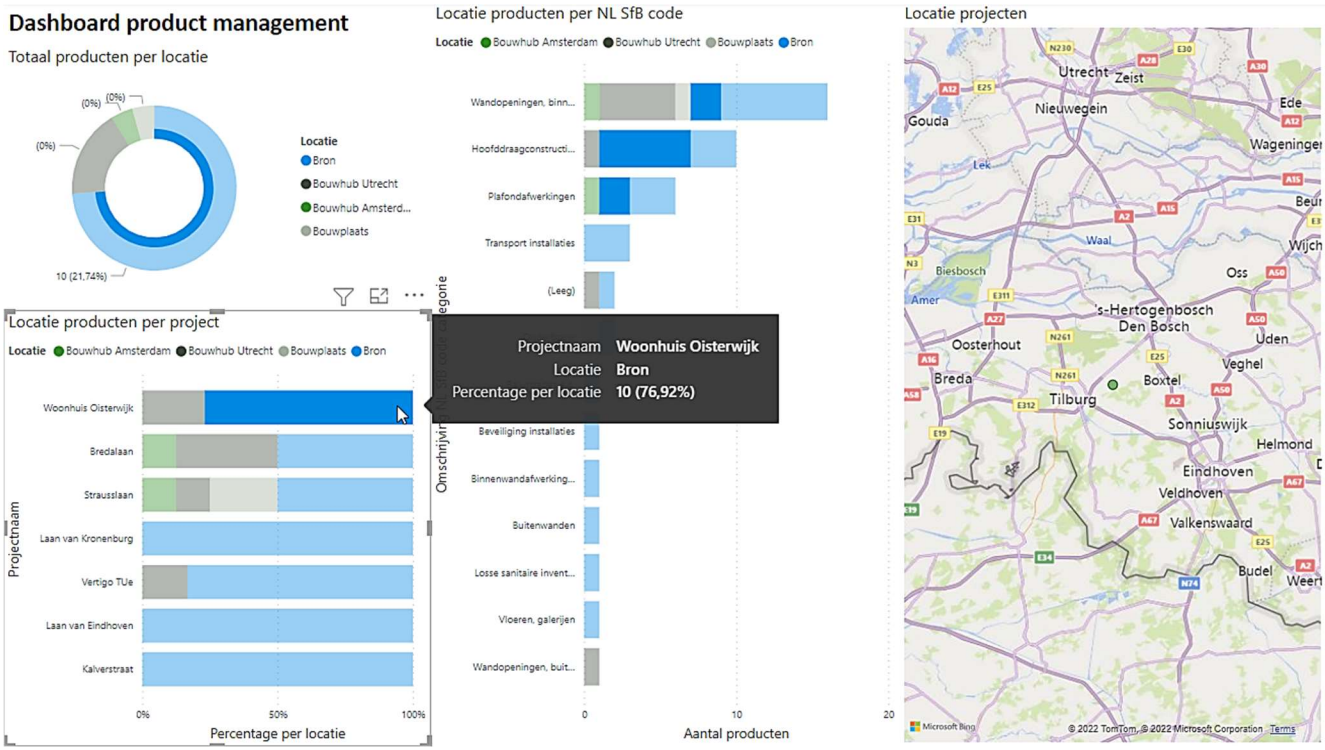

Figure 62 Dashboard product management project 'Woonhuis Oisterwijk' to be dismantled

Moving the mouse pointer over the selected products, as shown in Figure 63, displays the number of products in the selected project. In this example, for the selected project 'Woonhuis Oisterwijk', there are still 2 interior openings to be dismantled and a total of 9 interior openings to be dismantled across all projects. The geographic map on the right side of Figures 63 and 64 shows the location of the project. This map automatically zooms in and out according to the selection criteria.

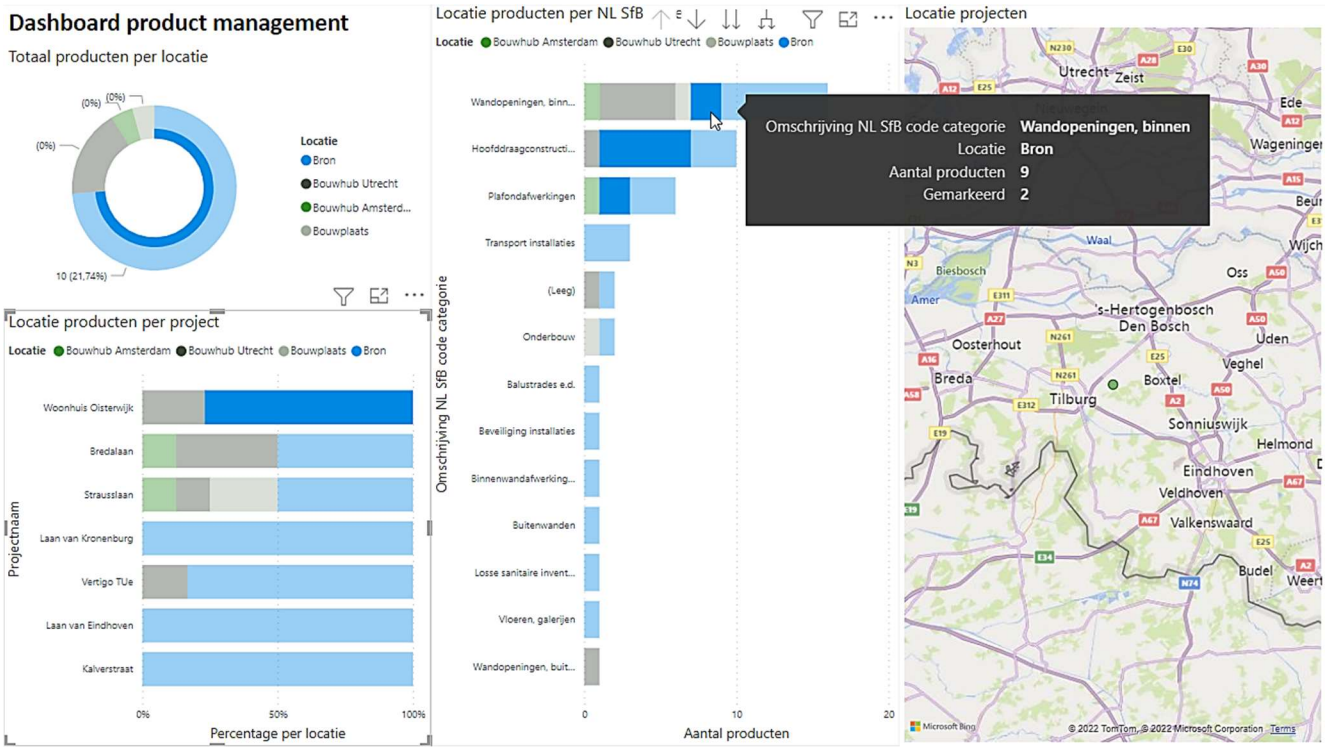

Figure 63 Dashboard product management project 'Woonhuis Oisterwijk' interior openings

Finally, in Figure 64 you can see that the other products from the 'Woonhuis Oisterwijk' project have already been dismantled and stored on the circular building hub in Utrecht. By moving the mouse pointer over the selected item, you can see that 3 products (23.08%) have been dismantled and transported to the circular building hub in Utrecht.

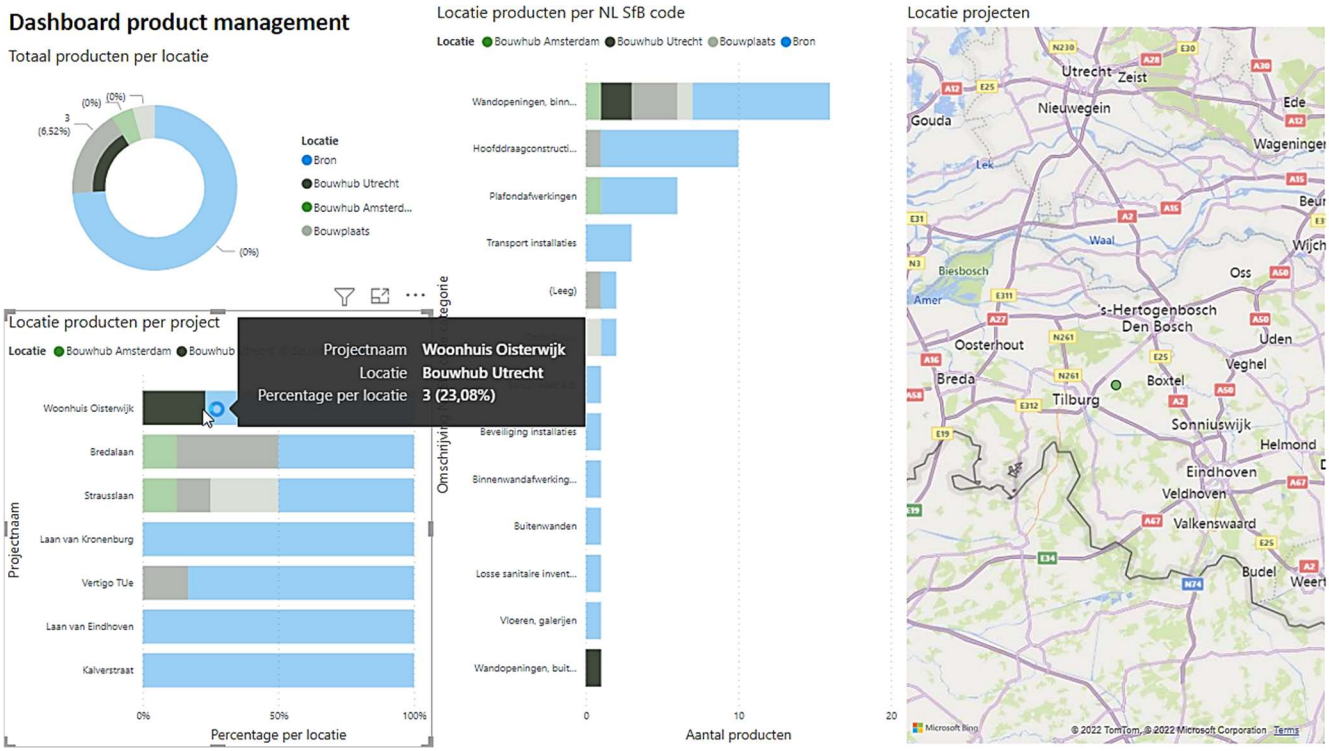

Figure 64 Dashboard product management project 'Woonhuis Oisterwijk' Building hub

During the face validity with the commercial manager of the graduation company, the dashboard for product management received positive feedback. The information is presented clearly and understandably. The interactivity with the dashboard by clicking on a data point and the other data transforming around that data point, as shown in Figures 63 and 64, is insightful and provides more in-depth information. The dashboard shows clearly what is possible with the data inventoried by the inventarisation application.

