REMANUFACTURING AS A STRATEGY FOR A CIRCULAR BUILT ENVIRONMENT

An investigation into the potential of remanufacturing of disassembled façade elements of De Satelliet. DNB Complex

MSc Thesis

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ii. Reading guide

Dear reader,

For a fast understanding of all the contents of the report, please read the introduction and summary of all chapters. It is requested that one pays attention to the last chapters to truly understand the impact of remanufacturing and how one can start the conversation to introduce and in future implement remanufacturing in the building industry to transition into a Circular Built Environment.

The chapter 1 opens the discussion and elaborates the research framework. The chapters 2 & 3 lay the introduction to circular economy and a circular built environment. The concept of remanufacturing is discussed in chapter 4, followed by case studies of successful examples of reman in chapter 5.

The chapter 6 talks about the role of digitalization in the transition to CE. The Chapter 7 is introduction to the design for reman canvas made by the author. The chapter 8 & 9 are dedicated to the analysis and evaluation of the case study of EoL elements of De Satelliet.

Chapter 10 presents all the assessments done to evaluate reman as a strategy and chapter 11 gathers all the results for comparison between reman and building a new façade. The chapter 12 is dedicated to answering all the research questions, and chapter 13 & 14 close the report with discussion & conclusions followed by reflection.

Happy reading!

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Rhea Ishani

iii. Abstract

The building industry is material intensive and is responsible for approximately 40% of the total waste generated across the European Union. It operates on a 'take-make-dispose' model due to which key issues such as resource scarcity, waste generation, and environmental pressure occur. The circular economy has been attributed to the need to utilize waste flows more effectively, thereby reducing raw material demand. By 2050, the Dutch Government aims to transition to Circular Economy and organize the building industry in a way to ensure sustainable construction by use, reuse, maintenance and dismantling of objects.

Remanufacturing is a strategy of the circular economy that supports this approach. It is a process of returning a used product to its original performance with a warranty that is equivalent to or better than that of newly manufactured product. It is an important component of resource efficient manufacturing as it reduces the dependency on virgin materials.
Through research, it was observed that the principles of circular economy are well established theoretically but lack guidelines that make them applicable in practice. Therefore, the thesis focuses to find out "how" remanufacturing of building products be implemented as a strategy to accelerate the progress towards a circular built environment.

The project develops a remanufacturing canvas and list of criteria through literature study of successful examples of remanufacturing such as Xerox, Caterpillar, Canon, Philips MRI Systems and Davies Office furniture. Further the proposed canvas is validated through a case study of the building De Satelliet of DNB complex to investigate their remanufacturing potential of EoL façade elements which were disassembled with an intention of giving a second life. The study includes crafting guidelines for the remanufacturing of EoL façade elements. Remanufacturing as a strategy was evaluated through assessments based on Cost, Embodied energy, and thermal performance of the façade elements. The results from the assessments were in favour of remanufacturing. However, it was concluded that while remanufacturing depicts the power of smaller loop and follows all the principles of circular economy, it is important to note that remanufacturing process shifts a large amount of responsibility from a customer to the manufacturer. There is always a risk of creating more impact than virgin production and hence decisions must be supported through results from calculations of embodied carbon and LCA.

Keywords: Remanufacturing, Circular economy, EoL facades, Second Life

iv. Contents

Contents

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v. List of Abbreviations

ARO	Asset recovery operation
B2B	Business to Business
B2C	Business to Consumer
BAU	Business as Usual
CDW	Construction & demoltiion waste
CE	Circular Economy
CEBM	Circular Economy Business Models
DBFMO	Design, Build, Finance, Maintain, Operate
DfX	Design for X (where X could be M, A. E. R. D. Rem etc)
DfD	Design for Disassembly
DT	Digital Twin
EMEA	Europe, Middle East and Africa
EOC	End-of-Contract
EoL	End-of-Life
EoS	End of Service
EoU	End of Use
EPR	Extended Producer Responsibility
ESG	Environment Social Governance
GDPR	General Data protection Regualation
IoT	Internet of things
IR	Independent Remanufacturer
LCA	Life Cycle Assessment
LCC	Life Cycle Coordination
MCI	Material Circularity Indicator
MP	Material Passport
OEM	Original equipment manufacturer
OICs	Operator Instruction Cards
PLC	Product Life Cycle
PSS	Product Service System
Refurb	Refurbishment
Reman	Remanufacturing
WEEE	Waste Electrical and Electronic Equipment

Figure 1 - List of Abbrevations that have been used in the report. Source: Author

01 Research Framework

The chapter presents the framework and explains the motivation of the project, problem statement, objectives, highlights the research methodology and concludes with scope and limitations of the project.

1. Research Framework

1.1 Brief Background

The extraction and utilization of resources has been the foundation for societal advancement and the creation of wealth. In our societies, these resources have been and will continue to be used to provide food, shelter, transportation, communication, and a variety of other basic functions. Every country strives to climb the material ladder to advance its development and well-being. More resources are required to support the world's growing population. Globally, welfare is steadily rising, and with it, the number of resources required per person. Economic development invariably leads to technological advancement, which means that products become more expensive. The most significant of these challenges of a linear economy are related to resource availability, waste generated by resource production and consumption, and environmental pressures caused by resource production and consumption. (4.1.1 Introduction to Remanufacturing - TU Delft OCW, n.d.)

Many organizations and governmental bodies are exploring different approaches to sustainability have been implemented. The Authors Mc Donough and Braungart in their research state that with the speed at which the planet's resources have been exploited, expanding the usable value of material by industrial evolution will be crucial to sustain human activities for many years to come (De los Rios & Charnley, 2017)

The Built landscape

Buildings account for a significant percentage of total energy consumption in European countries (42 percent). The construction business is a material-intensive industry. In 2019, the globe consumed 100.6 billion tonnes of materials (Kanters, 2020) In the context of moving toward more sustainable practices, resource efficiency is defined as a broad concept aimed at reducing resource use and limiting environmental impacts throughout a building's lifecycle, from material extraction for use in construction to resource use during occupancy and maintenance to material recovery at demolition (Dosch, 2018). As a result, selecting low impact building materials has become a critical consideration in the design of future structures. (Kanters, 2020).

The authors Potting, Hekkert & Worrell (2017), (Potting et al., 2017) explain circular economy strategies in the 9R framework. It aims to reduce the consumption of virgin materials and natural resources to reduce waste production. They outline the 9 strategies that contribute to smarter product use and manufacture (R0-R3), followed by extending the lifespan of products and their parts (R3-R7), and then useful applications of materials (R8 and R9)

Circular Economy in The Netherlands

A report titled, 'A Circular Economy in the Netherlands by 2050' highlights the vision of the Dutch Government: "By 2050, the Dutch Government aims to transition to Circular Economy and organize the building industry in a way to ensure sustainable construction by use, reuse, maintenance and dismantling of objects (Netherlands Enterprise Agency, 2019)." Remanufacturing is a strategy of the circular economy that supports this approach. It is a process of returning a used product to its original performance with a warranty that is equivalent to or better than that of newly manufactured product (Charter & Gray, 2008).

The circular economy is guided by an idea of the closed loop system of production and consumption (Stahel, 2016). Remanufacturing technology has been viewed as a closed loop strategy where end-of-life and end-of-service products are returned to their original or even better condition (Singhal et al., 2020). The study focuses on remanufacturing as a strategy for the building industry to close material loops, reduce dependency on virgin materials and production of waste. The chapter is organized as follows: section1 contains the problem statement, section 2 contains the methodology, section 3 elaborates the results in section 4 the results are evaluated, and section 5 draws the conclusion of the study.

1.2 The Problem Statement

The building industry is material intensive and has significant impact on the economy and environment. It is responsible for approximately 40% of the total waste generated across the European Union (Boorsma et al., 2019). In the present scenario, the industry operates on the principles of the linear economy. However, because the linear economy is based on 'take-make-dispose' model, key issues such as resource scarcity, waste generation, and environmental pressure occur.

The circular economy has been attributed to the need to utilize waste flows more effectively, thereby reducing raw material demand. EMF, a UK-based charity that is actively working on the concept of circular economy and defines it as "An economy that is circular or regenerative by design aims to keep products, components, and materials as valuable as possible at all times, distinguishing between technical and biological cycles" (Macarthur, n.d.). By 2050, the Dutch Government aims to transition to Circular Economy and organize the building industry in a way to ensure sustainable construction by use, reuse, maintenance and dismantling of objects (Netherlands Enterprise Agency, 2019).

Remanufacturing is a strategy of the circular economy that supports this approach. It is a process of returning a used product to its original performance with a warranty that is equivalent to or better than that of newly manufactured product. It is an important component of resource efficient manufacturing as it reduces the dependency on virgin materials. Additionally keeping the components, for long life cycles leads to restoring the embodied material in use for longer, significant energy use, and emissions can be avoided. According to (Stahel, 2016) smaller the loop (technical cycle), the more profitable it is. (Macarthur, n.d.) further, describes the power of smaller loop in terms of greater savings with respect to embedded costs in terms of labour, energy, capital, and external factors (GHG emissions).

The integration of digital platform and support systems in other industries are considered as important drivers of remanufacturing. They have proved to enable remanufacturing by enabling design upgradability to ensure market adaptability and enriching customer relationships. Remanufacturing is more valuable than recycling as it protects the complete shape of the product. This closed loop product extension; lower impact approach fits within the frame of Circular Economy. Circular economy is not an end goal but a means to introduce sustainable practices.However, despite all the advantages of remanufacturing, it has not been applied in the building industry on a large scale. This is unfortunate considering building products are mass-produced and standardized. Buildings contain large volumes at products, made of high value materials available at fixed locations. This is because the design activity of building products is centred around single use.

Moreover, building products are not standalone entities but and are always integrated with other assemblies. The ownership period is shorter than the life of the product, which makes it difficult to retrieve them at EOL. Furthermore, it is a dynamic and fragmented industry that involves many stakeholders during the decision-making process. As mentioned before, the integration of digital platforms and support systems in other industries have contributed to the success of remanufacturing. However, an approach to digital platform and support system for Design for remanufacturing (DfRem) in the industry is still missing.

To begin with the focus is on developing a design for remanufacturing canvas and list of criteria to discuss the potential of remanufacturing (reman) in the building industry. Second is to validate the canvas through a conversations and interactions with experts and professionals. Third is critically evaluate the remanufacturing potential of disassembled EoL façade elements of De Satelliet.

1.3 Objective

The main objective of this research is to develop a framework to guide the remanufacturing process of end-of-service/life facades and to evaluate if the disassembled elements of De Satelliet can be remanufactured.
Following the problem statement, the main objective of this research is:
"To introduce remanufacturing as a strategy in the building industry by one, making a canvas and list of criteria. Two is to validate the same through discussion and interaction with company experts and three is to reinforce this with a live example by creating guidelines for remanufacturing EoL facades."

1.3.1 Sub Objectives

From which, the following sub objectives follow:

- S01 – To develop a list of criteria by studying successful examples of remanufacturing in other industries
- S02 – To identify the parameters and characteristics of a product designed for remanufacturing through literature study and exploring examples of successful remanufacturing practices in other industries.
- S03 – To validate the reman canvas and list of criteria through analysis of a live case study
- S04 – To understand the role of architects and designers in implementing the design for remanufacturing in the building industry.

1.4 Research Question

The main objective of this research project is to understand how remanufacturing can be introduced as sustainable strategy and provide guidelines for the remanufacturing of EoL facades by considering the example of disassembled elements of De Satelliet. Thus, the main research question formulated is:

"How can remanufacturing of building products be implemented as a strategy to accelerate the progress towards a Circular Built Environment?"

This research is supported by a live case study from the disassembled façade elements of De Satelliet. From which the following sub research questions arise:

1. What is remanufacturing, and how is it different from the other 're' strategies of the circular economy?
2. What are the conditions and criteria for successful remanufacturing and how can these be applied to the building industry?
3. What guidelines must be followed to begin the remanufacturing process for an EoL Façade product?
4. What are the challenges involved in the remanufacturing of EoL façade products & how can they be overcomed?
5. What is the role of architects and designers to enable and promote products to be designed for remanufacturing?

1.5 Design Question

The research will lead to creation of a design for remanufacturing canvas that will assist in evaluating the remanufacturing process of EoL façade elements of De Satelliet and development of a water tightness concept to restore the product. Thus, the design question formulated is,

"How can the air and water permeability concept be developed for an EoL façade such as De Satelliet to extend its lifecycle"

1.6 Methodology & Approach

The method of research adopted consisted of literature reviews that guided the development of a preliminary canvas. Through interviews and discussions with professionals and company experts, the canvas was further developed and refined. Next, the research focused on analysis of a live case study - De Satelliet. Eventually, the study focused on developing guidelines for the remanufacturing of EoL facades and compared them to brand-new facades (made with virgin materials) by attaching values to variables such as cost and labour.

1.6.1,2 Data Collection & Literature Review

The up-to-date and advanced literature reviews are conducted to understand remanufacturing as a strategy through definitions and theories. To get a perspective on current scenario, 20 successful examples of remanufacturing were listed, and a product canvas is made. This highlighted the process that was followed to make the reman process economically and environmentally feasible.

As a next step five examples that match the complexities to building products are chosen to analyse the criteria, principles and policies that made the reman process successful. Further the focus was shifted to the product level to understand the parameters and process that make them manufacturable over multiple lifecycles. The Analysis procedure outlines barriers, drivers, market demand, value proposition, revenue streams, supply, and logistics to outline key challenges and related solutions faced by each company.

Additionally, a SWOT analysis is done to first understand the positive and negative aspects of the choices made by each company. The analysis from case studies stands as validation to the theories and concepts gathered from papers. The standard search terms for Circular Building products and remanufacturing include: 'Eco design', 'Digitalization for Circular Economy', The research material also included previous thesis reports, Ph.D. results, Journals, and reports from European Remanufacturing Network, r2pi projects. The search results were organized into groups of Remanufacturing: as a strategy, Circular Economy, Remanufacturing in other industries, Digitalization in CE, Circular Building Products.

1.6.3 Analysis of Live case study - De Satelliet

The previous phase ends with the development of a conceptual design for remanufacturing canvas (reman canvas) that can guide remanufacturing in the Building Industry. The canvas had to be further shaped from the perspective of the building industry. Therefore, interviews and discussions with experts & professionals from the industry became the main body of work to understand the current working of the façade industry. To get more insight on the current situation in the building industry, a live case study was chosen. The research project focused on analysing the EoL elements of the façade, and critically examine the disassembly process. A list of risk and potentials was made and the entire process of remanufacturing an EoL façade was mapped since the inception of the project.

1.6.4 Development of improved canvas

The conclusions from the interviews assisted in refining the canvas further and arriving at an improved canvas. This process also was instrumental to understand the engineering guidelines, design criteria and limitations. The summary from all the interviews was gathered and analysed. The guidelines made from conversations turned into worksheets which provided information on the cost and labour that would be required to remanufacture the façade and introduce in the next life cycle.

1.6.5 Evaluation & Conclusion

The research findings and interviews were summarized to arrive at the final reman canvas. The inference from the analysis of the live case study and feedback from interviews served as a validation to the canvas. The analysis from the thermal and a detail description of cost will aid in making a detail comparison between the new vs remanufactured façade elements. The results were summarized in the form of tables and charts. In some cases, the results from software's helped in suggesting improvements for redesign concept. The guidelines also highlight the specific computational platforms that can be incorporated in the future for efficiency in the process.

The Phase 1 will answer the research questions 1,2 & 3 and lay a conceptual framework for design. Phase 2 is focused on answering the research questions 4, 5 & 6 at a product level. The Phase 3 & 4 will validate the answers to all the research questions and highlight the role of architects and designers in the process of promoting remanufacturing as a strategy as a concluding remark. The figure gives a thematic organization of the research methodology.

Methodology diagram

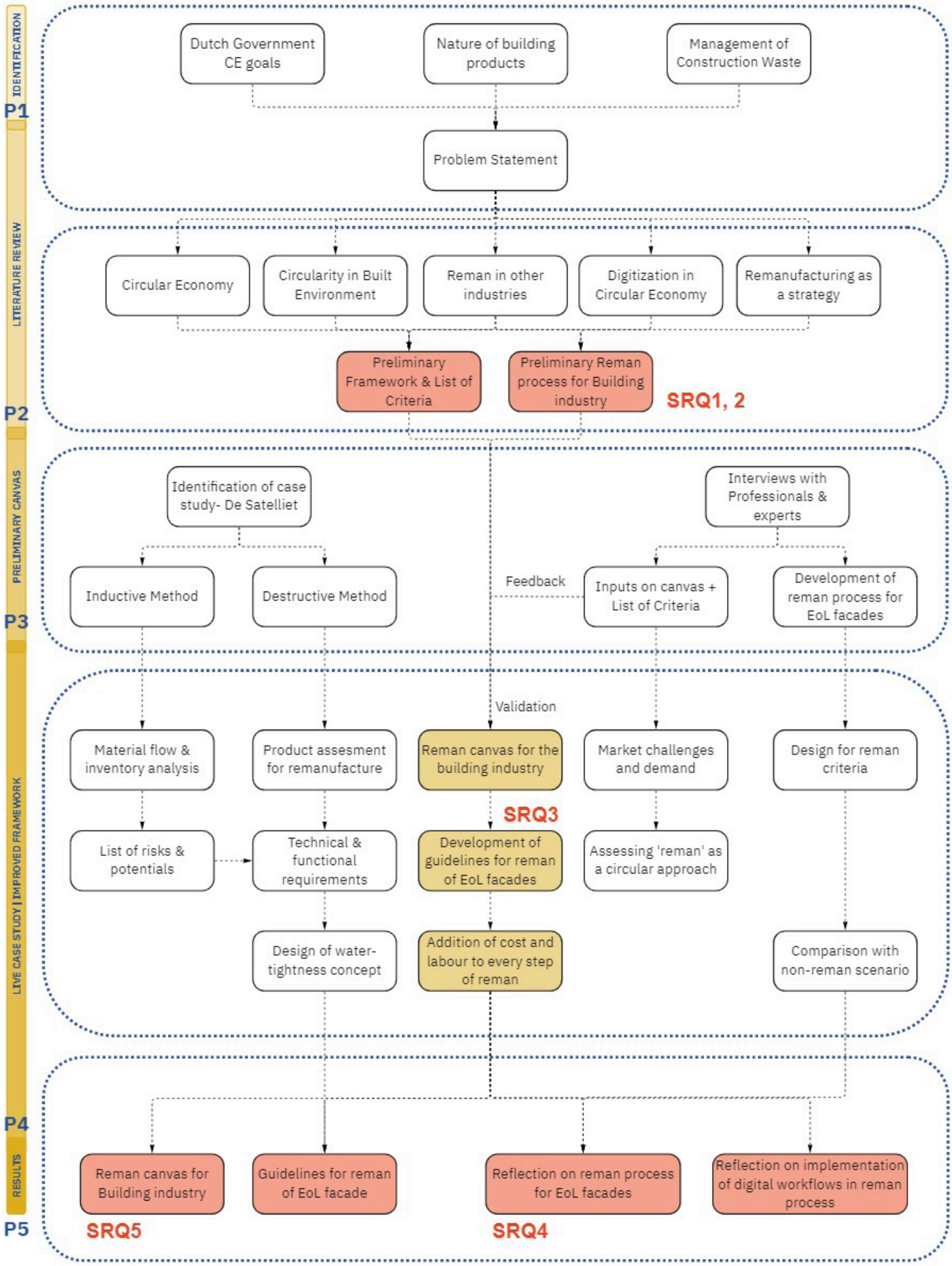


Figure 2 - Diagram explaining the methodology and approach followed during the research project. Source: Author

1.7 Relevance

1.7.1 Scientific Relevance

The topic finds itself under the broad realm of Circular Economy and aims to explore the potential of remanufacturing for the building industry. A building, rather than being viewed as a single product, should be viewed as a collection of products. According to a study on Lifecycle stages and modules by Orr, Gibbons, and Arnold (2020), the extraction, processing, manufacturing, and transport of materials up to the point where they leave the factory gate to be taken to site contribute to roughly half of the carbon emissions calculated throughout the lifecycle of a building. Buildings account for a significant portion of total energy consumption in European countries (42 percent) (Kanters, 2020). The future designs and manufacturing of building products should consider resource scarcity, supply, and demand.

One attempt of transitioning to a circular economy is being done by TU Delft together with other stakeholders who are working on developing on a Product Service System for Façade Industry to bring in the concept of Extended Producer Responsibility (EPR). Building products have many similarities to remanufactured products from other industries in that they contain large volumes of products in fixed locations with high value materials, creating opportunities for remanufacturing. Due to a dynamic and fragmented market with multiple stakeholders involved in the decision-making process, the building industry has always lagged in keeping up with emerging technologies. Other related industries (automotive, aerospace, and logistics, for example) have demonstrated successful integration of remanufacturing due to early adoption of these business practices. The design for remanufacturing canvas developed in this thesis project will serve as a conceptual framework to guide remanufacturing of building products.

1.7.2 Professional Relevance

A report on 'A Circular Economy in the Netherlands by 2050' emphasizes that the vision for the construction industry is to be organized in a way that the design, development, operation, management, and disassembly of buildings are respected to ensure sustainable construction, use, reuse, maintenance, and dismantling of objects. From case studies, we know that smaller loops are more profitable than larger, which in essence means that in most cases, remanufacturing can be a better strategy for material efficiency and resource recovery than recycling. This makes the topic relevant at a professional level.
Several companies in the Netherlands and abroad (MADASTER, Circular Cloud, New Horizon) are developing various methods, strategies, and roadmaps to integrate digital technologies to implement a Circular Economy. However, a majority of them address problems at the building scale. The project aims to focus on a building product level to intervene and bring in circular choices that can change the way they are designed and sold to be recovered at EOL. This way they can undergo remanufacturing process and be reintroduced in the next lifecycle.

1.7.3 Social Relevance

As every country climbs up the material ladder, there is a growing demand for new materials and products. As resource scarcity, waste management and climate change are the issues we are trying to protect ourselves from. The concern is not so much that there isn't any left, but that it may be difficult to upscale the production capacity quickly enough. There is a frantic search ongoing for new sources of materials, not just in the ground but also in deep seas and even in space. As our energy system is based on fossil fuels, the use of energy leads to massive amounts of CO2 emissions. In as far as the energy is used to produce resources, these CO2 emissions may be attributed to the resources themselves. These challenges are the main reason to go for a circular economy, and that is what we must keep in mind whenever we assess specific and concrete options for improved circularity.

The market demands change swiftly, and adaptive remanufacturing serves as a strategy for two reasons, first being that it is a smaller loop than recycling (which is more common than reman) and secondly it ensures economic viability and resource efficiency. Remanufacturing returns the product to "as new" or even better condition with a comparable warranty to the original product. Through case studies we have seen that construction of a reman design platform ensures successful implementation of reverse logistic channels, creation of a value network and gives the opportunity to offer customers upgrades that can match with the growing needs. The project focuses on going a full circle, from exploring potential of remanufacturing for the building industry to application of methods to make it successful, thereby highlighting the social relevance of the project.

1.8 Scope & Limitation

- The design for remanufacturing canvas that is made as a product of the research project must be treated as content to start the discussion for remanufacturing in the building industry. The list of criteria is not exhaustive nor are they complete. Through discussions with experts, it was seen to be valuable and further work needs to be done to refine it.
- The design section of the thesis is limited to the development of water and air tightness concept of the façade
- The re-design of elements, parts, and connections of the EoL product of De Satelliet is beyond the scope the thesis
- The thesis will indicate the type of conceptual digital workflows that can be adapted in the guidelines to remanufacture EoL façade products.

1.9 Graduation Timeline

		Calendar Week	Nov		December					January				Febraury				March					April				May					June					July
Task ID	Research Objective	Activity	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24	W25	W26	W27	W28	W29	W30	W31	W32	W33	W34	W35
1		Study on Circular Economy (CE) & Strategies of CE																																			
2		Circular Built Environment & Building Products																																			
3		Digitization in CE																																			
4	Literature Review & Data Review	Remanufacturing as a strategy																																			
5		Case Study: 20 examples of reman in other industries																																			
6		Ways to inculde digital methods, role of ICT																																			
7		Conceptual framework of reman for building Industry																																			
8		Choosing a case study building and A-Product																																			
9		Case study on the chosen A-Product																																			
10		Comparison with list of criteria & conceptual framework																																			
		Analysis of Design criteria, guidelines, legislation																																			
11	Design and Ananlysis	Inductive method																																			
12		Company/Stakeholder interviews																																			
13		Redesigning of water tightness concept																																			
14		Development of Framework-document & mention digital methods																																			
15		Further research to close the loop																																			
16		Evaluation																																			
17	Evaluation and reflection	Report																																			
18		Presentation																																			

Table 1- Graduation timeline guiding the project.
Source: Author

02

Circular Economy

The chapter presents the theory and principles of Circular Economy

2. Circular Economy

2.1 Introduction to concept of Circular Economy

The extraction and utilization of resources has been the bedrock of societal advancement and wealth creation. These resources have been and will continue to be used in our societies to provide food, shelter, transportation, communication, and a variety of other basic functions. Every country strives to advance its development and well-being by climbing the material ladder. To support the world's growing population, more resources are required. Globally, welfare is rising, as is the number of resources needed per person. Economic development invariably leads to technological advancement, which raises the cost of goods. The most significant of these linear economy challenges are related to resource availability, waste generated by resource production and consumption, and environmental pressures caused by resource production and consumption.

The Circular Economy arose from the need to utilize waste flows more effectively, reducing our demand for raw materials. The EMF, a charitable organization based in the United Kingdom that is actively working on the concept of circular economy, defines it as "a circular economy is one that is restorative and regenerative by design, and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles." (Macarthur, n.d.)

2.2 The principles of circular economy

A report by Ellen McArthur Foundation (EMF) has briefly laid out the five principles which form the core of Circular Economy. They are described as follows according to (Macarthur, n.d.)

- Design out waste: When the biological and technical components (or 'nutrients') of a product are designed with the intention of fitting within a biological or technical materials cycle. It is designed for disassembly and refurbishment and as a result, waste does not exist.
- Build resilience through diversity: Modularity, versatility, and adaptability are prized characteristics that must be prioritized in an uncertain and rapidly changing world. Diverse systems with many connections and scales are more resilient in the face of external shocks than systems built solely for efficiency.
- Rely on energy from renewable sources: Ultimately the goal is to design systems that strive to run on renewable energy sources.
- Think 'in systems': Understanding how parts influence one another within a whole, as well as the correlation of the whole to the parts, is critical.
- Waste is food: On the biological nutrient front, the ability to reintroduce products and materials into the biosphere via non-toxic, restorative loops is central to the concept. On the technical nutrient side, upgrades are also possible, and this is known as upcycling.

2.3 *The Butterfly diagram of Circular Economy by EMF*

The Butterfly diagram was created by EMF to explain the concept of circular economy. It is restorative in nature and entails careful material flow management. They are biological and technical nutrients, according to authors Mc Donough and Braungart. While technical nutrients are designed to circulate at a higher quality without entering the biosphere. On the other hand, biological nutrients are designed to re-enter the biosphere after cascading through various applications. The circular economy's design out waste principle states that products should be designed to fit into a biological or technical cycle by allowing for disassembly and refurbishment. This way the biological nutrients are returned to the earth, and the lifecycle of man-made materials is extended and reintroduced through the use of strategies such as reuse, remanufacture, refurbish and recycle.(Macarthur, n.d.)

1. Maintenance/Prolong: A strategy of keeping the product and materials in use by prolonging their lifecycle by designing for disassembly, maintenance, and repair.
2. Reuse/Redistribution: A method of reusing a product for multiple lifecycles with minimal or no modifications. done to it.
3. Refurbish/Recondition: A method of restoring a product's functionality by replacing or repairing faulty or near-failure components. It refers to cosmetic changes made to a product's appearance to improve it. The warranty issued is usually less than that of a remanufactured or new product.
4. Remanufacture: A process of returning a used product to as-new condition by disassembling to component level and rebuilding it. The warranty issued is generally equal to or comparable to that of a new product.
5. Recycling: The process of reducing a component to its raw material form so that it can be reused in a subsequent manufacturing cycle. It depletes the embodied energy and value added to the raw material during the initial manufacturing process.

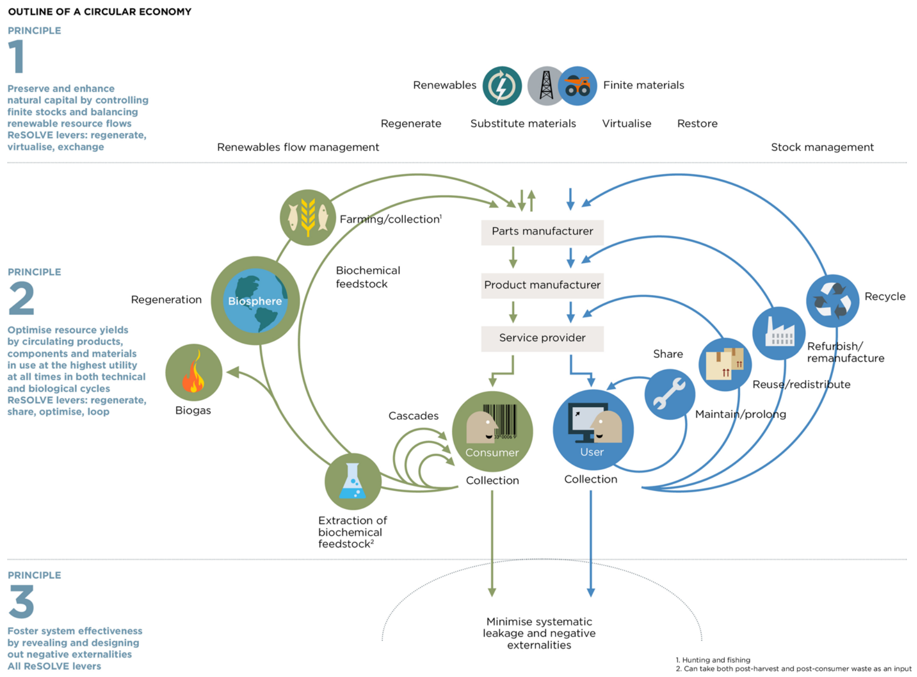


Figure 4 - The Circular economy diagram by EMF illustrating the technical and biological products and material cycle through their systems. Source: (Macarthur, n.d.)

2.4 Schools of thought

The Ellen McArthur Foundation (EMF) established schools of thought. They are synthesized according to (Macarthur, n.d.) as regenerative design, performance economy, cradle to cradle, Industrial ecology and biomimicry. The research elaborates on the first four in the following paragraphs.

- *Regenerative design*: This idea came to life, in 1970 when John T. Lyle outlined a challenge to imagine a society in which all activities were based on the value of living within the limits of renewable resources. It was determined that all systems can be orchestrated in a regenerative manner.

- *Performance Economy*: In 1976, architect Walter Stahel sketched his vision of a circular economy in loops. His Product-Life Institute pursues four main goals: product-life extension, long-life goods, reconditioning activities, and waste prevention. Stahel spoke of 'functional service economy' which focused on selling services over products.

- *Cradle to Cradle:* Developed by Michael Braungart and Bill McDonough, the Cradle-to-Cradle framework focuses on design for effectiveness in terms of positive impact products, which distinguishes it from traditional design approaches that focus on reducing negative impacts. The idea further elaborates that, it is preferable to design products in such a way that disassembly and component recovery are simple, either to upgrade some elements or to reuse individual parts for the next lifecycle.

- *Industrial Ecology:* It is the study of materials and energy flows through industrial systems. It aims to develop closed-loop processes in which waste is used as an input, thereby eliminating the concept of an undesirable by-product

2.5 The sources of value creation in Circular Economy

The principle of circular economy has been worked out to not just talk about the broader picture or the larger goal, but also outline the specific sources of core economic value creation potential. The economics and strategies can differ significantly for different materials, components, and products. Below are four different principles of circular value creation established by EMF that are applicable (Macarthur, n.d.).

- *Power of smaller loop*: Referred to as the power of inner circle by (Macarthur, n.d.). Setting up circular systems can make economic sense whenever the costs of collecting, reprocessing, and returning the product, component, or material into the economy are lower than the costs of the linear alternative (including the avoidance of end-of-life treatment costs). In general, smaller the circles are, greater the savings with respect to embedded costs in terms of material, labour, energy, capital, and the external factors like GHG emissions, water, or toxic substances.

- *Power of circling longer:* In the circular economy, products, components, and materials are reused for a longer period. This can be accomplished by completing more consecutive cycles or by spending more time within a cycle. However, rapid product innovation leads to increased operating and maintenance costs, as well as losing out on efficiency gains. Thereby, depleting the potential for positive arbitrage.

- *Power of cascaded use and inbound material/product substitution*: The arbitrage value creation potential in these cascades is rooted in the lower marginal costs of reusing the cascading material as a substitute for virgin material inflows and their embedded costs (labour, energy, material) This include externalities, versus the marginal costs of bringing the material back into a repurposed use.

- *Power of pure, non-toxic, or at least easier-to-separate inputs and design:* The power of this fourth major lever adds to the previously mentioned value creation potential and provides a slew of additional benefits. Each of the levers necessitates a certain level of material purity and product and component quality to generate maximum value.

2.6 The relevance of 'Reman' in the R-hierarchy

A circular economy follows a closed loop approach in which materials from an EoL product are reintroduced into the technical cycle, avoiding waste generation. To reduce material consumption in product chains and transition to a circular economy, various approaches known as R-strategies have been developed. In Figure 2.1, the R-List represents a range of strategies ranging from high circularity (low R number) to low circularity (high R number) (high R number). They are divided into three categories. Under Smart product use and manufacture. R0 – R2 are considered circular strategies even though they do not involve reuse or reapplication, because they aim to reduce the number of resources in the product chain.

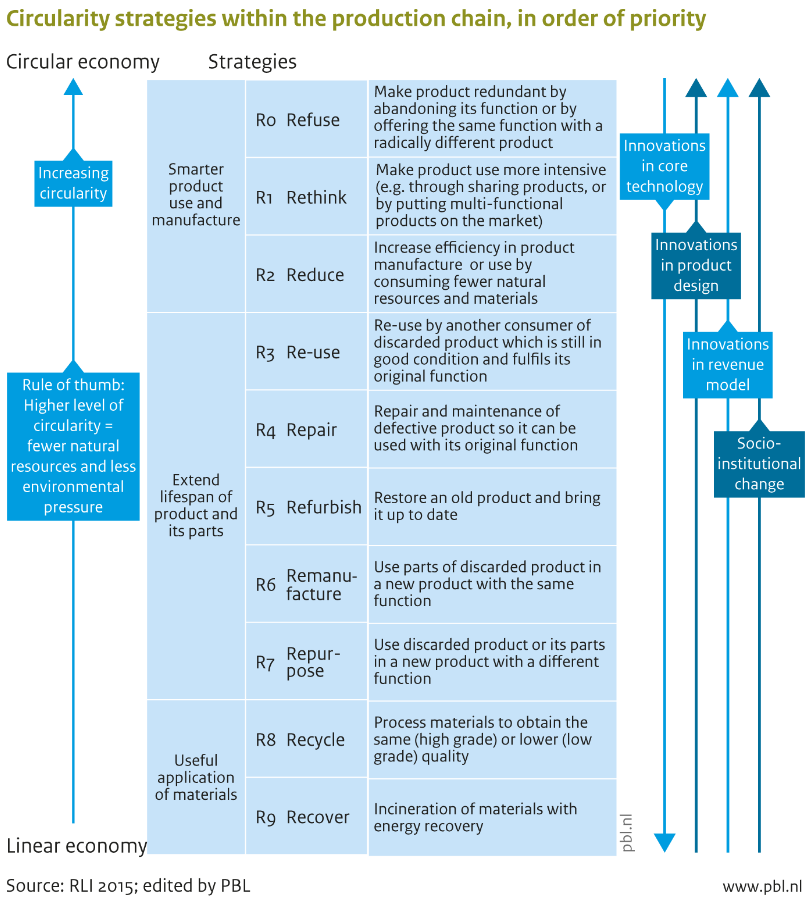


Figure 5 - shows all the R0-R9 strategies of a circular economy outlined by (Potting et al., 2017), RLI 2015

Remanufacturing is the sixth strategy in the 9R framework of strategies by Potting, Hekkert and Worrell (2017) explained in the Figure 5. It is defined as the process reusing parts of a discarded product, in a new product with the same function. Authors Stahel (1981) and (Macarthur, n.d.) state that smaller the loops, more effective and profitable it is. In a discussion between repair and remanufacturing, of which the former is a smaller loop. The authors Miemczyk and Campus (2006) observe that the changing consumer behaviour and market demand for 'new' and 'as-new' products is huge. This makes remanufacturing a better option than repair. Thereby we can conclude that the decision of a "re" strategy depends on a variety of factors such as market demand, value creation and differ from product to product (Miemczyk & Campus, 2006).

2.7 Resource Cycles: slowing, closing & narrowing loops

The study by (Bocken et al., 2016) builds on the theories of McDonough and Braungart (2002) and Stahel (1981) to discuss two fundamental strategies toward the cycling of resources shown in figure 6.

- *Slowing resource loops*: The utilization period of products is extended and/or intensified through the design of long-life goods and product-life extension (i.e. service loops to extend a product's life, for example, through repair, remanufacturing), resulting in a slowdown in the flow of resources. Figure 7 gives an overview of the design strategies to slow resource loops with an example.
- *Closing resource loops:* Recycling closes the loop between post-use and production, resulting in a circular flow of resources.
- *Resource efficiency:* also known as narrowing resource flows, is the goal of using fewer resources per product. Figure 8 gives and overview of the design strategies for closing resource loops.

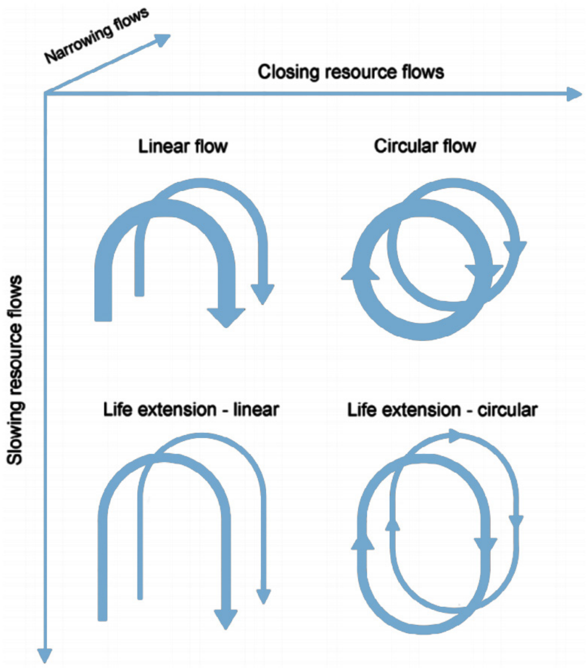


Figure 6 - Categorization of linear and circular approaches by (Bocken et al., 2016)

2.8 Circular product design strategies to slow resource loops

To realize a sustainable product, it is imperative that circular economy concerns are integrated during the early design process(Bocken et al., 2016). Adopting a certain design strategy can shape the use phase and direct its end-of-life scenario.

2.9 Circular business model strategies

The shift to circular economy has become necessary today as we deal with climate change, resource scarcity and problems in waste management. It has been viewed as a promising approach to help reduce global sustainability pressures. Business models define how a company operates and are regarded as an important driver of innovation and growth. Figure 9 shows the different business models designed for slowing and closing resource loops. Integrating circular economy concerns early in the product design process is critical because once product specifications are established, only minor changes are usually possible – it is difficult to change once resources, infrastructure, and activities have been committed to a specific product design. (Ramani et al., 2010) Business model selections define the architecture of the business and its expansion paths, but once established, companies frequently face significant challenges in changing business models. The authors Bocken, Pauw, Bakker and Grinten (2016) review the key product design and business model strategies that fit the approach of slowing and closing of resource cycles.

2.10 Summary

- The circular economy is restorative in nature, relying on renewable resources and monitoring and tracking the use of toxic chemicals through the incorporation of conscious design practices.
- It entails careful resource management in biological and technological cycles. Biological nutrients are allowed to safely re-enter the biosphere, whereas nutrients in technical cycles are designed to circulate in high quality without entering the biosphere.
- The CE promotes a 'functional-service' model, which aims to extend manufacturers' ownership of their ***products and shift to a product-service model***. This change in ownership encourages the adoption of business models that produce long-lasting products that are easy to ***disassemble, reuse, and remanufacture, thereby contributing*** \` ***to the development of smart product innovation.***
- So far, the research on circular economy is best understood at a theoretical level. The Author did not find many examples where the principles of circular economy were put into practice in a direct manner.

Overview of design strategies to slow resource loops		
Design strategy	Branches	Example
Designing long-life products	Design for attachment and trust	Philips MR systems,
	Design for reliability and durability	Xerox and Canon machines
Design for product-life extension	Design for ease of maintainance and repair	Caterpillar engines
	Design for upgradability and adaptability	Daves furniture, Philips MR systems
	Design for standardization and compatibility	Xerox
	Design for dis and reassembly	Caterpillar

Table 2- Overview of design strategies to slow resource loops by (Bocken et al., 2016)

Business model to slow product loops					
No.	Strategy	Definition		Elements	Examples
1	Access and performance model	Providing capability or services to satisfy user needs without needing to own products	Value proposition	Value Proposition: Delivery of service	Car sharing
			Value creation and delivery	Value Creation and delivery: hassle of service and maintenance is taken over by retailer.	Document management (Xerox)
			Value capture	Value capture: pricing per unit of service	Tuxido hire Phone leasing
2	Extending product value	Exploiting residual value of products, from manufacturing to customers and back to manufacturing.	Value proposition	Value Proposition: exploit residual value, by repair, remanufacturing etc.	Automotive- remanufacturing parts
			Value creation and delivery	Value creation: Take back systems to enable consistent product returns (collaborate with retailers, logistic companies and collection points)	gazelle offering consumers cash for electronics
			Value capture	Value capture: Reduced material costs can lower overall cost.	Clothing return initiatives Reused material markets
3	Encourage sufficiency	Solutions which actively seek to reduce user consumption by increasing durability, upgradability, service warrantees etc.	Value proposition	High quality durable products, with high levels of service (repairable, reusable). No "build-in obsolescence"	Premium brands such as Vitscoe, Patagonia, energy service companies
			Value creation and delivery	Non consumerist approach. Sell what is needed	
			Value capture	Often a premium model, high price per product can justify volumes	
Business model to close product loops					
No.	Strategy	Definition		Elements	Examples
1	Extending resource value	Exploiting the residual value of resources: collection/ sourcing of waste materials/ resource to energy etc..	Value proposition	Exploiting residual value of resources	1.Recycle bank 2.Interface - collecting and 3. supplying fishing nets as raw 4. material for carpets 5.Kalundborg Eco-Industrial Park
			Value creation and delivery	New collaborations and take back systems	
			Value capture	Use wasted resources and create new value	
2	Industrial Symbiosis	A process-oriented solution concerned with using residual outputs from one process as feedstock from another, benefitting from geographical proximity of businesses	Value proposition	Process oriented solution, converting residue from one process to feed stock to another across close businesses	AB Sugar, waste = value practices
			Value creation and delivery	Collaborative agreements to reduce costs across the network	
			Value capture	Joint cost reduction and potential creation of new business lines on former waste streams	

Table 3- Overview of business models to slow & close resource loops by (Bocken et al., 2016)

03 Circularity in the built Environment

The chapter presents the introduction to a circular built environment and reflects on how principles of CE can be implemented in the built environement.

3. Circularity in the Built Environment

The construction business is a material-intensive industry; in 2019, the globe consumed 100.6 billion tonnes of materials. (Kanters, 2020) In the context of moving toward more sustainable buildings, resource efficiency is defined as a broad concept aimed at reducing resource use and limiting environmental impacts throughout a building's lifecycle, from material extraction for use in construction to resource use during occupancy and maintenance to material recovery at demolition. (Dosch, 2018) As a result, selecting low impact building materials has become a critical consideration in the design of future structures. (Kanters, 2020) To make a gradual transition to the circular economy, there is a need to investigate how the products have evolved and what development can be expected in the future. Building materials are important because of the immense social and environmental impact of extracting, processing, and maintaining them.

A Circular Built Environment is "an approach to achieving sustainable development goals through business models that support waste minimization by reducing, reusing, recycling, and recovering materials throughout a product's entire life cycle" (Klein, 2019). Three principles of circular economy explained in chapter 2 are relevant to remanufacturing in the building industry and are explained below. This section draws feedback from the authors Beurskens and Bakx where the applicability of the principles of the EMF in building design are discussed. With relevance to remanufacturing the following principles are elaborated namely, thinking in systems/cascades, design out waste and waste is food respectively.

3.1 Principle 1: Thinking in Systems

The built environment as represented in figure 9 can be viewed as a series of levels starting from the smallest scale of materials to components, building and cities and so on. They are bound together by technology, design, Flows & resources, stakeholders, economy, and management. A circular economy differs from linear economy with respect to consideration of 'time' as one of its many dimensions. Buildings are often perceived as singular entities. Authors Beurskens and Bakx (2015) refer to buildings as an assemblage of products that continuously change and adapt to the needs of the user. Several authors offer a systematic approach to sustainable building that connects the various components, materials, and functions of the structures. Stewart Brandt has developed a time model for several layers in a building based on Duffy's concepts.

The principle of "thinking in systems" is defined by EMF as:

"the ability to understand how parts influence one another within a whole, and the relationship of the whole to the parts" (Macarthur, n.d.)

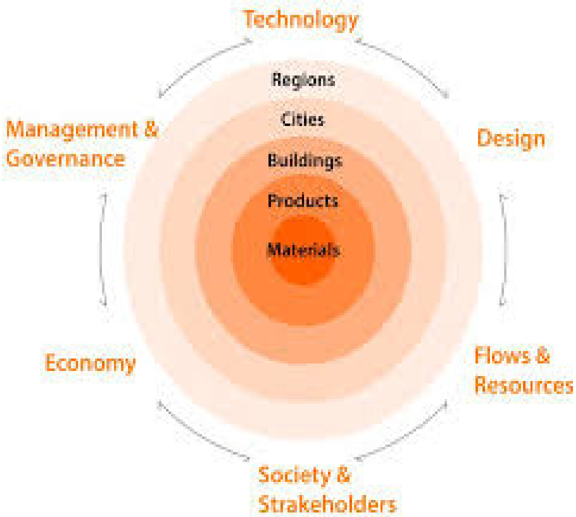


Figure 9- Circular Built Environment Diagram. Source: (Circular Built Environment, n.d.)

The figure 10 represents Brand's concept of 'shearing layers' which is a collection of functional layers of a building characterised by their life spans into six layers which are illustrated in the figure.

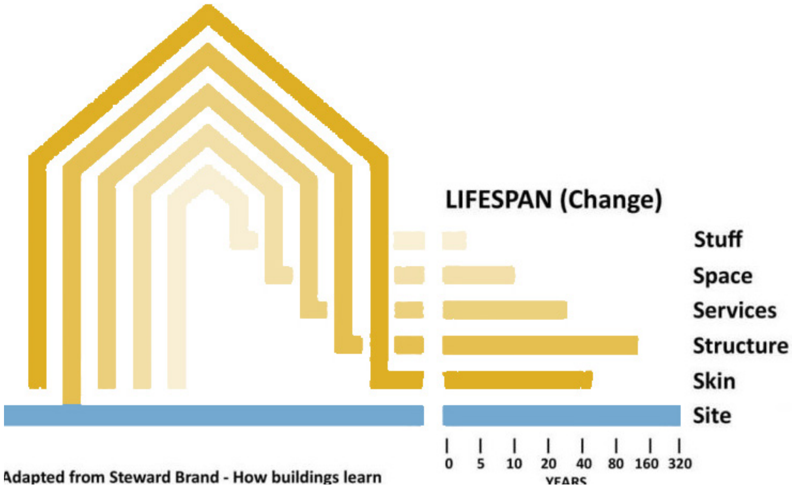


Figure 10: A representation of Brand (1994)'s shearing layers. Source: (https://nxtgenhouses.com/how-buildings-learn/).

3.1.1 Hierarchy of product levels in the building industry

Building products are diverse and extensive in number. Mick Eekhout (2008) developed a hierarchical range of building products in the increasing order of their complexity and added value. The figure 11 developed by him begins with raw material and gradually works it way to the building scale. (Methodology for Product Development in Architecture - Mick Eekhout - Google Books, n.d.) . (Klein, 2013) developed it further where each step in the range corresponds to a new product level and classified the following product levels and defined them as follows.

- *Materials* are defined as the raw ingredients that have not been shaped or treated in any way, such as glass or steel. This also includes composite materials.

- *Standard materials* are intermediate goods that are available in standardized form: I-beams, tubes, coils, and bricks are some examples.

- A *commercial material* is formed for the purpose of a specific product or project, such as extruded aluminum profiles for window frames or rubber gaskets.

- *Elements* are made from a variety of commercial materials. Glass panes, aluminum spacers, and silicone are used to make an insulated glass unit.

- A *sub-component i*s a closed assembly of elements that serve a single purpose, such as a window frame, a sun-shading device, or a building services component.

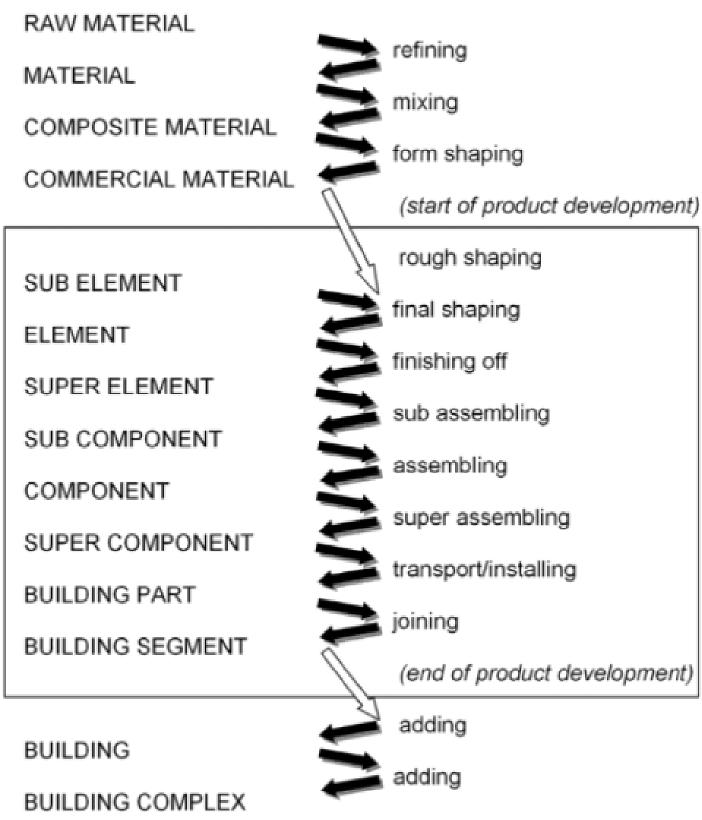


Figure 11: A Hierarchy of product levels in the building industry, developed by Mick Eekhout (Eekhout, 2008) and adapted by (Klein, 2013)

• Author Eekhout (1997) defines components as an "independent functioning building unit made up of a number of composing elements." It is built "off-site and transported to the job site." As an example, consider a unitized façade part.
• A building part is defined as a collection of elements and components with the same technical main function, such as a curtain wall or the primary load-bearing structure of the building.

3.2 Principle 2: Designing out waste

The principle of "designing out waste" is defined by EMF as:
"Waste does not exist when the biological and technical components (or nutrients) are designed by intention to fit within a biological or technical materials cycle, designed for disassembly and refurbishment" (Macarthur, n.d.)

The authors (Bocken et al., 2016) discuss the applicability of this principle in the building industry and conclude that it translates into design for remanufacturing, disassembly. However, the difference between remanufacture, repurpose, and refurbish is not unclear, and no further guidance on how to apply this in practice. The first step to implementing the above-mentioned concepts is to first view the building as a hierarchy of components, categorised at different levels namely system, sub-system, component, and material level. The following sections discuss the theories and concepts from different authors to view to buildings in a different perspective to implement circular principles.

3.2.1 Hierarchy of building material

Following the trend after Brand (1994), Eekhout (1997), Durmisevic (2006) developed the hierarchy of building material levels. The hierarchy reflects the technical/physical levels along with the functional levels of a building. She described that a building should be seen as a hierarchy of material levels and divided them into the following.

• *Building level:* Represents the arrangement of systems that carry out major building functions (load bearing, enclosure, partitioning, and servicing).

• *System level:* Represents the arrangement of components that undertake system functions (bearing, finishing, insulation, reflecting, distributing, and so on).

• *Component level:* The layered or frame assembly of component functions, which are assigned through the elements and materials at the lowest level of building assembly, is represented.

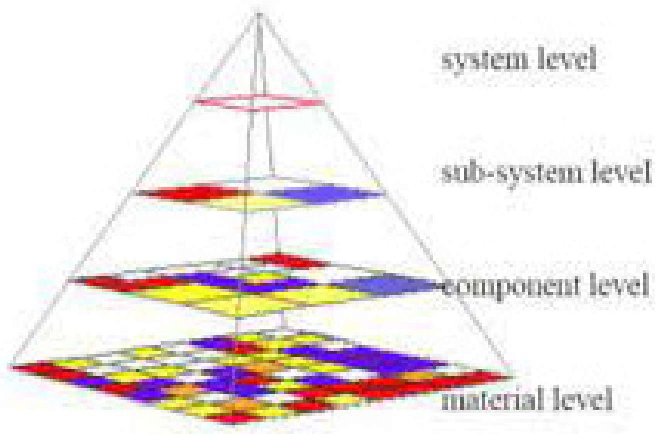


Figure 12 -Showing a Hierarchy of Building product levels, developed by Mick Eekhout (Eekhout, 2008) and adapted by (Klein, 2013)

3.2.2 *Circular building product levels*

The previous sections highlighted the different concepts proposed by different authors to categorise building product levels. Although each of them has their individual strengths and weaknesses, they can all be put together to define the concept of circular product levels. This also represents the application of the principles of Circular economy (by (Macarthur, n.d.) as discussed in the section chapter of the report) in the building industry.

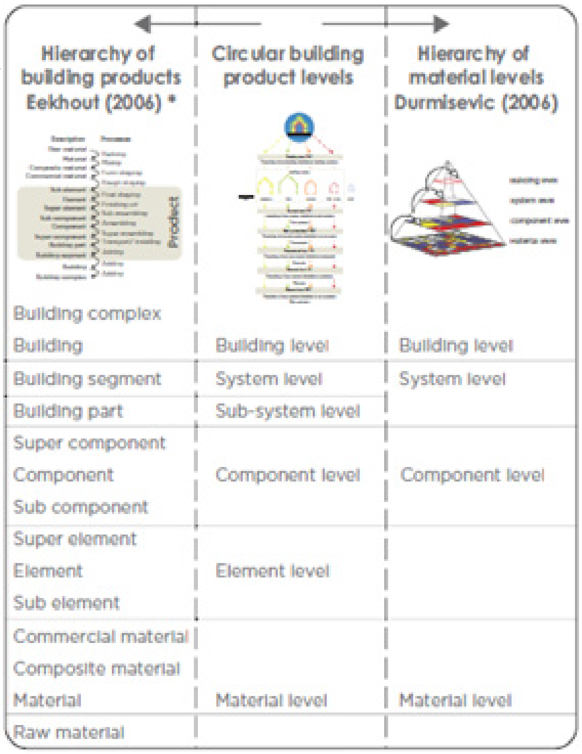


Figure 13 - Comparison of circular building product levels with hierachy of building products (Eekhout, 2008) and material levels Durmisevic (2006)

3.2.2 *Circular building design principles*

The EMF's principle in building design is studied by the authors of (Bocken et al., 2016) and for the purpose of this research, design for adaptability and disassembly has been elaborated in the following paragraph.

Design for adaptability & disassembly: The circular building principle of 'design for disassembly' should be incorporated into building design to allow building components to have multiple lives and reduce building waste generation. This principle broadens the applicability of the various re-life options. Disassembly must be non-destructive in general to reuse the sub-systems, components, or elements without destroying embodied value (embodied energy and labour) in the materials.

3.3 Principle 3: Extracting resources from waste

The current construction practices aim to design structures to last 50-60 years, although some of them are demolished before this and have a shorter service life (Gorgolewski & Ergun, 2013). As discussed in the previous sections of this chapter, when we view buildings as an assemblage of products, we refer to different life cycle and at different levels, namely building, component and material level. Due to differences in composition, they have different service lives.

The current method of design, construction and business model do not allow segregation and potential to recover valuable materials whose life cycle can be prolonged and can sometimes be introduced in another component. The Authors Durmisevic and Brouwer (2002) describe three alternate scenarios for the life cycle of materials under definitions of technical lifecycle (duration of functional performance required) and functional lifecycle (duration for which it can serve its purpose).

- *Functional lifecycle < technical lifecycle:* possibility of disassembly of buildings into reusable components for reuse
- *Functional lifecycle > technical lifecycle:* possibility of replacing end-of-life materials in a component
- *Functional lifecycle = technical lifecycle:* recycling of materials as an appropriate solution

The figure 14 represents the diagram of design domain by Beurskens and Bakx in which the circular building design principles are placed next to the corresponding circular building product levels. The circular principles 'Be self-sustaining with renewable energy has been placed at top, as it must be incorporated at the building level'

The principle of "Extracting resources from waste" is defined by EMF as:

"The ability to reintroduce products and materials back through improvements in quality" (Macarthur, n.d.)

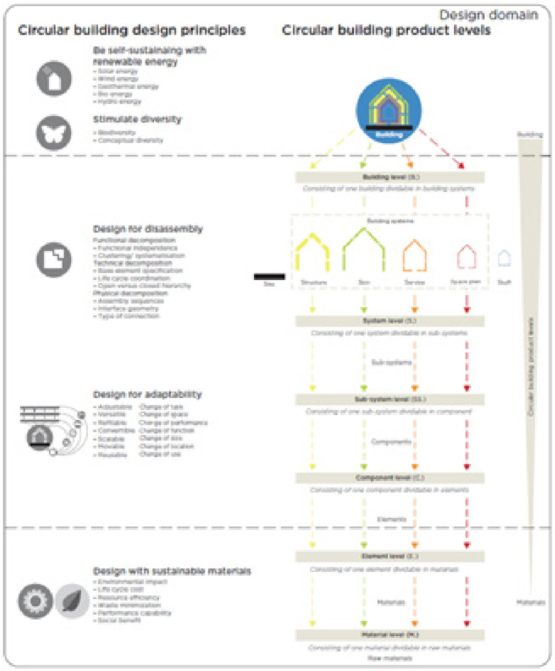


Figure 14- Design domain Describing the circular building design principles related to the circular building levels source: (Beurskens and Bakx, 2015)

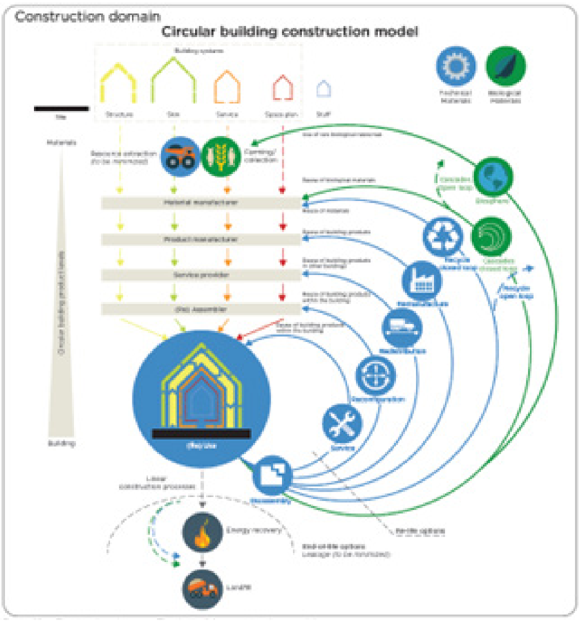


Figure 15 – The construction domain explained by Beurskens and Bakx, through the development of a circular building construction model. Source: (Beurskens and Bakx, 2015)

3.3 The circular building construction model

The figure 15 represents the Construction domain of the circular building construction model by authors Beurskens and Bakx. The linear line represents the linear economy guided by the attitude of take-make-waste model and the blue loops represent the strategies that can be incorporated to transition into circular economy. In the subsequent sections of the report, the research will focus and elaborate on the potential of integrating remanufacturing as a strategy in the construction industry to transition into circular economy.

In the circular economy, landfill is not an option. The EoL options are replaced by 're' options. In the section of sources of value creation in a circular economy, the power of smaller loop was highlighted. However, various authors such as Stahel expressed those strategies such as remanufacturing are more valuable than reuse and repair when external factors such as consumer preference and market demand are considered. All re-options are initiated by disassembly and is performed to either prolong or extend the life of components.

The process of disassembly must be non-destructive to maximum reuse of components. Service is an important step as it comprises of all actions performed to the building product to retore its quality and condition. This includes monitoring, maintenances, repairing and upgrade. These are crucial will be explained in detail in the future sections of the report.

3.5 Summary

The principles of ***Circular economy defined by EMF are abstract*** and do not provide guidance on how they could be applied in the building industry in practice. Further the concepts like ***design for disassembly, remanufacture are unclear in terms of their methods and application to the building industry.***

The option of thinking in cascades can be translated into continuing/ extending or prolonging the life of materials and components. However, doing so might not be a sustainable situation for every case. Further, ***building products are guided by changing legislation, market demand and evolution. Therefore, building products need more extensive guidelines for adopting circular strategies.***

The composition of an individual building products must be ***independent at a functional level,*** to all other functional levels of a building. Consequently, the components and materials within the same should also be seen as independent parts of the system, to enable transformations at a component and material level. This way (Durmisevic, 2006) guided the design of decomposable building structures, which can be regarded as one of the goals of circular economy.

Durmisevic's classification differs from that of Eekhouts classification of building products which is more at hierarchical definition and terminology of products. Whereas Durmisevic further classifies the building materials as technical and biological. However, the research does not specify functions for each system, which leaves room for interpretation and ambiguity.

04 | Remanufacturing

The chapter presents the concept of remanufacturing as a strategy to achieve circular economy.

4. Remanufacturing

The building industry is material intensive and has significant impact on the economy and environ¬ment. It is responsible for approximately 40% of the total waste generated across the European Union (Boorsma et al., 2019). At the moment, the industry operates on the principles of the linear economy. However, because the linear economy is based on 'take-make-dispose' model, key issues such as re¬source scarcity, waste generation, and environmental pressure occur. By 2050, the Dutch Government aims to transition to Circular Economy and organize the building industry in a way to ensure sustain¬able construction by use, reuse, maintenance and dismantling of objects. (Netherlands Enterprise Agency, 2019)

4.1 What is remanufacturing?

Remanufacturing is a strategy of the circular economy. *It is broadly defined as a process of returning a used product to its original performance with a warranty that is equivalent to or better than that of newly manufactured product (Gray & Charter, n.d.).* The process involves dismantling the product, restoring, replacing components, and testing individual components and the entire product. This is done to ensure compliance with the original design specifications. From a customer's perspective, a remanufactured product is the same as a new product. The warranty on remanufactured products is usually comparable to the warranty on the original product. The performance after remanufacturing is expected to be at least equal to the original specifications. In most cases, remanufactured products are better than new products,

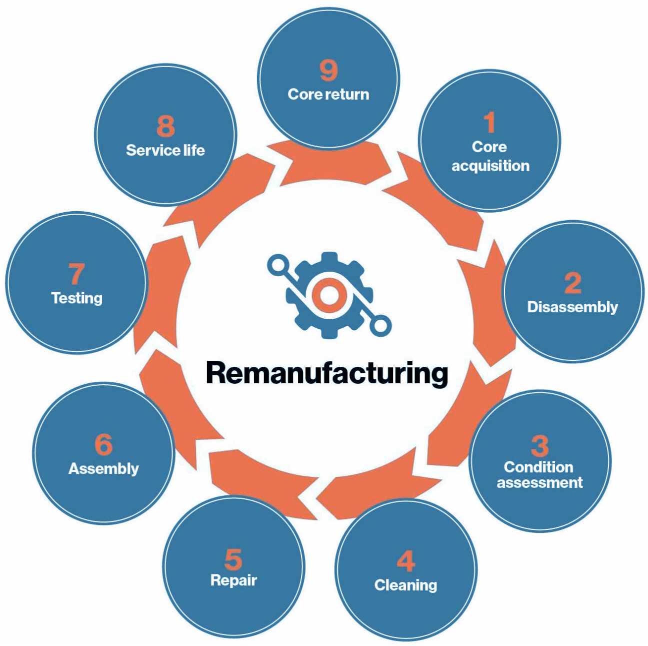


Figure 17- A diagram illustrating the remanufacturing process. Source:(What Is Remanufacturing? | Golisano Institute for Sustainability | RIT, n.d.), adapted by Author

as they have been upgraded to overcome the problems that might be still present in the newly manufactured products (What Is Remanufacturing and How Does It Benefit Jobs, the Economy and the Environment?, n.d.). It is an important component of resource efficient manufacturing as it reduces the dependency on virgin materials. Additionally keeping the components, for long life cycles leads to restoring the embodied material in use for longer, significant energy use, and emissions can be avoided. As discussed in the previous chapters, according to (Stahel, 2016) smaller the loop (technical cycle), the more profitable it is. (Macarthur, n.d.) further, describes the power of smaller loop about greater savings with respect to embedded costs in terms of labour, energy, capital, and external factors (GHG emissions). The integration of digital platform and support systems in other industries have proved to be important drivers of remanufacturing (as observed in the case study of Philips MRI systems and Canon printers in the future sections (Mfps, n.d.)).

They have proved to support remanufacturing by enabling design for upgradability to meet changing market preferences and enriching customer relationships. Remanufacturing is more valuable than recycling as it protects the complete shape of the product. This closed loop product extension; lower impact approach fits within the frame of Circular Economy. Circular economy is not an end goal but a means to introduce sustainable practices. (The Remanufacturing And, n.d.) explains the remanufacturing and recycling process do not assume a complete disassembly of objects is necessary.

4.2 Categories of remanufacturing enterprises

Remanufacturing is not a novel process and has been carried out since the early twentieth century. During the World War, it expanded significantly due to need to reuse military equipment to overcome the scarcity of new parts (Improving the Efficiency of Reman through Pre-Processing Inspection. Pdf, n.d.). In the literature on remanufacturing, it is observed that remanufacturing companies can be classified into two types, original equipment manufacturer (OEM) and Third-party remanufacturer. The latter is further divided into two types of namely outsourced remanufacturer, who co-ordinate with OEM, and independent remanufacturers. The method of core collection, remanufacturing facilities, supply chain are few of the important characteristics that make them different. (Lahrour et al., 2019) supports this explanation with a table depicted by Table 4 on characteristics of remanufacturing companies at the implementation of the reman process. Authors Lahrour, Brissaud & Zwolinski (2019) discuss each of enterprise as follows.

3.2.2 Remanufacturing by Original Equipment Manufacturer (OEM-R)

They are manufacturers that produced the product for the first time and have product expertise and is aware of the specifications and valuable information necessary for reman. Collecting the products back at EOL, gives a chance to remanufacture and upgrade with the knowledge about the product. The remanufacturing process can benefit in terms savings in material, energy costs, labour time. They rely on the brand image and market opportunity created by new products to sell reman products.

3.2.2 Remanufacturing by Original Equipment Manufacturer (OEM-R)

It is further classified into Outsourced-R and I-R as mentioned above:

- *Outsourced-R:* They work in co-ordination with OEM and perform the remanufacturing activity but rely on OEM for key activities such as reverse logistics and marketing. They are generally certified by OEM and are provided with knowledge and specifications to ensure successful of reman operations.

- *Independent Remanufacturer (I-R):* are company that takes back product cores at EOL from the customers. Due to lack of coordination between OEM, they proceed by reverse engineering to acquire knowledge about the product.

4.3 What are product cores?

In remanufacturing process, a core refers to the component or product that is extracted from an end-of-life product and will be retained through the remanufacturing process to be introduced into a new lifecycle. The company Xerox uses the term 'Hulk' as a synonym for 'core'. The author Nick Morley (2006) illustrates his concepts in a 'Remanufacturing Engineering Potential' model (Figure) that details the range in which the parameters meet for remanufacturing to be feasible. In his view, remanufacturing is unlikely to succeed when there is low value in the core, a high evolution rate, and no return channels. Additionally, he discusses the relevance of design to upgrade potential and re-constructability.

Cores are components of a product, that are usually composed of high value materials, designed for durability, and allow upgrades to be restored over multiple life cycles of a product. The remanufacturing process cannot exist without the presence of a core. The business model of a company is crafted fundamentally to enable collection of cores. Authors (Charter & Gray, 2008) explain that detailed product design can aid core collection and is an important criterion to be considered during the process of product design.

The return of core relies on both the design and the business model adopted. However, the design of the core occurs before manufacturing. A product's form, material, fastenings, etc, can all influence how effectively it can undergo and withstand the remanufacturing process, e.g., cleaning, disassembly, inspection. So, it can be stated that design for remanufacture contributes to the efficiency of remanufacturing. The design strategies will be implemented into product development as part of a business model that focuses on innovation and remanufacturing.

Closed loop supply chain relationships to enable remanufacturing

In the remanufacturing process, many kinds of relationships is observed between the manufacturers and the core suppliers. Authors Östlin, Sundin and Björkman (2008) identify seven different types of structural relationships and are listed along with their definitions in table 4.

Table : Closed loop supply chain relationships for remanufactuing

Term	Definition	Author
Ownership-based	The product is owned by the manufacturer and operated by the customer, as for example in a rental, lease or product-service offer.	(Östlin et al., 2009)
Service contract based	This type of relationship is based on a service contract between a manufacturer and a customer that includes remanufacturing.	(Östlin et al., 2009)
Direct order based	The customer returns the used product to the manufacturer, the product is remanufactured and the customer gets the same product back (if it is possible to be remanufactured)	(Östlin et al., 2009)
Deposit based	When the customers buy a remanufactured product, they are obligated to return a similar product, thus also acting as a supplier to the remanufacturer	(Östlin et al., 2009)
Credit based	When the customers return a used product they receive a specific number of credits for the return product, thus also acting as a supplier to the remanufacturer	(Östlin et al., 2009)
Buy back based	The remanufacturer simply buys the wanted used products from a supplier that can be the end user, a scrap yard or similar, or a core dealer.	(Östlin et al., 2009)
Voluntary based	The supplier gives the used products to the remanufacturer. The supplier can also be a customer.	(Östlin et al., 2009)

Table 2: defining the seven different methods of core collection. Source: (Östlin et al., 2008)

They have proved to support remanufacturing by enabling design for upgradability to meet changing market preferences and enriching customer relationships. Remanufacturing is more valuable than recycling as it protects the complete shape of the product. This closed loop product extension; lower impact approach fits within the frame of Circular Economy. Circular economy is not an end goal but a means to introduce sustainable practices. (The Remanufacturing And, n.d.) explains the remanufacturing and recycling process do not assume a complete disassembly of objects is necessary.

4.3 Design in the context of remanufacturing

Nasr and Thurston (2006) & Ramani (2010) explain the importance of connecting design and remanufacture. The product design not only influences manufacturing considerations, but also supply chain modelling and End-of-Life Management. Early decisions made during product design have proved to have significant impacts on sustainability. Authors (Nasr & Thurston, 2006) further elaborate that the societal benefits of remanufacturing such as energy, material consumption and reduced wastes cannot be fully achieved until design for remanufacture becomes an integral part of the product development process.

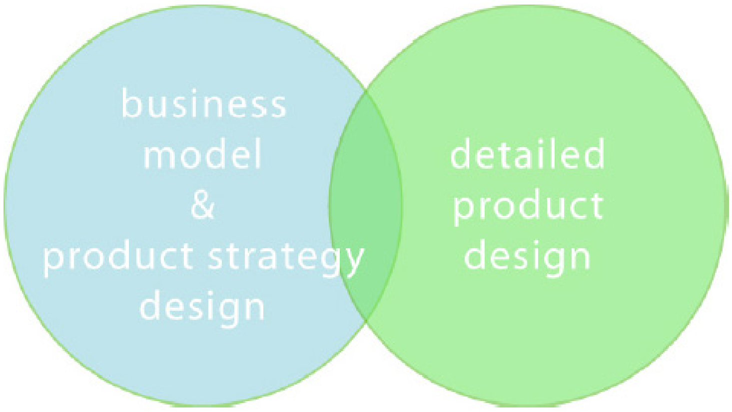


Figure 19 – The two inter-related levels of Design for Remanufcature by (Nasr and Thurston 2006) & (Charter & Gray, 2008).

This is supported by studies on companies such as Xerox and Canon who have integrated design for remanufacture as a part of the product design and development. Xerox began remanufacturing operations in early 1990s and is a pioneer in remanufacturing. The company has studied their products, market and have consistently made efforts to accommodate by designing for disassembly and modular product architecture (King et al., 2007). Product design for remanufacture is aided further by business models that recognize this opportunity.