The dashboard for product management can be further developed by the deconstruction company. For example, additional data can be added when a product is taken from the dismantling site to one of the circular building hubs. An overview can be made of all products in the circular building hub with the time it has been in stock. In conjunction with this data, Key Performance Indicators (KPIs) can be determined to keep track of reusable products that have been stored at the circular building hub for an extended period of time and not sold. By adding this data to the dashboard, managers can focus on the products that are not selling and take action. By adding KPIs, supply chain performance management is possible. As a result, it becomes possible to improve the current performance of the supply chain (Cai, Liu, Xiao, & Liu, 2009).

In addition, this dashboard can be further developed to add an additional canvas page so that when multiple products are selected, the product can also be displayed at a product-specific level. This gives the manager additional information to see if a product consists of 2 or 350 quantities. The current dashboard does not show this difference between inventoried products. Finally, for further development, an additional database with the dismantling time per product can be created and linked to the dashboard. This opens the possibility for the manager to make planning decisions as well. It can be concluded that it makes sense to store product data in a decentralized manner so that all data can be easily exchanged between all three applications and easily linked to each other and to other databases.

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CHAPTER 8.

Conclusion and recommendations

8. Conclusion and recommendations

This final chapter will provide an overview of the accomplishments of this research. First, Section 8.1 presents the conclusion of this research, discussing the main research question and sub-questions. Afterwards, in Section 8.2, the scientific relevance, as well as the societal relevance, is discussed. Lastly, in Section 8.3, recommendations for future research are described and a summary of recommendations for different stakeholders are given.

8.1. Conclusion

The answer to the main research question is the conclusion of this research, which is formulated as follows:

How can reusable building products from Construction Demolition Waste be connected with construction sites to improve the process and stimulate the use of reusable building products?

To answer the main research question, a literature review has been established and qualitative interviews were conducted; three applications have been developed in this study. This resulted in an in-depth process chain analysis of the deconstruction process from the decision to demolish to the mechanical demolition of the building. It can be concluded that it is still very uncommon to use reusable building products in newly designed buildings. This also became clear in the found barriers to reuse, where the lack of information on current marketplaces and standardization was one of the main barriers. To reach a fully operating circular economy it is important to keep the material loops from the Ellen MacArthur Foundation as tight as possible (Ellen MacArthur Foundation, 2013). To do this for the existing building stock, that does not contain a BIM model, it is important to know before the deconstruction and demolishing phase what products are in the existing stock. By inventorising what is in a building, the product value is captured and it will no longer be seen as CDW, but really as reusable products that contain a value.

Therefore, in this study, an inventarisation application has been built to collect data for reusable products and create a data standard, which can be seen as a product passport. The second developed application is a matching application, created for architects and contractors, which matches products from the stock of reusable products with JSON data from BIM models by using similarity matching. This eases the search process of reusable products and the search scope can be tightened or broadened on each parameter. In the proof of concept of the matching application, the JSON data must be handled manually by the user. The automatic connection of data between two environments, where the JSON data comes along in the back-end, is preferable and should be optimized before implementation. Lastly, the third application developed in this study is an interactive product management dashboard, created in PowerBI, to track the process of deconstruction projects. This application shows the possibilities of the inventoried data by the inventarisation application.

This study contributes to improve the process of using reusable products, which leads to the valorisation of the market of reusable products. By inventorising products in an earlier stage

in a standardised way before deconstruction or during a maintenance round, the value can be captured and this improves the chances to sell all reusable products before deconstruction to a new owner. Which in turn leads to more sales of reusable products and less transport costs and emissions. By increasing the supply of reusable products, the value of the applications increases. The answer to the main research question is given based upon the results of the following sub-questions:

> ***SQ1)*** *What is a circular built environment and what is the importance of reusing building products?*

The circular built environment aims to close the (biological and technical) loops and keep products and materials in the loops as long as possible and as valuable as possible, leaving no waste. Products and materials will thus not leave the cycle, which is important in view of the earth's finite resources and global warming. This is fundamentally different from the linear economy, where according to the 'take - make -waste' principle, all products are disposed of after use. To move to a circular economy, the 10R's of Cramer (2017), in Figure 8, should be considered, which shows the order of priority from refuse (prevent raw material use) to recover (incinerate waste with energy recovery). The first three principles all include reduce strategies. In fourth place is reuse as the best alternative if a product or material is to be used. The DfD principle helps to increase the reuse potential for new buildings when the building is deconstructed. The focus of this principle is on the design phase for new buildings so that the products can be reused in the future. However, the reusable products from the existing building stock should be kept as tight as possible in the circular economy cycles. The buildings to be deconstructed should be considered as material banks for reuse in new buildings to conserve the earth's finite resources and slow global warming. In conclusion, there is still a perception in the construction sector and in academic papers that recycling also falls under the term reuse. It is important to make a clear distinction between these terms in order to further increase the reuse potential and to give value to the term reuse.

> ***SQ2)*** *What is the current process chain for reusable building products from a deconstructed building, through the circular building hub towards the new building?*

Based on the literature review and the qualitative interviews, an in-depth process chain analysis was conducted. The results are presented in Appendix 4, Figure 24 and Figure 25 in Section 5.1, it was found that during the inventarisation of reusable products there is no standard format for the non-graphical information and photos and that the process of inventorising until offering the product on a webshop is inefficient and involves many unnecessary, time-consuming steps. The products could be transported directly to their new owner, which is the best alternative with the least environmental impact. The circular building hub can be used when storage is required. The location of the circular building hub is preferably close to a building hub to combine transport movements.

> ***SQ3)*** *How can the current process of reusing building products be optimized for maximum value and profit?*

Based on the process analysis and the barriers to reuse identified in the qualitative interviews (Section 5.2) and in the literature (Section 2.3), it can be concluded that reuse of products in

new designs is still an uncommon practice. Therefore, this research focuses on the found barrier to improve the process of matchmaking between the deconstruction company and the architect and contractor. It was found that there is no common data standard, which makes matching impossible. Therefore, a inventarisation application was developed to inventory reusable products on site, storing all non-graphical information in a structured way in a database. Subsequently, the data of the reusable products is matched with the JSON file data of the products from BIM models of the architect or contractor. This is developed in a web-based matching application where the architect and contractor can import their product information from a JSON file, which is then matched with the reusable stock of products from the deconstruction company on similarities in the properties in a predefined range. After matching, this range is editable by the end-user to tighten or broaden the scope on each property. By using the applications, the current process is standardized and optimized so that the value and profit is improved in comparison with the current process of reusing building products. To further improve the product reuse process, recommendations are made in Section 8.3.

> ***SQ4)*** *Which specifications of reusable building products are necessary for the management of the product?*

From the literature and qualitative interviews it was found that there is no BIM model available for the to be deconstructed buildings in most cases. Therefore, only visible detectable information can be inventoried on the deconstruction site. This has limitations for the information in reusable product passports compared to passports created for new products, which include data on, for example, the origin of the raw material and the chemical composition, these are for existing products not visibly detectable. Therefore, a distinguish in information is made, because adding too much information makes the inventory of the reusable product expensive and burdensome, while adding too little information leads to lack of matches and uncertainty for buyers. The final dataset is shown in Table 8 and Table 9 in Section 6.2.1. Ultimately from the data of a reusable product, a product passport could be generated.

> ***SQ5)*** *How should the inventarisation of the necessary building products for current and upcoming construction sites from BIM models be stored, such that reusable products can be matched with the stock?*

A data analysis of three BIM models revealed that there are many differences in modelling techniques and templates. To enable similarity matching, the BIM models should be structured according to a clear standard. For this research, a BIM model based on the BIM basis ILS standard is used to have a standard on how the basic information is structured. Following the BIM basis ILS, the non-graphical information from Table 10 was selected to export and found to be suitable for similarity matching. IFC supports a neutral file format for BIM tools interoperability. However, to increase the interoperability of BIM data, the data must be available in cloud based formats. Exchange format like JSON and XML are suitable for this interoperability because they are generic, scalable, and highly adaptable cloud-based data exchange forms. JSON was chosen in this study because it is a lightweight key-value style data exchange format and has higher parsing efficiency than XML (Afsari et al., 2017; Peng et al.,

2011). Unfortunately, the export function for .json files is not (yet) included in BMC software tools such as Solibri. Therefore, a detailed description is added in the matching application when downloading the specially made ITO for Solibri. The .csv file can be uploaded on a publicly available JSON converter after ITO in Solibri, which can then be downloaded. It could be discussed that it is too tedious and laborious for architects and contractors to create a JSON file of their products and that they should not have to work with coding. Therefore, one of the recommendations for further research is to extend the matching application and create a Revit plugin. This is because the optimal goal for the matching application is to drag, for example, a door with its information from one environment to another environment, with the JSON coming along in the bank-end. This research shows that similarity matching is possible and that this data management trick is an important optimization for further development.