Therefore, design for remanufacture can be considered on two levels shown in figure 19:
• Product strategy, which includes sales, marketing, customer service, and reverse logistics or core collection.
• Product design and engineering in detail, including core collection and functional design.

Product Strategy: Design for Remanufacture, as part of a business model, can reduce constraining issues while preserving facilitating properties for remanufacture. Design for Remanufacture can thus play a role in optimizing the remanufacturing process. This can be done in two stages.

• The product and its relationship to the remanufacturing process are evaluated to determine which Design for 'X' methods are required.

• Application of selected design techniques to optimize the remanufacturing process. Some aspects such as core collection rely on detail design to facilitate the business model in collection of cores, for instance PSS by Xerox and core deposit by caterpillar.

The inclusion of graphics (technique employed by Perkins Engines) can also help in conveying the information on core collection methods. The author focuses on more detailed product design and may only refer to business models in the context of core collection.

4.5 Design for Remanufacture

It is defined as a combination of design process where a product is designed to facilitate remanufacture. The design for remanufacture incorporates design for X strategies (DfX) that can facilitate the core collection. This process is guided by an assessment of the product over time. The value may vary in relation to material demand, market, supply, legislation, and technological improvements. (Charter & Gray, 2008).

The Author has described some of the DfX strategies, observed from case studies. It was also observed that many of these overlaps. For the sake of clarity, the project focuses only on the DfX Strategies mentioned below and links them with the examples studied as case study. Figure 20 describes the overview with the design approaches for design for remanufacture made by (Hatcher et al., 2011).

• *Design for core collection:* Detailed product design can communicate the end-of-life processes to the user. This can be done symbols, graphics positioned on the packaging or on any visible surface of the component. This plays an important role in informing the user to return the component at EOL. They can also inform additional features such as integration of RFID in the product. The figure shows an example of visual communication adopted at Perkins engines.

• *Eco design:* Through eco design the aim is to reduce the environmental impact throughout the life cycle of the product. Lifecycle thinking and management are two key factors that are backbone to this thought.
The two other specific eco-design strategies are:

- Improvement in energy and material efficiency
- Reduced Land use
- Design for optimizing functionality
- Design for reuse and others…

• *Design for disassembly (DfD):* it serves as an important part of end-of-life procedures. It enables the removal of parts without damage and reduce the remediation process and requirements for new parts to be replaced. Industries like Nokia, Xerox, Caterpillar, and other practice DfD.

• *Design for Multiple Lifecycles:* The process considers, cleaning, durability, reliability, and remediation. (Nasr & Thurston, 2006) elaborate that some components can be designated for single or multiple manufacturing recycle and for recycling or disposal. It is dependent on the product sector and in many cases, design for multiple life cycles also implies design for upgrade. For sake of clarity, the author has differentiated them as two different strategies.

4.6 Barriers to Remanufacturing

Although remanufacturing offers benefits, there are many potential challenges that it presents. A few of them are described below.

- ***Challenges in return flow/ Stabilizing the return flow***

Through literature studies, it is observed that efficient product retrieval is recognized as a challenging and critical aspect of remanufacturing process (Linder & Williander, 2017)(Östlin et al., 2009)(Lindkvist Haziri & Sundin, 2020)(King et al., 2007). The predictability and reliability of the return flow remains a challenge (Östlin et al., 2009). Together with this, the quality of the returned product is also unknown, which makes it difficult to maintain the labour and cost structure which makes reman process feasible (see example Canon (Mfps, n.d.))

- ***Restrictions in product category***

A study by (Bansal et al., 2020) records the basic characteristics required for design for remanufacture. Each criterion has been collected from a subsequent study and informed by different authors. The product parts, cost technology demand, worth potential and reverse channels. The table below defines each of the criteria. The product must have a core that is valuable and can be restored and reintroduced in the next life cycle.

- ***Not every product is designed to be remanufactured***

The design of a product plays a major role in determining if it can be remanufactured. For instance, if the product is designed to be disassembled efficiently, then its components can be separated without causing damage to it. Therefore, re-constructability is one of the important criteria for successful remanufacturing, The case study of different products (elaborated in chapter 5) shows how Xerox uses the concept of Platform (Modular) design to support remanufacturing process

- ***Risk of cannibalization***

The introduction of remanufactured goods serves as a competition against new goods. In many cases, customers are inclined towards the remanufactured products because they are "as good as new" and offer comparable warranty at a reduced price. This may lead to a decline in the demand for new products, which is referred to as 'Risk of cannibalization' This may hamper the company's profits as the new products generally generate more revenue as compared to remanufactured goods. (Linder & Williander, 2017) (Guiltinan, 2009; Michaud and Lierena, 2011) (4.1.1 Introduction to Remanufacturing - TU Delft OCW, n.d.)

- ***Fashion vulnerability***

Remanufactured products may face additional challenges in industries with rapid evolution rates and changing customer preferences. This is more likely to occur in industries where a product's worth is determined by its aesthetic value. In these cases, remanufactured products suffer a setback, placing additional pressure on implementing product design for modularity and upgradeability (Linder & Williander, 2017).

- *Capital tied-up*

To establish closed loop supply chain relationships when the products are sold as a service without providing ownership to the customer. A percentage of financial risk is transferred from the customer to the (re)manufacturer. Authors Linder and Williander suggest long term rental contracts as a counter solution. However, there is a risk that it may lead to a dull and uninteresting offer (Besch 2005).

- *Operational Risk*

Through implementation of selling goods as services, a manufacturer takes over a percentage of responsibility that was previously considered to be the customers. This increases the liability and operational risk of the company (Linder & Williander, 2017) .

- *Lack of Supporting Regulation*

The lack of relevant laws and regulations necessary to support Product Service Systems can be considered as a huge barrier to remanufacturing. According to the author Stahel (2010), Circular Business Models are impacted by the trend for taxes to be imposed on labour instead of raw materials.

- *Partner Restrictions*

The lack of communication channels and information between all stakeholders can also be considered as a challenge to introduce remanufacturing. Authors Linder and Williander point that the increase in differentiated material recovery, triggers the need to establish collaborative partner networks (Linder & Williander, 2017).

The barriers will be analysed more carefully in the chapter 5 along with the description of case studies.

4.7 Drivers to Remanufacturing

Customer

- *Price reductions:* As a result of cost savings from the product's material and energy recovery. Remanufactured products are typically sold at 60-80% of the cost of new products.

- *Availability:* A remanufactured product may have a shorter lead time than a new product especially ones that are made to order in another country Furthermore, remanufacturing may allow the customer to continue using obsolete equipment

- *Purchasing adaptability:* Since remanufacturers are genuinely interested in knowing where their products are and recovering them, they may offer a variety of services in addition to the initial sale. Leasing, take-back, upgrading, and supply-and-operate are all mutually beneficial: Capital costs can be amortized, supplier relationships can be strengthened, and "whole life solutions" eliminate the need for handling complications of waste management at the end of life.

Environment

- *Lower raw material consumption:* Since remanufacturing preserves much of the original product's material, less raw material is used than when producing new products. This is especially useful if the product contains critical raw materials that are scarce.

- *Lower energy consumption:* Because it limits the amount of raw material extracted/recycled and the manufacturing of new components, remanufacturing typically consumes less energy than manufacturing a new product.

- Lowering CO2 emissions: A reduction in energy consumption is usually accompanied by a reduction in CO2 emissions.

- Lowering the amount of waste disposed of in landfills: Not all end-of-life products and/or their components are recyclable and, as a result, end up in landfill. Thus, material flow is reduced by remanufacturing process by prolonging its life cycle

Remanufacturer

- *Local employment:* Since remanufacturing is generally done close to the market, even if a product was originally manufactured overseas, remanufacturing enables the creation of local jobs.

- *Increased profit margins:* The profit margins for Remanufactured products are frequently higher than those on newly manufactured item.

- *New manufacturing methods:* Because they are vital for success of businesses, leading remanufacturers embrace cutting-edge manufacturing processes such as lean techniques, human capital investment, and material traceability.

- *Improved customer relationships:* Remanufacturers who use trade-in programs can build strong relationships with their customers than those who rely on one-time purchases.

- *Skilled occupations:* Since it is more rewarding than production line jobs and often preserves traditional industrial skill bases, remanufacturing is a great place to develop problem-solving skills.

Technical design requirements for remanufacturing

The use of technical design for remanufacturing guidelines does not necessarily alter the process; rather, it modifies or adds requirements to the product architecture and design (Boorsma et al., 2019). The author studied these technical requirements described extensively in the literature of (Hatcher et al., 2011) Hatcher, Ijomah & Windmill (2011) and are presented in a tabular format shown in figure 20

Design for remanufacturing approaches	
Approach	*Authors*
DfRem metrics	Bras and Hammond (1996); Amezquita et al. (1995)
Fastening and joining selection	Shu and Flowers (1999)
RemPro matrix	Sundin (2004)
REPRO2	Zwolinski et al. (2006); Zwolinski and Brissaud (2008); Gehin et al. (2008)
DfRem guidelines	Ijomah et al. (2007a,b); Ijomah (2009)
DfRem metrics	Willems et al. (2008)
Hierarchical decision model	Lee et al. (2010)
Energy comparison tool	Sutherland et al. (2008)
Component reliability assessment	Zhang et al. (2010)
Modularisation	Ishii et al. (1994); Kimura et al. (2001)
FMEA	Lam et al. (2000); Sherwood and Shu (2000)
Platform design	King and Burgess (2005)
Active disassembly	Chiodo and Ijomah (2009)
Design for environment tools	Pigosso et al. (2009)
Quality Function Deployment (QFD)	Yuksel (2010)

Figure 19- Table showing the various approaches to design for remanufacturing adapted from (Hatcher et al., 2011)

4.8 Summary

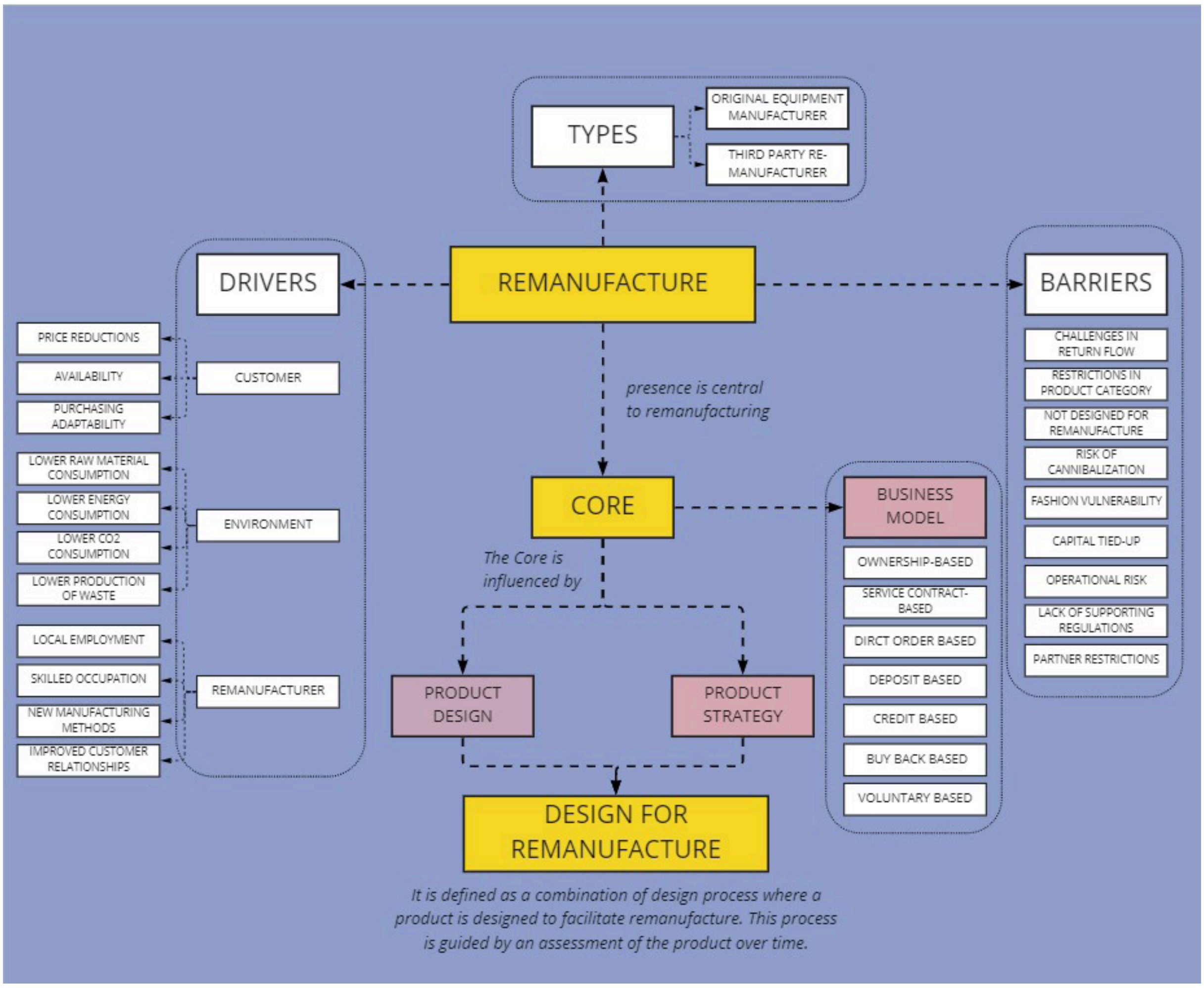


Figure 20: A flowchart that summarises all the concepts and terms for the chapter 4

05 Remanufacturing in other industries - case study

The chapter presents case study of successful examples of remanufacturing in other industries. The chapter is concluded with a list of criteria and parameters important for remanufacturing.

4. Remanufacturing in other industries - Case Study

5.1 Remanufacturing in other industries

After formulating the problem statement, the next step was to understand the concept of remanufacturing (elaborated in Chapter 4). Since the aim of the thesis was to build a canvas and a list of criteria, the observations made from the literature review had to be validated. For this purpose and to understand business models in more detail, twenty examples of successful remanufacturing companies were gathered. The primary data was analyzed to understand the business model employed for core collection, value proposition and the nature of product designed for remanufacture.

The examples were chosen depending on three topics, type of remanufacturer, complexity of the product and location of remanufacturing centers. This information was gathered through research papers, journals and from websites of companies and the Europe Remanufacturing Network (ERN) The table 5 shows the first twenty examples that were studied and gives an overall view on the process of selection. The detailed assessment of each of the examples can be found in the appendix (chapter 18)

Successful examples of remanufacturing across different industries					
No.	**Company**	**Sector/product**	**Type**	**Country**	**Reference**
1	Caterpillar	Automobile/Engine block	OEM	UK- Center for reman in EU America, Brazil, Mexico, Asia & many more	(Caterpillar Inc. | Extending Product Life, n.d.)
2	BMW	Automobile/ Steering gear	OEM / 3rd party	Germany	(Original BMW Remanufactured Parts, n.d.)
3	Autoelectro	Automobile/ Starter motors & alternators	Independant remanufacturer	Bradford, UK	(The Remanufacturing Case Study Tool, n.d.)
4	SCM Turbomotive Ltd	Automobile/Turbochargers & spare parts (full range)	Independant remanufacturer	Huddersfield, UK	(Charter & Gray, 2008)
5	Xerox	Electronics/ MFP	OEM	Venray(NL), Mitcheldean (UK), Dundalk(IRL)	(King et al., 2007)
6	The Bond Group	Electronics/ Refrigerator Display Cabinet	3rd party	Sheerness on the Isle of Sheppey, Kent	(The Remanufacturing Case Study Tool, n.d.)
7	Inrego AB	Electronics/Compuers & Smart phones	Independant remanufacturer	Sweden	(The Remanufacturing Case Study Tool, n.d.)
8	APD International	Electronics/Electro-mechanical modules for mid/high Volume printing systems, including Fusing & Xerographic module assemblies	3rd party/Independent remanufacturer	Gloucestershire, UK & Mikulov, Czech Republic	(The Remanufacturing Case Study Tool, n.d.)
9	Canon	Electronics/ Multifunctional Printers (MFP)	OEM	Giessen , Germany	(Mfps, n.d.)
10	Scandi-Toner AB	Electronics/ Toner cartridges	Independent remanufacturer	Karlstad, Sweden	(The Remanufacturing Case Study Tool, n.d.)
11	Sony (SCEE)	Electronics/ Playstation (original)	OEM / 3rd party	Many authorized centres around the world	(Charter & Gray, 2008)
12	Edwards Vaccum pump manufacturer	Machinery/ vaccum pumps	OEM/OER	Sweden	(Vacuum Pump Repair and Complete Remanufacturing - Edwards Vacuum, n.d.)
13	Hitachi Construction Machinery Europe (HCME)	Machinery/Hydraulic main pumps of construction machines	OEM/OER	Amsterdam, The Netherlands	(The Remanufacturing Case Study Tool, n.d.)
14	Buhler group	Machinery/ Die cast machines	3rd party reman	140 locations around the world, Almere, The Netherlands	(Bühler Group | Innovations for a Better World, n.d.)
15	Miliken Earth Square	Interior/ Carpets	OEM	Wigan, UK	(Charter & Gray, 2008)
16	Davies Furniture	Furniture/ Office desks	Independant remanufacturer	Albany, New York, USA	(Davies Office | Sustainable Office Furniture Solutions, n.d.)
17	Desko	Furniture/ Office desks:Duo Slinger Table	Independent remanufacturer	Amsterdam, The Netherlands	(The Remanufacturing Case Study Tool, n.d.)
18	Steelcase |Orangebox	Furniture/ Task seating chairs	OEM	Treforest, Wales, UK	(Steelcase - Office Furniture Solutions, Education & Healthcare Furniture, n.d.)
19	Philips	Medical Equipment/	OEM	Best, The Netherlands	(Economy & Model, 2020)
20	Liebherr-Ettlingen GmbH	Automobile/ Drive components - small hydraulic components to V12 diesel engines	OEM	Ettlingen, Germany	(The Remanufacturing Case Study Tool, n.d.)

Table 5: Overview of the 20 successful examples of remanufacturing studied. Source: Author

5.2 Deeper analysis with five chosen examples

Through the study of twenty examples, an overall idea of the remanufacturing concept was understood. However, to define the criteria's that led to the success of remanufacturing had to be mapped. For this purpose of analysis at product level, five out of twenty examples were chosen. This choice was guided by three criteria's namely, product complexity, material intensive nature and high volumes of production. 'This led to choosing Xerox, Davies furniture, Philips MRI Systems, Caterpillar, and Canon EMEA.

Hitachi Construction Machiney Europe	Inrego AI	Xerox	Steelcase Orangebox	SCM Turbomotive Ltd.
Scandi-Toner AB	Desslo	Bülher Group	Davies Furniture	Edwards Vaccum Pump
Sony (SCEE)	Philips MRI Systems	BMW	The Bond Group	Caterpillar
Liebherr-Ettlingen GmbH	Canon EMEA	APD International	Autoelectro	Miliken Earth Square Carpets

Figure 22 - Five companies chosen for further analysis to assist in development of design for reman canvas

5.3 Philips SmartPath

5.3.1 Remanufacturing by Original Equipment Manufacturer (OEM-R)

Philips focused on a 5-year sustainability program called "Healthy people, sustainable planet" – during the period 2016-2020. The motivation of the program was to integrate principles of reducing the environmental impact and careful management of resources. One of the goals for the year 2020 was to generate over 15% of the turnover from solutions related to circular economy. That year Philips signed the 'Large Capital Equipment Pledge' which promised to "take back and repurpose all the large medical systems that its customers are prepared to return" (Economy & Model, 2020).

The study focuses on SmartPath portfolio - a circular business model employed for the MRI systems by Philips. SmartPath focuses on helping customers get the most out of their MRI equipment investment over time. This is accomplished by maintaining equipment functionality and extending the life of the equipment; and making it simple for clients to upgrade to the most up-to-date technology (Smartpath | Philips Healthcare, n.d.).

5.3.2 Demographic trends

The demand for health care increases with increasing population and in today's times it translates to increasing demand for MRI scans. In most countries, the private sector facilities are increasing in number and most cases are being outsourced from public hospitals. Philips MRI business operates in a competitive market with other companies such as GE Healthcare and Siemens healthcare. With the incoming of non-traditional players such as apple in MRI devices, the area of innovation is following the trend of digitization in the sector.

5.3.3 *Trends in technology & growing customer needs*

The imaging capability of an imaging equipment were determined by improvements to MRI hardware which translated into the power of key magnet components. One of the latest developments was with respect to increase in bore size The improvements in magnet are recently beginning to plateau and the focus on increasing imaging quality relies now on improvement in software. With the increasing focus on software developments, the MRI machines are now being fully connected to hospital software platforms and rely on software for operating the machines (Smartpath | Philips Healthcare, n.d.).

Initially the service life of an MRI was generally between 8-10 years. The reports show that hospitals continue to run their MRI equipment for over 15 years (Economy & Model, 2020). It highlights that there is a strong demand for refurbished units. Hospitals prefer to gain access to MRI systems either by leasing or outsourcing services to cut the cost. This has made radiology departments to become cost centres and are focusing on efficiently generating outcomes within a fixed budget. This trend aligns with the aims of Philips SmartPath, which offers the customers to enhance the equipment features thought the service life.

Product canvas - SmartPath Portfolio by Philips				
Key Partners	**Key Activities**	**Value propositions**	**Customer relationships**	**Customer Segments**
Financing partner (internal or external)	Software development	SmartPath - Enhance	Consultative & collaborative	University research hospitals
	Product design & development	SmartPath - Optimize	Long-term over the product lifecycle	Non-research public hospitals
		Financing solutions (options & upgrade)		Private specialist institutes & high-end providers
Key Resouces	**Channels**	**Cost structure**	**Revenue Streams**	**Social & Environmental**
Installed Base	Direct sales and account management	Sales and account teams	Software subscription sales (recurring revenue)	Equipment utility and value is maximised over its lifetime
Decision-support system	Indirect channels/ distributors	Product/software development	Sale of options and upgrades ("add-on" incremental revenue)	Enhanced patient care

Figure 23 - Remanufacturing Product Canvas of Philips.
Source: Author adapted by (Economy & Model, 2020)

5.3.4 *Rules & Regulations*

This section is further divided into health care policy and policies driving investment behaviour in MRI. Policies driving the MRI equipment says that it is an important technology in hospitals. The government rules and policies are regulated to ensure that every health care facility uses the most advanced machines and how they manage the equipment over its lifecycle.

5.3.4 *Rules & Regulations*

This section is further divided into health care policy and policies driving investment behaviour in MRI. Policies driving the MRI equipment says that it is an important technology in hospitals. The government rules and policies are regulated to ensure that every health care facility uses the most advanced machines and how they manage the equipment over its lifecycle.

5.3.5 *SmartPath portfolio*

According to a report by (Economy & Model, 2020) states that MRI machines are equipment that need substantial investment in terms of infrastructure (due to the weight of the machine) for procurement and installation. The SmartPath portfolio is a collection of four features: Optimise; Enhance; Transform and Trade-In.

5.3.6 *Value proposition*

The SmartPath portfolio approach by Philips focuses on enhancing value and upgrade the equipment to adapt to the consumer needs during its service life. Its features Enhance and Transform are valuable for optimizing and enhancing the value within product lifetime.

5.3.7 *Optimize*

The customer has an option to buy the "Technology Maximiser" which offers continuous software and hardware upgrades when they become available. A study by (Economy & Model, 2020) says that this enables customers retain MR systems with the latest state-of-the-art upgrades for up to 5 years after the installation process.

5.3.8 *Enhance*

After the purchase of an MR product, the consumers have the opportunity to add new functionalities to adapt to changing requirements. They can be purchased as add-ons and if in case of a budget constrain, these options can be purchased as a part of existing 'sale and lease back' or a new contract. (Economy & Model, 2020) highlights that generally MR leasing arrangements is between 5-7 years.

5.3.9 *Reverse Logistics*

A Sales and marketing team within Philips is responsible for managing relationships with companies and keeping a tab on the leasing contracts. However, Philips also sells its equipment through distributors which serve as indirect channels.

5.3.10 *Revenue Streams*

While Philips SmartPath portfolio features of enhance and upgrade allow the consumer to add new functionalities and software developments as they are released. In exchange for creating and delivering this value, they serve as revenue streams for Philips.

5.3.11 *Key resources, activities & partners*

This section elaborates the key resources, activities and partners of Philips SmartPath Portfolio as described in (Economy & Model, 2020).

Installed base of MR machines

Shifting focus from sales of new equipment to creating lifetime value has given Philips a chance to incrementally increase the value they create for customers while harnessing mutual opportunities to grow, collaborate and develop lifecycle solutions as a long-term partner for healthcare institutions.

Decision support platform

With a shift in focus from new sales to creating value, the sales and management team have been empowered by a great deal to identify and execute opportunities of revenue. Philips has developed a decision-support platform that helps the sales and account managers to monitor the upgrades that the consumer makes and providing options when the consumers wish to replace the equipment at the end of life.

Key Activities

Software and product design development are a part of Philips key activities. As mentioned earlier, Philips operates in a competitive market and the new innovations in MR machines are focused on software developments with respect to imaging and user interface and developing life cycle upgrades.

5.3.12 Business Model overview with SmartPath for extending product lifetime & closing the loop

Value Proposition

The key elements of this section and transform and trade-in. Transform refers to a complete on-site overhaul of the hardware and software components excluding the magnets which will be reused from the original equipment. Whereas trade-in enables the customer to trade the existing machine for a new one. Depending on the age of the returned equipment, Philips refurbishes the equipment and sold back into the market under the brand name Diamond select (Economy & Model, 2020)

Transform

SmartPath to dStream is less expensive, less disruptive, and faster than purchasing a new machine. Upgrades to dStream can be performed to MR machines that are three product generations old or newer. This opens a lot of possibilities for improvement (Economy & Model, 2020). When a new MR system is built it usually necessitates the complete reconstruction of the room or parts of the hospital wing, as well as the installation of new building systems (such as air conditioning). This can take several weeks.

Trade-in

This is a program that highlights the benefits of retuning the equipment to customers, at the same time this allows. The sources that bring direct value to Philips after take back of the products are from extending the service revenue and capturing stock of used parts and equipment for refurbishment.

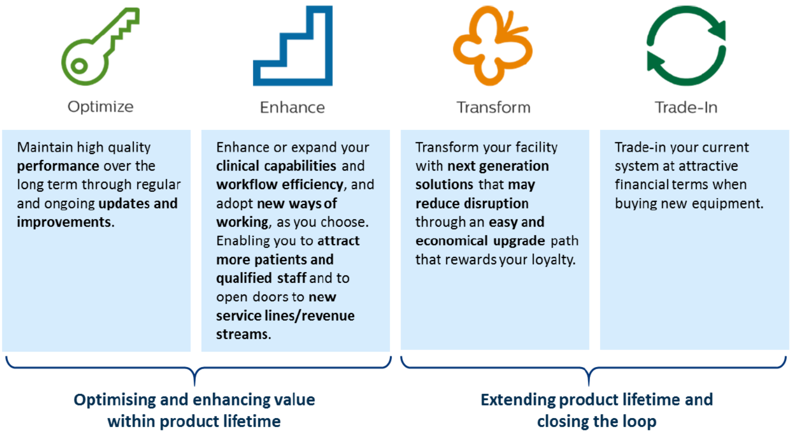


Figure 24 - Elements of the SmartPath Portfolio. Source: (Economy & Model, 2020) Adapted from Philips

5.3.13 Diamond Select refurbished machines

This has been applied across all refurbished systems and has developed a strong brand name over the years. This is a strong feature as consumers know the quality of the product, they will receive on purchase. They are a part of the product line up and have a presence on the product catalogue (Smartpath | Philips Healthcare, n.d.)

Trade-in Desk – This is a key place that determines the value of the equipment that is returned to the customer at the End of contract/ service life. This also helps the sales team make proposals with monetary value that can be received at certain points during the lifecycle of a product (Smartpath | Philips Healthcare, n.d.)

Figure 25: Philips Diamond Select refurbished machines. Source: (Philips Achieva 1.5T MRI - Medical Outfitters, n.d.)

5.3.14 Creating brand value

Philips launched Diamond select series, which is a part of the product catalogue. This is a validation of the fact that the company is developing good quality products that the customers can trust and are aware of the quality of the product that is being delivered. This makes SmartPath to dStream conversions, MRI refurbishment and trade-in valuation the key activities at Philips Healthcare systems.

5.3.15 Cost Structure

The elements that form the cost structure for part of this business model of closing the loop are Manufacturing the hardware for the SmartPath to dStream on-site transformations, Refurbishment of MRI systems in Best, Netherlands and finally trade-in value offered for consumers buying a new MRI machine, which starts ways of enabling sales and incremental revenue (Economy & Model, 2020).

5.3.16 Role of ICT & technology in improving profitability

Decision making platform

Philips developed a decision-making platform to help sales and management team identify and promote the SmartPath portfolio and help consumers understand the benefits that it can bring during its service life and assist return of products at the end of its service life through the same channels. The key benefits of the platform are.

- Account managers selling options and upgrades benefit from effective decision support. The platform enables faster and easier transaction processing, allowing managers to focus on the customer relationship and providing the best service possible.
- Proactively initiating timely contact (touch points) and conversations with customers, allowing account managers to develop a better understanding of the customer and establish longer-lasting relationships.
- When an MR machine is nearing or has reached the end of its useful life and the customer is considering, or is likely to consider, replacing it: Offering attractive trade-in and take-back terms for MRI equipment.

Role of software and digitization in MRI

When it comes to creating value for customers with MRI equipment, software is becoming increasingly important. It can improve machine operation and imaging outputs, as well as image data processing and management and diagnostic applications. Software is a critical component of the SmartPath value proposition. With the overall trend of digitisation in radiology and diagnostics, the importance of providing customers with software solutions and applications will grow. It will also enable hardware upgradeability, allowing it to remain relevant and provide better value to customers for longer periods of time (extending lifetime).

5.3.17 SWOT Analysis

After studying the SmartPath portfolio by Philips in detail, a SWOT analysis was made. This highlighted the key features and opportunities that made this a unique successful example of remanufacturing. Through this case study the importance of integration of digital workflows was understood. In the later chapters, the relevance of the example to the building industry will be discussed and evaluated.

SWOT Analysis for Philips SmartPath Portfolio and remanufacturing process	
Strengths	Weakness
Lifecycle roadmap of updates and upgrades	Creating an integrated and seamless proposition
Strong refurbished product proposition	Integrated lifecycle contracting
Trade-in value & enhanced trade-in value	Financial and contractual processes
Long-term service based contracts	Sales team incentives
Decision-support platform	
Design for upgradeability	
Design for backward compatibility	
Oppurtunities	Threats
Digitisation	Regulations – Environmental health and safety
Technical/technological developments	Policy – disincentives for older equipment upgrade
Demand for cost efficiency and productivity	Policy & Regulations – Public sector procurement practices
Demand for cost predictability and focus on value	Customers – slow uptake of servitised propositions
Customer drive towards standardisation of MR processes	Customers – traditional procurement mindset
	Competition from new entrants

Figure 26 - SWOT Analysis of Philips SmartPath. Source: Author adapted by (Economy & Model, 2020)

5.4 Davies Furniture

5.4.1 Introduction

The industrial revolution bought the notion of take-make-dispose, and industries today and changing their ways to move towards sustainable practices with an aim to design for closing material loops. Research shows that supply chain management, resource recovery and growing energy costs are main factors that bring sustainability to modern manufacturing practices (Krystofik et al., 2018) In response to this need remanufacturing through isolation of product cores is a strategy that helps achieve circular economy. This process suits products that are durable and designed to be upgraded to create additional lifecycles by remanufacturing multiple time. One such example is Davies office furniture- a third party remanufacturer, in the United States of America and remanufactures furniture from popular office furniture companies such as Steelcase, Herman Miller.

5.4.2 Motivation of the case study

This case study focuses on how third-party independent remanufacturer works around a remanufacturing focused business model where it benefits by creation of a cost-effective method of collection of cores at the EoL of a product. In this case office furniture, with a focus on material acquisition, remanufacturing, and transportation processes.

5.4.3 Scope

The case study focuses on modular office desk furniture particularly on, a set of three constitute components – work surfaces, storage units and wall panels that constate an area of 8.73m2. The most common indexing practice used virgin panels in 48” W X 65” H. A complete workspace system supports the user for a service life of 10 years, which is also the length of Davies warranty. The case study aims to understand the benefits of adaptive remanufacturing over traditional remanufacturing process by exploring the case of reman over more than a single product lifecycle. (Davies Office | Sustainable Office Furniture Solutions, n.d.)

5.4.4 Competition & changing trends

In the context of office furniture, design evolves with change in style and customer preferences and remanufacturers therefore have access to existing product designs that are noncompetitive probably obsolete This makes challenging to create products that are better than as-manufactured conditions to maintain a consistent customer base (Krystofik et al., 2018). With respect to virgin production of office furniture, (Krystofik et al., 2018) points that welding and powder coating are the most significant contributors to Cumulative Energy Demand (CED).

5.4.5 Customer needs

At Davies office, a customer has the opportunity to mix-and-match to create a unique selection of new, pre-owned, or remanufactured business furniture (Remanufactured Office Furniture | Davies Office, n.d.). (Krystofik et al., 2018) quotes an example where Davies office, recognized the preference in open work environments that caused a shift in customer preferences with respect to divider panels, being shorter than they were in the past. The incoming cores were still full height.

Here Davies office restored some of them to their original height, it had the opportunity to create shorter panels and adding features more conducive to open work environments, in cases that suited the customer preference. Davies office employs a process called indexing, which aims to make the products better for current need than it was as new. This makes them more competitive than virgin products. (Aziz et al., 2016) considers this method to design for remanufacturing by “Designing for upgradability” that is intended to achieve and maintain functional equivalence with respect to virgin production to sustain the remanufacturing process.

During the reman process Davies adds a new layer of laminate during the second and third remanufacturing cycles, and this accumulation of laminate material is the most significant difference between product life cycles. When the addition of a new layer becomes unfeasible due to increase in surface thickness that will bring the component out of tolerance thereby rendering it incompatible. Davies stripes all laminate from the component to add a new single later to the surface of an intact core.

Table : Remanufacturing Product Canvas				
Product canvas - Adaptive remanufcaturing at Davies furniture				
Key Partners	**Key Activities**	**Value propositions**	**Customer relationships**	**Customer Segments**
	Product design & development	High quality furniture and buy back at EOL	Brokerage, product exchange and banking program	For Offices of Small & medium business owners
	Reverse logistics trough simple database	Mainatainance services & Leasing contracts		
Key Resouces	**Channels**	**Cost structure**	**Revenue Streams**	**Social & Environmental**
Indexing process of office furniture received at EOL	Direct sales and account management with customer	Remanufactruing options	Resale of remanufactured furniture with warranty comparable to new	Reduction in carbon footprint
Product exchange, banking program		Sales organization		Raw material saving
		Service delivery organization		

Figure 27- Remanufacturing product canvas of remanufacturing operations at Davies Furniture. Source: Author

5.4.6 Key activities

Adaptive remanufacturing – The process of indexing outlined in the previous section, is an unique method that allows the company to make changes to their product offerings to suit the changing market preferences without causing a big change in the supply chain (Krystofik et al., 2018) defines Adaptive remanufacturing as the use of an EOL product core to create a similar but non-identical product whose function and use characteristics are effectively equivalent to the original new product, use adaptive remanufacturing.

Adaptive design and remanufacturing not only improves the environmental profile beyond standard remanufacturing, but also improves economic viability by maintaining competitiveness with evolving contemporary markets. After indexing the residual material cannot be immediately used and is most often sent to recycling. The most common indexing practice uses virgin panels in the 48" W X 65"H panels

Eco-Friendly Technologies

The team at Davies reduce the amount of solid waste produced by using cutting-edge technologies, which has a negative impact on the environment. The cutting process employed maximizes efficiency, and our algorithms determine the best way to use any of our resources (Remanufactured Office Furniture | Davies Office, n.d.). The figure 28 shows an example of the before and after condition achieved through adaptive remanufacturing process at Davies Furniture.

Figure 28- Reuse of existing core to create new tops. Source: (Remanufactured Office Furniture | Davies Office, n.d.).

5.3.17 Remanufacturing operation & reverse logistics

The remanufacturing process at Davies begins from the end user who is considered as a material supplier, with a small amount from primary manufacturer and a small percentage sent to landfill. In remanufacturing at product level, Davies employs various levels of product disassembly dependent on the product category and product core. The most common remanufacturing activities at Davies furniture are cutting, welding, powder coating and reupholstering to suit the new design criteria and requirements. (Walisongo, 2020)

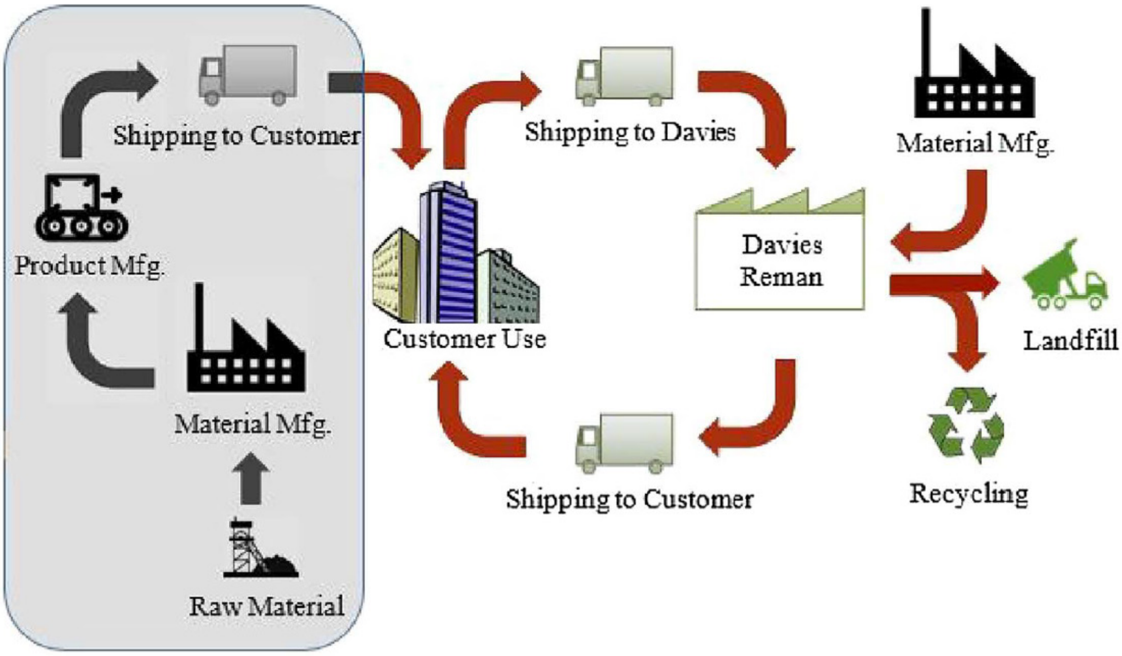


Figure 29- Davies remanufacturing system boundary, with closed loop supply chain. Source: (Krystofik et al., 2018)

5.4.8 *The Value network*

The raw material supply for Davies Furniture is office furniture at EOL either due to condition degradation, business relocation, closure or change in style or preference. This is sourced through product exchange, Banking program, and finally through a voluntary based core sourcing. By creating additional life cycles Davies furniture recovers valuable material and creates products that can go back into the market, thereby creating additional life cycles. This way Davies furniture embodies circular economy in two ways:

- Its operations create valuable products from waste products perceived to be of low value (Kathiravale & Muhd Yunus, 2008)
- The logistic channels operated by Davies furniture are structured to in minimize waste opportunities, and maintain a viable resource stream and consistent customer base.

5.4.9 *Business model circularity assessment*

Product Life Extension

A study by (Krystofik et al., 2018) concluded that adaptive remanufacturing (i.e indexed) process of workspace component products showed no appreciable difference in CED or material use in comparison to those remanufactured to be restored in their original design. After initial remanufacturing process, the calculated independent life cycle impacts of a second remanufacturing cycle performed on an adaptively remanufactured product were like those of the first cycle. This states that the impact of adaptive remanufacture is likely to grow over subsequent cycles, but in a slower growth while compared to traditional remanufacturing.

Adaptive reman and supply chain circularity

Adaptive remanufacturing enables creation of new product types from a given core family. This allows remanufacturers to diversify their product offerings and provides insulation against supply chain uncertainty. There exists no standardized system to record the number of remanufacturing cycles a product has undergone. This brings in uncertainty with respect to material replacement and environmental impact.

5.4.10 *SWOT Analysis*

The study on Davies Furniture concluded with a SWOT analysis. This helped to summarize the concepts applied by Davies furniture to make their remanufacturing-focused business a success. The important take away from the study was the concept of adaptive manufacturing and remediation. The former is responsible for building products suitable for changing market and latter for ensuring that remanufacturing process is economically and environmentally feasible.

SWOT Analysis for remanufacturing process at Daves furniture	
Strengths	Weakness
Adaptive remanufacturing and indexing process	Collection of retired products is a key logitstic task
Strong technical competence and high quality of remanufacturing	Challenges in core availability, processing products to meet market demand
Design for multiple product lifecycled and market adapatibility	
Reverse logistics to enable core collection	
Oppurtunities	Threats
Developing technical ability to convert cores to match market demands	Limited warning to impeding product changes
Recover materials and use them economically with minimum additional energy requirements is challenging	Unstable supply of cores

Figure 30- SWOT Analysis of remanufacturing process at Davies furniture. Source: Author

5.5 Canon

Canon adopted a philosophy in 1988 and is popularly known as “Kyosei” which translates as “Living and working together for the common good”. This is Canon’s approach to Environment, Social, and Governance (ESG). In 1990, it was the first company to successfully introduce the toner printer cartridge recycling programme and in 2017, it is reported to have collected 394,000 tonnes of cartridges globally (Why We Remanufacture - Canon Europe, n.d.)

5.5.1 Motivation of the study

This case study focuses on the section of Document Solutions (DS) of Canon Europe. They are part of the broader Office Business unit and include various printing systems and Document solutions. Canon’s 2017 (latest year available for figures) Annual report says that over 45.7% of Canon’s global revenue is generated from the Office Business Unit sector, is the motivation to study the chosen product (Mfps, n.d.). Every office printer that is returned to Canon EMEA at the end-of-contract is subjected to a decision guided by Canon EMEA’s European guidelines, followed by which it can take three different routes of remanufacturing, refurbishment, or recycling. The case study focuses on barriers, enablers of circular economy model regarding remanufacturing of Canon EMEA’s printer machines. During the remanufacturing process at Canon, it is found to have reused up to 91% of parts by weight.(Why We Remanufacture - Canon Europe, n.d.)

5.5.2 Demographic trends

In this context, the demographic trends refer to the printing behaviour. The demand for printer units is declining every year as the younger generation relies on greater utilization of alternatives such as printers and tablets for viewing in comparison to printed material, thereby increasingly replacing the need for printing. The number of prints by a customer has been declining approximately 5% every year (Mfps, n.d.). This switch is also supported by the sustainable use of resources such as paper and ink.

5.5.3 *Technological trends*

At this point, the printer/copier technology is considered to be mature and established and most of the innovation can be seen in areas of user interface and software applications, to bring everything on the same stream (Mfps, n.d.)

5.5.4 *Rules & Regulations*

The relevant regulations that are followed by Canon EMEA are:
Extended Producer Responsibility (EPR) requirements, the Eco-design Directive, health & safety regulations, WEEE Directive, and the revised Waste Framework Directive (Why We Remanufacture - Canon Europe, n.d.) Canon EMEA works to ensure all equipment meets the regulations by designing new equipment however, this is a challenge in case of remanufacturing operations because the returned products are designed and manufactured many years ago and after the reman operation, the used equipment must be returned to the market in "as new condition" (Mfps, n.d.).

5.5.5 *Business model assessment*

As mentioned before, Canon EMEA employs two key patterns of circular business model namely remanufacturing and refurbishment, the report will only focus on remanufacturing. Remanufacturing is focused on specific machines and is relatively centralized. The Managed Print Service (MPS) which will be explained later has more in the case study, adds more complexity and features to the circular economy model (Why We Remanufacture - Canon Europe, n.d.)

5.5.6 *Demand for remanufactured units*

As mentioned before, remanufacturing is carried out for specific products, and the EQ80 product is the focus of discussion. The remanufactured units have a significant advantage of sustainability due to their low manufacturing carbon footprint (Mfps, n.d.). Most often they are sold as a sales package deal to incentivize the purchase of reman units. Small and Medium business segments are more inclined to purchase remanufacturing units due to price advantage. There is a growing awareness among the consumers about sustainability, and this draws more consumers towards remanufactured units, although continuously fighting the bias of low-quality stereotypes concerning 'second hand' products (Why We Remanufacture - Canon Europe, n.d.).

5.5.7 *Value proposition*

Canon EMEA's circular business model's value propositions are based on the broader business strategy for new unit sales. This comprises of first, the product that is at the core of the proposition along with lease contracts, consumables supply, maintenance and support services, and managed services, which are all part of the traditional offering (Mfps, n.d.)

5.5.8 *The printer product & leasing*

Canon EMEA sells a range of equipment to customers through a leasing contract that typically spans four to six years (Mfps, n.d.). These are given out by Canon EMEA who is the OEM and several third-party leasing companies. Canon EMEA however ensures to stay close to its assets to decide on how to manage them at End-of-contract (EOC) (Mfps, n.d.)states that this is possible as Canon has the right to buy the machines from a third party. At the end of a lease contract, the customers have the following options:

- Upgrade to new equipment under a new lease
- Extending the existing lease
- Buying the machine and keeping track of the assets

5.5.9 *Consumables*

The consumables refer to toner cartridges and paper sold for the office machines. They serve as an important source of revenue and profit, over the lifetime of every installed base (Machines in Field) (Why We Remanufacture - Canon Europe, n.d.)

5.5.10 *Managed Print Service (MPS)*

Managed Printed Service is a feature that is scalable and modular. It can be adapted to the changing/growing needs of a customer along with the possibility to add new in new features to the technology platform such as mobile printing. It is a service where the customers can outsource their print management to Canon EMEA, which analyses the printing habits and can offer a cost-effective solution to a customer. It is also the most relevant value-added service in the context of circular economy as it helps to monitor the assets by the company during the operational service life of the equipment (Mfps, n.d.).

5.5.11 *Remanufactured EQ80 Printer*

The remanufacturing process at Canon EMEA is guided by the EU Remanufacturing policy. Canon EMEA designates specific models for remanufacturing by targeting the best-selling models that have the functionality and features that continue to attract consumers in the market (Mfps, n.d.). The specified machines are stripped out and rebranded as EQ80 ("Environmental Quotient 80") which states that at least 80% of the machine has been built from reused equipment's returned to Canon EMEA. The series EQ80imageRUNNER ADVANCE C5000 is an example of a Remanufactured EQ80 Printer, and it bears the following features:

- Products restored to "as new condition" and receive a warranty comparable to new products.
- They offer the same build quality and performance as the Canon new products.
- The equipment will be designed to comply with new regulations and must be updated before being sold in the general market.

5.5.12 *Remanufacturing Facility*

Canon has a centralized remanufacturing facility that handles end-to-end remanufacturing facilities in Giessen, Germany that occupies over 87400 square meters. In addition to remanufacturing, the Giessen plant also undertakes printer refurbishment for the Germany and France NSO (Mfps, n.d.). Reverse logistics is a key activity for Canon EMEA, and in order to make the process of take back process more efficient, the used machines are picked up when the new units are delivered and this way, they become a part of the same transaction. This makes Reverse logistics a key activity for Canon EMEA.

5.5.12 *Remanufacturing cost structure*

The Fixed costs, such as plant and equipment (the Giessen facilities), and variable costs, such as labor and materials, are the key cost drivers for remanufacturing (e.g. new components purchased and installed in machines replacing those that are no longer usable) (Mfps, n.d.). In the past, the lower unit cost of remanufactured printers allowed Canon EMEA to sell them at a more appealing and lucrative price point than new machines. Due to increasing competition, the cost of new equipment models has decreased in recent months. Though remanufacturing prices are still competitive when compared to new equipment, the price difference between a remanufactured and a new model is gradually diminishing. This appears to be one of the reasons why buyers prefer to purchase fresh items.

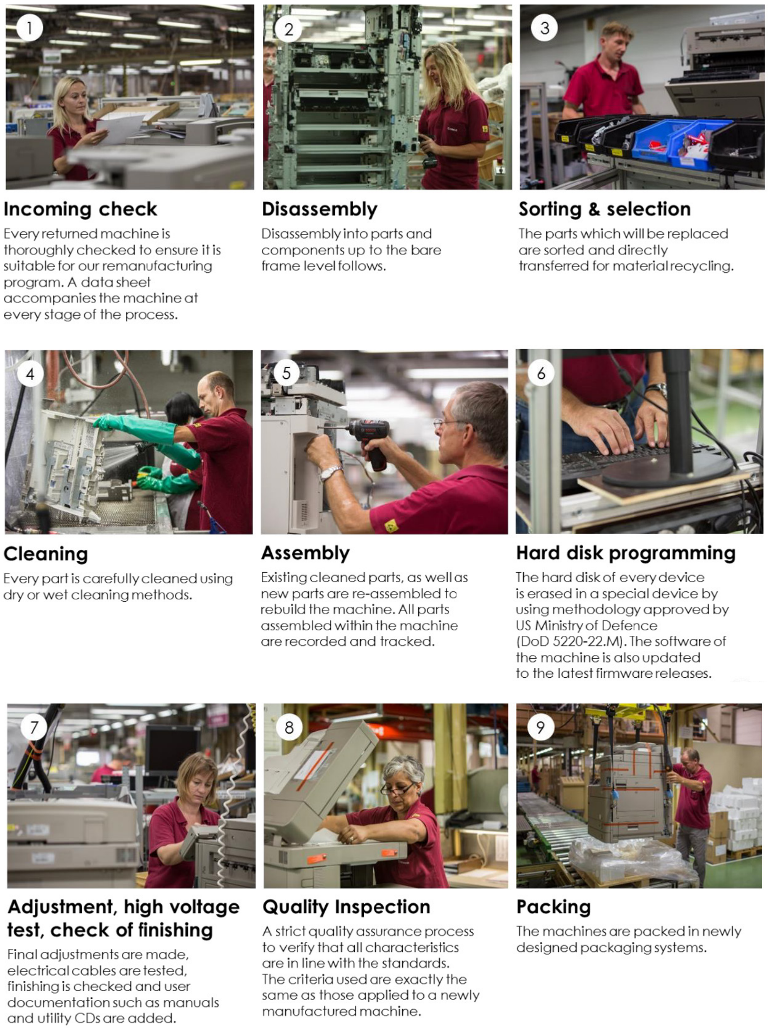


Figure 33- The cdetailed remanufacturing process at Gissen, Germany. Source: (Mfps, n.d.) Canon EMEA

5.5.14 *The Value network*

Units are returned to the NSO before being sent to Canon's Giessen facility. Units go through a similar sales process to new products after being remanufactured: Canon EMEA's Document Solutions business segment controls the assets at first, before selling them to clients through NSOs (Mfps, n.d.). The money earned from remanufactured equipment sales, as well as recurring revenue from consumables and add-on services if units are supplied under a service contract, is the primary value flow.

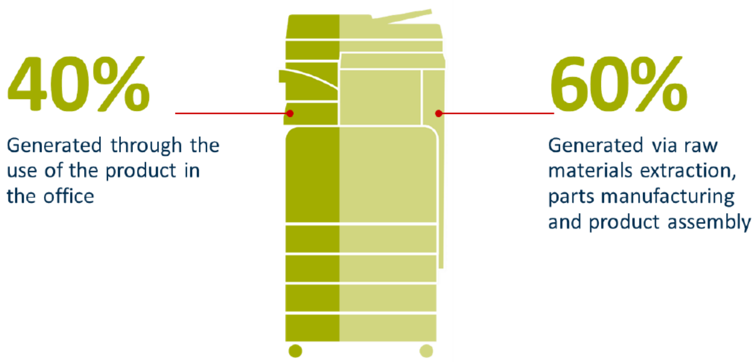


Figure 32 -The carbon footprint of Remanufactured WQ80 printer. Source: (Mfps, n.d.) Canon EMEA

5.5.14 SWOT Analysis

The above-mentioned strengths, weaknesses, opportunities, and threats and shown in figure are examined in greater detail in the sections that follow. Tabulation of the criteria helped in understanding the strengths and shortcomings with respect to the esign on the Business model of Canon EMEA. Furthermore, its similarities and differences with respect to the building industry were also understood and will be explained in the analysis section which will be presented at the end of this chapter.

SWOT Analysis for Canon EMEA remanufacturing process	
Strengths	Weakness
Quality and volume of Machines In Field.	Focus on new product – Sales incentives.
Managed Print Service offering.	Focus on new product – Product line-up strategy.
Strong technical competence and high quality of remanufacturing	Relatively high cost of remanufacturing
NSO responsiveness to market conditions	Difficulty of standardization.
	Complexity caused by bespoke configurations.
	High cost of reverse logistics.
Oppurtunities	Threats
Growing customer acceptance of remanufactured and refurbished machines	General preference for 'buying new'.
Value-based procurement	Public sector procurement policies.
Maturity of core technology	Sustainable procurement focused on energy efficiency
	Highly competitive, declining market –price erosion of new machines

Figure 34 - SWOT Analysis of Canon. Source: Author

5.6 Xerox

5.6.1 Rules & regulations

The introduction of legislation by the WEEE Directive makes manufacturers liable for their products beyond their End-of-life. The smaller loops will add more value to meet the criteria of Extended Producer Responsibility (King et al., 2007). The European Union has introduced Extended Producer Responsibility legislation (EPR), which the OECD (Organisation for Economic Co-operation and Development) defines as "the principle that manufacturers and importers of products should bear a significant degree of responsibility for the environmental impacts of their products throughout the product life-cycle, including impacts from material selection, the manufacturing process, and use and disposal of the products at the end of the life cycle." This enactment rests on the argument that the environment impacts must be determined in the key design phase, where choices with respect to material, process and technology is made by the manufacturer.

WEEE Directive on Waste Electrical and Electronic development has implemented and a repost says that from 2004, Original Equipment Manufacturers (OEM) in the EU are legally bound to take responsibility of treatment and disposal of post-consumer products. The objectives of WEEE include:

- Reducing waste generated by end-of-life electrical and electronic equipment (EEE),
- Improving and maximizing recycling, re-use, and other forms of waste recovery from end-of-life electrical and electronic equipment, and
- Minimizing the environmental impact of their treatment and disposal.

Remanufacturing Product canvas of Xerox				
Key Partners	**Key Activities**	**Value propositions**	**Customer relationships**	**Customer Segments**
Opcos for leasing and maintaining contacts	Product design & development	Low cost, high performance sustainable printer	Product leasing and take-back at EOL	Small & Medium Businesses (SMB)
	Remanufacturing design platform	Mainatainance services & Leasing contracts		Large Businesses/Corporat e
	Reverse logistics trough simple database	Asset Recovery Operation (ARO)		
Key Resouces	**Channels**	**Cost structure**	**Revenue Streams**	**Social & Environmental**
Machines in the field	Direct sales and account management - Dundalk factory channels	Remanufactruing options	Resale of remanufactured & refurbished printers	Reduction in carbon foortprint
Signature Analysis	Indirect channels/distributor s	Machine takeback cost (incl. reverse logistics)		Raw material saving
Stock Planning Database		Sales organization		
Shamrock Phase		Service delivery organization		

Figure 35- Remanufacturing product canvas of Xerox. Source: Author

5.6.2 *Value proposition*

Xerox started an initiative called the Asset recovery operation (ARO) with an aim to first remove all old photocopy machines from the waste stream and second to process them for resale. To encourage return, an incentive scheme was introduced in The Netherlands. This became more popular and successful as the years passed. A report by (King et al., 2007) stated that in 1989, 5% of the scrapped machines were remanufactured and by 1997 this had grown to 75% of the 80,000 copiers returned. This resulted in decrease in the percentage of waste being directed towards landfill as in 1993 it accounted for 41% and by 19995 it had decreased to 21%. Xerox spread its remanufacturing facilities around the globe. By 2001, Xerox had remanufacturing facilities in US, UK, NL, Australis, Mexico, Brazil & Japan (Miemczyk & Campus, 2006).

5.6.3 *Channels*

(King et al., 2007) report shows that the Dundalk factory serves as a supply route for both new and remanufactured products. This has two practical advantages: mixed orders can be easily arranged, and return logistics are seamlessly linked to forward journeys. As a result, there is a significant cost savings (King et al., 2007).

5.6.4 *Key Resources*

Signature Analysis: (King et al., 2007) defines it as an important part of Xerox's diagnostic procedure for determining the condition of a returned product. Several key characteristics are set during the initial design of a component, and then test procedures are developed to allow these characteristics to be assessed when they return. As a result, certain components are specifically designed to allow for testing because they are known to have long-term value. A unique operating "signature" is created, allowing a simple test procedure to determine whether the component is within acceptable tolerance levels for continued use.

Stock Planning Database: Xerox has developed a Stock Planning database, partly through a process of learning over time and partly through design intent, so that exact stock orders of replacement parts can be ordered. This allows suppliers to make a single purchase for both new build and remanufacturing operations, which reduces costs. Furthermore, using direct field maintenance data, the company can determine which components need to be replaced in order to meet the demanding "as new" quality level (King et al., 2007).

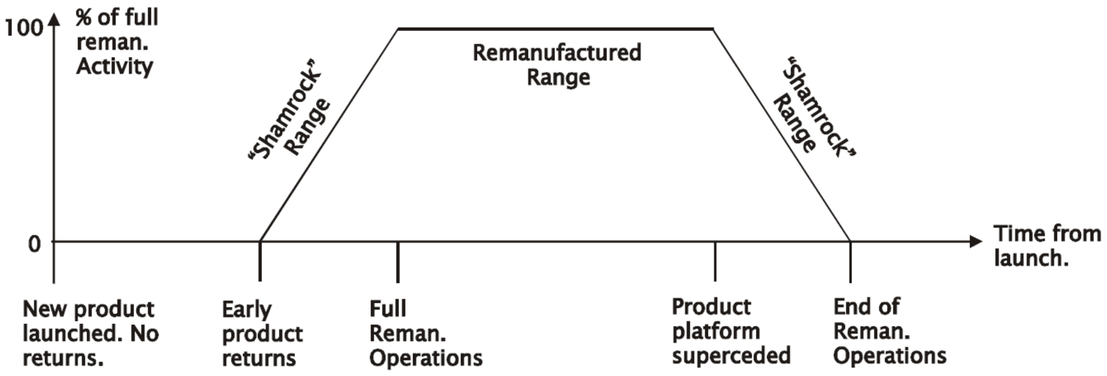


Figure 36 - The Shamrock Phase explained. Source: (King et al., 2007)

Shamrock Phase:
Xerox has developed a well refined launch and closure process for remanufacturing. As mentioned earlier the products have been designed to allow for remanufacturing. The Dundalk site can prepare in advance for new remanufacturing lines. It uses the same assembly lines as the new build as a large percentage of the equipment can be pre-installed to be ready for use. (King et al., 2007) describes the Shamrock operation which entails taking a returned product and repairing and reconditioning it extensively, but not completely remanufacturing it. As a result, the product is clearly sold at a lower quality level, but Xerox learns a lot about the finer disassembly procedures and collects data on component quality. Once enough of these are processed, a full remanufacturing operation is initiated. As the demand for this product declines, only the best Category 2 products are returned. Because it is much more difficult to guarantee "as new" quality after several remanufacturing cycles, Xerox returns the product line to a "Shamrock" operation to meet final demand on a strictly "refurbished" quality level.

5.6.5 Product leasing

Xerox "buys back" products from individual country Operating Companies to ensure a consistent supply of category 2 or 3 products returns to Dundalk. In effect, this is a cash bonus that ensures there is an incentive to withdraw the required assets. According to other research, the availability of "cores" for remanufacture is frequently the second most serious problem after disassembly issues (King et al., 2007).

5.6.6 Key Activities

Reverse logistics
Xerox Operating companies have created a database that is used by TNT to conduct a simple filtering operation. This decides the route the machines should take between Asset Recycling Centre at Mitcheldean for remanufacturing or Covertronic for material recycling. TNT also performs a disablement procedure to ensure that the machines are not accidentally being sent to the market before remanufacturing. (Miemczyk & Campus, 2006)
(King et al., 2007) report describes that in the remanufacturing process at Dundalk except for category 1 machines (immediately sold back by OpCos) all other End of Use (EoU) products are transported to Xerox's Surplus Equipment Warehouse in the Netherlands via a reverse logistics process. To incentivize the OpCos, the Xerox Warehouse "buys back" each product at a predetermined rate based on demand. Staff at the warehouse make an initial assessment of the condition of Docutech products as follows:

- Category 2 – in good condition, suitable for re-entry into Dundalk
- Category 3 – damaged but still fit for return to Dundalk
- In the Netherlands, category 4 waste is written off (as salvage) and recycled.

5.6.7 Remanufacturing facility

As mentioned in the previous section, successful remanufacturing practices made spread its remanufacturing facilities around the globe. Xerox spread its remanufacturing facilities around the globe. By 2001, Xerox had remanufacturing facilities in US, UK, NL, Australis, Mexico, Brazil & Japan. A report by (King et al., 2007) describes the Xerox remanufacturing facilities are in three factories: Mitcheldean (UK), Venray (NL) and Dundalk (IRL).

- A mid-sized multifunction product is fully remanufactured and resold in the European market by Venray. The annual production rate is around 1000 units.
- The Fuser Manufacture Centre at Mitcheldean remanufactures high-value fuser roll components in addition to new production. Separate studies conducted by the authors assessed the environmental impact of this operation and discovered that remanufactured rolls can have as less as 14% of the impact of new construction. Each year, approximately 400,000 units are remanufactured.
- Both large industrial printers (Docutech) and multifunction products are remanufactured in Dundalk. The annual production rate is around 650 units. Additionally, 400 smaller DC12 machines are remanufactured at the Dundalk facility.

(Miemczyk & Campus, 2006) describes that the Mitcheldean Asset Recycling Centre employs 58 people to remanufacture two Xerox photocopier models: the Hodaka and the Silverstone. The entire photocopier is remanufactured in both cases.

5.6.8 Remanufacturing operation

(Miemczyk & Campus, 2006) outlines the remanufacturing operation of a photocopier in 7 different stages:

- Stage 1: Machine receipt
- Stage 2: Parts Disassembly
- Stage 3: Parts Clean & Paint
- Stage 4: Parts Rebuild
- Stage 5: System Integration to Customer Orders (SITCO)
- Stage 6: Final Quality Assurance (FQA)
- Stage 7: Packaging & Shipping

5.6.9 Cost structure

In a report on case study of Xerox (Miemczyk & Campus, 2006) describe a list of criteria that is considered before performing remanufacturing process to decide the feasibility of the operation. They are as follows.

- The revenue generated by remanufacturing parts
- The material value-added components
- The market demand for the parts
- The frequency with which the parts are replaced
- The state of the returned parts

Figure37:Xerox reuses of existing core to create new tops. Source: (Telenko et al., 2016)

5.6.10 The Value Network

Xerox uses remanufactured products to provide customers with a mix product portfolio. As a result, a customer is presented with a mix of new and remanufactured products to suit their specific operating conditions and budget. In this manner, Xerox sells remanufactured products through the same network of sales personnel as new products, with the same incentives, bonuses, and rewards.(King et al., 2007)

Figure 38- Docutech Sub-Assembly | Remanufacturing operations at Xerox. Source: (King et al., 2007)

5.6.11 The Value Network

The main circular business model patterns examined within the case study is the remanufacturing model of Xerox that are operating successfully between three factors Mitcheldean (UK), Venray (NL) and Dundalk (IRL). Additionally, Xerox has made remanufacturing through a mixture of strategic intent and close monitoring.

These are enabled by several circular patterns employed by Xerox

- *Access:* The report by (Miemczyk & Campus, 2006) showed that a large percentage (around 80%) of the machines are leased by Xerox to the customer. As mentioned earlier, it has a reverse logistics process within the Xerox Warehouse "buys back"the machines at a given rate, depending on the demand. This is done to incentivize OpCos. As a result, Xerox stays close to its assets and can make decision at the end of life/contract of the equipment.
- *Performance:* The use of a design platform has allowed Xerox to take into consideration design upgradability as it allows key modules to be replaced without the need to remove other components.
- *Resource Recovery:* The business team that is responsible for a new product, is also responsible for its remanufacture.(King et al., 2007) describes that there exists no "handover" system within xerox, which makes the designers and planners who design new product take full responsibility of its remanufacture.
- *Design for remanufacturing:* (King et al., 2007) describes that one of the most important strategic intent for Xerox was to design for remanufacture. The designs made early during the design process have enabled the disassembly, inspection, and remanufacturing operation to be efficient. The report by (King et al., 2007) also throws light on the Modular Product Architecture and explains that the standardization of parts have allowed for cost savings and made remanufacturing successful.

5.6.11 The SWOT analysis

The above-mentioned strengths, weaknesses, opportunities, and threats and shown in figure are examined in greater detail in the sections that follow. Tabulation of the criteria helped in understanding the strengths and shortcomings with respect to the design on the Business model of Xerox. Furthermore, its similarities and differences with respect to the building industry were also understood and will be explained in the analysis section which will be presented at the end of this chapter.

SWOT Analysis for remanufacturing opertaions at Xerox	
Strengths	Weakness
Strong return loop established for the collection of machines at end of lease or service life	Remanufacturing process is only limited to machines that are originally sold under a rental agreement. constitutes to 80% of total machines in market
Signature Analysis	maintaining a continuous supply of labour to meet the demand of remanufacturing fue to unstable rate of return
Stock Planning database	
Design for disassembly & Modular product architecture	
Oppurtunities	Threats
Establishment of remanfacturing design platforms can enable the process	Regulations by WEEE and other legislation bodies affect remanufacturing process
Shamrock phase enables Xerox to be ready for remanufacturing of new machines	Highly competitive, declining market –price erosion of new machines

Figure 39- SWOT Analysis of Xerox. Source: Author

5.7 Caterpillar

5.7.1 Introduction

Caterpillar is the world's leading manufacturer of construction, and mining equipment. Along with diesel and natural gas engines, it manufactures industrial gas turbines and diesel-electric locomotives (caterpillar.com). Caterpillar manufactures heavy machinery and develops practices that allow for greater value recovery during the remanufacturing process. The company has been able to increase profit margins while still producing high-quality components. Rather than aiming to use less material, consideration is given to designing a product that will be remanufactured several times (Design and Business Model for Heavy Machinery Remanufacturing, n.d.).

In 1973 Caterpillar began remanufacturing their engines and components and in 1998 they purchased Perkins Engines Ltd, UK. Caterpillar were able to enter the European market and with the purchase of an existing plant, they were able to offer their European Customers (Gray & Charter, n.d.)

- Reduce the transportation costs
- Improve their response time significantly
- Allows for more customized products to meet the needs of regional customers

Over the years, Caterpillar has grown to locate its remanufacturing facilities in 9 locations across the globe. A study by (Sakao et al., 2010) records that in 2005, the global remanufacturing operation by CAT reused 43 million tons of core material. By choosing to remanufacture over recycling, CAT has prevented 52 million tonnes of Co2E from entering the atmosphere. Every remanufactured product that leaves the factory has been examined through a stringent quality test procedure, and in most cases, it passes along the same production line as that of a new product.

5.7.2 Key activities

Keeping hold of the core

Caterpillar employs a unique method to stay close to its assets and guarantee collection of cores at its end of life. During the purchase of a remanufactured part, CAT delivers it in a reusable container for which the customer pays a deposit. The customer is expected to use the container while returning a part to CAT. This ensures undamaged delivery of core. When the core reaches CAT, this deposit is reimbursed. A report by (Sakao et al., 2010) says that this system has helped reduce wooden packaging waste by 70% in Shrewsbury, UK which is their European Centre for excellence for Europe, Africa and the Middle East.

Process Simplification

The remanufacturing operations in Shrewsbury as studied by (Sakao et al., 2010) say that they use patented processes, procedures and tools to dismantle, modify and reassemble products. This gives an opportunity to remanufacture a variety of components. Highly skilled workforce can be remanufactured at a single site without creating more remanufacturing lines. This way the remanufactured component leaves the site "better than new" and incorporates latest design features available for the original specifications of the same product.

Product canvas - Remanufacturing at Caterpillar				
Key Partners	**Key Activities**	**Value propositions**	**Customer relationships**	**Customer Segments**
	Product design & development	High quality CAT remanufactured machines	Deposit based model of core collection	Construction and automobile heavy machinery equipment
	Reverse logistics trough simple database	Mainatainance services & Leasing contracts		
Key Resouces	**Channels**	**Cost structure**	**Revenue Streams**	**Social & Environmental**
Core deposit	Direct sales and account management with customer	Remanufactruing options	Resale of remanufactured parts and equipments	Reduction in carbon fortprint
		Machine takeback cost (incl. reverse logistics)		Raw material saving
		Sales organization		
		Service delivery organization		

Figure 40 - Remanufacturing product Canvas of Caterpillar. Source: Author

5.7.3 SWOT Analysis

The above-mentioned strengths, weaknesses, opportunities, and threats and shown in figure are examined in greater detail in the sections that follow. Tabulation of the criteria helped in understanding the strengths and shortcomings with respect to the design on the Business model of Caterpillar. Furthermore, its similarities and differences with respect to the building industry were also understood and will be explained in the analysis section which will be presented at the end of this chapter.

SWOT Analysis for remanufacturing process at Caterpillar	
Strengths	Weakness
Core deposit method	Evolution rate and change in technology
Demand for remanufactured equipment	Ensuring return of core at EOL
Strong technical competence and high quality of remanufacturing	
Design for disassembly & upgradability	
Oppurtunities	Threats
Developing new technology & methods for improved material recovery	Regulations by Government bodies affect remanufacturing process
Creation of a brand value	

Figure 41 - SWOT Analysis of Caterpillar. Source: Author

5.8 *Inference from case studies*

By studying the key problems and solutions of each case study, a few patterns were observed. They all shared many similarities and differences. The general observations that can be summarized from all the tables are.

- All the products studied indicated the presence of a core, which was designed to be returned at EoL and supported by a business model
- Innovative incentives were crafted to persuade consumers to return the core at Eol
- In the case of Xerox, Canon remanufacturing was driven by Legislation implemented by Governmental bodies.

Key Problems and Solutions analysed for the case study of Caterpillar				
Company	Key Challenges	Solutions	Valuable criteria that arise	Authors
Caterpillar	To make sure that core is returned to CAT rather than rebuilt by 3rd parties, who will not access to the full technical data and test procedures	The core desposit is set above the market price for the used part so that the customer has an incentive to return the core to CAT, only CAT remanufactured parts will carry a full warranty and give the customer guaranteed reliability & performance	Method of core collection	(Caterpillar Inc. | Extending Product Life, n.d.) (Gray & Charter, n.d.)
	How to gather together sufficient core when a new product is introduced?	CAT will offer customers new equipment at remanufactured process in exchange for used core.	Reverse logistics	(Caterpillar Inc. | Extending Product Life, n.d.) (Gray & Charter, n.d.)
	How to persuade customers that a remanufactured product is as good as new?	The "as new" warranty reassures customers that they will be buying a quality product with excellent after sales support should they need it. Strict quality procedures ensure that the customers experience is trouble free, building trust and confidence in remanufactured products.	Creating brand value	(Caterpillar Inc. | Extending Product Life, n.d.) (Gray & Charter, n.d.)
	How to find new ways of salvaging more components?	CAT is constantly developing new technology and methods of materials recovery and will continue to do so.	Design for remanufacturing	(Caterpillar Inc. | Extending Product Life, n.d.) (Gray & Charter, n.d.)