> ***SQ6)*** *How to design a system (web application) that involves different stakeholders and end-users to match product information?*

In the inventarisation application, the account manager of the deconstruction company is the only end-user. The account manager fulfils the supply side of the stock by identifying reusable products on the deconstruction site. In the matching application, architects and contractors are the direct end-users, they want to reserve reusable products for their future projects. From the qualitative interviews it became clear that architects and contractors are searching in two ways which are both included in the matching application. First, by a tree-view, to openly see what is available per product type and design from what is available (MDD). Secondly, by having a design in a BIM model and searching for similar reusable products to use. Reusable products are rarely a perfect match, so in coordination with the graduation company, a range of 10% is set on all properties, which are manually editable by the end-user. The PowerBI Dashboard is created for the deconstruction company's manager to take action and make adjustments if needed. This process of how the applications work together is shown in a simplified version in Figure 65.

> ***SQ7)*** *Can a proof of concept be developed to test the application, and what optimizations does it need after validation?*

Both the inventarisation and matching application are validated separately. The inventarisation application is validated by means of a beta validation with the account manager at a deconstruction site, with positive test results. The VRD specifies the requirements stated in the URD, which are accomplished. The inventarisation application is able to add, edit and remove projects and products which are linked to the database. From the beta validation, it is expected that the current inventarisation application results in a time-saving of 120 minutes (36%). If the inventarisation application becomes also available for the foremen, an additional 30 minutes and transportation time and cost can be saved, bringing the total time-saving towards 150 minutes (38%), not even including the transport time and costs of the account manager. For the inventarisation application, the beta validation resulted in only minor optimizations, such as an additional button to release the products for sale, currently the products are directly available in the matching application. An Alfa validation was performed for the matching application, with a positive test result and all ‘must have’ criteria from the requirements from the URD are met. The matching application can be used

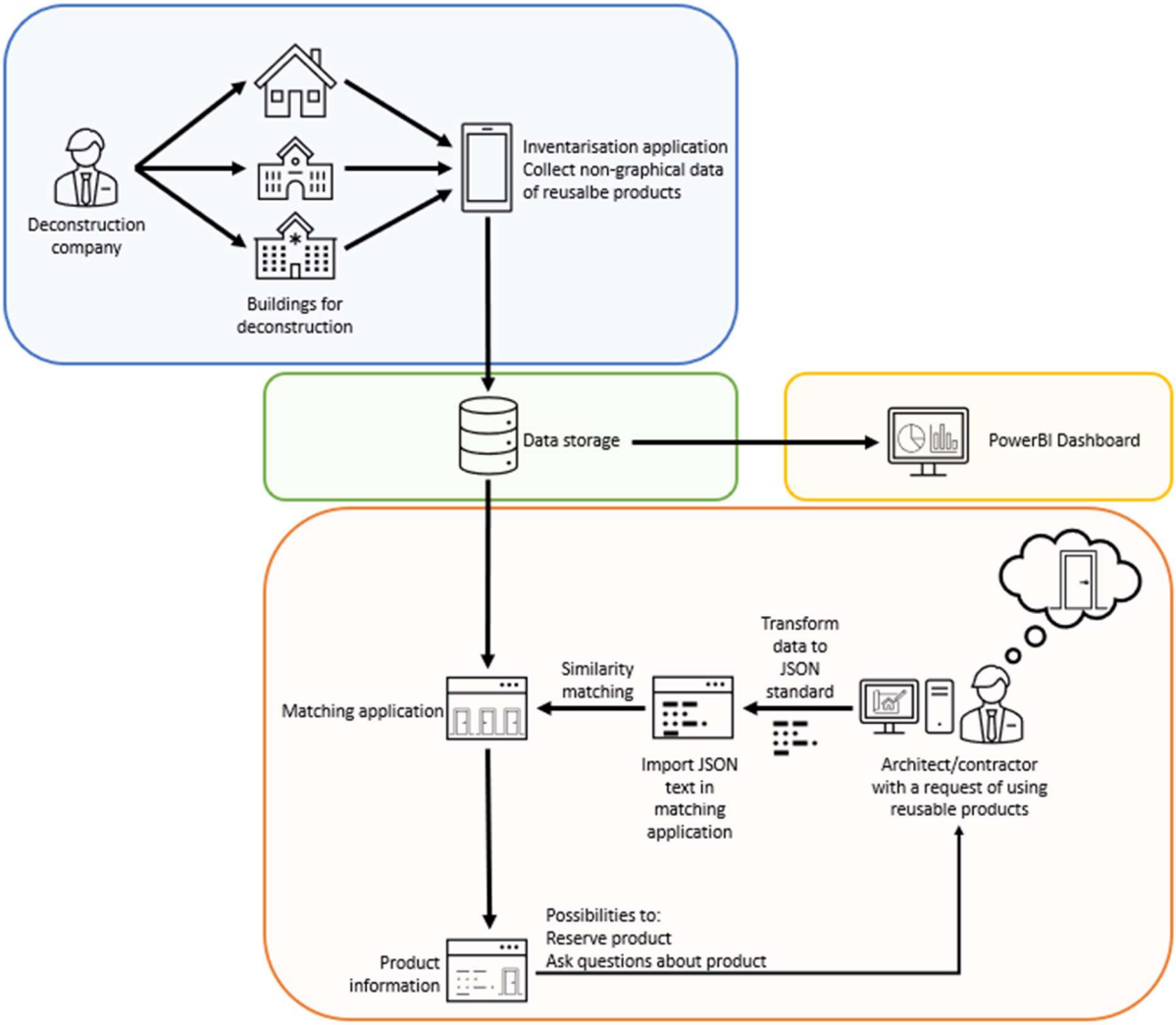

Figure 65 System architecture (simplified version)

by the two identified methods, by a tree structure without filters and by matching the stock of reusable products with product data from a JSON file. The prototype of the matching application should be further developed before it is released to the market. For the matching application more optimizations were identified which are also included in the recommendations. The most important optimization is an automatic conversion to a JSON file standard. Architects and contractors should not have to convert and work with the code themselves, as this makes the search time-consuming. Also, a direct connection with a Revit plugin would save this time-consuming conversion. However, It can be concluded that it makes sense to store product data in a decentralized manner so that all data can be easily exchanged, not only between the three applications, but also easily exchanged with other databases.

8.2. Contribution

This research has shown a combination of engineering methods and research with positive proof of concept and contribution in both scientific and societal aspects which lead to valorisation of the market. Starting with the in-depth process analysis of the deconstruction process of the graduation company. No in-depth analysis of a deconstruction process has been published in the literature yet. Therefore, other researchers can use this process analysis and find further optimizations to improve the deconstruction process. This deconstruction process is based on the workflows of the graduation company, so it should be considered that minor changes may occur for other deconstruction companies. In addition, this research contributes to the advancement of a standard for reusable products during inventarisation and proposes product passports for reusable products, which have been, so far, barely researched. By enhancing the reuse process, further research will discover other opportunities to reuse the products that are currently being recycled, which declines the amount of recycled products and tightens the loops in the circular economy. Reusing products in general lead to a reduction of carbon- and nitrogen emissions.

This research also creates awareness of the opportunities that the JSON data exchange format presents for the AECO sector in the transition towards a more cloud-based data technologies. The use of the JSON file format in this study makes the matching application platform independent. The low-code environment has the advantage that both applications could be developed during the time of this research. To date, no tool has been found that shows the connection of JSON data from the AECO with low-code platforms. Thus, this positive proof of concept demonstrates the potential of low-code environments. However, it is critical to note that the code cannot be reused by other researchers. Both applications can only be used by the graduation company, where it is further developed for implementation. Overall, the applications can lead to inspirations for further scientific research. Lastly, this research shows that matching between properties is possible between a decentralised database and a JSON file. By automating the JSON handling in the back end, in stead of manual insertion, is even further improving the scientific relevance and brings the construction sector closer to BIM level 3.

To conclude, this research contributes to the transition to a more circular built environment by improving and stimulating the reuse process. It contributes to improving the current product cycles in the Netherlands to move from recycling to reusing products, which has the least negative impact.

8.3. Recommendations

The conducted research contains recommendations for developers and future research as well as for the stakeholders involved in this research. Recommendations for the applications are already presented in the validation of all three applications in Chapter 7. Therefore, this section discusses the challenges and recommendations for further research. This section concludes with a summary of recommendations for future researchers, developers and deconstruction companies, and architects and contractors.

It is recommended from this research to conduct further research on the matching application. The large scope of this research provides an overall view of the current process and barriers of reusing building products, including three application. The large scope resulted in only a manual input of the JSON code in the developed matching application to show the proof of concept. Therefore, further scientific research on decentralization of databases in the AECO sector is recommended to link decentralized databases with BIM models. A link from the matching application with reserved reusable products to BIM models could further improve the interchangeability of data with decentralized databases. For example, a door from one environment could be dragged from one environment to another, where the JSON code should come along in the back-end. The properties with the information of the reusable products then can be added and metric data can be automatically changed.

In addition to the direct link with BIM models, further research on decentralization of data can be conducted by linking databases from different sources (e.g., a direct linkage to the National Milieu Database). When this link is made with the developed matching application, it can show the user direct benefits of reusing products by showing how much CO_2 can be saved. This can help convince the client to use reusable products. Open source data is the key to getting access to all kinds of data at a certain level of information. This is in line with the BIM level 3 approach in the wedge diagram of Figure 16. In the current matching application, architects and contractors have to manually import the JSON file themselves. This should be done automatically to get to BIM Level 3, or can be realized externally. In both cases, the databases are connected with each other and the JSON data is passed back and forth in the back-end without much intervention.

A challenge related to the above recommendations is the issue of data privacy for the deconstruction companies. The data of the deconstruction companies must be secured in their environment, but should also be transferable to other databases, such as a BIM model. Therefore, an opening should be created in the back-end to make this connection.

As for the inventarisation application with a positive beta validation, it can be implemented by the graduation company with only minor adjustments. From the literature review, qualitative semi-structured interviews, and process chain analysis, it is found that the chance of selling a product is higher when a building is inventoried prior to the deconstruction process because the deconstruction period is relatively short and the construction period is longer. This could potentially save storage and additional transportation costs. Therefore, it is suggested that reusable products should be inventoried earlier in the process, such as during a maintenance round in the use and maintenance phase. The reusable value is then captured

earlier in the process and it becomes clear which reusable products will be released in the upcoming years, improving the chances of selling and using more reusable products.