Key Problems and Solutions analysed for the case study of Canon				
Company	Key Challenges	Solutions	Valuable criteria that arise	Authors
Canon	The technology of printers and copiers is mature and well-established. The majority of product innovation is now taking place in areas such as user interface and software applications (for example integrating document scanning with end-user desktop software).	Machines in Field (MIF) refers to all Canon printers that are currently in use by customers. Canon EMEA's recurring revenue (services and consumables) is driven by this. MIF is an important resource for Canon EMEA's circular business model because it brings in equipment that can be remanufactured or refurbished for resale.	Machines In Field	(Mfps, n.d.) (Why We Remanufacture - Canon Europe, n. d.) (Kathiravale & Muhd Yunus, 2008)
	With changing work patterns, flexible and versatile print solutions are required. Customers want print solutions that support flexible/multi-site work, co-working spaces, and mobile workers. Customers are also looking for end-to-end,'managed,' flexible, and secure solutions.	Customers can outsource print management to Canon EMEA via Managed Print Service (MPS). Canon EMEA examines printing habits and customer requirements to determine the most cost-effective solution. Canon EMEA recommends the best equipment, feature configuration, and setup, as well as working with the customer to establish performance metrics.	Managed Print Service, integration of a digital platform, role of ICT	(Mfps, n.d.) (Why We Remanufacture - Canon Europe, n. d.) (Kathiravale & Muhd Yunus, 2008)
	How to generate revenue from the remanufacturing channels?	Canon EMEA provides office machine consumables to customers (directly or through resellers). These include toner cartridges and paper, and they are a significant source of revenue and profit over the life of a unit. As a result, the installed base (or Machines In Field, MIF) of Canon printers generates recurring revenue from consumables.	Revenue Streams - remanufacturing	(Mfps, n.d.) (Why We Remanufacture - Canon Europe, n. d.) (Kathiravale & Muhd Yunus, 2008)
	How to increase demand for remanufactured products?	Business segments are typically the primary market for remanufactured units sold under the "EQ80" brand. Remanufactured units are sold in "as new" condition and can be incorporated into a sales transaction in a way that meets customer specifications while lowering the price due to their lower cost.	Creating brand value	(Mfps, n.d.) (Why We Remanufacture - Canon Europe, n. d.) (Kathiravale & Muhd Yunus, 2008)

Key Problems and Solutions analysed for the case study of Davies Furniture				
Company	Key Challenges	Solutions	Valuable criteria that arise	Authors
Davies Furniture	Market preferences change rapidly, the original style and/or function of EOL office furniture may be obsolete, and thus non-competitive at the time of reman	Challenged to create products that are better than their as-manufactured condition to achieve fitness for the current market.	Adaptive remanufacturing/indexing	(Krystofik et al., 2018) (Remanufactured Office Furniture | Davies Office, n.d.)
	third party remanufacturers cannot exist without OEM producing products from valuable material	a remanufacturing-focused business model must aim at a cost-minimizing co-ordination of EOL product collection and remanufacturing activities. Thus transforming products designated as waste to valuable products.	Reverse Logistics and method of core collection and closed loop supply chain and upgrade potential	(Krystofik et al., 2018) (Remanufactured Office Furniture | Davies Office, n.d.)
	Non OEM unlike OEM dont have the oppurtunity to consider scenarios of stable design or dictate or anticipate changes in design	Third party remanufacturer must develop products that are 'better' than their as-manufactured condition to maintain economic viability and achieve fitness in the market	Market adaptability & upgrade potential	(Krystofik et al., 2018) (Remanufactured Office Furniture | Davies Office, n.d.)
	remanufacturing is a good product life extension strategy that can be employed to durable products. However, as the market preferences change, they tend to become obsolete even if they can be economically remanuafctured	Adaptive remanufacturing enables designers to update, reconfigure, customize previously obsolete products to meet the new market requirements. This allows remanufacturers to utilize the embodied value of a product until loss of material intergrity that can affect the economic viability of a reman operation.	Adaptive remanufacturing/indexing	(Krystofik et al., 2018) (Remanufactured Office Furniture | Davies Office, n.d.)
	Sustainable remanufacturing requires a reverse supply of remanufactured products, where there is uncertainity in the product supply stream ,with respect to high variability in product type and condition. This is important in terms of material and product intensities.	Adaptive remanufacturing enables creation of new product types from a given core family. This allows remanufacturers to diversify their product offerings and provides insulation against supply chain uncertainty.	Multiple remanufacturing cycles - Design for remanufacturing - detailed Product design	(Krystofik et al., 2018) (Remanufactured Office Furniture | Davies Office, n.d.)

Figure 42 - Key challenges and solution tabulated from Caterpillar, Canon, and Davies Furniture Source: Author

- Davies furniture followed a complete loop, by sourcing EoL furniture, which was otherwise considered as waste to make meaningful products.
- In case of Canon and Xerox, the innovation in terms of product design had reached a plateau, and the focus was shifted towards implementing software solutions and improving the products to be returned and make reman process profitable.

Key Problems and Solutions analysed for the case study of Davies Furniture				
Company	Key Challenges	Solutions	Valuable criteria that arise	Authors
Xerox	The rate of technological changes is increasing and to meet the market demands, Xerox has released new models of digital photocopiers in the market.	Xerox is making a policy shift from remanufactauring entire units to reman of subassemblies.	Evolution -Technological rate	(King et al., 2007)(Miemczyk & Campus, 2006)
	How to increase demand for remanufactured products?	Xerox uses remanufactured products to create a mix portfolio i.e a mix of new and remanufactured products to suit the operariong conditions and budget for its customers. It sells the remanufactured products with the same bonuses, rewards and incentives as new products.	Value proposition & creating brand value	(King et al., 2007)(Miemczyk & Campus, 2006)
	How to realize cost savings from remaufacturing of a product, for a company?	Xerox's manin design strategy is the use of Modular product Architecture - platform design. The standardization of parts helps achieve cost savings.	Design for remanufacturing - Modular Design - Platform Design	(King et al., 2007)(Miemczyk & Campus, 2006)
	How to ensure collection of cores at EOL of a product?	Xerox "buys back" products from individual OpCons. This serves as a cash bonus and an incentive that is in place to pull back important assets	Reverse Logistics, method of core collection-Product leasing	(King et al., 2007)(Miemczyk & Campus, 2006)
	How to ensure availability of spare parts for remanufacturing?	Xerox has developed a Stock Planning database so exact orders of replacement parts can be placed. This allows the company to determine which components need replacement in order to satisfy the demand of "as new" quality level	Stock Planning Database	(King et al., 2007)(Miemczyk & Campus, 2006)
	How to easily enable remanufacturing a product?	Creation of a remanufacturing design platform which is a strategic architecture of components that forms a platform of components with dedicated values remanufactured for multiple lives into which a series of high ebergy using components are added.	Remanufacturing Design Platform	(King et al., 2007)(Miemczyk & Campus, 2006)
	What is the effect of Rules and regulations on remanufacturing?	Xerox's environmental policies put them ahead of rules and regulations and turned remanufacturing into a profitable business and ensured resouce recovery and material efficiency. However, at present Xerox faces a number of policy issues including supply instability and implications of environmental legislation on material and part markets and terms need to become more efficient.	Evolution rate-Legislation, Supply & Reverse Logistics	(King et al., 2007)(Miemczyk & Campus, 2006)

Key Problems and Solutions analysed for the case study of Philips MRI Systems				
Company	Key Challenges	Solutions	Valuable criteria that arise	Authors
Philips	Healthcare services are always under the pressure to do more with less, some of them continue to use the MR equipment for over 15 years. In this case, adadpting to the customer needs is becoming a challenge.	This is relevant for solutions that enable Healthcare facilities to continously enhance and upgrade their machines thereby maximising value from existing assets which is consistent with Philips SmartPath offering	A contemporary policy like SmartPath	(Philips Achieva 1.5T MRI - Medical Outfitters, n.d.) (Smartpath | Philips Healthcare, n.d.)(Economy & Model, 2020)
	The innovations in MRI are moving from improving magnets to software developments for increasing imaging quality and connection to everything on a single platform	Introduction of a decision-support platform - once a machine has been installed the sales team is able to suggest relevant upgrades and developments to customers, and offer incentives and propose early turn-in machines for a new MRI system	Integration of digital platforms, role of ICT	(Philips Achieva 1.5T MRI - Medical Outfitters, n.d.) (Smartpath | Philips Healthcare, n.d.)(Economy & Model, 2020)
	How to increase demand for remanufactured products?	The "Diamond Select" proposition, which applies to all Philips refurbished systems, is well-known in the market, and customers understand what they are getting in terms of quality. This also allows sales teams to better understand and communicate the proposition.	Creating brand value	(Philips Achieva 1.5T MRI - Medical Outfitters, n.d.) (Smartpath | Philips Healthcare, n.d.)(Economy & Model, 2020)
	Keeping products and materials at their highest value as long as possible. It was a complex challenge in the past to determine the right offering of options and upgrades for a customer	encompassibg Optimise, Enhance, Transform and Trade-in options to the customer by continous montioring through use of ICT platforms	Role of ICT and introduction of a contemporary policy like SmartPath	(Philips Achieva 1.5T MRI - Medical Outfitters, n.d.) (Smartpath | Philips Healthcare, n.d.)(Economy & Model, 2020)
	How to enable future-proofing to enhance the value proposition?	Philips designs the whole life cycle while designing a new product. This enables future-prrofing and enhances the customer value proposition. Digitisation is a key component of upgradebility, where capabilities can be improved in the future through software updates and additional clinical software application	Role of digitisation and design for remanufacturing - design for upgradability	(Philips Achieva 1.5T MRI - Medical Outfitters, n.d.) (Smartpath | Philips Healthcare, n.d.)(Economy & Model, 2020)

Figure 43-Key challenges and solution tabulated from Xerox and Philips. Source: Author

5.9 Summary

1. The process of remanufacturing is a ***combination*** of ***product design*** and a business model and strategies crafted to support it
2. The Rules and Regulations implemented by Governmental organizations played a key role in motivating and shaping the reman planning
3. The sale of products as a service (P.S.S) over granting ownership is advantageous. However, it ***shifts immense amount of new responsibility*** which was initially considered to be the consumers. This also assisted in the process of collection of cores, without which reman ceases to exist.
4. The ***cost structure plays an important role in determining the feasibility*** of the reman process. In case of Canon, new revenue streams through the sale of consumables were initiated to support reman process. While on the other hand, Xerox struggled with maintaining labour for reman, due to a lack of stability in the return flow of products
5. The ***creation of incentives*** and policies was key in persuading consumers to return the core at a product's EoL
6. The ***role of ICT and Customer support*** was found to be important for a company to in ***stay close to the assets and assist the sales and accounts*** team to provide upgrades and ensure return of products before or at EoL.

06 Digitalization in Circular Economy

The chapter presents an overview of potential of advanced workflows in assisting the transition to circular economy

6. Digitalization in Circular Economy

6.1 Introduction

The case studies discussed in the previous chapter also highlight that the building industry in lagging in areas of implementation of digitalization in comparison to the other industries. Several Authors believe that the industry is aware that there is no alternative to Digitalisation and therefore the challenge lies in its implementation. (Heinrich & Lang, 2019)

It can be said that the innovation and evolution in information technology opens large opportunities for the implementation of tools for a circular economy. Building products are very complex products. The increasing complexity of building products require the automation and implementation of data standards as a pre-requisite rather than an addition. This can also result in the profits in supply chain.

6.2 Application of digital technologies

The Author discusses the key technologies that are grouped into three architectural layers by (Pagoropoulos et al., 2017) as Data collection, Data integration and Data Analysis. The figure explains what each of these layer's entail. They will be briefly discussed in the sections below:

- *Data Collection*

a. *Radio Frequency Identification (RFID):* A data collection technology has received much interest in the context of the circular economy. It uses electromagnetic fields to identify and track tags attached to the object. It has helped track material flows to enable value recovery through the implementation of strategies such as reuse, recycle, repair and remanufacture. (Pagoropoulos et al., 2017), (Govindan et al., 2015) argue that implementation of IT together with RFID can assist is transition to closed-loop systems. RFID systems can connect all products tagged with RFID chips to a network to provide regular information about the product's lifecycle to partners involved in the project.

b. Internet of Things (IoT): Sensors, actuators connected by networks to computing systems to monitor or manage health across systems together can be defined as IoT. It can collect information from sensors to connect stakeholders across the value chain.

- *Data integration*

a. Relational Database Management Systems: refer to systems concerned with data organization in formally described tables They enable the integration of heterogeneous data sources by specifying a data architecture to support the information architecture's analytical requirements. As they integrate the wealth of information produced by heterogeneous data collection systems such as IoT, ERP, and CRM systems, data handling systems help to achieve the goals of the Circular Economy (Pagoropoulos et al., 2017).

b. Product Lifecycle Management systems: They are information management systems that can integrate data, processes, business systems, and, eventually, people in a large enterprise. PLM systems aid in the transition to the Circular Economy by integrating information across multiple life cycles and stakeholders in the value chain. Authors like Lieder, Rashid (2016) emphasize the importance of PLM systems at the company level because they allow for the monitoring of products and parts across multiple lifecycles.

The authors argue for a product passport to be defined as "a set of information about the components and materials that a product contains, and how they can be disassembled and recycled at the end of the product's useful life." PLM systems can enable near-real-time consumption and the optimization of stock and material flows. This is helpful in implementation of strategies of circular economy.

- ***Data Analysis***

Machine learning is a practice that relies on algorithms to learn from data rather than rules-based programming. Also known as Artificial Intelligence (AI), this is the application of machine learning algorithms such as Neural Networks that rely on mass data processing rather than a complex set of rules to identify patterns in data and make predictions (Pagoropoulos et al., 2017). In the context of the Circular Economy, machine learning can be used to support process and system optimization based on massive amounts of data. The author provides a brief explanation but does not indulge into Data Analysis as it is beyond the scope of the project.

6.3 Materials Passports

As defined by (Bokkinga, 2018), " a material passport od a digital model, a database with valuable information on all the materials, elements and components present in the building" This is valuable information because it contains data relevant to circular economy. For example, it contains the information to define the value of recovery of a certain product. This data is entered into and extracted from of reports customized to the needs of diverse users.
The material passport's range is classified into separate hierarchy levels. These include the materials, components, products, and systems that go into constructing a structure. For instance, a material passport has the potential to define the value of a certain material for its recovery. A product passport does the same by defining characteristics that promote its recovery (Heinrich & Lang, 2019).

Through literature study it was observed that several authors believe that materials passports have the potential to promote and influence circular product design, material recovery and easy transfer of information between all stakeholders. In the future, they will play a major role in facilitating reverse logistics, enable recovery of products, materials, and components. They will also play a role in the assessment of flows, especially regarding critical materials. They also have the power to guide the implementation of circular strategies by eliminating waste and reduce the use of virgin resources.

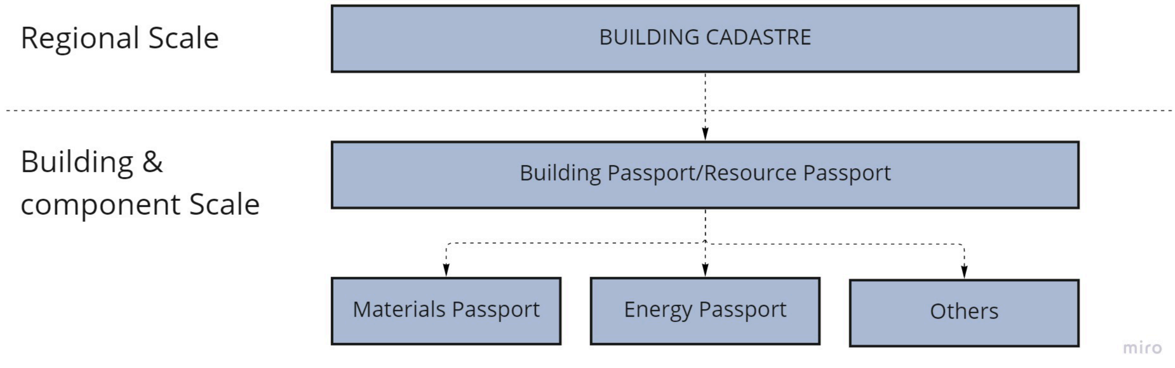


Figure 44 - Flowchart showing the hierarchical classification of materials passports from a regional to building scale. Source: (Barker & King, 2006)

6.6 Exploring the potential of Digitalization

The previous sections of this chapter highlighted the advantages of adopting digital workflows. This section is dedicated to match the current barriers to remanufacturing to the solutions to them through adoption of digital workflows. The Author has made these connections very briefly and at a conceptual level. However, the study was conducted with a note that adoption of workflows will enable efficient transfer of data and therefore assist in transition to a circular built environment.

The first barrier to remanufacturing that was observed in case of building products was the lack of product data. This information can be stored as materials passport and integrated in BIM models (digital twins). This is important information during remanufacturing process. The availability of product data, packaging and handling instructions allow easier remanufacturing process. During phase 1: Desk research, laser scanning, point clouds can be employed to collect material information from existing buildings. The figure 48, 49 explain this concept in a flowchart

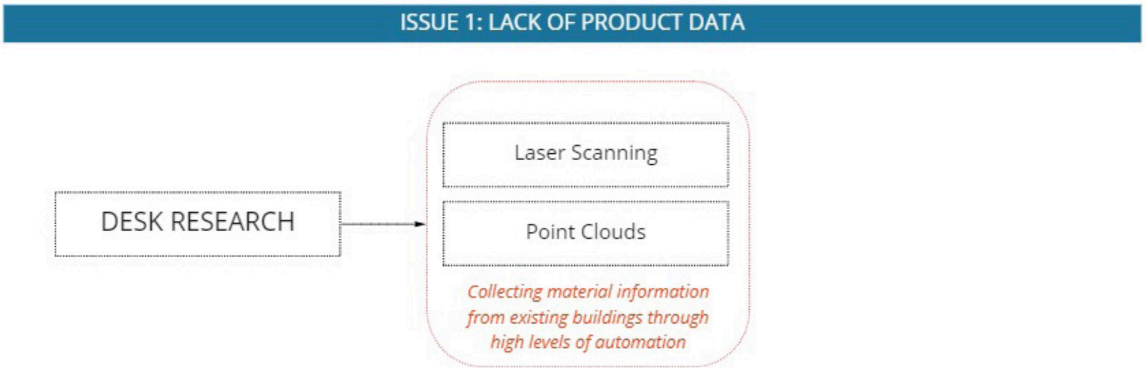


Figure 48- Describing the potential of Digitalisation in assisting desk research that is done to gather data of an EoL facade in a building. Source: Author

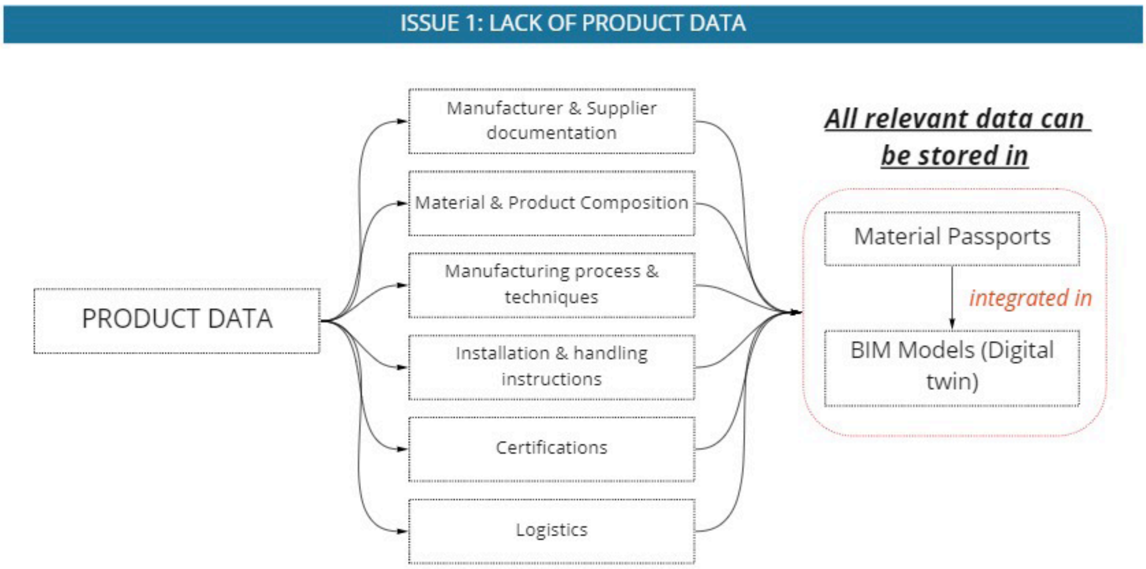


Figure 49- Describes the different levels of product data that are important to guide the reman process. Source: Author

The second barrier that was observed in the Phase 1 was collection of information from existing buildings during on-site assessment. This process when done manually may contain imprecision and inaccuracies. Augmented reality (AR) can be employed to collect information from existing buildings and avoid errors and inaccuracies that may arise during manual inspection and assessment. This is explained in figure 50 as a flowchart.

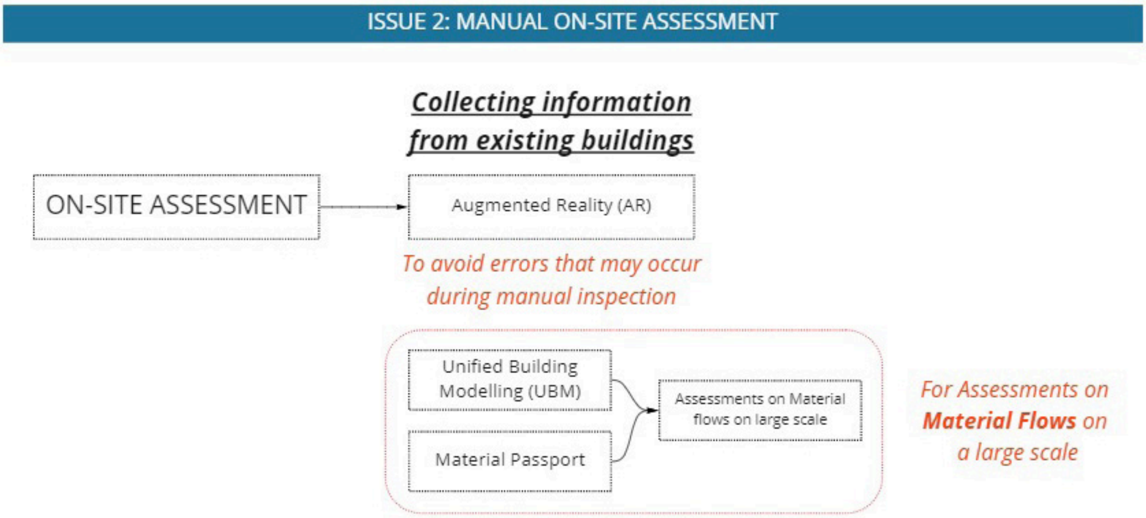


Figure 50 - Describing the potential of Augmented Reality (AR) in assisting on-site assessment. Source: Author

The third barrier is similar to the second in terms of collecting data from existing buildings. The second approach to collection of information from existing buildings is by employing Artificial intelligence (AI). For instance, AI can be used to gather dimensions from a façade through an automated scan. This is explained in figure 51.

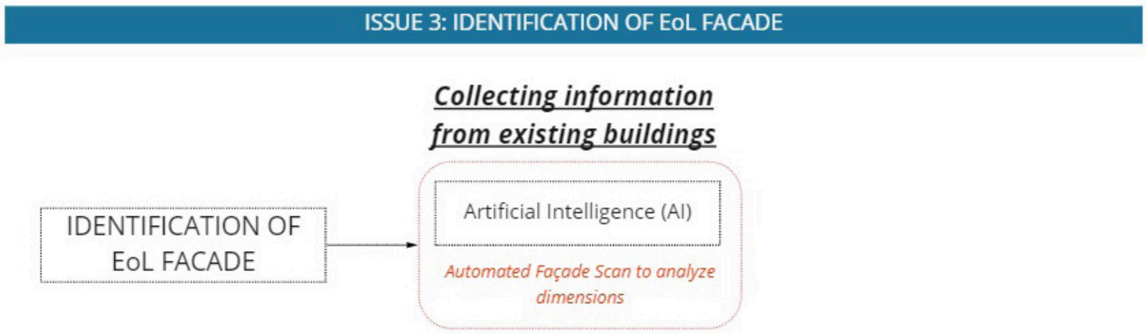


Figure 51- Describing the potential of using AI to identify and collect information from an EoL façade. Source: Author

The fourth barrier with respect to remanufacturing is the lack of information on packaging & handling, disassembly, or remanufacturing of a product. In general, the design of most building products is centred around single use. The integration of a "reman product profile" as a subset of information in materials passport makes all the product data important for remanufacturing available to a stakeholder who is responsible for this process. This section is elaborated in the future sections of the report.The figure 51, 52 are flowcharts that shows the overall concept of a remanufacturing product profile.

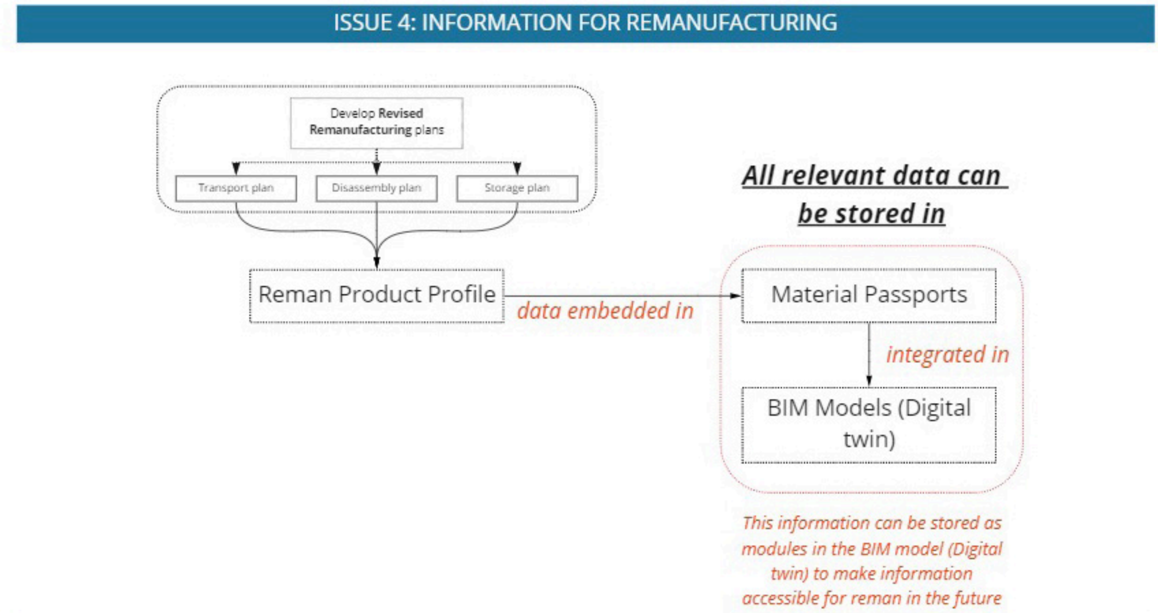


Figure 52-Describing the potential of storing all the relevant product data for remanufacturing. Source: Author

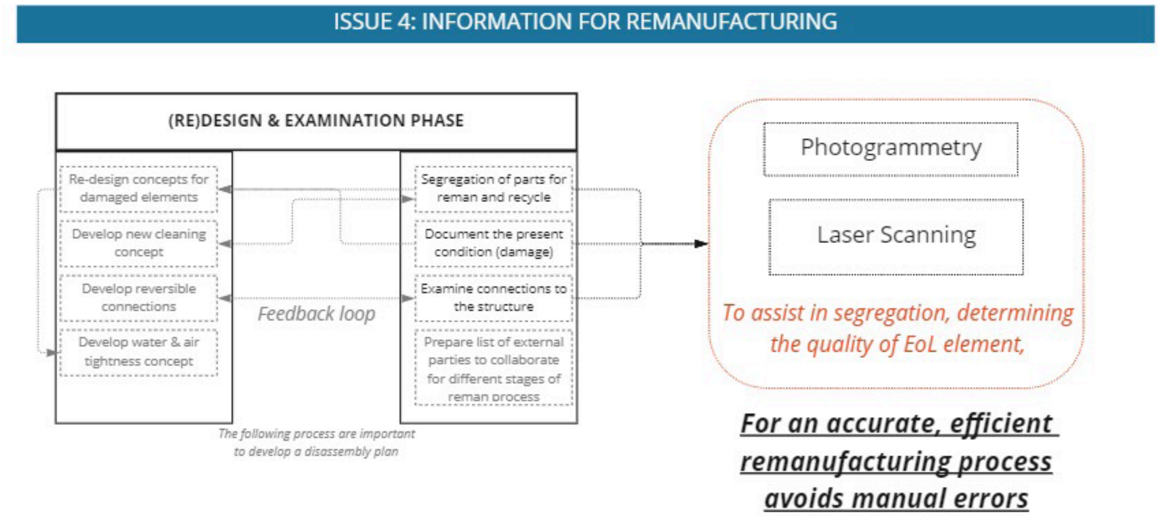


Figure 53-Describing the potential of digitalisation to avoid errors and allow for an efficient reman process. Source: Author

The second sub barrier that is related to this is the monitoring the company assets throughout a products life cycle. The use of RFID tracking when implemented can assist in monitoring and most importantly also record the number of cycles a product has gone through. This also gives the companies a chance to intervene in various stages and generate revenue. For example, in case of façade industry monitoring a product and surface treatment when required become new ways of generating revenue. The figure 54 elaborates this as a flowchart.

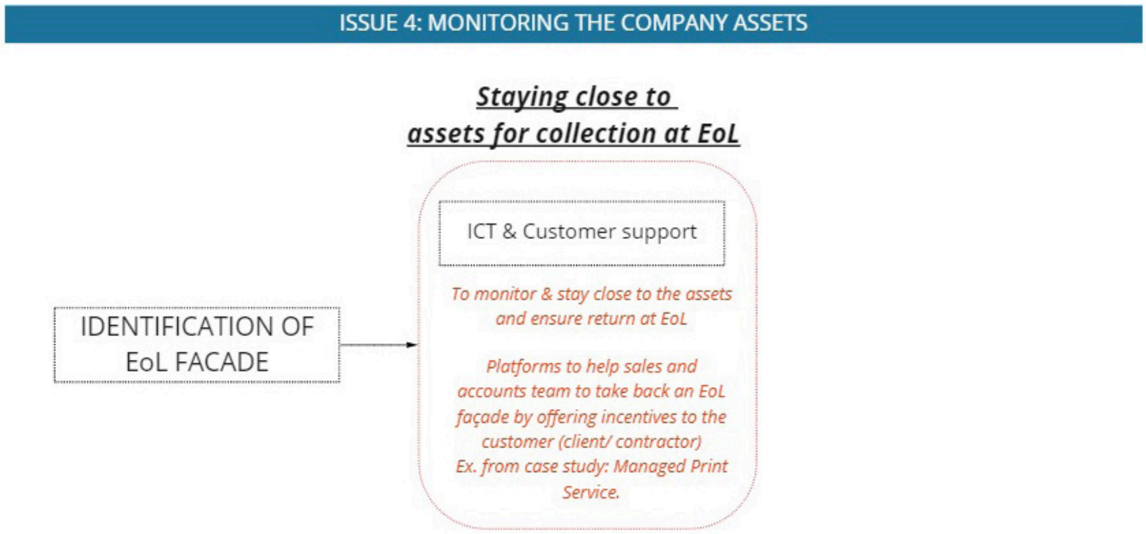


Figure 54- Employing ICT and Customer support services to monitor and stay close to assets. Source: Author

The third sub barrier in the topic of monitoring the company assets is the identification of EoL components to take back at EoL. By supporting the sales and accounts team with digital workflows, they can efficiently track and monitor the product. This also helps persuade customers to return a particular product at or before EoL. Various examples of workflows adopted to support the sales and account managers was recorded in the case studies. The building industry due to its complex and fragmented nature, is slow at accepting new workflows. The figure 55 explains the concept in the form of a flowchart.

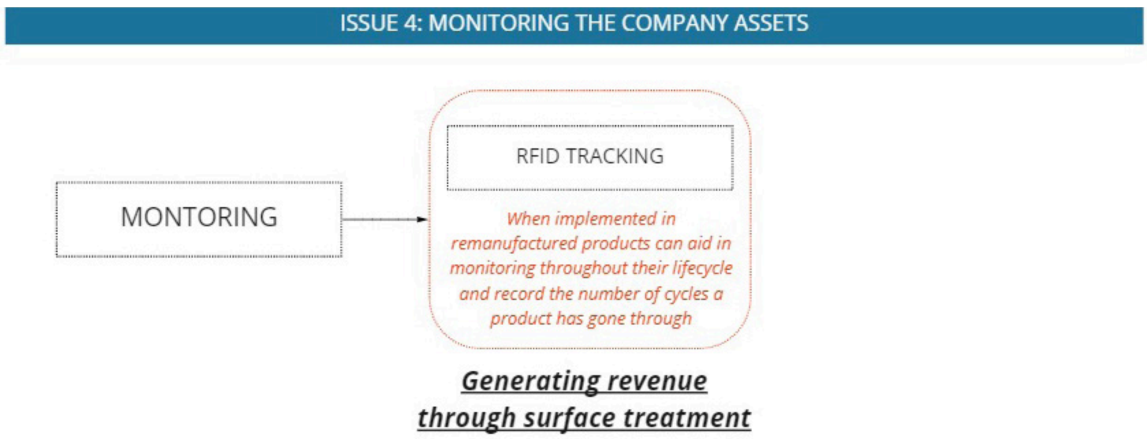


Figure 55-Describing the potential of employing RFID tracking methods to monitor the company's assets. Source: Author

The fifth barrier in a remanufacturing process is the quality assessments. To develop a good business case and prove the economical viability of a project, it is important to arrive at an expected quality after disassembly. In large scale projects, the preliminary assessments are a challenge. By adopting laser scanning and photogrammetry, the assessment and inspection processes can be held efficiently. The figure 56 explains the concept in the form of a flowchart.

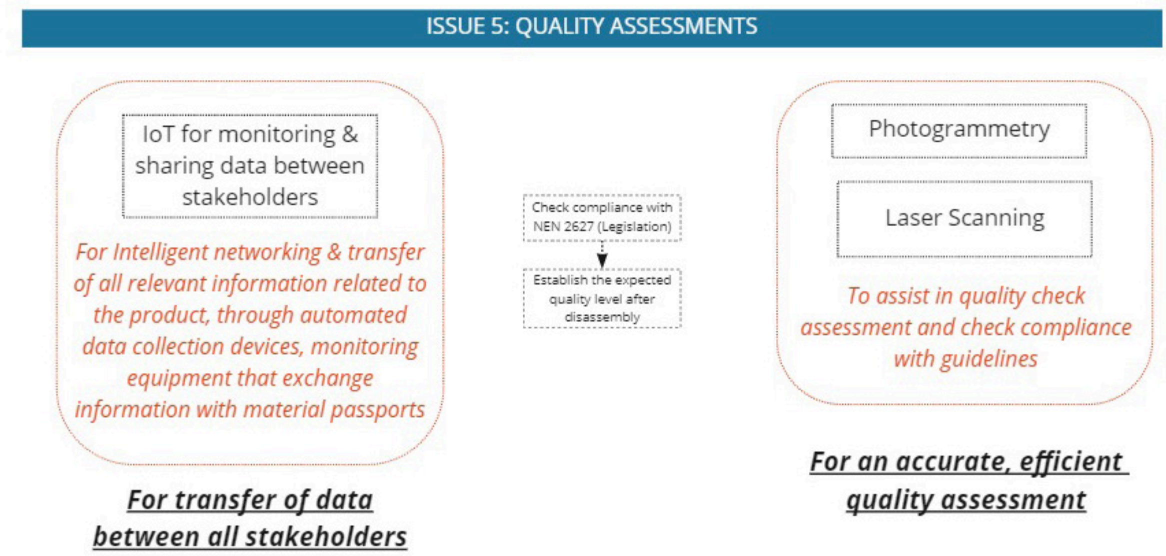


Figure 56-Introducing computational workflows for transfer of data between all the stakeholders. Source: Author

The last barrier that can also be seen as a growth opportunity is with creating a demand for remanufactured products. It was also observed in case studies that different companies advertised and established a brand value for their remanufactured products. This is an important aspect of consumer awareness. By creating a brand value, the customers are aware of the quality of remanufactured product. This plays a role in creating demand for it. The figure 56 explains the concept in the form of a flowchart.

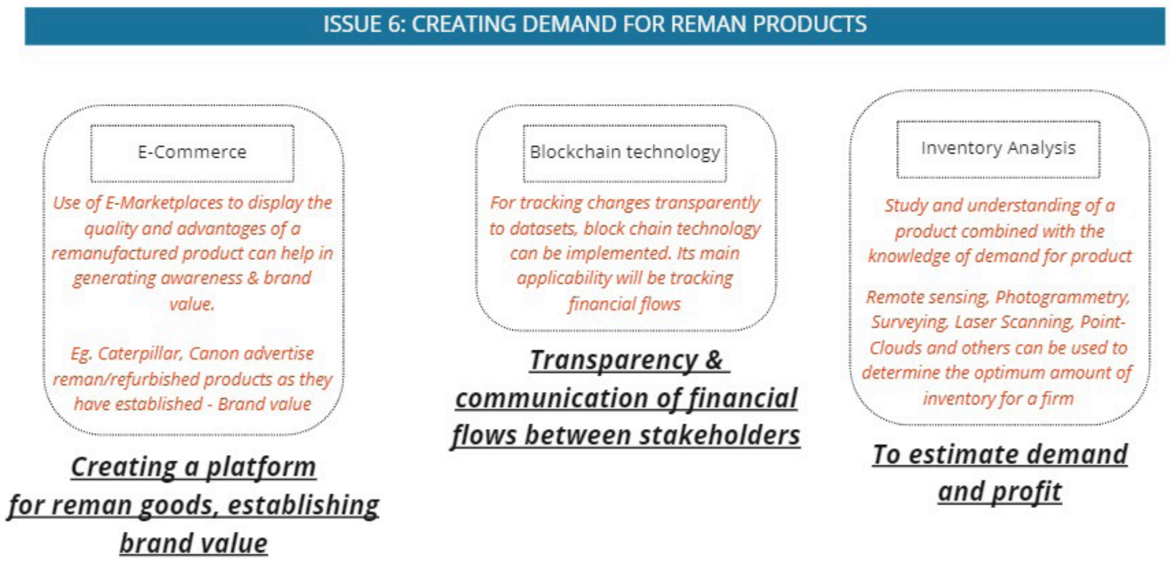


Figure 56-Introducing computational workflows for transfer of data between all the stakeholders. Source: Author

6.7 *Metrics to assess remanufacturability*

As a continuation of the work on Boothroyd and Dewhurst on effective metrics for Design for Assembly. The Authors (Bras & Hammond, 1996) took this further to establish the remanufacturability metric for the following categories

- Cleaning
- Damage correction (includes repair, refurbishment, and replacement metrics)
- Quality Assurance (includes testing and inspection metrics)
- Part interfacing (includes assembly and disassembly metrics)

Theoretically the ideal number of parts is established and each of the part is allotted 3 seconds each for assembly. The figure 56 shows the important concepts. The column -metric denote the key criteria that need to be measured to obtain a remanufacturability (Bras & Hammond, 1996). A category is further defined as a grouping of closely related inter-dependent metrics. Indices represent numerical value that are obtained as a result of substitution of formulas.

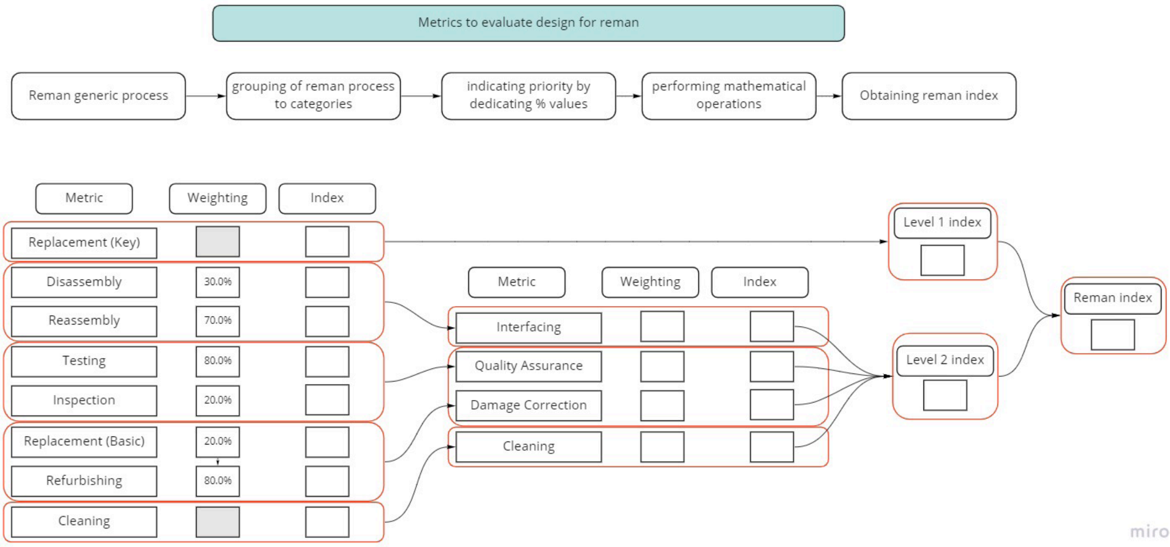


Figure 57- Structure for assessing the remanufacturability. Source: (Bras & Hammond, 1996)

The figure 57 represents the structure of calculating the reman index. The reman index can be defined as the weighted value thay denoted the remanufacturability of the product (Bras & Hammond, 1996). The nect step is so set a weight, and this is as a method of prioritization matrix legend shown in gigure 58. The values obtain from the matrix are entered nto the weighting colum and the indices are calcualted using the formaulas. There is a formula established for each step of remanufacturing. The Formulae mentioned here correspond to each step of reman and help understand the performance of design of product with respect to every stage of remanufacturing.

Prioritization Matrix Legend

5	(row) requires much more investment than (column)
3	(row) requires more investment than (column)
1	(row) requires the same investment as (column)
1/3	(row) requires less investment than (column)
1/5	(row) requires much less investment than (column)

	blown	abraded	baked	washed	Score	Relative Importance	Approximate Cleaning Score	Usable Cleaning Score
blown	1.0	0.3	0.2	0.2	1.7	7%	1.00	1
abraded	3.0	1.0	0.3	0.3	4.7	18%	2.69	3
baked	5.0	3.0	1.0	1.0	10.0	38%	5.77	6
washed	5.0	3.0	1.0	1.0	10.0	38%	5.77	6
					26.4	100%	15.23	

Figure 58- shows the prioritization legend matrix, which is an important step in calculation of reman index. Source: (Bras & Hammond, 1996)

$$\mu_{Disassembly} = \left(\frac{(\#\ Ideal)(1.5\ sec)}{(Time_D)} \right)$$

$$\mu_{Assembly} = \left(\frac{(\#\ Ideal)(3\ sec)}{(Time_A)} \right)$$

$$\mu_{Inspection} = \frac{(\#\ Ideal\ Inspections)}{(\#\ Parts\ -\ \#Repl)}$$

$$\mu_{Testing} = \frac{(\#\ Tests)(10\ sec)}{(Time_T)}$$

$$\mu_{Cleaning} = \frac{(\#\ Ideal)(1)}{(Cleaning\ Score)}$$

$$\mu_{Refurbish} = \left(1 - \frac{(\#\ Refurb)}{(\#\ Parts)} \right)$$

$$\mu_{KeyRepl} = \left(1 - \frac{(\#\ Key\ Replaced)}{(\#\ Key)} \right)$$

$$\mu_{BasicRepl} = \left(1 - \frac{(\#Repl\ -\ \#Key\ Repl)}{(\#\ Parts)} \right)$$

Figure 59 - Overview of all the formulae corresponding to each step of reman. They are important to calculate the reman index.

6.4 Remanufacturing product platforms

Authors Barker and Andrew believe that for a Product service system (P.S.S) to succeed the products must be designed to facilitate disassembly and inspection. Therefore, by adapting a remanufacturing product platform, the single life components can be separated from multiple life components. The figure 45 shows the logic of the platform.

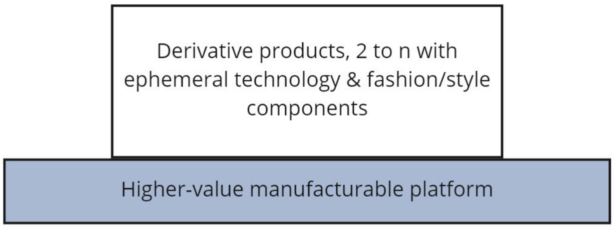


Figure 45 - The remanufacturing design platform concept. Source: (Barker & King, 2006)

The concept of platform design as described by authors (Barker & King, 2006) is "an approach to design where a base platform is designed such that it can be used as the basis for a family of derivative products. From the study and evaluation of Xerox's operations, authors (King et al., 2007) & (Miemczyk & Campus, 2006) conclude that the single most efficient way of enabling products to be remanufactured is through design of remanufacturing design platforms. The authors define it as "a strategic architecture of components that forms a platform of remanufactured components for multiple lives onto which a series of ephemeral or high energy using components are added" They suggest that the platforms should integrate assessments of remanufacturing with future life efficiency.

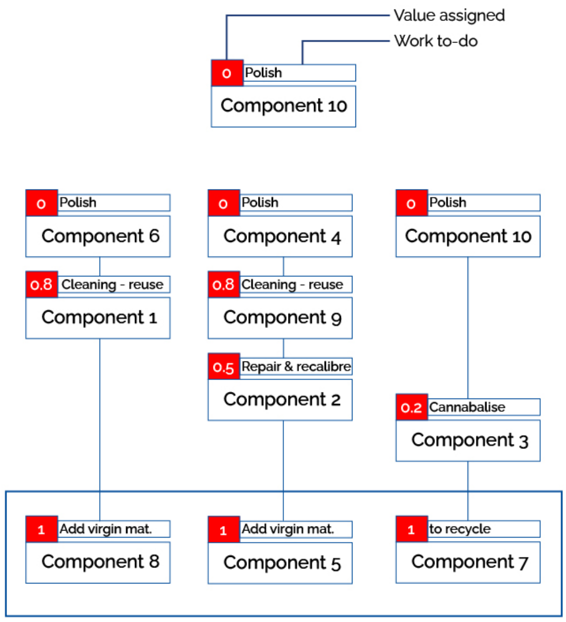


Figure 46- The remanufacturing product profile at Xerox designed by (King et al., 2007) & (Miemczyk & Campus, 2006)

Thus, by arranging remanufacturing-potential components in the platform, the more ephemeral or high-energy-using components would be built on top of this base. These would be removed and recycled at the end of their useful life, leaving the platform available for remanufacturing. Some of the remaining components may still be of good enough quality to be reused, while others may be suitable for remanufacture. As a result, their utility will be somewhere between 0 and 1; for example, a utility of 0.8 may indicate that the component only needs cleaning before re-use, whereas a utility of 0.5 indicates that the product needs to be repaired and calibrated. Components with a utility of 0.2 may be useful only when used to reclaim minor parts. As a result, an old product should be considered as a collection of discrete components each with different end-of-life utility values by a manufacturer. After the first product life cycle, such an arrangement would enable the derivative components to be more easily disassembled for recycling, and a new product to be built from the remanufactured platform. It is hoped that by using the platform approach, a major barrier to current remanufacturing will be removed, allowing each second-life product to be updated with the latest technologies and customer styles. At the moment, this is the barrier preventing many consumer products from being remanufactured, as there is no market for obsolete products (Barker & King, 2006).

6.5 Conceptual development of reman product profile for a building product

After reading through the concept of reman product platform as designed by Authors king and Barker. The Author has tried to apply the concept as a subset to materials passport. As discussed in the previous section of the report, materials passport contains valuable data that provide valuable information and promote recovery of a product at its EoL.
Therefore, reman product profile can be a subset of the materials passport. The first part is the Assessment of the condition of the product through laser scanning and photogrammetry. As a next step, the information on the following can be made available.

1. Disassembly plan
2. Packaging and handling instructions
3. Remanufacturing plan
4. Life Cycle Assessment

After assessing the above information for the product, the profile must take into consideration the current condition and arrange all the components and sub-assemblies by giving each of them a specific value that denoted the amount of work required to remanufacture it. This way the single life components are separated from multiple life components. Additionally, to a producer an EoL product is seen as a collection of components each with different EoL utility values.

Since all components are not designed for remanufacture, the reman product profile has the potential to judge the economic and environmental viability of remanufacturing process. This when integrated with BIM (Digital twin) will make the product data available to every stakeholder throughout the lifecycle of the product. The adoption of Reman product profile influences the design, selection and assembly. This pushes the designer to design products for disassembly and inspection. Eventually this will contribute to eliminating the major barrier to current remanufacturing process.

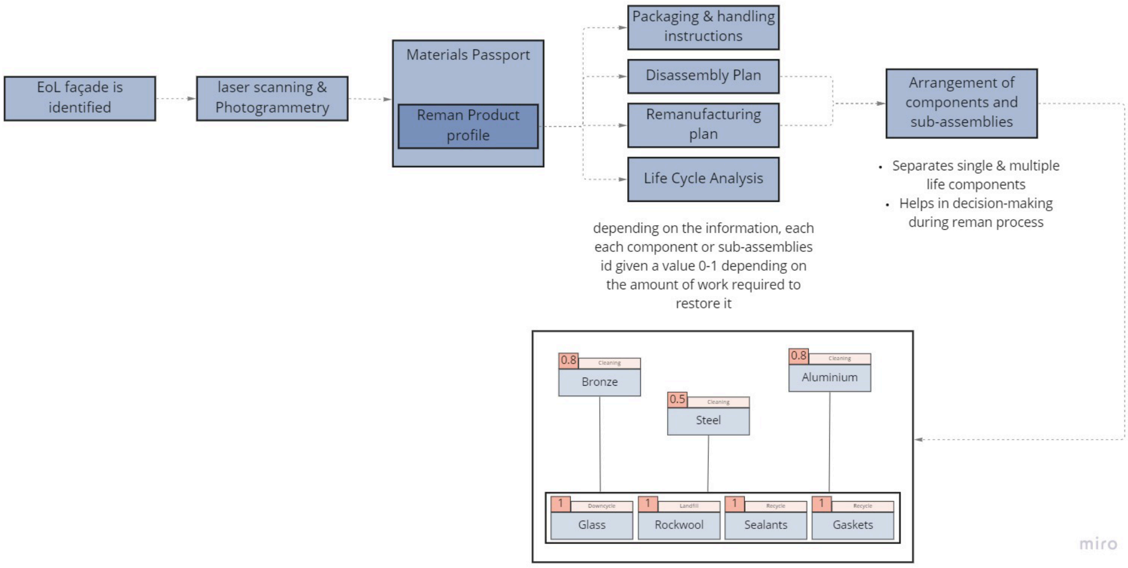


Figure 47 - Figure showing the conceptual workflow for the development of a reman product profile. Source: Author

6.8 Summary

1. The construction industry has always been slow in accepting new advancements in technology due to complex and highly fragmented nature. The transition towards circular built environment can be viewed as an interdisciplinary task, that must involve all the stakeholders in the construction value chain.

2. The building products are extremely complex which is why the ***information must be stored in different ways, transferred, and updated to reflect every change.*** The exchange of this information between stakeholders is a valuable and important task in transition towards a circular economy. Several authors believe that there is ***no alternative option to digitalization*** and it's only a matter of time before it is fully applied to achieve a streamlined process of work (Heinrich & Lang, 2019)

3. A digital twin must be made accessible to all stakeholders that can control and initiate a change. It can therefore be concluded that the availability of material and product data is a crucial aspect in the functioning of a circular economy

4. Several authors quote and believe that a circular supply chain is as strong as its weakest link (Heinrich & Lang, 2019)

5. Authors Heinrich and Lang oversee a change in roles within the industry during the transition to circular economy. The introduction of roles namely urban miner and digital architect are most likely to be present today and will increase in the near future.

6. The ways of incorporating digital workflows is elaborated at a conceptual level in the future chapters of the report. Its importance is accentuated as it incorporated as a criteria in the canvas explained in the next chapter (7)

07 Framework for remanufacturing in the building industry

The chapter presents the design for remanufacturing canvas developed as a combination of case study & literature review

7. Design for Remanufacturing Canvas

7.1 Motivation of the framework

Despite all the advantages of remanufacturing mentioned in the previous sections, it is observed to have not been applied in the building industry on a large scale. This is unfortunate considering building products are mass-produced standardized, high value materials available at fixed locations in large volumes. Buildings contain large volumes at products, made of high value materials available at fixed locations.

This is because the design activity of building products is centred around single use (Boorsma et al., 2019). At the end of their functional or service life (EOL) they are replaced by a completely new unit. Remanufacturing has not been applied in the building industry on a large scale because the industry has not developed the required business model, logistics and technologies, processes, operations that are required to take back an EOL product, remanufacture it and introduce it in the next life cycle. Moreover, the design of the products does not support disassembly or inspection which are crucial to developing a business case for remanufacturing of an EoL product.

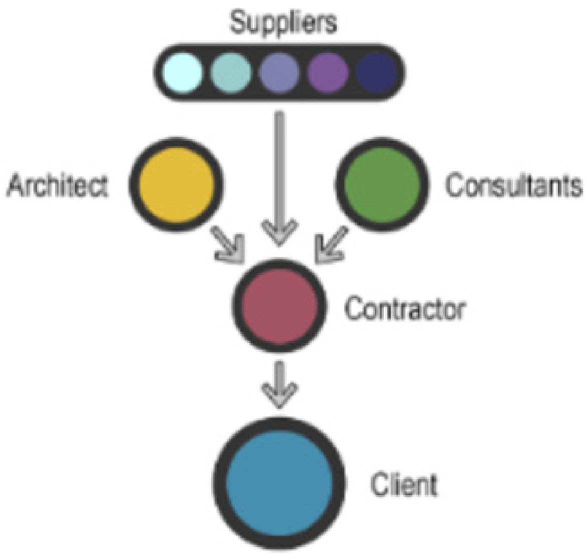


Figure 53- Legal system of a typical building contract in the Netherlands (Azcarate-Aguerre et al., 2017).

It is important to note that building products are not standalone entities but and are always integrated with other assemblies. The ownership period is shorter than the life of the product, which makes it difficult to retrieve them at EOL. Furthermore, it is a dynamic and fragmented industry that involves many stakeholders during the decision-making process. As mentioned before, the integration of digital platforms and support systems in other industries have contributed to the success of remanufacturing. However, an approach to digital platform and support system for Design for remanufacturing (DfRem) in the industry is still missing. Authors Boorsma, Tsui and Peck, (2009) further explain the elaborate decision-making process due to the number of stakeholders in the building industry, by illustrating the example of a façade equipment manufacturer shown in the figure 7.1. Therefore, the framework has been designed to lay the foundation to initiate remanufacturing for the building industry.

7.1 Motivation of the framework

After studying literature on remanufacturing and design for remanufacturing, a set of criteria were developed namely, method of core collection, type of remanufacturer, consumer awareness, materials recovered during the remanufacturing process etc. As a part of next step twenty successful examples were identified by using the keywords "successful remanufacturing", "eco-design"," automobile industries". The journals from the ERN (European Remanufacturing Network and company websites assisted in developing a product canvas of all the twenty examples. As a next step, regarding time five examples namely Philips MR systems, Davies furniture, Canon Multi-Functional Printers, Caterpillar, and Xerox photocopiers were chosen as they matched the product complexities, material intensive nature and number of stakeholders were comparable to building products.

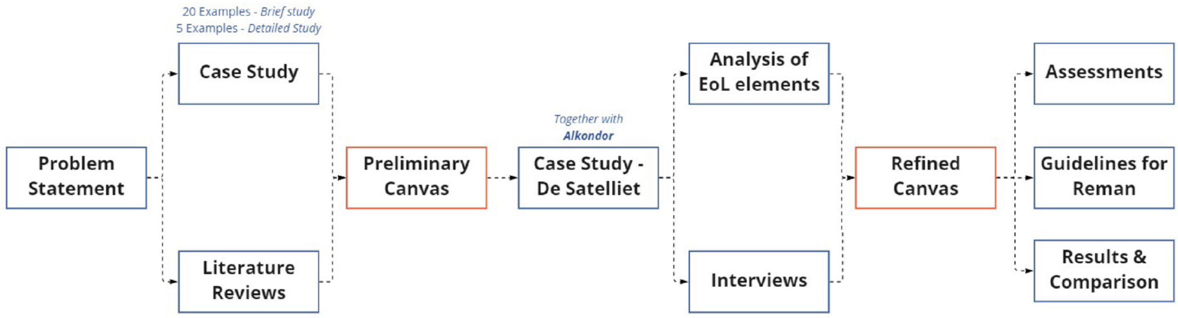


Figure 61 - Methodology adopted during the research. Source: Author

7.3 Design for remanufacture

Nasr and Thurston (2006) established the relationship between design and remanufacture by demonstrating that when design for remanufacture becomes an integral part of the product design, remanufacturing can lower material and energy consumption, as well as reduce waste production. All remanufacturing process begins with the presence of the core. As discussed in the previous sections, in remanufacturing a core refers to the component or product that is extracted from an end-of-life product and will be retained through the remanufacturing process to be introduced into a new lifecycle. The company Xerox uses the term 'Hulk' as a synonym for 'core'.

The design of the core occurs before manufacturing. A product's form, material, fastenings, etc, can all influence how effectively it can undergo and withstand the remanufacturing process, e.g., cleaning, disassembly, inspection. So, it can be stated that design for remanufacture contributes to the efficiency of remanufacturing. The design strategies will be implemented into product development as part of a business model that focuses on innovation and remanufacturing. The authors Charter and Gray (2008) established that design for remanufacturing consists of two interrelated levels:

- ***Product strategy:*** This entails sales, marketing, service support and reverse logistics (core collection)
- ***Detailed product design:*** It is the creation, development, testing and manufacturing or implementation of a physical product or service.

There are some aspects of remanufacturing that cross both levels, for instance for collection of cores at EoL, may require the business model to shape this aspect. Whereas the core collection process can also be communicated to the stakeholders and end user through presence of graphics on the product. The aim of the research is to gather all the criteria's that contribute to the success of remanufacturing process in other industries. As a next step, the criteria are tabulated alongside the case studies to validate them through literature. As a final step the research aims to investigate the

7.4 *List of criteria*

In the chapter 5, the key problems and solutions related to every case study was mapped. This resulted in some concepts that could be traced back to the literature that was studied and explored in Chapter 4 remanufacturing. The repetitive concepts were gathered in a list and tabulated against the five case studies. The figure shows the list of criteria and the case studies mapped to give a general idea and lay foundation to the discussion of remanufacturing for the building industry. This led to the development of a preliminary list of criteria extracted from the marriage of analysis of literature review and case studies.

The list of criteria's however had to be checked for its relevance to the building industry. The following chapters discuss the outcome of conversation with company experts and mentors in this field whose outputs have been employed to refine the canvas further.

The canvas has been named design for remanufacture canvas and its foundation is based on the conclusion from previous chapter that remanufacturing is a combination of detailed product design and business model combined with product strategy. The criteria's were then arranged to be branches of the same. However, there was an overlap observed in some of the criteria. It was noticed that they shaped both the domains i.e., product design and Business model & product strategy.

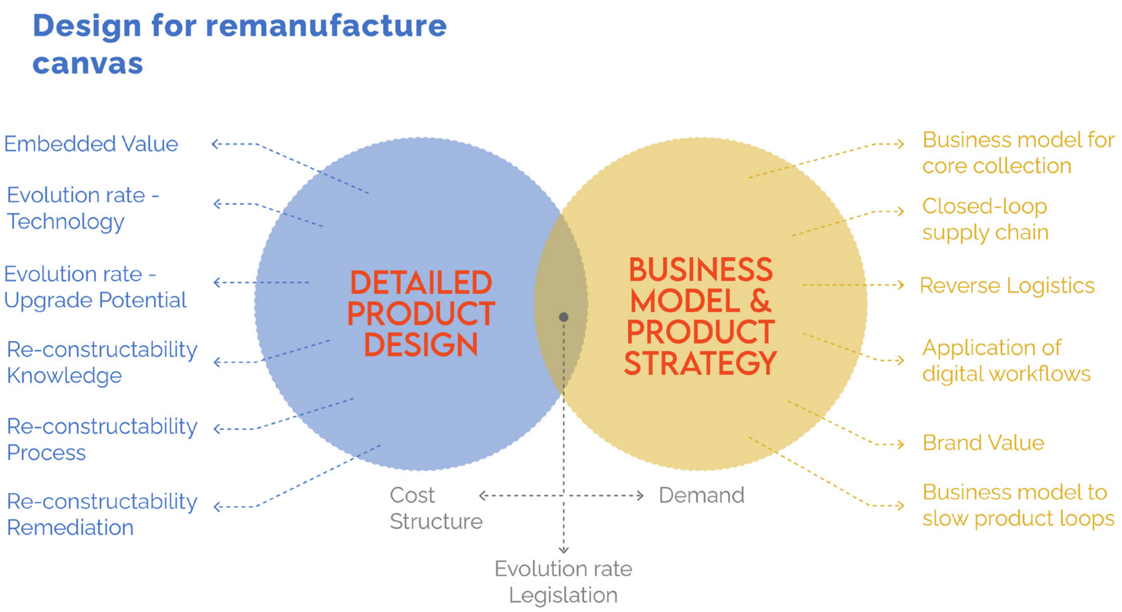


Figure 62- The design for remanufacture canvas. Source: Author

No	Name of the Criteria	Definition	Observed in the case study of	Author
Gathered from Case Study				
List of Criteria				
Detailed product design				
1	Embedded value	The core product must be durable and should contain a high value.	Philips, Canon, Xerox	(Charter & Gray, 2008), (Mfps, n.d.), (Economy & Model, 2020)
2	Evolution rate - technology	The technology under consideration should be capable of restoring the product and remaining stable over multiple lifecycles.	Canon, Philips, Xerox	(Charter & Gray, 2008), (Mfps, n.d.), (Economy & Model, 2020),(Lund, 1998; Fegade et al., 2020)
3	Evolution rate - Upgrade potential (All DfX Strategies)	A product must have the ability to be upgraded. Market demand and preferences change rapidly, so a remanufactured product has to maintain effective functional equivalence with the existing virgin product to preserve economic viability.	Applicable in all case studies	(Charter & Gray, 2008), (Mfps, n.d.), (Economy & Model, 2020)
4	Re-constructability- Knowledge	The skilled labor for remanufacturing should be made available at a single remanufacturing facility with standard protocols in order to prevent the establishment of new remanufacturing channels, some of which may not be cost-effective	Philips	(Economy & Model, 2020)
5	Re-constructability - Construction process	The component should be made of standard interchangable parts. The construction procedure during a reman operation should be set by standardized protocols, to make the process efficient	Canon, Xerox, Davies Furniture	(Krystofik et al., 2018), (Mfps, n.d.)
6	Re-constructability - Remediation	Reamanufacturing over multiple lifecycles should be enivronmentally feasible and economically viable. This ensures that the process is not impratical and expensive compared to remanufacturing of new products.	Canon, Xerox, Davies Furniture	(Krystofik et al., 2018), (Mfps, n.d.)
Product Strategy				
7	Business model for core collection	The cores are collected through a specifically designed business model. The reman process relies fundamentally on the collection of core.	Applicable in all case studies	(Charter & Gray, 2008), (Östlin et al., 2009)
8	Closed-loop supply chain	The logistic channels of a product must be structured to simultaineously minimize waste oppurtunites and maintain both a viable resource stream and consistent customer base.	Davies Furniture	(Krystofik et al., 2018)
9	Reverse logistics	Channels for the reverse flow of returned products must exist. These are related to revenue streams as well.	Applicable in all case studies	(Charter & Gray, 2008), (Mfps, n.d.), (Economy & Model, 2020),(Ayres et al., Huang et al., 2020)
10	Application of digital workflows	Digitisation is a key component of upgradebility. This is valuable for sales and management team to continuosly monitor the company's assets while offering the customer latest upgrades and incentives to turn-in the products at/or before EOL	Philips, Canon	(Mfps, n.d.), (Economy & Model, 2020)
11	Brand value	To make the remanufactured product well-known in the market helps customers understand what they are getting in terms of quality. This also allows sales teams to better understand and communicate the proposition.	Philips, Caterpillar	(Sakao et al., 2010), (Economy & Model, 2020)
Union of both fields				
12	Evolution rate - Legislation	Evoluton rate is guided by the Rules and Regualtion that are released by higher authorities and Government Institutions. They impact the remanufacturing of products in terms of colletion of cores, material recovery and resale of remanufactured products into the market	Applicable in all case studies	(Charter & Gray, 2008),
13	Cost Structure	The overall cost of procurement and reprocessing the core should be low, when compared to the residual value-added.	Canon	(Mfps, n.d.)
14	Demand	There should exist sufficient demand for the remanufactured product.	Applicable in all case studies	(Charter & Gray, 2008), (Ayres et al., 1997; Duberg et al., 2020)
Business model to slow product loops				
B1	Access and performance model	Providing capability or services to satisfy user needs without needing to own products	Xerox	(Barker & King, 2006), (Bocken et al., 2015)
B2	Extending producer value	Exploiting residual value of products, from manufacturing to customers and back to manufacturing.	Automotive-remanufacturing parts	(Bocken et al., 2015)
B3	Encourage sufficiency	Solutions which actively seek to reduce user consumption by increasing durability, upgradability, service warrantees etc.	Vitscoe, Patagonia	(Bocken et al., 2015)

Table 4- Detailed list of criteria, gathered from the case study. Source: Author, derived from various case studies as indicated and mentioned above

7.5 *Logic behind the arrangement of criteria's*

The logic that follows the arrangement of criteria in the two domains of detailed product design and business model strategy is that Embedded value, technology, upgrade potential, knowledge, construction process and remediation fall in the domain of product design as they are directly influenced by each other. They are shaped by the product design team who possess the knowledge and therefore make critical decisions that influence and shape the nature of the product.

The Business model for core collection, closed loop supply chain, reverse logistics, ICT & Customer support, creating a brand value fall in the domain of product strategy. This is shaped by a team of sales, marketing, and supply chain specialists, who craft innovative solutions to ensure return of cores at EoL and create channels to support this return of products, along with incentives to persuade the customer to return the products.

The business model also falls in the domain of the above-mentioned team of strategy experts who are responsible for implementing a business model that supports the design of the product and therefore guides remanufacturing of the same at EoL. They have been gathered directly from the case study under the section of business models to slow product loops, which directly support remanufacturing as the latter aims to prolong the life cycle of a product by designing it to have the potential to be reintroduced into multiple lifecycles.

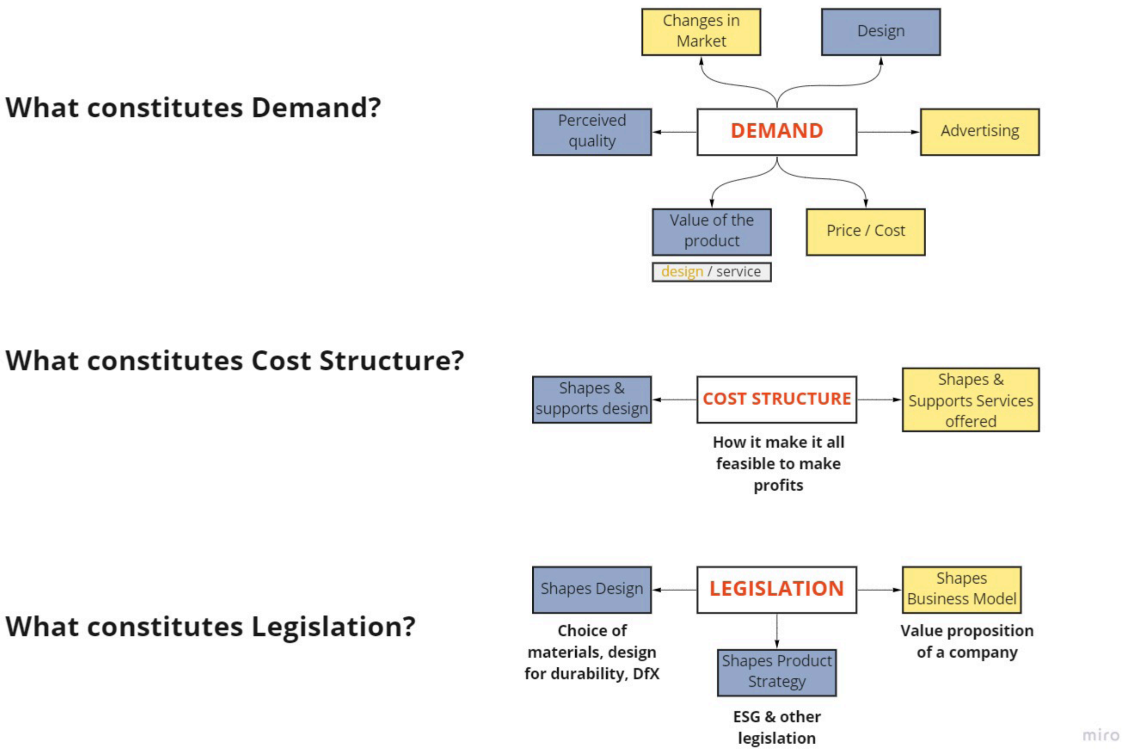


Figure 66- What constitutes demand, cost structure and legislation? Source: Author, adapted from various case studies

A small exercise was performed, where the criteria were placed against the case studies to verify how many of them were applicable to each of them. The table 5 shows the frequency of the appearance of each criterion in the case study. It can also be observed that not all criteria's are followed by each of the. Hence it can be concluded that the list of criteria's must not be considered as a checklist but rather as a set of options, the combinations of which can be used to arrive at a circular building product.

Categary	Name of the criteria	Canon	Philips MRI Systems	Davies Furniture	Caterpillar	Xerox
Detailed product design	Re-constructability | Construction process					
	DfX Strategies | Evolution rate - Upgrade potential					
	Knowledge & Skillset					
	Evolution rate - technology					
	Embedded value					
Product Strategy	Closed-loop supply chain					
	Reverse logistics					
	Business model for core collection					
	Application of digital workflows					
	Labour / Skilled workforce					
Union of both fields	Evolution rate - Legislation					
	Cost Structure					
	Brand value					
	Demand					
Business model for closing resource	Access and performance model					
	Extending producer value					
	Encourage sufficiency					

Table 5 -The frequency of appearance of criteria in each case study has been tabulated. Source: Author

7.6 Comparison of list of criteria v/s case studies

The previous exercise of mapping the frequency of appearance of criteria in case studies was taken to the next step, to elaborate the method or the way in which it was incorporated by the case. The table 6 shows an overview of how the criteria's were implemented.

7.7 Parameters important at product level

As the canvas and the list of criteria talk about the business model and product strategy, it focuses on the broader picture. However, for an efficient remanufacturing process, there are certain parameters that are important at a product level. During the literature review a few of the important parameters supported by various authors were gathered. The table 6 shows an overview and definition of each of these parameters. It is important to note that this is not an exhaustive list but a work in progress table that has the scope to be improved further and establish definitions applicable for building products.

Category	Name of the criteria	Canon	Philips MRI Systems	Davies Furniture	Caterpillar	Xerox
Detailed product design	**Re-constructability | Construction process**	Strategically planned to ensure operational efficiency and economies of scale	SmartPath to dstream planning - a cost effective solution	Adaptive remanufacturing process	Well established reman operations	Well established reman operations
	DfX Strategies | Evolution rate - Upgrade potential	Design for Disassembly	Design for Multiple Lifecycles	Design for Upgradability	Design for Multiple Lifecycles	Modular design
	Knowledge & Skillset	Standardized reman protocol for every component	SmartPath portfolio protocols	Indexing	Standardized protocols for reman process	Standardized protocols for reman process
	Evolution rate - technology	Areas of user interface and software applications	Areas in software and interface applications	Design of furniture with changing demands	Areas of sustainable equipment - designed for biofuels	Areas of software and interface applications
	Embedded value	The core is designed for Multiple lifecycle	Installed base of MR system can be upgraded	Salvageable parts of EOL furniture	The core of equipment is designed for Multiple Lifecycle	The core is designed for Multiple lifecycle
Product Strategy	**Closed-loop supply chain**	Machines in Field are brought back at EOL	Machines approaching EOL are returned to Philips	New furniture products made by EOL furniture (waste)	Equipment retuned at EOL is remanufactured	Equipment retuned at EOL is remanufactured
	Reverse logistics	Leasing policies & Direct Sales via NSO's for high value equipment	SmartPath portfolio-Direct sales and account management	Product exchange & direct sales with customer	Through a simple database	Through simple database and policies - Asset Recovery option (ARO)
	Business model for core collection	Buy back based, Ownership based	Ownership based model	Voluntary based banking program	Deposit- based model	Buy-back & Ownership model
	Application of digital workflows	Machines in Field (MIF) and Managed Print Service (MPS) monitors the assets	Decision-making platform helps sales and management team to monitor assets	-	-	-
	Labour / Skilled workforce	Skilled labour present at Giessen, Germany	Skilled Labour available at Best, NL	Skilled labour at reman facility in Albany, NY USA	Skilled labour at various reman facilities across the globe	Skilled labour at Dundalk (IRL) Mitcheldean (UK) & Venray (NL)
Union of both fields	**Evolution rate - Legislation**	Guided by WEEE's Extended producer Responsibility	New Health Care policies with ownership of MRI equipment	-	-	Extended Producer Responsibility -
	Cost Structure	Fixed cost of running the reman plant & variable cost - Labour & materials	Product and software development.	Reman process, sale and service delivery organization	reman options, machine take back, sales and delivery organization	reman options, machine take back, sales and delivery organization
	Brand value	EQ80-low cost, high performance sustainable printer	Customers rely on Diamond Select refurbished machines	Customers rely on Davies brand of furniture	Customer rely on the Caterpillar tag of remanufactured equipment	Customer rely on the Xerox brand of remanufactured equipment
	Demand	Small & Medium Businesses and large Corporations	Private Hospitals and Scan centres	Small and Medium size offices	Loyal customers of heavy machinery	Small & Medium Businesses and large Corporations
Business model for closing resource loops	**Access and performance model**	Majority of the printers are leased tha owned which allows Canon to take back at EoL. MPS focuses on delivering performance	MRI leasing & financing models provides options for customers to shift ownership and Managed Service model focuses on achieving performance objectives			
	Extending producer value			By turning EoL furniture which is otherwise considered waste, a closed loop supply chain has been maintained and lifecycle has been extended		
	Encourage sufficiency				Caterpillar engines are designed to be durable and the core can be introduced in multiple life cycles.	Xerox has adopted platform design (modular) which has led to production of a robust durable product whose core can be introduced in multiple life cycles.