The author expects that if the demand for reusable products will increase, the limitations in the policy and the building decree arise and a policy for reusable products will be needed. Therefore, the author of this study suggests a research towards the current policy and find out what changes are needed to create more opportunities for direct reuse. For example, is it possible to say that a 70 year old steel construction beam still has more than 80% of its capacity. Currently every beam has to be measured separately and this is an expensive and time consuming process if we have to calculate and measure every time. Next, rules could also be established for the possible insurance of second-hand products. Show what is possible with good examples and think from that perspective how the policy and building decree could be changed for the better in a safe way. Another example would be to eliminate the 21% tax that is currently paid on used products, this tax has been paid in the past as well. Also, the possibility of receiving subsidies from the government when using second hand products should be explored.

The final recommendation from this research is to combine the data from the inventarisation application with semantic models from a 3D scan. Most of the current building stock does not contain a BIM model. Therefore, 3D scans are becoming more popular to scan the current building stock. 3D scanning tools can be used to graphically inventories' a building in a semantic model with metric information. The 3D scanning software can already recognize multiple objects using artificial intelligence (AI). Combining 3D scanning tools with the inventarisation application is an interesting research topic to add visibly recognizable information from the inventarisation application to the 3D scanned semantic model.

Recommendation summary for further researchers

1. Conduct research towards decentralization of databases in the AECO sector to link decentralized databases with BIM models.
2. Conduct research towards linking the reusable products stock with recognised objects in semantic models of 3D scans.
3. Conduct research towards the current policy and building decree in regards with reusable products and suggest opportunities for implementation to boost the market of reusable products.

Recommendation summary for developers and deconstruction companies

1. Collaborate with other deconstruction companies to create one central marketplace with reusable products, where products have the same information standard, e.g. the information standard created in the inventarisation application.
2. Before implementation of the inventarisation application it is recommended to switch towards a SQL database as storage method. The switch is necessary to support larger volumes and be able to create complex data relationships.

3. Further development of the inventarisation application is by adding QR codes for every inventorised product. To scan and track the location of each product.
4. Finish the sales-part of the matching application, pilot the matching application and verify the usability, chosen parameters and identify future requirements.
5. Develop a database that it is save and secure, but still is available to make a connection in the back-end to transfer JSON code.
6. After implementing the matching application, it is recommended to track what the most important parameters are and often used ranges, by e.g. using Artificial Intelligence (AI) or a Stated Choice Experiment to improve the basis range.
7. Collaborate with a developer of 3D scans to combine the inventarisation application to enrich semantic models.
8. Pilot the product passports of reusable products with current projects to identify problems and to establish procedures for implementation in the same standard of product passports for new products.

Recommendation summary for architects and contractors

1. Use standardization in the BIM models like the BIM Basis ILS and NAA.K.T.
2. Next to setting goals of being emission free as a construction company in 2030, also set goals for the project-specific emissions.
3. Take responsibility and design according the 10R principle of levels of circularity.
4. Collaborate with deconstruction companies to understand the opportunities of reuse.

CHAPTER 9.

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CHAPTER 10.

Appendices

10. Appendices

Appendix 1_Informed consent

Informatieblad voor onderzoek "Fabian Breteler"

1. Inleiding

U bent gevraagd om deel te nemen aan het onderzoek 'Improving the process of reusable building components'.

Deelname aan dit onderzoek is vrijwillig: u besluit zelf of u mee wilt doen. Voordat u besluit tot deelname, willen wij u vragen de volgende informatie door te lezen, zodat u weet waar het onderzoek over gaat, wat er van u verwacht wordt en hoe wij omgaan met de verwerking van uw persoonsgegevens.

U bent natuurlijk altijd vrij om vragen te stellen, of deze informatie te bespreken met voor u bekenden.

2. Doel van het onderzoek

Dit onderzoek is opgezet door F.H.R. Breteler en wordt uitgevoerd onder leiding van Dr. Ir. P. (Pieter) Pauwels en Dr. Ir. Q. (Qi) Han. Het onderzoek betreft een samenwerking tussen de TU/e en Beelen NEXT.
Het doel van dit interview is om:

- Een goed beeld te krijgen van het gehele proces van het toepassen van herbruikbare bouwmaterialen van sloop- en bouw perspectief.
- Het identificieren en valideren van de barrieres van hergebruik.
- Het identificieren van gebruikers vereisten voor de mobiele en web applicatie.

3. Wat houdt deelname aan de studie in?

U neemt deel aan een onderzoek waarbij we informatie zullen vergaren door een semi-gestructureerd interview. Dit interview zal op 1 moment worden afgenomen en duurt ongeveer 30 minuten. Tijdens dit interview worden uw antwoorden opgenomen vai een audio-opname. Nadien wordt er een transcript uitgewerkt van het interview.

4. Welke persoonsgegevens verzamelen en verwerken wij van u?

Tijdens het onderzoek worden de volgende gegevens van u verzameld.

- Naam & e-mail (voor contact)
- Bedrijf & functietitel

5. Potentiële risico's en ongemakken

- Er zijn geen fysieke, juridische of economische risico's verbonden aan uw deelname aan deze studie. U hoeft geen vragen te beantwoorden die u niet wilt beantwoorden. Uw deelname is vrijwillig. Dit betekent dat u uw deelname op elk gewenst moment mag stoppen door dit te melden bij de onderzoeker. U hoeft niet uit te leggen waarom u wilt stoppen met deelname aan het onderzoek.

6. Vergoeding

U ontvangt voor deelname aan dit onderzoek geen vergoeding.

7. Vertrouwelijkheid van gegevens

Wij doen er alles aan uw privacy zo goed mogelijk te beschermen. De onderzoeksresultaten die gepubliceerd worden zullen op geen enkele wijze vertrouwelijke informatie of persoonsgegevens van of over u bevatten waardoor iemand u kan herkennen.

De persoonsgegevens die verzameld zijn via audio-opnamen in het kader van deze studie, worden opgeslagen op goed beveiligide computersystemen waartoe onbevoegden geen toegang hebben. Om uw privacy te waarborgen worden uw naam en mailadres gescheiden van uw onderzoeksgegevens bewaard. In de rapportage zullen resultaten niet herleidbaar zijn tot de identiteit van individuele deelnemers. Na transcribatie van het interview worden de audio-opnamen direct vernietigd.

De onderzoeksgegevens worden indien nodig (bijvoorbeeld voor een controle op wetenschappelijke integriteit) en alleen in anonieme vorm ter beschikking gesteld aan personen buiten de onderzoeks-groep.

Tot slot is dit onderzoek beoordeeld en goedgekeurd door data steward Sjef Öllers en de ethische commissie van de Technische Universiteit Eindhoven.

8. Vrijwilligheid

Deelname aan dit onderzoek is geheel vrijwillig. U kunt als deelnemer uw medewerking aan het onderzoek te allen tijde stoppen, of weigeren dat uw gegevens voor het onderzoek mogen worden gebruikt, zonder opgaaf van redenen. Het stopzetten van deelname heeft geen nadelige gevolgen voor u of de eventueel reeds ontvangen vergoeding.

Als u tijdens het onderzoek besluit om uw medewerking te staken, zullen de gegevens die u reeds hebt verstrekt tot het moment van intrekking van de toestemming in het onderzoek gebruikt worden.
Wilt u stoppen met het onderzoek, of heeft u vragen en/of klachten? Neem dan contact op met de onderzoeksleider.

Onderzoekers: Fabian Breteler (e-mail: f.h.r.breteler@student.tue.nl)
Dr. Ir. P. (Pieter) Pauwels (e-mail: p.pauwels@tue.nl)
Dr. Ir. Q. (Qi) Han (e-mail:q.han@tue.nl)

Locatie: VRT. 9.10
The Built Environment
Eindhoven University of Technology (5600 MB)

Indien u klachten of opmerkingen heeft over het onderzoek, kunt u dit bespreken met de hoofdonderzoeker: Fabian Breteler.

Dit onderzoek wordt uitgevoerd vanuit de Technische Universiteit Eindhoven en is de verwerkingsverantwoordelijke in de zin van de AVG. Indien u specifieke vragen hebt over de omgang met persoonsgegevens kun u deze ook richten aan de functionaris gegevensbescherming van de TU/e door een mail te sturen naar functionarisgegevensbescherming@tue.nl. U hebt daarnaast het recht om een klacht in te dienen bij de Autoriteit Persoonsgegevens.

Tot slot heeft u het recht een verzoek tot inzage, wijziging, verwijdering of aanpassing van uw gege- vens te doen. Ga voor meer informatie naar https://www.tue.nl/storage/privacy/. Dien uw verzoek daartoe in via privacy@tue.nl.

***** Scroll naar beneden voor het toestemmingsformulier *****

Door dit toestemmingsformulier te ondertekenen erken ik het volgende:

1. Ik ben voldoende geïnformeerd over het onderzoek door middel van een separaat informatieblad. Ik heb het informatieblad gelezen en heb daarna de mogelijkheid gehad vragen te kunnen stellen. Deze vragen zijn voldoende beantwoord.
2. Ik neem vrijwillig deel aan dit onderzoek. Er is geen expliciete of impliciete dwang voor mij om aan dit onderzoek deel te nemen. Het is mij duidelijk dat ik deelname aan het onderzoek op elk moment, zonder opgaaf van reden, kan beëindigen. Ik hoef een vraag niet te beantwoorden als ik dat niet wil.
3. Ik geef toestemming voor de verwerking en opslag van de gegevens die ik in het kader van het interview heb verstrekt ten behoeve van het onderzoek " Improving the process of reusable building components ". De informatie verstrekt in de interviews wordt beveiligd opgeslagen op de servers van de TU Eindhoven.
4. Ik begrijp dat de informatie die ik verstrek niet naar mij teruggeleid kan worden in rapporten en wetenschappelijke publicaties over dit onderzoek.
5. Geïnterviewde geeft aan liever wel met naam en bedrijf in interview vermeld te worden, daarom wordt deze specifiek niet geannonimiseerd in het rapport.