Table 6 - Comparison of list of criteria with each case study to analyse how each of them influenced in making the reman process successful in each. Source: Author

Parameter	Definition	Author
Product design for diaassembly	Existence of technology to restore the product. The technology or method must be able to extract a component without damaging the parts	(Charter & Gray, 2008)
Standarized construction of parts	The product must be built of standard interchangable parts	lie et al. (2019)
Technology	The technology under consideration should be capable of restoring the product and remaining stable over multiple lifecycles.	(Lund, 1998; Fegade et al., 2020)
Cost	The cost of the core is relative to savings in product cost achieved through reuse of core.	(Charter & Gray, 2008)
Demand	There should exist sufficent demand for the remanufatured product to make it economically viable & sustain the enterprise	(Ayres et al., 1997; Duberg et al., 2020)
Legislation	Evaluation of disposal options an environmental impact of legislation	(Charter & Gray, 2008)
Assessment	Determine the products suitability, sustainability parameters, economic viability and practicality of remanufacturing process	(Charter & Gray, 2008)
Worth	The core product must be durable and should contain a high value	Singhal et al. (2020)
Potential	The product must have features that make it upgradable	(Shu and Flowers, 1999; Lindkvist, 2020)
Reverse channels	Channels for the reverse flow of returned products must exist. These are related to revenue streams as well.	(Ayres et al., Huang et al., 2020)

Table 7- Parameters important at a product level for remanufacturing. Source: Author derived from various case studies

7.8 Comparing characteristics of Case study products v/s building product

Recording similarities and differences between builing products and case study products

No	Xerox | Daves furniture | Caterpillar | Canon & Philips	Building products
1	Comparitively less, but is still material intensive	Material intensive
2	Standardized and mass produced	Standardized and mass produced
3	Design activity by manuafcturers centered around design for disassembly, allowing upgrades over multiple lifecycles.	Design activity by companies centered around single use
4		Dynamic and fragmented industry
5	At EOL of a product, the OEM-R have the right to decide on a suitable "re" option	Large number of stakeholders involved in decision making processs
6	Relatively shorter life span enables the owner to return the product at EOL	Lifespan is long and period of ownership is short. This makes it difficult to retrieve products at EOL
7	All products are returned to the manufacturers or third party companies they were purchased from	For repair a general company consulted over OEM
8	Supply amd demad is montiored by sales and management team	The supply and demand statistics are generally not recorded regularly
9	Reverse logistics channels & ownership contracts are established for producer to take back at EoL	Reverse logistics channels and ownership are not entirely established

Table 8 - A comparison of the similarities and differences between building products and the case study products. Source: Author

7.8 Summary

1. After a thorough study, it can be concluded that design for remanufacture is a ***combination of product design and business & product strategy***.

2. From the comparison of List of criteria with every case study, it can be established that the ***canvas*** made by the Author ***must not be regarded as a checklist*** to achieve successful manufacturing practice, but a combination of them can be made to achieve a circular building product.

3. This can be seen in how each of the case study employs a unique implementation of criteria. A combination of them is used to achieve a circular product.

4. The canvas must be treated as a piece that can be used to start a conversation and draw boundaries to achieve remanufacturing process.

5. The canvas has been made with a focus for remanufacturing, but the many of the criteria are applicable to all the other “re” strategies namely, recycling, reuse, repair and refurbish

6. This canvas was applied to the case study-De Satelliet to test its relevance to the building industry. This was done through conversations with company experts and has been elaborated in the upcoming chapters of the report.

08 De Satelliet: Analysis of EoL facade elements

The chapter presents the inductive method adopted in the analysis of EoL façade elements of De Satelliet.

8. De-Satelliet: Analysis

8.1 Project Information

- Location: Westeinde 1, Center, Amsterdam
- Coordinates: 52°21’31.62”N, 4°54’0.47”E
- Architect(s): J. Abma, Marius Frans Duintjer
- Start design – Completion: 1961 – 1968 / 1985 – 1991
- Client: Ministry of Finance
- Main contractor: JP van Eesteren
- Gross floor area: 55,000 m^2
- Content: 212,000 m^3
- Construction costs: 38.5 million euros
- Literature:
- De Volkskrant – 13-9-1957.
- Algemeen Handelsblad – 28-01-1959.
- Algemeen Handelsblad – 20-09-1960.
- NRC – 25-09-1985
- The Area of the Cylindrical tower is 8,000 m2

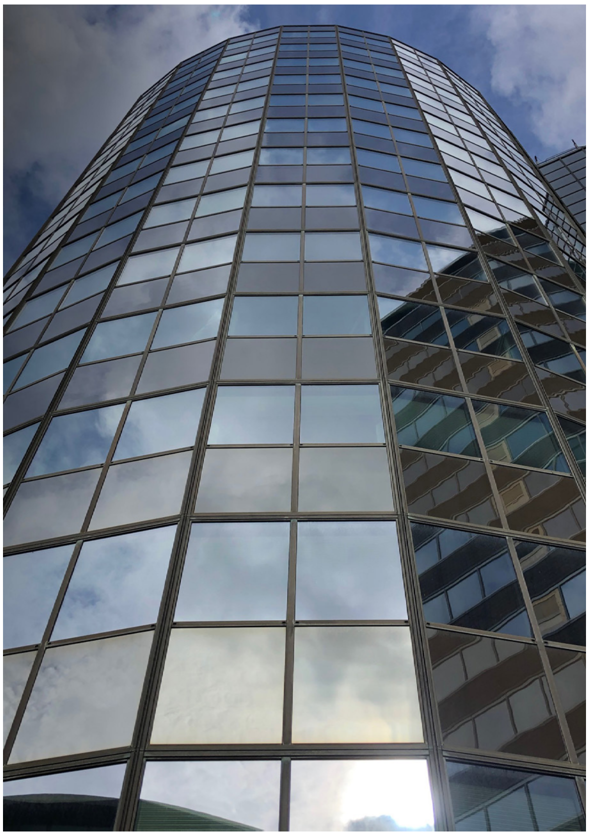


Figure 71 - Picture of the facade of De Satelliet. Source: Alkondor

De Satelliet, the cylindrical tower of De Nederlandsche Bank, gets a second life.

The cylindrical tower of the De Nederlandsche Bank office building, De Satelliet, will be given a second life in Amsterdam. The tower’s (so-called) constructive dismantling at its current location was completed. The plan is to reassemble the disassembled parts and use them to construct a new building in another part of Amsterdam. The Satellite is dismantled by New Horizon. It was seen that a large percentage of CO2 emissions is saved by choosing dismantling over demolition. The disassembled elements were transported from the site by electric boat to a storage location in Zaandam (Amsterdam-Noord), where they are prepared for reuse. RE:BORN is a developing investor and is the new owner of the materials.

About De Nederlandsche Bank

In the invitation to tender for the renovation of its head office, DNB explicitly challenged the contractors to come up with sustainable, circular solutions. Strukton Worksphere, which won the European tender, did so by including dismantling and rebuilding the Satellite as part of its contract.

Garden replaces the Satellite

The round tower by architect Jelle Abma was added almost 30 years ago in the courtyard of the DNB office. By using the available space in the main building more efficiently, the round tower is no longer needed, and it is replaced by a garden accessible to the public.

8.2 Design Concept

The building for De Nederlandse Bank consists of a square shaped low rise building with 3 floors of approximately 100 by 120 meters and a 66 m high office tower with 15 floors. There are 2 courtyards. The façade of the tower is covered with brown-red-tiles. In 1991, the bank expanded by construction of a cylindrical tower designed by J. Abma of Abma +Dirks + Partners (De Nederlandsche Bank - Van Westeinde Naar Frederiksplein - Vereniging Vrienden van de Amsterdamse Binnenstad, n.d.).

It consisted of 14 floors with mirrored curtain wall and was placed in the largest courtyard. (De Nederlandsche Bank, Amsterdam, M. Duintjer | Architecture Guide, n.d.) Frederiksplein – The De nederlandsche bank building was one of the most talked-about buildings in Amsterdam in the 1960s. The Paleis voor Volksvlijt once stood on Frederiksplein, a symbol of openness. In 1991 the building was expanded with a round cylinder of fourteen floors, to a design by J. Abma of the bureau Abma + Dirks + Partners.

8.3 Facade

The cylindrical façade of the De Satelliet is designed and built as a window wall system. The façade is built with a simple array of materials such as Aluminium and Bronze profiles with a combination of supporting insulation, stainless steel angles and gaskets. The use of the bronze profile and the cylindrical geometry of the façade distinguishes it from the general design of stick systems.

The Façade was built by Gellinger AG 8404 Winterthur, Switzerland. The fourteen storied building had a façade made of 13 different kind of façade panels. They are named as A, A' B, C, C', C2, C3, Cs, C's, C2s, D, D', G, G'. The effective width of a façade panels is 2864 c/c, and the length is 3750. This is also the floor-to-floor height. The figure 68 shows the folded elevation of the tower with all the different façade elements.

8.4 Materiality

The intention of the thesis project is to evaluate if the disassembled façade of De Satelliet can be remanufactured. The first step in the evaluation process was to understand the specifications of the disassembled façade and to recognize the valuable parts. A hierarchy diagram is made to highlight the different elements of the façade and are mapped next to their respective function. To get an insight on the façade performance in thermal and sound insulation the calculations are performed from the existing situation. Some of the specific detailed information was recovered from a report submitted to Alkondor on façade performance (See appendix)

8.5 Assumptions made

Based on the Literature review in the previous chapters, the following assumptions can be made:

1. As per Brand's concept of shearing layers, the façade can be distinguished into different layers that have different life span and perform a different function.
2. Based on (Eekhout, 2008) and Durmisevic (2006) 's definition the façade is a hierarchical range of components with different complexity and can be segregated to different levels corresponding different value.

3. Based on the research on circular economy by Ellen Mc Arthur it can be concluded that for each of the components, there is sustainable strategy as an alternative to demolition that fits the Cradle-to-Cradle model as described in the previous chapters.

The objective of this chapter is to perform an analysis of the disassembled façade of the De Satelliet based on the above assumptions. The motivation of the project is to analyse if the disassembled façade elements can be remanufactured.

8.6 *Defining Function*

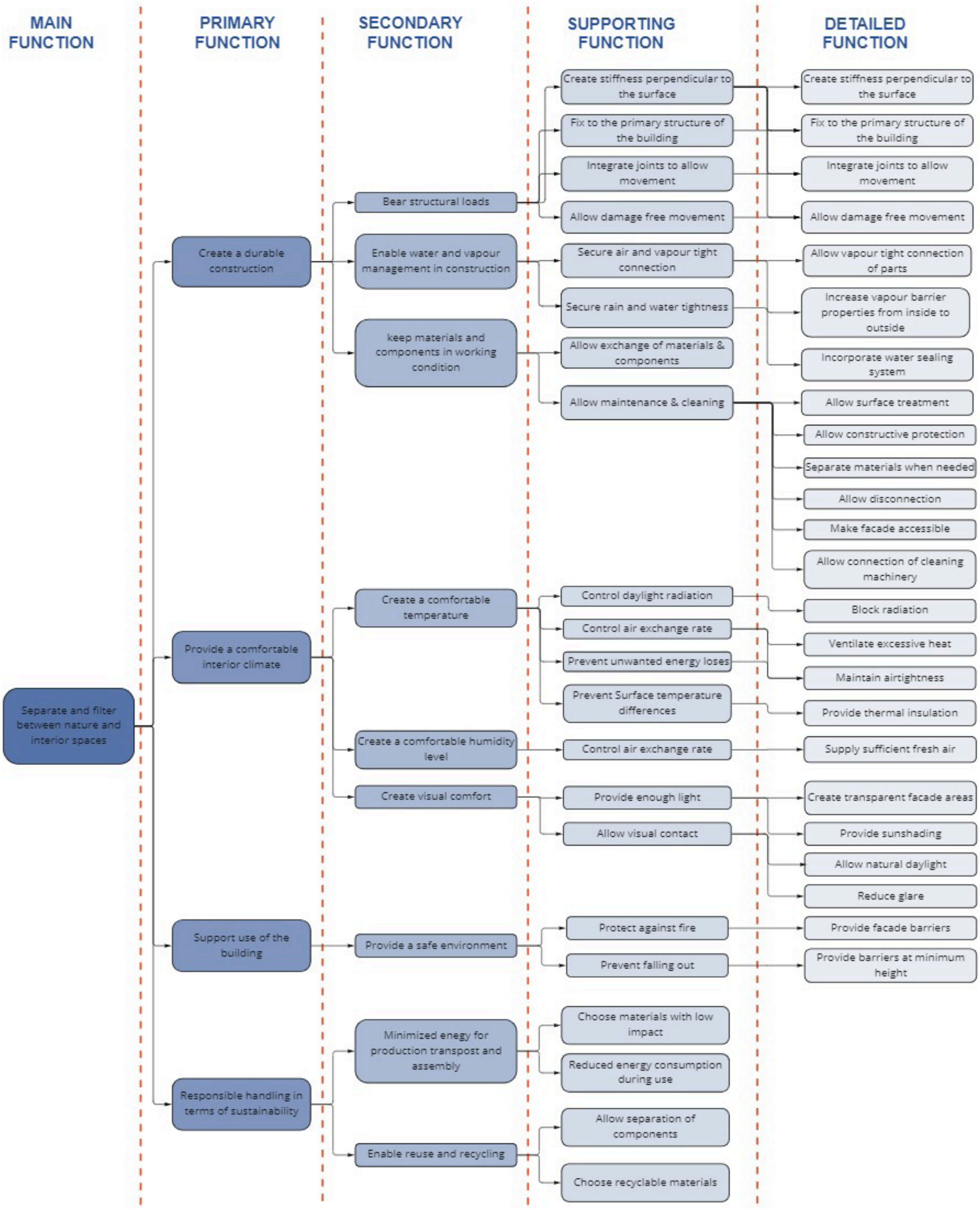


Figure 69 - Representing the fundamental functions of a façade. Source: (Klein, 2013), adapted by Author

A façade is a complex building product. To define the importance of each layer and consequently map its function, a façade tree was developed which is similar to the function chart laid out by (Klein, 2013) and (Hövels, 2007). The basic functions namely, enabling faultless use of the building and keeping materials and components intact (Klein, 2013) are not listed as they as they do not relate to specific façade components. A simplifies façade function tree diagram.

8.7 Defining Hierarchy

To define the hierarchy of the disassembled element, the general model which is an adaptation of combining levels from Dumisevic's model and Eekhout's model.

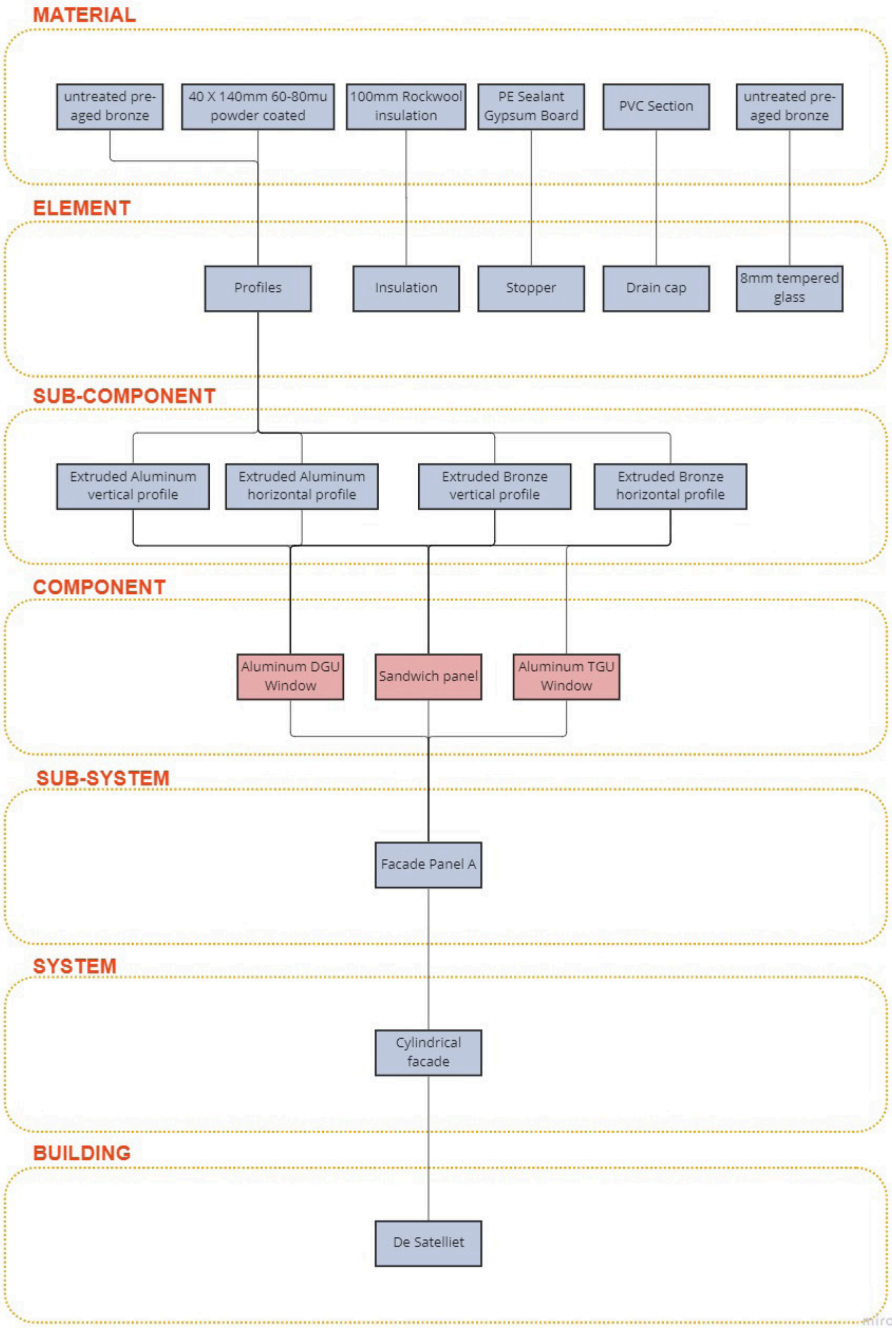


Figure 70- Representing the hierarchy of one facade element of De Satelliet. Source: Adapted by (Durmisevic, 2006) & (Methodology for Product Development in Architecture - Mick Eekhout - Google Books, n.d.)

8.8 Present conditions of the disassembled units

The disassembled façade is stored in a warehouse in Zaandam, near Amsterdam. The interview with Martijn Veerman from Alkondor highlighted that façade builder Alkondor was involved very late in the project. Due to absence of a disassembly plan, the façade elements were not transported and stored in a correct manner. This has caused damage to many façade elements, making the remanufacturing process more challenging and adding more pressure on labour. The photographs below show the present condition of the disassembled units.

This section describes the disassembly process followed in the project. The present condition of the façade elements is an example to derive many lessons for the development of remanufacturing and disassembly plan. The lessons learnt through evaluation of this led to the motivation to creation of guidelines for reman of EoL façades. This is explained in detail in chapter 10 of the report. It begins with the inspection phase to the final phase of reman and reassembly.

Though interviews and discussions during site visit, the following observations were made:

1. The entire building including the structure and the façade of the building De Satelliet was disassembled. The plan is to give them a second life in another building in Amsterdam.

2. After disassembly the façade elements were stacked horizontally on wooden blocks on site.

3. The elements were then transported to the storage facility by electric boats. The façade elements were lifted in packages of groups of 5.

4. At the storage facility, they are placed horizontally on the concrete floor on residual wood pieces (bobbins) by a forklift with extended forks under the roof of the shed.

This incorrect method of disassembly has caused major damage to the façade elements which will result in a complicated and laborious remanufacturing process as discussed with the Façade builder – Alkondor. The figure 71 shows the present condition of the units in storage facility in Zandaam near Amsterdam, The Netherlands.

Figure 71 - A & B: The present condition of the units in the storage facility near Amsterdam.C: Shows the way the elements were transported. Source: Author (Pictures A & B), captured during a site visit. & Alkondor (Picture C)

. The present conditions of the units can be summarized as follows:

1. The façade elements were stacked on wooden bobbins of unequal height which has caused the façade elements to warp and skew. This has also led to tension in the connections and joinery causing joints to break and become loose
2. The horizontal method of storage is not suitable as it leads to unequal transfer of forces leading to irreversible damage to elements. It accumulation of dirt and dust on the elements.
3. Care must be taken during the process of transport and storage. The presence of water during transportation or at the storage facility can destroy the fire-resistant material due to absorption. In the case of façade elements of De Satelliet, it was noticed that the fire-resistant material Promatec has been damaged.
4. The horizontal method of lifting the façade with lifting straps has damaged the T-connectors due to these forces. The damage is visible noticed by the presence of a large crack and causing the t-connector to snap.

Summing up the damages that were observed and documented in the storage facility are;

1. The t-connectors have been damaged.
2. The fire-resistant material (Promatec) has absorbed water and expanded thereby squeezing the insulator
3. The Aluminium and bronze profiles have been fitted with rockwool and foils. The foils are torn and its contribution to the façade is unknown.
4. The grooves with inner seal are pressed to close and have been squeezed. This requires labour to straighten the facades.

8.9 Summary

1. The ***incorrect disassembly process*** has led to a ***large amount of damage*** which could have been ***avoided*** if the facade builder was involved very early in the process.
2. The quality of De Satelliet elements is good and is a proven example of how an ***investment in high quality materials*** enables the designer to prolong its use and curb the impact that might arise during virgin production.
3. The improper ways of storage and disassembly has increased the ***pressure on labour*** to remanufacture façade elements to achieve a respectable quality that abides the legislation and inspection standards.
4. As an observation from this study, it can be established that a disassembly and remanufacturing plan is vital before dismantling and disassembly of elements.
5. The plan can help in ***determining the expected damage*** and quality of the element after the process of disassembly.
6. The remanufacturing process has introduced new roles in the construction industry e.g., Urban miner and remanufacturer (third party or OEM). Thus, it can be proved that remanufacturing also leads to creation of new roles and jobs in the market.

09 Evaluation of EoL facade elements of De Satelliet

The chapter presents detailed evaluation of the façade elements of De Satelliet

9. Evaluation of EoL facade elements of De Satelliet

9.1 *List of Risk & Potentials*

As discussed in the previous sections, the façade was built a long time ago and therefore it may not completely match the performance offered by a brand-new façade. Through interviews and discussion, it was understood that it is important to seek clarity on how the old façade was built to be able to recover the important components from EoL. The knowledge will help in design of new water and air tightness concept along with design of structural connections that are crucial to the functioning of the façade.

The estimated list of risk and potentials have been made after conversations with the façade builder in charge of the project – Alkondor and through observations from site visits and pictures. It is defined and elaborated in the future chapters after the inspection and testing of elements in the factory. The report does not include information on all the tests conducted because as of now, it is a work in progress stage and has a longer timeline that is beyond the scope of this graduation thesis.

9.1.1 Risks

1. Due to incorrect disassembly process, the façade panels have been dented, scratches and have glass breakages
2. The thermal break (that was previously rolled into the profiles) has been damaged as due to the unequal stacking on the pegs. It is difficult to repair this as the profiles have been compressed and it is difficult to release and add a new insulator back in
3. Many profiles were observed to be deformed. They contained a rubber seal for air tightness (on the inside of the façade element)
4. The advantage of the rockwool filling in the profiles is unknown now. This will be inspected further
5. The Promatec – a fire insulation material has absorbed water and expanded which makes it difficult to use.
6. During the inspection phase at the storage facility, it was observed that the Colorbel panels are difficult to separate and remove.
7. During the process of transportation and disassembly, the t-connectors have been damaged and have lost their integrity in about two thirds of the elements. Further inspection and market research can determine if they can be counterfeited.
8. Due to the damage incurred to the inner seals many panels, it is important to chart a systematic refurbishment process to make it efficient.
9. During the site visit, corrosion of aluminium and bronze panels was detected, which are difficult to refurbish
10. All the gaskets and rubbers must be replaced, and the rebates must be straightened
11. It is currently unknown if the structure and thermal performance of the façade meets the current standards.
12. The glass panels must be replaced and configured to match new performance.
13. The glazing beads do not fit and must be replaced with new ones

9.1.2 Potentials

1. The façade is made from superior quality a high valuable material such as Aluminium & Bronze
2. The highest value is in reusing the entire façade, The Aluminium and Bronze profiles are sturdy and promising for reuse
3. The Bronze present in the façade is very valuable and has the possibility to be cleaned. This was tested by the company - NiroQom
4. There is a potential to insert a turn-tilt window in the existing frame
5. There is a possibility to repair the broken T-connectors. In some cases, new ones can be made and refitted.
6. Due to the presence of a large cavity in the façade, the thermal performance can be expected to be fair and decent
7. Some of the units were replaced with triple glazing units (TGU's) which maybe are in a good condition for reuse.
8. The rubbers present in the interior of the façade are promising and appear to be in good quality.
9. From the façade drawings, it can be concluded that the façade was designed and engineered well to have a good thermal break, and contains a god thermal bridge interrupter
10. At this point, remanufacturing and reassembly of profiles seems promising.
11. The extent of damage to the sandwich panel (glass+rockwool) is unknown and they have the potential to be reused.

9.2 Tolerances & Movements

After a careful study of the drawings, the tolerances and movements were mapped.

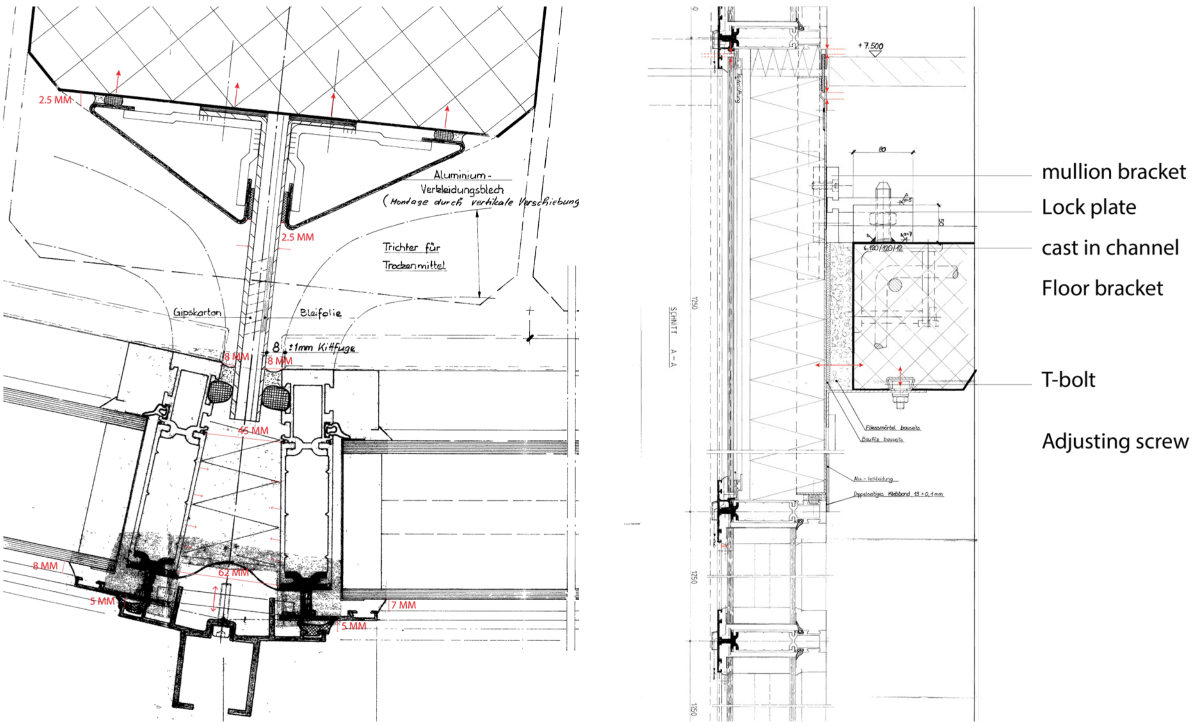


Figure 73- The red lines mark tolerances in the facade elements. Source: Author drawings were provided by Alkondor

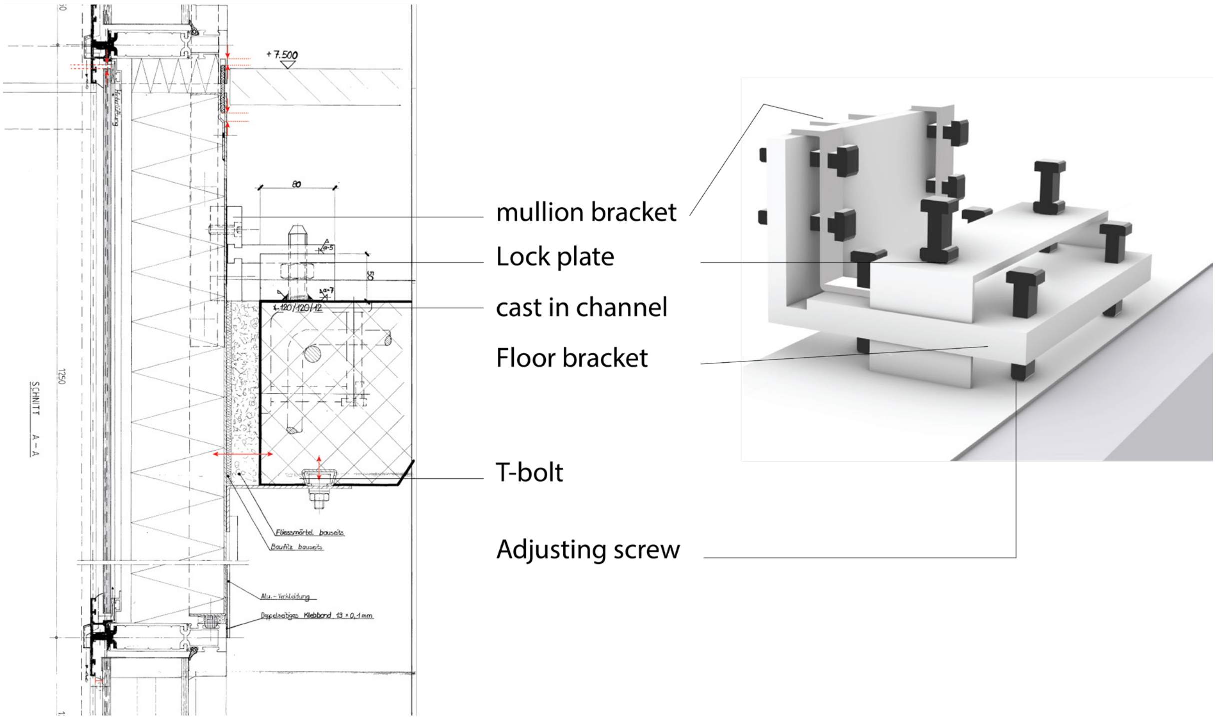


Figure 74 - A 3D view of the Floor bracket that holds the facade. Source: drawings by Alkondor, adapted by Author. Model by Author

9.3 Analysis of thermal performance of existing facade

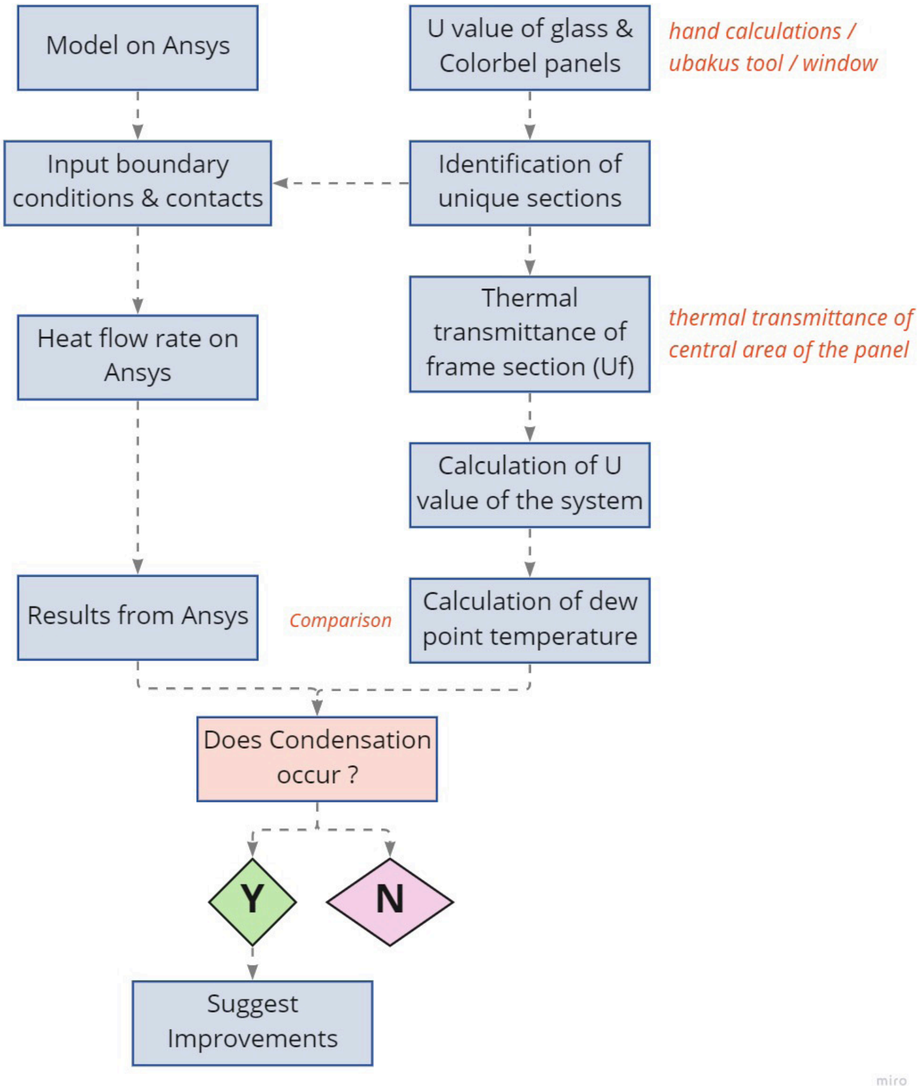
Condensation affects many buildings and can bring drastic consequences such as dampness, growth of moulds, corrosion of materials which can lead to long term deterioration of the building including structural failure. The parameters used to analyse the thermal transmittance of the frame section, linear thermal transmittance of the junction with glazing or opaque panel and condensation within the façade are described in ISO 10077-2:201 (Thermal Assessment of a Facade - Colorminium, n.d.)(Delft, 2017).

9.3.1 Thermal transmittance of the frame section

In this section, the rate of heat transfer through the assembly of a frame is calculated and expressed as a U-value. The U value of the Colorbel panel was gathered from the (U-Value Calculator | Ubakus.Com, n.d.) and the methodology adopted was also influenced and studied from (Thermal Assessment of a Facade - Colorminium, n.d.). The table below provides the final system U value. The detailed calculations can be seen in the appendix.

Uf - thermal transmittance of the frame section, in W/(m^2-K);
L_f^{2d}- thermal conductance of the section, in W/(m^2-K);
U_p - thermal transmittanceof the central area of the panel in W/(m^2-K);
b_f - projected width of the frame section (without protruding gaskets
b_p- visible width of the panel, in m.