Ik heb bovenstaande verklaringen gelezen en begrepen en ben het eens met al deze verklaringen.
Gelieve slechts één van de volgende opties te kiezen:

□ **Nee, ik ga niet akkoord**

□ **Ja, ik ga akkoord**

Naam Deelnemer:

Handtekening:

Datum:

Naam Onderzoeker: F.H.R. Breteler

Handtekening:

Datum:

Appendix 2_ Questions semi structured interviews

Semi-structured interview script - Deconstruction company EN

Introduction

- Introduction of researcher
- Thanking participant for participating
- Explaining the study
- Explaining the structure of the interview
- Ask for permission for recording the interview, interview will be transcribed and the interviewee will be anonymised. Only their role and company name is shown.

Warm up questions

- What is your current role in the company your working for?
- How long have you been active in this role?
- Do you have any other work experience in this field of study?

Interview

Process and barriers

Are you familiar with the term circular demolition and what does it mean to you?

- How does the process look like of using a reusable product from dismantling till selling?
    - Do you also store products?
- What are barriers you often encounter in the process of dismantling and selling of a second-hand product?
- What do you think is needed to boost the market for second-hand construction products?
- Do you reuse products from every building you adopt? Why/why not? What are the key indicators?

Application

Do you think a mobile app can help you in the process to upload new products in the webshop?

- What are for you the most important functionalities for uploading/maintaining and deleting products?

Do you know BIM?

- If so, how well do you know BIM?
- If they do know BIM, do you think that a web application for matching BIM models with a database can promote the use of reusable products?
- What would you like to change or add to improve/facilitate the process of second hand building products?
- If they do know BIM, do you think integrating BIM in a tool will help the architect and contractor in the process of finding reusable building products?
- What are for you important functionalities that this tool should have?

Cool off

- Are there any additional questions from your side?
- Would you like to add anything that I might have missed to ask for this research?
- Final words and thanking them for their time
- Do you want to receive a copy of the research after graduating?
- Are you willing to participate in a beta version?

Semi-structured interview script – Architect/Contractor EN

Introduction

- Introduction of researcher
- Thanking participant for participating
- Explaining the study
- Explaining the structure of the interview
- Ask for permission for recording the interview, interview will be transcribed and the interviewee will be anonymised. Only their role and company name is shown.

Warm up questions

- What is your current role in the company your working for?
- How long have you been active in this role?
- Do you have any other work experience in this field of study?

Interview

Process and barriers

Are you familiar with the term circular design and what does it mean to you?

Have you ever used a reusable product in one of your projects?

- Where did you look for reusable products?
    - What were you looking for?
    - How easy did you found what you were searching for?
    - In which phase of a building design are you looking for reusable products?
- If so, can you take me into the process of all steps that you took to reuse a reusable product?
- Did you need to store the product?
    - How was this process?
    - If so, was there a lot of time in storage?
- What are barriers you encounter in the process of reusing a product?
- What do you think is needed to boost the market for second-hand construction products?

Application

Do you know BIM?

- If so, how well do you know BIM?
- If so, do you think integrating BIM in a tool will help you in the process of finding reusable building products?
- What are for you important functionalities that this tool must have?
- What would you like to change or add to improve/facilitate the process of second hand building products?

Cool off

- Are there any additional questions from your side?
- Would you like to add anything that I might have missed to ask for this research?
- Final words and thanking them for their time
- Do you want to receive a copy of the research after graduating?
- Are you willing to participate in a beta version?

Semigestructureerd interview script – Deconstructie bedrijf NL

Introductie

- Introductie van onderzoeker
- Dankwoord voor meedoen aan onderzoek
- Uitleg van de studie
- Uitleg over de structuur van dit interview
- Vraag om goedkeuring opname interview, interview zal worden getranscribeerd en de geïnterviewde wordt geanonimiseerd.

Warm up question

- Wat is uw huidige functie in het bedrijf waarvoor je werkt?
- Hoelang werkt u al in deze functie voor dit bedrijf?
- Heeft u nog andere werkervaring in dit studiegebied?

Interview

Processen en barrières

Bent u bekend met de term circulair slopen en wat verstaat u daaronder?

- Hoe ziet het proces eruit van het hergebruiken van een product van demontage tot verkoop?
    - Slaan jullie ook producten op?
- Wat zijn barrières die u vaak tegenkomt in het proces van een tweedehands product demonteren en verkopen?
- Wat denkt u dat nodig is om de markt van 2de hands producten in de bouw een boost te geven?
- Hergebruiken jullie bouwproducten uit elk gebouw wat jullie aannemen?
    - Waarom wel/niet? Wat zijn de belangrijkste factoren hierin?

Applicatie

Denkt u dat een mobiele app u kan helpen voor het uploaden van nieuwe producten voor de website?

- Wat zijn voor u de belangrijkste functionaliteiten voor het uploaden, onderhouden en verwijderen van producten?

Bent u bekend met BIM?

- Zo ja, kunt u mij vertellen wat u ervan weet?
- Indien ze bekend zijn met BIM, denkt u dat een webapplicatie voor het matchen van BIM modellen met een database het proces van het vinden van herbruikbare producten kan bevorderen?
- Wat zou u willen veranderen of toevoegen om het proces van 2de hands bouwproducten te verbeteren/vermakkelijken?

Cool off

- Heeft u nog verdere vragen van uw kant?
- Is er iets wat u nog meer wilt vertellen over dit onderwerp wat ik mogelijk kan meenemen in mijn onderzoek?
- Laatste woorden en bedanken voor de tijd
- Willen ze een kopie van het onderzoek ontvangen na het afstuderen?
- Zou je mee willen doen aan de bèta validatie van de applicatie?

Semigestructureerd interview script – Architect/aannemer NL

Introductie

- Introductie van onderzoeker
- Dankwoord voor meedoen aan onderzoek
- Uitleg van de studie
- Uitleg over de structuur van dit interview
- Vraag om goedkeuring opname interview, interview zal worden getranscribeerd en de geïnterviewde wordt geanonimiseerd.

Warm up question

- Wat is uw huidige functie in het bedrijf waarvoor je werkt?
- Hoelang werkt u al in deze functie voor dit bedrijf?
- Heeft u nog andere werkervaring in dit studiegebied?

Interview

Processen en barrières

Bent u bekend met de term circulair ontwerpen en wat verstaat u daaronder?

Heeft u al eens een hergebruikt product in één van uw projecten toegepast?

- Waar zocht u naar in de zoektocht naar een herbruikbaar product?
    - Waar was u naar op zoek?
    - Hoe makkelijk vond u waar u naar opzoek was?
    - In welke fase van het gebouwontwerp zocht u naar deze herbruikbare producten?
- Indien ja, kunt u me meenemen in het proces van alle stappen die u doorlopen hebt in de zoektocht naar een herbruikbaar product?
- Moest u het herbruikbaar product ook zelf opslaan?
    - Zo ja, hoe ging dit proces?
    - Zo ja, hoelang heeft het product uiteindelijk opgeslagen gelegen?
- Wat zijn de barrières waar u tegenaan loopt in het proces van een herbruikbaar product toepassen?
- Wat is er volgens u nodig om de markt voor herbruikbare producten te boosten?

Applicatie

Bent u bekend met BIM?

- Zo ja, kunt u mij vertellen wat u ervan weet?
- Zo ja, denkt u dat een BIM model integreren in een tool u kan helpen in het proces van herbruikbare producten zoeken?
- Wat zijn voor u belangrijke functionaliteiten die zo'n tool moet hebben?
- Wat zou u willen veranderen of toevoegen om het proces van 2de hands bouwproducten te verbeteren/vermakkelijken?

Cool off

- Heeft u nog verdere vragen van uw kant?
- Is er iets wat u nog meer wilt vertellen over dit onderwerp wat ik mogelijk kan meenemen in mijn onderzoek?
- Laatste woorden en bedanken voor de tijd
- Willen ze een kopie van het onderzoek ontvangen na het afstuderen?
- Zou je mee willen doen aan de bèta validatie van de applicatie?

Appendix 3_Approval letter ERB interviews

Mr. Fabian Breteler

f.h.r.breteler@student.tue.nl

EINDHOVEN UNIVERSITY OF TECHNOLOGY

Date
November 13, 2021

Reference
ERB2021BE55

Ethical Review Board TU/e

T +31 (0)40 247 6259
ethics@tue.nl

intranet.tue.nl/ethics

Ethical review research proposal

Dear Mr. Breteler,

It is a pleasure to inform you that the Ethical Review Board (ERB) has discussed and approved your application "Improving the process of reusable building components - Connecting the Construction Demolition Waste flows with construction sites to improve the process and stimulate the use of reusable building components".

The Board wants to draw your attention to the terms and conditions in the appendix.

Success with your research!

Sincerely,

Dr. D. Lakens
Chair Ethical Review Board TU/e

Enclosures
1

The ERB retains the right to revise its decision regarding the implementation and the WMO[1]/WMH[2] status of any research study in response to changing regulations, research activities, or other unforeseen circumstances that are relevant to reviewing any such study. The ERB shall notify the principal researcher of its revised decision and of the reasons for having revised its decision.

[1]WMO: Law on Medical Scientific Research involving Human Beings (in Dutch: Wet medisch-wetenschappelijk onderzoek met mensen)

[2]WMH: Medical Device Directive (in Dutch: Wet op de medische hulpmiddelen)

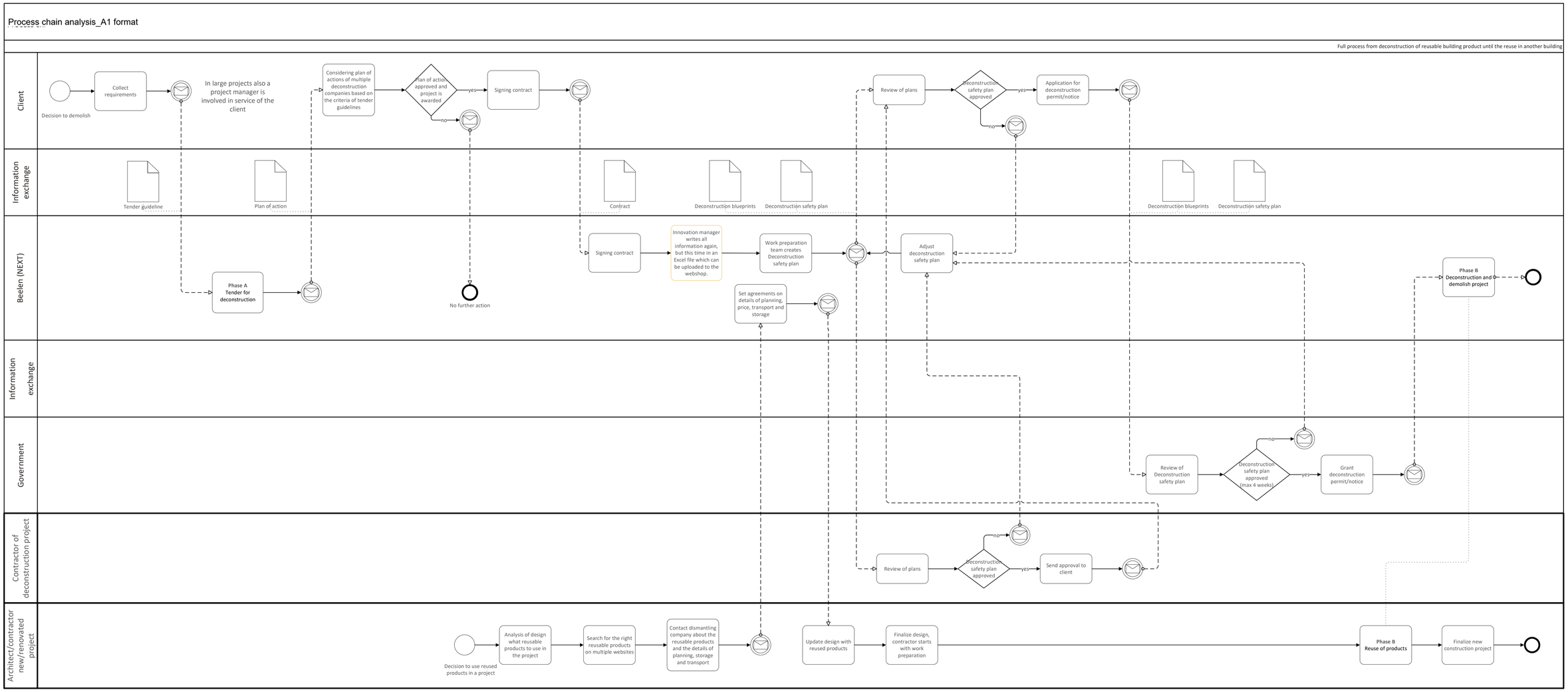
APPENDIX 1

Terms and conditions

Amendments
When considerable amendments are made to the design of the study or educational activity, or when the time period between ERB approval and start of the study is longer than one year, please consult the ERB.

Privacy and research data management
The ERB would like to point out that collecting, handling and storing personal information is subject to the General Data Protection Regulation. Please visit TU/e intranet for the latest information and regulations on www.tue.nl/rdm

Appendix 4_Process chain analysis



Appendix 5_URD Inventarisation application

Improving the process of reusable building components

F.H.R. Breteler

Connecting reusable products from the Construction Demolition Waste flows with construction sites to improve the process and stimulate the use of reusable building products.

Version

1

Date

06-04-2022

Table of content

1. Introduction

1.1. Purpose

The purpose of this User Requirements Document (URD) is to describe the exact requirements of the user with respect to the software. The requirements in this URD become a mutual agreement between the graduation company and the developer graduation student Fabian Breteler. The URD is intended to create a common ground between both parties involved in the project, about what is technically feasible and realistic and what is not feasible in the software task.

1.2. Scope

The inventarisation application is a mobile application for the graduation company created by graduation student Fabian Breteler of the master of Construction Management & Engineering. It is built to improve the current process of inventarisation of reusable products and is named the inventarisation application. The system allows the account manager to add projects and products with information and photos. The account manager only has to fill in the data once and can manage and edit the data at any preferable moment from the inventarisation application. The inventarisation application is designed as a mobile application to ensure high usability and accessibility on every site visit.

The inventarisation application will be connected to a database that can store key-value data and photos. From this database, the matching application can query the key-value data and match between properties of the JSON file from the BIM models of the architects and contractors. The inventarisation application will contain a login functionality for authentication, authorization and securing the data. For the matching application, a separate URD is created and shown in Appendix 6_URD matching application.

1.3. Definitions

In Table 1 a list is shown of all definitions of terms defined.

Table 1 Overview of definitions of terms

User	A person or system interacting with the applications.
Administrator	A person who has full access to the inventarisation and matching application.
Account manager	A person who can create, edit and delete projects and products in the inventarisation application. The account manager is inventorying products on site.
Reusable product	A product that can be inventoried by the account manager during a site investigation. If this reusable product can be dismantled and sold.
Project	A project which contains reusable products.
Inventarisation application	The mobile application for the account manager to register reusable products on site.
Matching application	The application for the online matching of reusable products and BIM models.
BIM-models	A BIM model of the upcoming building that is created by the construction team.

2. General Description

2.1. Product Perspective

The project is to create a mobile application for the account manager to register and manage the information of reusable products. The inventarisation application will fill the database that is used by the matching application.

2.2. General Capabilities

The main capabilities of the highest and high importance requested are described below:

- The inventarisation application must have a registration interface for new projects and new products.
- Existing projects and products can be managed within the inventarisation application.
- The possibility to add one or more products for a single project.
- The possibility to upload 8 photos of a product to get a good visible image of the reusable product.

2.3. General Constraints

There are three minor constraints to the inventarisation application:

The first minor constraint is regarding the BIM model of architects and contractors. The key-value data of the BIM models need to be analysed carefully to identify the data to match on. These key values from the BIM models must have the same format as the non-graphical key-value data in de database. Otherwise, no or only a few matches can be made. E.g. if the length from the BIM models is in mm's, the length in the database should also be in mm's to make a match possible.

Another minor constraint is that the inventarisation should be easy and simple to use during a site visit. Complicating or an overflow of information will cost time and money in the process of inventorying products.

Lastly, the applications shall be used by Dutch people only, therefore the application is developed in the Dutch language. The Microsoft environment is also in Dutch, which makes it harder to code.

2.4. User Characteristics

The mobile application will only be accessed and managed by the account manager. An account manager should be able to:

- Create new projects and products
- Edit and manage information of projects and products that are inventoried in the mobile application
- Delete projects and products

The administrator is in charge of access control of all accounts within Beelen (NEXT) and has unlimited access to projects and the database itself. An administrator can give or take the rights of an account manager to make use of the mobile application. If the application shows sufficient proof of concept, the application can also be used by all foremen to identify extra reusable products that the account manager missed during a site visit.

2.5. Environment Description

2.5.1. Back-end

For the proof of concept, SharePoint lists are used to store all project and product information. This storage is chosen, due to the integration with Microsoft PowerApps as front-end and the agility of application development. SharePoint lists are using MS SQL Server as a database management system for its operations. The SharePoint lists are storing all information regarding project and product information. The ProjectID is used as a foreign key to identify the project details for each product. The SharePoint lists are used for matching the stock of the reusable products with product information from the JSON file in the matching application. In the SharePoint lists, non-graphical information and photos (as a text file) are stored.

2.5.2. Front-end

The inventarisation application is created in PowerApps, which is a low code app development of Microsoft. PowerApps is using the low code language: Microsoft Power FX. This is the standard Power Apps coding language, is open source and is based on Microsoft Excel. PowerApps will be used to view and manage the project and product information. The inventarisation application will be available on IOS and Android in the PowerApps environment.

2.6. Assumptions and Dependencies

2.6.1. Data Assumptions and Dependencies

1. There is project and product data available in abundance to fill the database for the research. Otherwise, extra project and product information need to be created by the developer.

2.6.2. External Dependencies

1. A connection with the existing Beelen NEXT webshop is only possible if the ICT company of the website is willing to connect the database.

2.6.3. Internal Dependencies

1. Between the front-end interface and the data in a direct manner.

3. Specific requirements

To categorize the requirements that came forward during the literature study and expert interviews, the MoSCoW-method is used. Using the MoSCoW- method, the requirements can be categorised based on the following priority (Tudor & Walter, 2006):

- M(ust have) – For those requirements with high priority that must be met at the end of the project, otherwise there would be little to no use for the system.
- S(hould have) – For those requirements that are important, but not vital for the system. Not meeting these requirements can be painful, but the system will still be viable.
- C(ould have) – For those requirements that are desirable, but less important.

- W(on't have) – For those requirements that have been discussed, it has been agreed on to drop these for the current deliverable in order to protect the scope of the application and focus on the more important requirements.

3.1. Authentication & Authorization requirements

ID	Requirement	Priority
AUT01	The system allows account managers to log in to the mobile application using their email and password.	MUST
AUT02	When the account manager is logged in, the system allows logging out of their account.	MUST
AUT03	The system allows the account manager to change the password of their account.	WON'T
AUT04	When the account manager has forgotten their password, the system allows the account manager to reset the password with their email.	WON'T

3.2. Project requirements

ID	Requirement	Priority
PRJ01	The account manager shall be able to create a new project.	MUST
PRJ02	The account manager shall be able to edit and delete existing projects.	MUST
PRJ03	The existing projects overview shall display a list of all inventoried projects with project number and name.	MUST
PRJ04	The existing projects overview shall be searchable based on the project number or name.	SHOULD
PRJ05	When a project is selected, an overview of all products is shown.	MUST
PRJ06	The account manager shall be able to add all relevant information, identified in chapter 6, for a project.	MUST
PRJ07	The account manager shall be able to add a description while adding a project.	SHOULD
PRJ08	The account manager shall be able to add photo's that are generic for the project.	SHOULD

3.3. Product requirements

ID	Requirement	Priority
PRD01	The account manager shall be able to add one or more products for a single project.	MUST
PRD02	The account manager shall have the possibility to upload 8 photos of a product.	MUST
PRD03	The account manager shall be able to retake a photo of a product.	MUST
PRD04	The project number should be automatically added to the product page.	MUST
PRD05	The unique product ID shall be automatically added to the product page and is automatically ascending.	MUST

PRD06	The account manager shall be able to add all relevant information, identified in chapter 6, for a product.	MUST
PRD07	From the add product screen, there shall be two buttons, one to add another product and one to go back to the menu screen.	MUST
PRD08	When a product is selected, the information and photo's shall be editable and deletable.	SHOULD
PRD09	Products shall be able to be selected and deleted at once.	SHOULD
PRD10	Multiple products shall be able to be selected and uploaded to the existing webshop of Beelen NEXT at once.	COULD
PRD11	Products shall be able to be ranked on NL-SfB code.	COULD
PRD12	The location of the product shall be able to be edited to keep track of the product.	COULD

3.4. Other requirements

ID	Requirement	Priority
OTH01	The system shall be simple and fast.	MUST
OTH02	Photos are saved as text to keep the application fast.	COULD
OTH03	Project and product overview pages are scrollable if necessary.	MUST
OTH04	The system shall send a reminder mail one month before the planned dismantling date.	WON'T
OTH05	The system shall store all data in a secured database.	MUST
OTH06	The SharePoint list shall be connected with the current Webshop of Beelen NEXT.	WON'T
OTH07	The inventarisation application shall be available in Apple and Android environments.	MUST

Appendix 6_URD Matching application

Enhancement of the process of reusing building products

F.H.R. Breteler

Connecting reusable products from the Construction Demolition Waste flows with construction sites to improve the process and stimulate the use of reusable building products.

Version

1

Date

06-04-2022

Table of content

1. Introduction

1.1. Purpose

The purpose of this User Requirements Document (URD) is to describe the exact requirements of the user with respect to the software. The requirements in this URD become a mutual agreement between the graduation company and the developer graduation student Fabian Breteler. The URD is intended to create a common ground between both parties involved in the project, about what is technically feasible and realistic and what is not feasible in the software task.

1.2. Scope

The matching application is a web-based application for the graduation company created by graduation student Fabian Breteler of the master of Construction Management & Engineering. This application is created to improve the current process of finding the right reusable products by the architect or contractor. The system allows the user (architects and contractors) to match non-graphical information in a JSON file format from their BIM models with the current stock of reusable products of Beelen NEXT. The matching application will be created in a canvas project and will not be published on a website. After positive proof of concept the matching application can be further developed as a website. Therefore a login page, question page on products and basket for reserved products will be kept outside the scope.

The matching application will be connected to the database of project and product information of reusable products. From this database, the matching application can query the key-value data and match between properties of the JSON file from the BIM models of the architects and contractors. The matching application allows to make the match and see the product information. The sale of the product will be kept outside the scope of this research.

1.3. Definitions

In Table 1 a list is shown of all definitions of terms defined.

Table 1 Overview of definitions of terms

User	An architect, contractor or system interacting with the applications.
Administrator	A person who has full access to the inventarisation and matching application.
Account manager	A person who can create, edit and delete projects and products in the inventarisation application. The account manager is inventorying products on site.
Reusable product	A product that can be inventoried by the account manager during a site investigation. If this reusable product can be dismantled and sold.
Project	A project which contains reusable products.
Inventarisation application	The mobile application for the account manager to register reusable products on site.
Matching application	The application for the online matching of reusable products and BIM models.
BIM-models	A BIM model of the upcoming building that is created by the construction team.

2. General Description

2.1. Product Perspective

The project is to create a web application for the architect and contractors to match the data of JSON files, coming from BIM models. The matching application is using the stock of reusable products from the inventarisation application which is stored in SharePoint lists.

2.2. General Capabilities

The main capabilities of the highest and high importance requested are described below:

- The matching application must have a text file to paste the JSON file in.
- It should be possible to match the product information in the JSON file with the product information of the reusable stock.
- A perfect match is rare, therefore the closest matches should be shown as a match.
- All product information should be visible after making the match.

2.3. General Constraints

There are three minor constraints to the matching application:

The first minor constraint is regarding the BIM model of architects and contractors. The key-value data of the BIM models need to be analysed carefully to identify key values to match on. There are basic standards like the BIM Basis ILS who give standards for a common base structure. The BIM basis ILS is used as a standard, to make sure the keys are the same in every model. If the keys are not the same and the BIM basis ILS is not used correctly, no matches will occur.

The second minor constraint is regarding the amount of supply of reusable products from Beelen NEXT. If the supply of reusable products investigated by the inventarisation application is small, only a few matches can occur and the range is big. If the supply is large, the range of selected matches is smaller and a better match can occur.

Lastly, the applications shall be used by Dutch people only, therefore the application is developed in the Dutch language. The Microsoft environment is also in Dutch, which makes it harder to code.

2.4. User Characteristics

The matching application will be accessible by the users, account managers and administrators.

2.4.1. Account manager

The account manager should be able to access the matching application to answer asked questions about products and help users with buying the product and discuss transport/storage possibilities. Due to time reasonings, this is kept outside the scope and can be further developed after positive proof of concept of the matching functionalities.

2.4.2. Users

The users can access the matching application and search products in two ways, from the interviews.

- Through a tree-structure overview page, where based on the NL SfB code all products are searchable.
- By pasting the JSON file on the web page and pressing the match button. The closest matches will return.
- Matched products and products from the tree-structure overview page can be selected. A product overview page with all project and product information is shown.

2.4.3. Administrator

The administrator is in charge of access control of all accounts within Beelen (NEXT) and has unlimited access to projects and the database itself. An administrator can give or take the rights of an account manager or user to make use of the matching application.

2.5. Environment Description

2.5.1. Back-end

The matching application is created in PowerApps, which is a low code app development of Microsoft. PowerApps is using the low code language: Microsoft Power FX. For the back-end, PowerApps is used for navigating between screens and filtering products.

For the project and product information of reusable products, SharePoint lists are used. The back-end consists of SharePoint lists, which uses MS SQL Server as a database management system for its operations. The SharePoint lists are storing all information regarding project and product information. The ProjectID is used as a primary key to identify the project details for each product.

Power Automate is used in the back-end to automatically parse the JSON file and set parameters to match with reusable products. This stream is connected to the PowerApps match button.

2.5.2. Front-end

The matching application is created in PowerApps, which is a low code app development of Microsoft. PowerApps is using the low code language: Microsoft Power FX. This is the standard Power Apps coding language, is open source and is based on Microsoft Excel. The application is only available in PowerApps because it is made on a canvas page. A canvas page is chosen for the proof of concept to save time and costs.

2.6. Assumptions and Dependencies

2.6.1. Data Assumptions and Dependencies

1. There is project and product data available in abundance to fill the database for the research. Otherwise, extra project and product information need to be created by the developer.

2.6.2. External Dependencies

1. A connection with the existing Beelen NEXT webshop is only possible if the ICT company of the website is willing to connect the database.

2.6.3. Internal Dependencies

1. Between the front-end interface and the data in a direct manner.

3. Specific requirements

To categorize the requirements that came forward during the literature study and expert interviews, the MoSCoW-method is used. Using the MoSCoW- method, the requirements can be categorised based on the following priority (Tudor & Walter, 2006):

- M(ust have) – For those requirements with high priority that must be met at the end of the project, otherwise there would be little to no use for the system.
- S(hould have) – For those requirements that are important, but not vital for the system. Not meeting these requirements can be painful, but the system will still be viable.
- C(ould have) – For those requirements that are desirable, but less important.
- W(on't have) – For those requirements that have been discussed, but it has been agreed on to drop these for the current deliverable in order to protect the scope of the application and focus on the more important requirements.

3.1. Authentication & Authorization requirements

ID	Requirement	Priority
AUT01	The system allows account managers and users to log in to the matching application using their email and password.	COULD
AUT02	When the account manager and users are logged in, the system allows to log out of their account.	COULD
AUT03	The system allows the account manager and users to change the password of their account.	WON'T
AUT04	When the account manager and users has forgotten their password, the system allows the account manager and user to reset the password with their email.	WON'T
AUT05	The system allows the user to make an account to save their matches.	COULD

3.2. Matching specific requirements

ID	Requirement	Priority
MSR01	The user shall be able to search reusable products in two ways: 1. Through a tree-structure based on the NL SfB code. 2. By importing a JSON file to match on properties.	MUST
MSR02	The user shall be able to select a NL SfB code in the tree-structure, whereafter all products are shown with the selected NL SfB code.	MUST
MSR03	The user shall be able to select a product from the tree-structure search and will go to the product detail page.	MUST
MSR04	The user shall be able to paste the output from the JSON file on the web page.	MUST
MSR05	The user shall be able to press a button to match the products.	MUST
MSR06	The user shall be able to see the three nearest possible matches if available in stock.	MUST

MSR07	The user shall be able to press a button to show all other matches within the same NL SfB code.	COULD
MSR08	The user shall be able to select a matched product and go to the product information page.	MUST
MSR09	The system shall allow the user to compare information between the products.	WON'T

3.3. Product information requirements

ID	Requirement	Priority
PIR01	All available product information, including photos, are shown of the selected product.	MUST
PIR02	All available project information shall be shown of the selected product.	MUST
PIR03	The user shall be able to go back to the matched products.	MUST
PIR04	The user shall be able to add the product to a basket.	WON'T
PIR05	The user shall be able to ask questions on a product and will be saved.	WON'T
PIR06	The user shall be able to pay the product and discuss transportation and delivery date.	WON'T
PIR07	The account manager shall be able to answer the questions of the users.	WON'T
PIR08	A product passport shall be able to be downloaded from the product after reservation.	WON'T

3.4. Other requirements

ID	Requirement	Priority
OTH01	Product information pages are scrollable if necessary.	MUST
OTH02	The system shall send the account manager a daily mail with new questions on products.	WON'T
OTH03	The system shall send the user a mail if the questions is answered.	WON'T
OTH04	The system shall not store JSON data from projects due to security reasonings.	MUST

Appendix 7_ Material passport CB'23 filter 'future'

applied	Informatie	Eenheid / vorm
	Objectnummer	cijfer/lettercombinatie
	Eigenaar Bouwwerk	Naam, straatnaam, huisnummer, postcode,
	Bruto vloeroppervlak	m^2
	Levensduurverwachting	getal
	Datum oplevering / bouwjaar / realisatiedatum	dd/mm/jjjj
	Bouwvergunning archiefnummer	123456
	Lengte	mm
	Breedte	mm
	Hoogte	mm
	Diameter	mm
	Inhoud	m^3
	Bouwjaar/Realisatiedatum	Naam
	Conditie (incl peiljaar) volgens NEN 2767	Peiljaar+ score 1 t/m 6
	Garantie start- en einddatum	dd/mm/jjjj - dd/mm/jjjj
	Decompositie object (NEN 2660/NTA 8035)	tekst
	Functie object	tekst
	Functionele eenheid	stuks/m^1/m^2/m^3/kg
	Type verbinding(en)	A-Click, B-Schroef, C-bout/moer, D-Lijm, E-Schuif, F-Las, G-Haak, J-Klem
	Aantal verbindingen	
	Doorkruizingen	
	Vorminsluiting	
	Robuustheid/Slijtvastheid	
	Vervangbaarheid	
	Flexibiliteit - adaptiviteit	
	Gestandaardiseerde maten	ja/nee
	Kwaliteit van het materiaal	
	Demontageinstructies/-handleiding	pdf
	Tekeningen	Tekening-id's
	Bestandheid tegen emissies	
	Uitgevoerde emissietesten	VOC content, TVOC emissie na dag3, TVOC emissie na dag 28, R-waarde, anders, geen
	Chemische samenstelling	CASnr(s)
	Toxisch materiaal (volgens REACH)	ja/nee
	Contact bij normaal gebruik met mens en omgeving via;	Huid, inademing, inname, blootstelling water, blootstelling grond, anders,
	Reverse logistics / terugname-garantie	ja/nee
	Restwaarde afspraken	ja/nee
	Alternatief (Circulair) verdienmodel	ja/nee

Appendix 8_Comparison second-hand marketplaces

	Online second-hand marketplaces for construction products						
	Beelen NEXT		Insert		Gebruiktebouwmaterialen.com		
Product information	Applied	Unit	Applied	Unit	Applied	Unit	Extra explanation *
ID or Article number		Integer		Integer		Integer	
Title		Category		Category		Category + measurements	
Availability (amounts)		Integer		Integer		Integer	
Material		Text		Text		Text	
Measurements		Integers (cm)*		Integers (both: cm or mm)		Integers (cm)*	In description text.
Description of product		Text		Text		Text	
Location		Circular building hub*		Specific project location		The circular building hub	Exact location unknown, due to multiple circular building hubs.
Quality		General		Technical/esthetical		General (in description)	
Weight						kg*	Not for all products
Amount of CO2						kg*	Not for all products
Availability (date)		Only current availability*		From / till date		Only current availability*	No dates are shown, only the avaible stock is shown.
Price		€/amount		€/amount or €/amount		€/amount	
Pick up and sending details						Text*	Address pick up details, sending details and price.
Project information (deconstruction site)							
Provider				Deconstruction company			
Project name				Text			
Location				Address, postal code + city Dismantling site			

Legend

	Information visible on website
	Information not clear on website
	Information not on website

Appendix 9_VRD inventarisation application

Enhancement of the process of reusing building products

F.H.R. Breteler

Connecting reusable products from the Construction Demolition Waste flows with construction sites to improve the process and stimulate the use of reusable building products.

Version

1

Date

06-04-2022

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1. Introduction

1.1. Purpose

The purpose of this Validation Requirements Document (VRD) is to validate the exact requirements of the user with respect to the software. This validation report is a result of the use of the application by the end-user. The VRD is based on the User Requirements Document (URD) which is drawn up between the developer and end user and is a mutual agreement between the graduation company and the developer graduation student Fabian Breteler. The VRD is intended to validate the set requirements in the URD, the end-user (account manager) will provide feedback on the application, give recommendations and necessary improvements for implementation.

1.2. Scope

The inventarisation application is a mobile application for the graduation company created by graduation student Fabian Breteler of the master of Construction Management & Engineering. It is built to improve the current process of inventarisation of reusable products and is named the inventarisation application. The system allows the account manager to add projects and products with information and photos. The account manager only has to fill in the data once and can manage and edit the data at any preferable moment from the inventarisation application. The inventarisation application is designed as a mobile application to ensure high usability and accessibility on every site visit.

The inventarisation application will be connected to a database that can store key-value data and photos. From this database, the matching application can query the key-value data and match between properties of the JSON file from the BIM models of the architects and contractors. The inventarisation application will contain a login functionality for authentication, authorization and securing the data. For the matching application, a separate URD is created and shown in Appendix 6_URD matching application.

1.3. Definitions

In Table 1 a list is shown of all definitions of terms defined.

Table 1 Overview of definitions of terms

User	A person or system interacting with the web application
Administrator	A person having full access to the web application and mobile application
Account manager	A person who can create, edit and delete projects and products in the mobile app
Reusable product	A product identified by the account manager during a site investigation. This reusable product can be dismantled and sold
Project	A project which contain reusable products
Mobile application	The application for the account manager to register reusable products
Web application	The application for the online matching of reusable products and BIM-models
BIM-models	A digital Building Information Model (BIM) of the upcoming building made by the construction team

2. Validation of specific requirements

To categorize the requirements that came forward during the literature study and expert interviews, the MoSCoW-method is used. Using the MoSCoW- method, the requirements can be categorised based on the following priority (Tudor & Walter, 2006):

- M(ust have) – For those requirements with high priority that must be met at the end of the project, otherwise there would be little to no use for the system.
- S(hould have) – For those requirements that are important, but not vital for the system. Not meeting these requirements can be painful, but the system will still be viable.
- C(ould have) – For those requirements that are desirable, but less important.
- W(on't have) – For those requirements that have been discussed, it has been agreed on to drop these for the current deliverable in order to protect the scope of the application and focus on the more important requirements.

In the tables below all requirements from the URD are reviewed if the requirement is accomplished in the application. Next, additional comments on the requirements and overall application are shown.

2.1. Authentication & Authorization requirements

ID	Requirement	Priority	Accomplished? Yes	No
AUT01	The system allows account managers to log in to the mobile application using their email and password.	MUST	X	
AUT02	When the account manager is logged in, the system allows logging out of their account.	MUST	X	
AUT03	The system allows the account manager to change the password of their account.	WON'T		X
AUT04	When the account manager has forgotten their password, the system allows the account manager to reset the password with their email.	WON'T		X

2.2. Project requirements

ID	Requirement	Priority	Accomplished? Yes	No
PRJ01	The account manager shall be able to create a new project.	MUST	X	
PRJ02	The account manager shall be able to edit and delete existing projects.	MUST	X	
PRJ03	The existing projects overview shall display a list of all inventoried projects with project number and name.	MUST	X	
PRJ04	The existing projects overview shall be searchable based on project number or name.	SHOULD	X	
PRJ05	When a project is selected, an overview of all products is shown.	MUST	X	

PRJ06	The account manager shall be able to add all relevant information, identified in chapter 6, for a project.	MUST	X	
PRJ07	The account manager shall be able to add a description while adding a project.	SHOULD	X	
PRJ08	The account manager shall be able to add photo's that are generic for the project.	SHOULD	X	

2.3. Product requirements

ID	Requirement	Priority	Accomplished? Yes	No
PRD01	The account manager shall be able to add one or more products for a single project.	MUST	X	
PRD02	The account manager shall have the possibility to upload 8 photos of a product.	MUST	X	
PRD03	The account manager shall be able to retake a photo of a product.	MUST	X	
PRD04	The project number should be automatically added to the product page.	MUST	X	
PRD05	The unique product ID shall be automatically added to the product page and is automatically ascending.	MUST	X	
PRD06	The account manager shall be able to add all relevant information, identified in chapter 6, for a product.	MUST	X	
PRD07	From the add product screen, there shall be two buttons, one to add another product and one to go back to the menu screen.	MUST	X	
PRD08	When a product is selected, the information and photo's shall be editable and deletable.	SHOULD	X	
PRD09	Products shall be able to be selected and deleted at once.	SHOULD	X	
PRD10	Multiple products shall be able to be selected and uploaded to the existing webshop of Beelen NEXT at once.	COULD		X
PRD11	Products shall be able to be ranked on NL-SfB code.	COULD	X	
PRD12	The location of the product shall be able to be edited to keep track of the product.	COULD	X	

2.4. Other requirements

ID	Requirement	Priority	Accomplished? Yes	No
OTH01	The system shall be simple and fast.	MUST	X	
OTH02	Photos are saved as text to keep the application fast.	COULD	X	
OTH03	Project and product overview pages are scrollable if necessary.	MUST	X	

OTH04	The system shall send a reminder mail one month before the planned dismantling date.	WON'T		X
OTH05	The system shall store all data in a secured data base.	MUST	X	
OTH06	The SharePoint list shall be connected with the current Webshop of Beelen NEXT.	WON'T		X

Comments on inventarisation application:
The app is very user-friendly and easy in use. Pictures can be made easily of the product and are automatically added to the product page with all specifications.
The specifications are now clearly structured and it is easy to see which products are in each project. In particular, keeping the information organized and working efficiently with the app is really a plus. Products are easy to search back.

An improvement might be a button to select products or projects that are available on the matching application, because not all products are directly after inventarisation available for sale. Another way is to sell the product already beforehand, but add a flag to the product that the product is not ready for sale yet, if there are many requests for the products, Beelen NEXT can use this information to convince the building owner to give the tender the deconstruction company.

If a link could be made with the existing web shop of Beelen NEXT this would be ideal. For the current process this is a real improvement and has value for the full inventorying process.