9.3.1 Methodology followed for calculation of thermal performance



$$U_f = \frac{L_f^{2D} - U_p\, b_p}{b_f}$$

Figure 75 - (top) Methodology followed for the calculation of thermal performance. Source: Author (bottom) formula used to caluclate the thermal trasmittance at the frame section. Source: (Delft, 2017) NEN-EN-ISO 10077-2

Detail	Description	Uf	Lf2d-(Up*bp)	Lf2d [W]	Up	bf	bp
S1	Glazing-mullion-glazing	-1.469343434	-0.1322409091	0.4133590909	2.728	0.09	0.2
S2	Panel-mullion-panel	4.716565657	0.4244909091	0.4990909091	0.373	0.09	0.2
S3	panel-transom-glazing	-4.09020202	-0.3681181818	0.1774818182	2.728	0.09	0.2
S4	glazing-int transom-panel	0.7302489177	0.06134090909	0.1359409091	0.373	0.084	0.2

Table 9- Hand calculations to arrive at the thermal transmittance at the individual frame section.Source:Author

9.3.2 Calculating the U value of the entire system

The formulas were extracted from the (Delft, 2017) NEN-EN-ISO 10077-2 and the final system value of the façade was calculated to be 1.6164. The formula used for the final calculation is written below. Where U1, U2 are the U values of the glass and Colorbel panel respectively and Uf1, Uf2, Uf3 and Uf4 are U values of individual sections of the frame. The sections are mentioned in the elevation diagram included in the chapter. The sections lines in red indicate the areas where the thermal transmittance of the frames was calculated, and the area of the frames were considered in the respective places

$$\frac{(U1 \times A1)+(U2 \times A2)+(Uf1 \times A3)+(Uf2 \times A3)+(Uf3 \times A4)+(Uf4 \times A5)}{\text{Sum of all areas}} \quad 1.616449833$$

Figure76 - the formula employed for the calculation of the u-value of the system. Source: Author, adapted from NEN-EN-ISO 10077-2

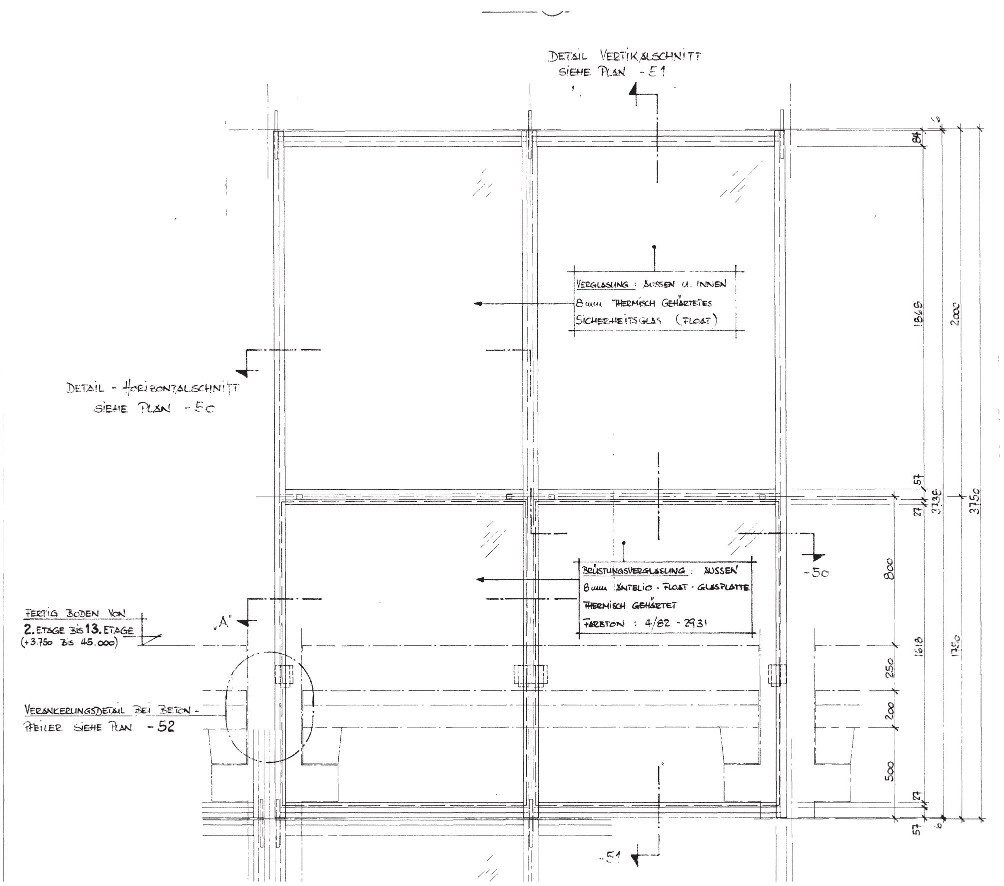


Figure77- The elevation of one of the profiles used to indicate the section lines for the assessment. Source: Author, drawings received from Alkondor

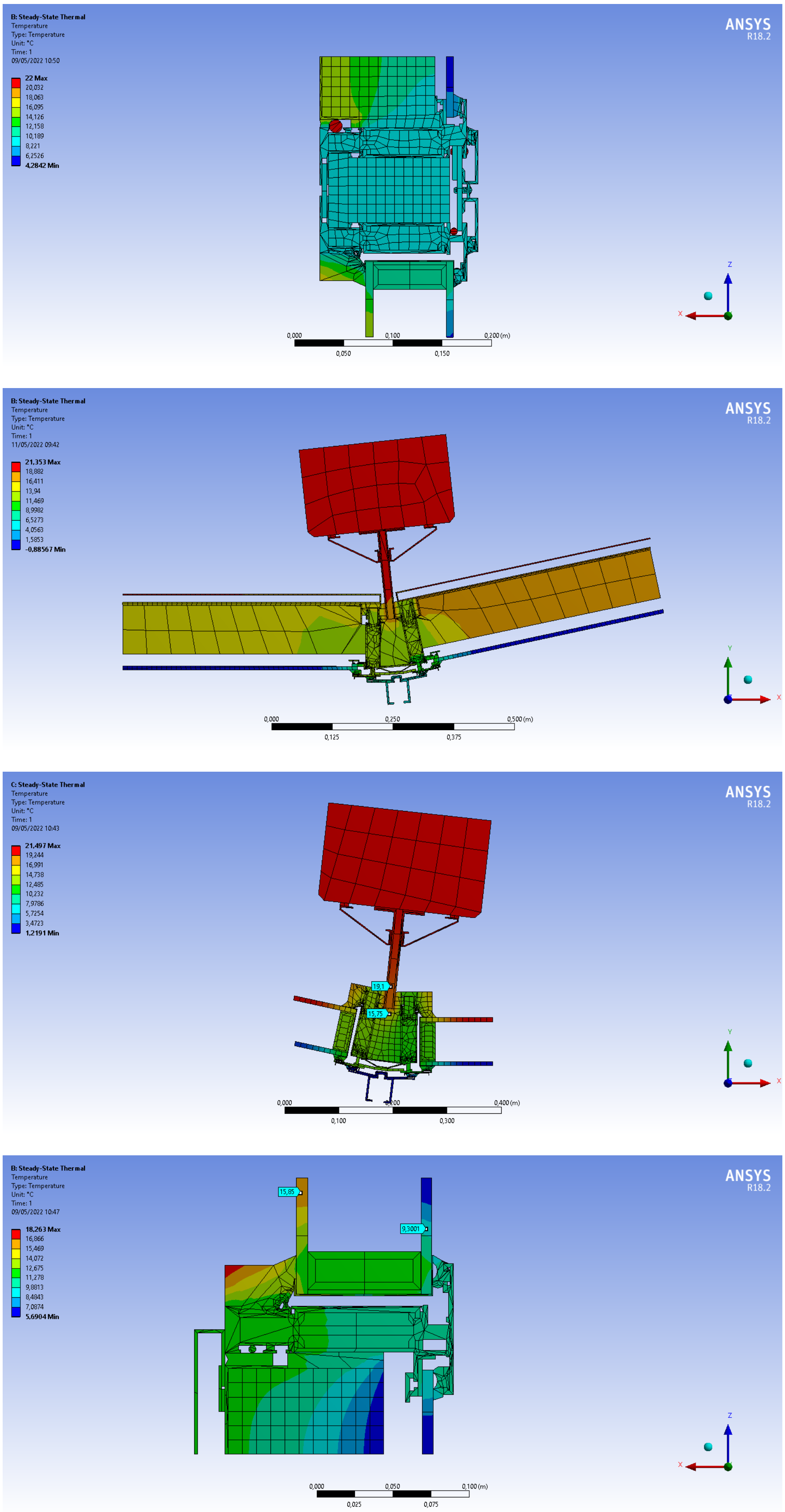


Figure 78- The thermal analysis performed on Ansys for 4 sections of the profile.
Source: Author

9.3.2 Conclusions from the thermal analysis & calculations

The formulas were extracted from the (Delft, 2017) NEN-EN-ISO 10077-2 and the final system value of the façade was calculated to be 1.6164. The formula used for the final calculation is written below. Where U1, U2 are the U values of the glass and Colorbel panel respectively and Uf1, Uf2, Uf3 and Uf4 are U values of individual sections of the frame. The sections are mentioned in the elevation diagram included in the chapter. The sections lines in red indicate the areas where the thermal transmittance of the frames was calculated, and the area of the frames were considered in the respective places

9.4 Development of water tightness concept

This section of the thesis was done with collaboration with Alkondor. The water tightness concept is crucial and most important for the functioning of a façade element. Therefore, it becomes a crucial part of the remanufacturing process. As mentioned earlier, the façade was built a long time ago, and the due to breakage of seals during disassembly. The water tightness and air permeability were damaged and had to be developed to match the performance of a new façade. The EoL façade elements were examined, and through discussion with facade experts in Alkondor, a new water and air tightness concept is made.

The design of the new water tightness system is still at a very nascent and conceptual stage. It needs to be modelled, tested, and improved further. The thesis project presents one direction to the potential solution. However, due to lack of time the design process had to be concluded and the progress made during the process is presented in the form of drawings and 3d models.

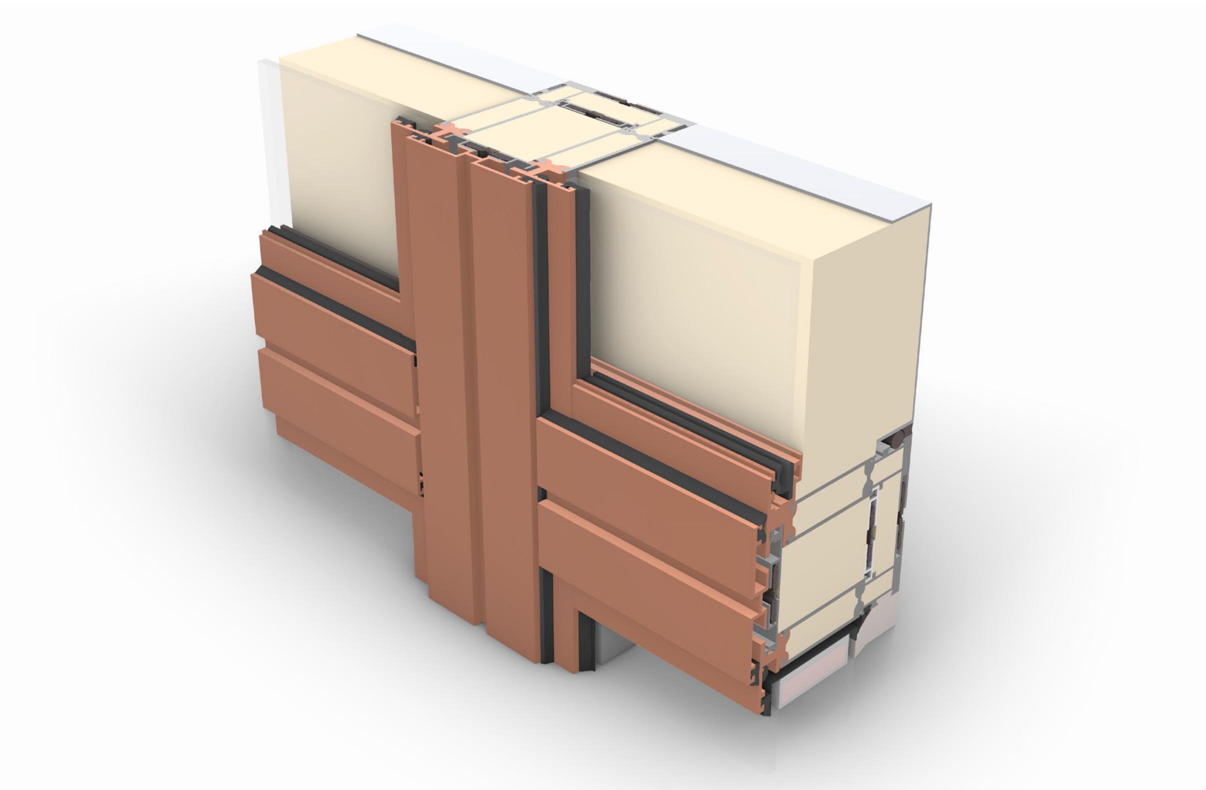


Figure 79 - The design of water tightness and air permeability concept at the junction of 4 corners. Source: Author

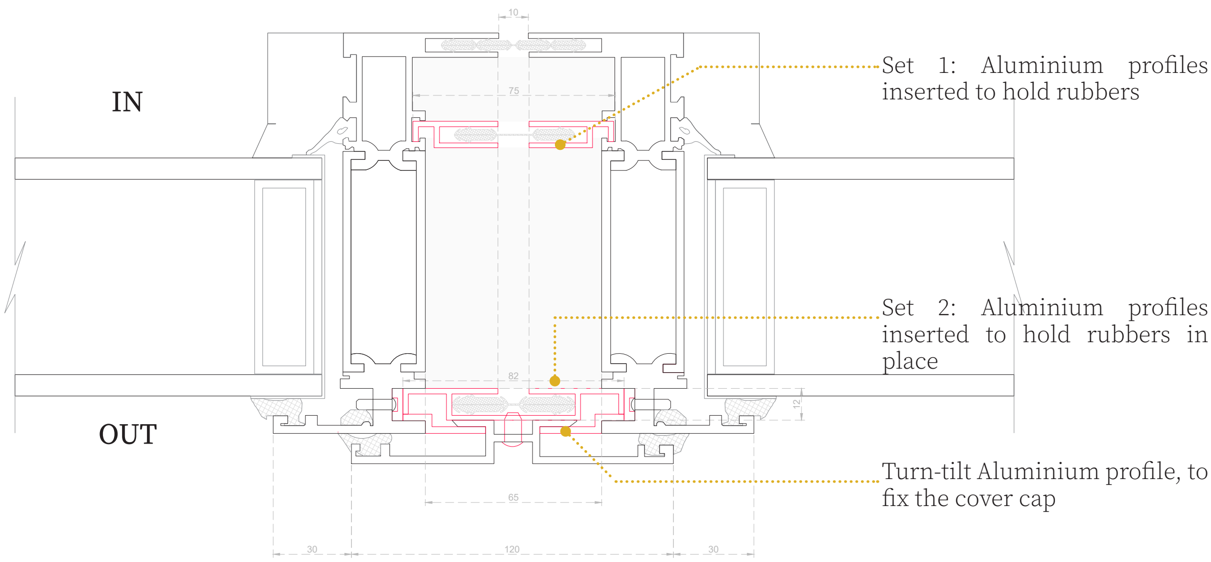


Figure 80 - The design of water tightness and air permeability concept at the junction of 4 corners. Source: Author

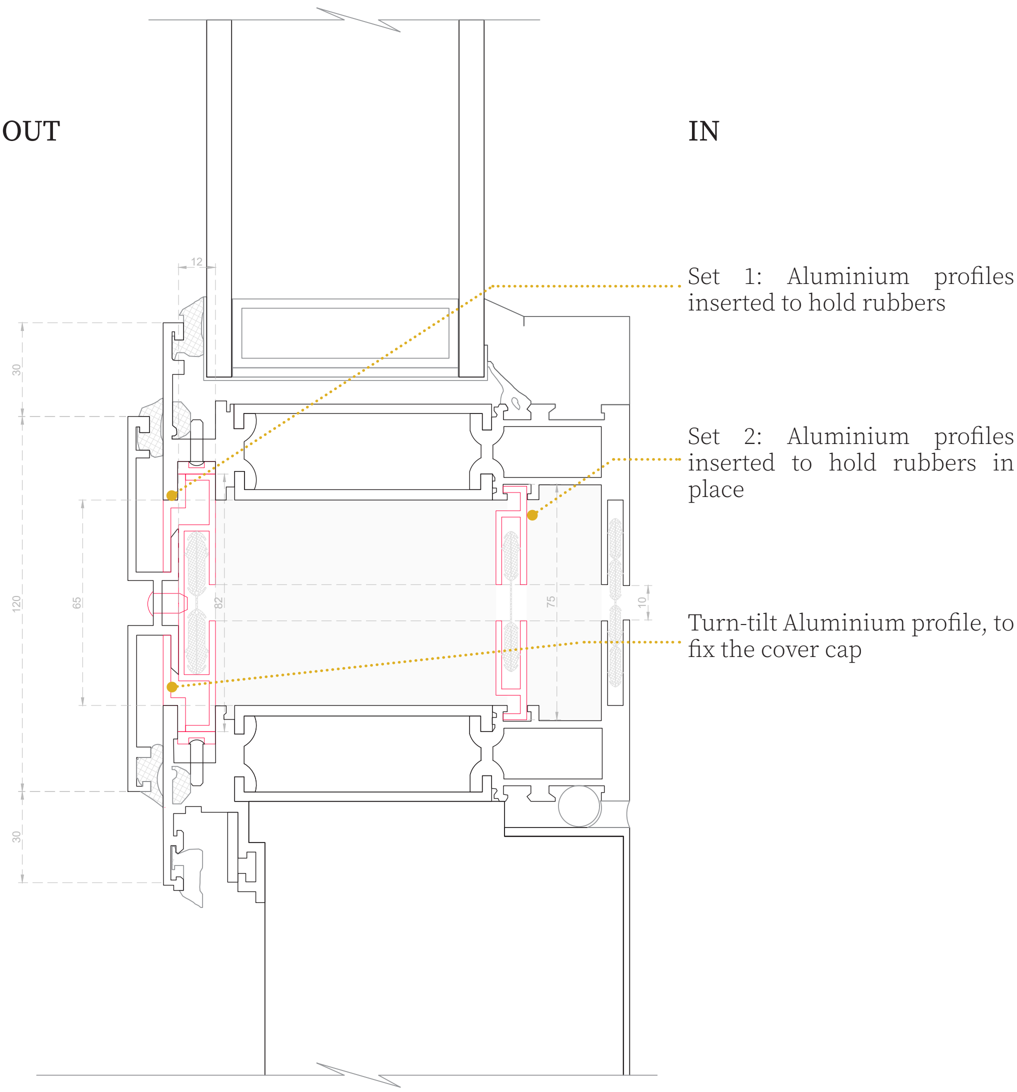


Figure 81 : Vertical section of the facade showing the new profiles inserted to support gaskets. Source: Author

The concept was to add slender aluminium profiles in the junction of two corners to hold the gaskets. Two sets of profiles are added to achieve 3 layers of defense in the facade. The cover cap is held together by inserting a profile that its turned to lock the cover cap and the new profiles. This acts as a bridge between the cover cap and the inner profiles thereby providing an area to bolt them. The idea of turn & lock profile has not been tested on a model but is a conceptual idea that has been drawn and explained with the help of a 3D model. The drawings show the new aluminium profiles, gaskets and turn & lock profiles marked in red

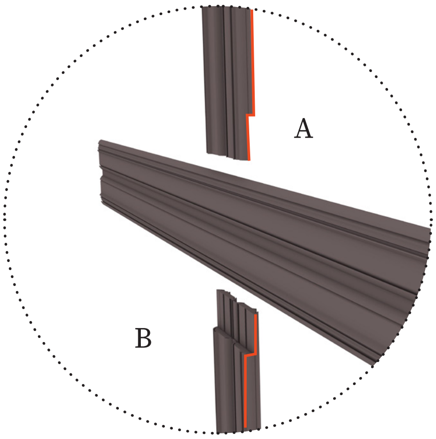


Figure 82 - The arrangement of rubbers that is crucial part to enure the facade is water and air tight. Source: Author

To lock the incoming water and mositure from entering the inside, the placement of rubbers have been designed to be continous throughout the length of the facade, to ensure a good seal. The figure, shows how the top and bottom rubbers have been cut to overlap from the top (refer to A) and continue from behind (refer to B). This arrangement is a very important detail at the junction of four profiles. The Assembly order represented by figure shows step by step how the entire junction comes together.

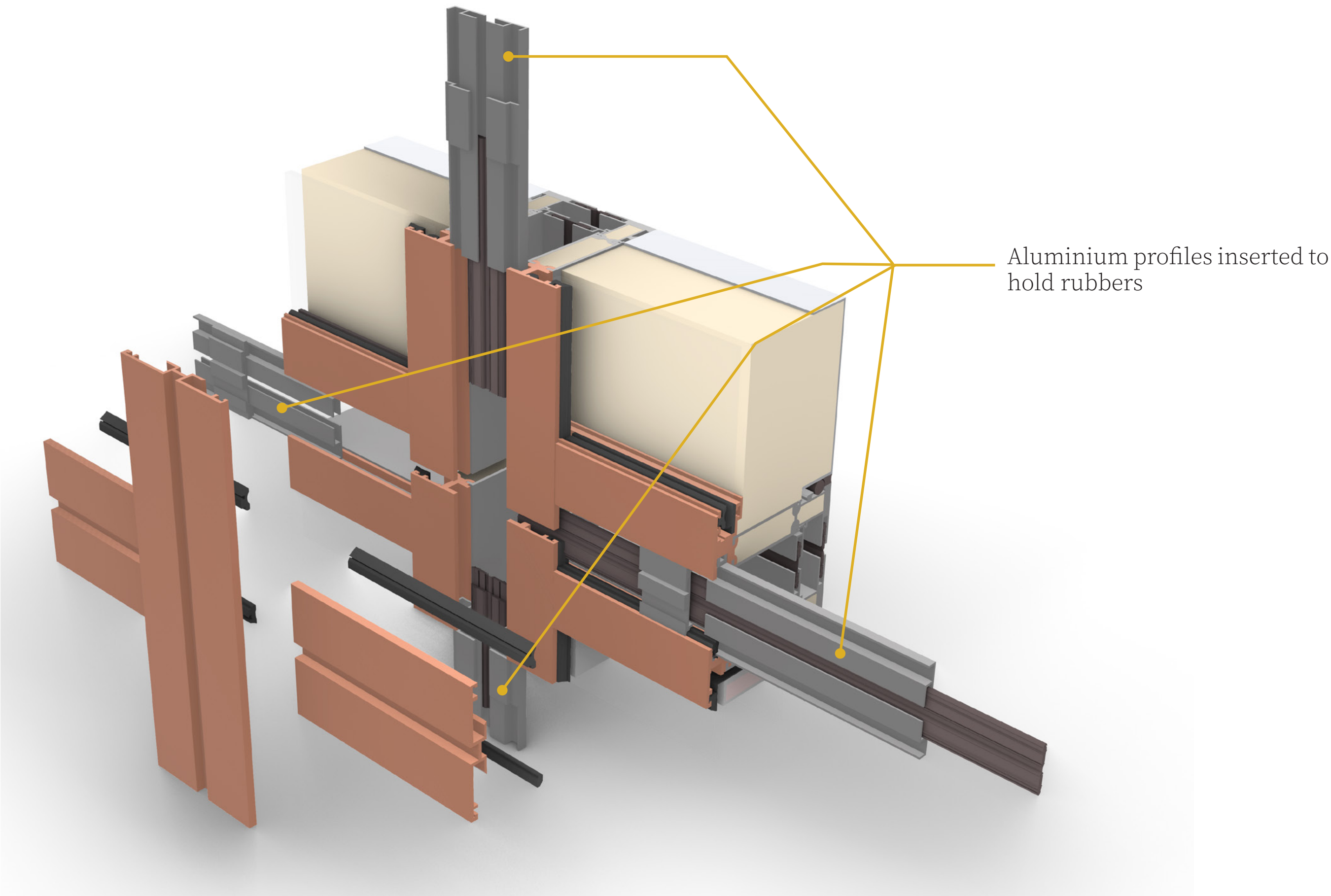


Figure 83 - Exploded view of the junction of 4 profiles. Source: Author

9.4.1 Assembly order

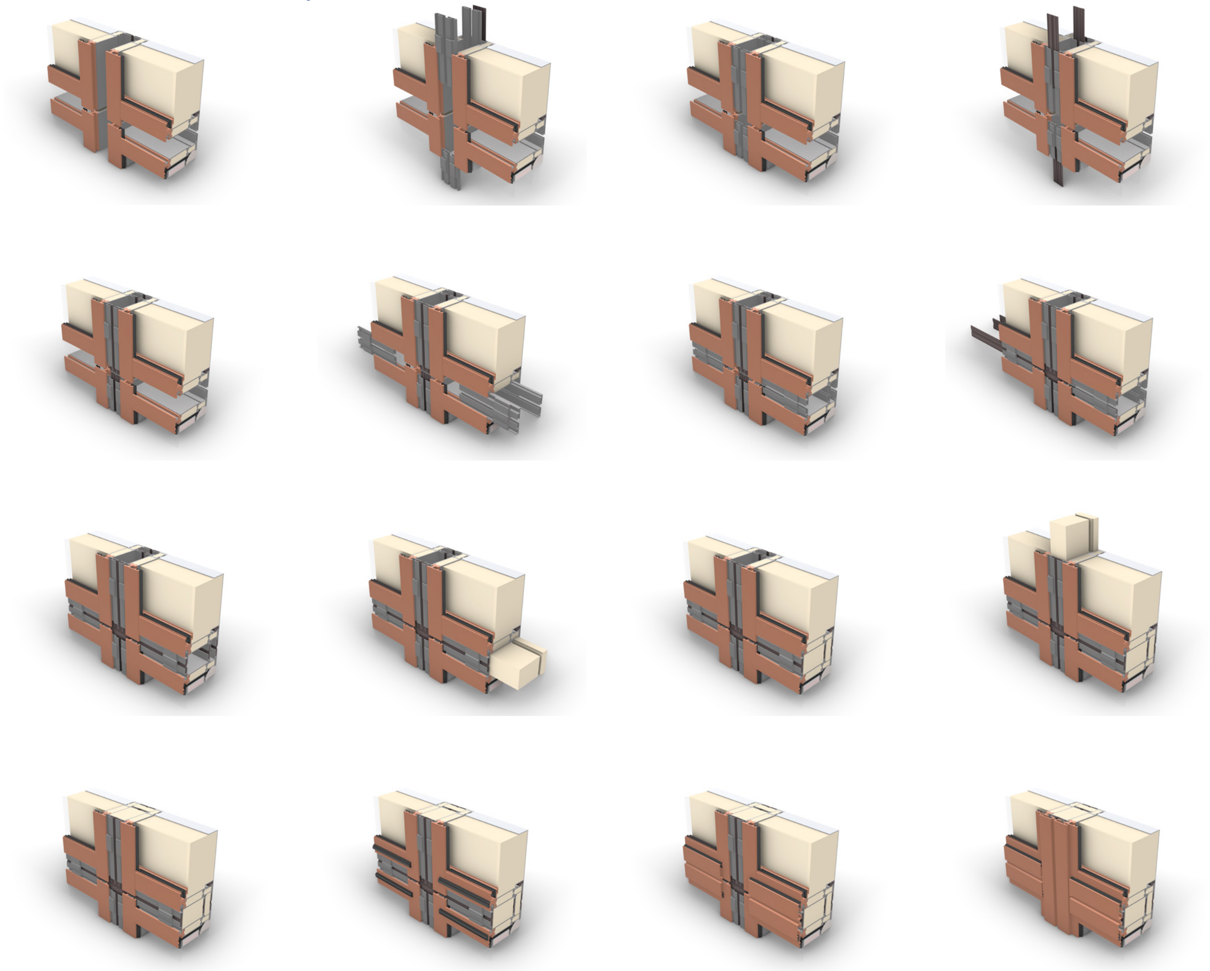


Figure 84 - Assembly order of the junction to ensure water and air tightness Source: Author

9.5 Summary

1. The risk and potentials mapped for De Satelliet in this chapter are comparable. It can be concluded that the most of the damage could have been avoided if the façade builder was involved in the early phases of the project & decision making before disassembly.
2. The façade of De Satelliet has a good Uf value which is an advantage for the reman process and contributes as an important factor to increase its demand.
3. The list of risks revealed that a majority of them could have been avoided if the façade builder was guiding the disassembly of facades.
4. This way the quality of the elements could be ensured and inturn decreased the pressure of labour in the remanufacturing process.
5. The hand calculations revealed that the U value of the system and still abides the building regulations.
6. The disassembled façade elements of De Satelliet, was conceptualised and built from very high-quality materials, which makes it promising to remanufacture and reuse. Therefore, the professionals at Alkondor consider the EoL façade elements of De Satelliet to be rare and one of a kind and believe that this situation is unlikely to occur with any other old building.

10 Assessment of the entire project

The chapter assess all the steps taken in the project to reach the deliverables and conclusions presented in the following chapters.

10. Assessment of the entire project

10.1 Introduction

The goal of the assessment is to evaluate 'reman' as a circular strategy for the building industry. The assessment is supported by analysis of the case study of EoL façade elements of De Satelliet, which has been discussed in the previous sections of the report. The study from all the previous sections can be concluded to say that the remanufacturing process requires co-operation by all the stakeholders in the industry such as the urban miner, façade builder, architect, contractor et.al. Therefore, the whole process, will be feasible if it only yields benefits to every party present in the project. The objective of the assessment is to quantify benefits

- Assess the canvas proposed based on feedback from the company experts
- Comparison of cost and labour required for reman process versus to building a new facade
- Environmental impact assessment in terms of embodied carbon emissions to evaluate the impact as a hypothesis. This is due to the lack of precedents making it difficult to gather data.

10.2 Importance of adopting circular principles in design of facades

A circular building is an entity that is self-sustaining with renewable energy wherein it is built up of circular building product levels that are designed for disassembly and upgradability, with a possibility of the proposed re-life options in a hierarchical manner. The current design of building products is centred around single use and the building industry has not fully established reverse channels to take back the product at EoL. When a EoL building product is demolished and recycled, the valuable embodied energy is lost.

From the previous sections it can be concluded that all building components must be regarded as independent units and consequently the components and materials within the façade should also be seen as independent parts of the system, to enable transformations at a component and material level.

Facades can reach the end-of-service due to a variety of reasons namely, exposure to external harsh environmental conditions, change in aesthetics and design features, energy regulations, change/adapt to new functions of the building. There is a plateau in the evolution of design in terms of increasing u value.

Another important feature to note is that despite the low life span, they account for at least 20% of the cost of construction, can have a surface to floor area of ratio of around 40% for most tall buildings. (The Tall Buildings Reference Book - Google Books, n.d.) Although the other parts of the building have tolerances in centimetres, the facades are attributed to have high quality precision, and complexity in detailing. A report on unlocking the potential of glass façade systems elaborates a research conducted by Cole and Kernan (Hartwell & Overend, 2019) which discovered that the façade is typically responsible for approximately 25% of the total initial embodied energy.

10.3 Exploring relevance of the canvas to the building industry

Summary of all the interviews

The section summarises all the interviews that were conducted to validate the design for reman canvas for its relevance in the building industry. The design for remanufacture canvas made by the Author (explained in Chapter 7 framework) was discussed with company expert and mentors. The table 10 categorises feedback under the column – how does it influence De Satelliet. By discussing its relevance to the case study, the gaps, and potential bridges to introducing remanufacturing for the building industry was understood. The column - key point of consideration summarizes the discussion and reflects on how the canvas can be improved further. For the purpose of the thesis, the canvas is a material that has the potential to begin the conversation on potential for remanufacturing for the building industry.

10.4 Lessons learnt from De Satelliet

On disassembly, logistics and storage

1. It is always advised to lift, transport and store façade elements vertically. Ror example using glass suckers. This ensures that the forces are distributed equally and can support the element in a secure manner
2. It is always recommended to transport vertically on one side. The option to transport upright is also preferred over horizontal lifting or transport
3. If a set of façade elements are lifted horizontally, care must be taken to place a beam under the elements which is then lifted by using lifting straps. This way by lifting them in one piece it will not cause damage
4. In cases where the transport must be horizontal and flat due to water ways of transport, it must be ensured that the surfaces are 100% flat and stored in a crate. A welded steel crate is most preferred, but it can be very expensive.
5. In cases where crates are used, cranes can be employed to lift them and aid in transport.
6. Similarly, during the process of storage, it must be ensured that they are placed on 100% flat surfaces to avoid damage to the façade elements due to unequal distribution of forces.
7. There are innovative sprays with which the glass can be sealed to reduce its exposure to scratches, moisture, and dirt.

10.5 Guidelines for remanufacturing process of EoL facades

The observations from analysis, site & factory visits and interviews were analysed to make a set of guidelines that can be followed for remanufacturing process of EoL facades starting from inception of the project to remanufacture and assembly. The guidelines are a compilation of all the information gathered through interviews and conversations. The guidelines were made and revised to include perspective of a researcher, a façade builder, and the client (RE:BORN), who are the Author, the experts, and professionals at Alkondor and the client respectively.
The guidelines have been divided into the following phases:

- Phase 1: Preliminary Planning Phase -This phase id dedicated to desk research and on-site inspection which is crucial to gather all the data and establish a business case.

Desin for remanufacturing criterias				
Ref.criteria	Hypothesis/question	How does it influence De Satelliet?	Interpretation	Key point for consideration
		Detailed product design		
Embedded value	What are valuable parts of the facade that can be introduced in multiple lifecycles?	Reusing the entire facade has the highest value. The frame is made of high value materials Aluminium and Bronze. The labour involved to disassemble the facade into fragements is high. So it is preferable to use it as is.	The frame can be reintroduced into the next cycle after reman process. This makes it feasible. The Glass, glazing beads, gaskets must be replaced. The facade can be upgraded to suit new design requirements	The use of high value materials in the design phase always pays back at EoL
Evolution rate - technology	What kind of evolution do you expect in the future with the design of facades?	The facade was built <30 years ago, and the new facades today are designed for high performance, which adds pressure on the remanufacturing process to make it comparable to a new product designed today	There is a plateau in the evolution in terms of U value, the new innovation is now driven by principles of Circular Economy.	The evolution in the future will be focused or lean towards achieveing circular design.
Evolution rate - Upgrade potential (All DfX Strategies)	What kind of evolution do you expect in the future with the design of facades?	The facade is made of high value materials, but it was not designed for disassembly, the environmental factors that lead to degrade of facade elements was not considered, which makes reman process difficult and labour intensive	Investing in high value materials in the first cycle gives a chance to prolong the life cycle of the product. A good strategy to identify and remanufacture high value facades like this.	The use of high value materials in the design phase always pays back at EoL
Re-constructability-Knowledge	Are the skillset of the present labour enough to remanufacture the EoL facade?	A percentage of the workforce at Alkondor possess the skillset to remanufacture the facade. To make this process efficient for large project, the workforce must be educated	To achieve efficiency in large reman projects, workforce must be trained and formats and modules of reman must be developed so it can be followed. Large projects will also require an upgrade line to achieve efficiency	For new facades, the information for reman process and guidelines can be embedded in the BIM modules (digital twins) to make it accessible for all stakeholders.
Re-constructability - Construction process	During reman process of facades, construction of which element is crucial than the other? Do you forsee making manuals and guidelines for an efficient process?	In case of De Satelliet, the process of disassembling the frame might turn to be very labour intensive and may make the whole process not feasible. Alkondor has profiles designed for disassembly.	The process of disassembly of frames is feasible if it is designed for it. In case of De Satelliet the profiles should be reused as is to make the reman process feasible.	Design for disassembly is key for facades.
Re-constructability - Remediation	What tests can be performed to assess the quality and impact of the remanufactured product?	The other stakeholders involved in the project namely IMPACT has calculated and produced a positive result on all the steps completed so far in the project	Through basic calculations by the Author it can be concluded that remanufacturing avoids the impact of raw material extraction, transport and manufacturing of virgin materials	remanufacturing can be more profitable than recycling as it retains the physical nature of the product
		Product Strategy		
Business model for core collection	Which business model would be suitable for collecting facade cores at EoL?	This was found to be extremely relavant but there was no solution/recent applied examples	The CiTg building together with Alkondor are working on a Facade as a service model, which explains that it is a service-based contract.	This criteria has relatable and has a lot of potential to be applied in the building industry in the future.
Closed-loop supply chain	How can the EoL facades be sourced in a circular manner? What is the greatest challenge in reclaiiming (parts) of the product?	This was found to be extremely relavant but there was no solution/recent applied examples	It can be expected to be implemented in the near future	This criteria has relatable and has a lot of potential to be applied in the building industry in the future.
Reverse logistics	How can channels be implemented to collect the product at EoL?	This was found to be extremely relavant but there was no solution/recent applied examples	It can be expected to be implemented in the near future	This criteria has relatable and has a lot of potential to be applied in the building industry in the future.
Application of digital workflows	In future, how can Alkondor stay close to its assets and ensure return/take back at EoL?	This was found to be extremely relavant but there was no solution/recent applied examples	The sale of services such as maintainance and surface treatment can make a facade builder stay close to & monitor the assets for take back at EoL	The application of RFID tracking and computational workflows can assist in transferring information between all stakeholders
Brand value	Do you think the facade remanufactured by your company will be bought as the customer is aware of your quality and service?	Brand Value is an important topic today and by investing time in this project will add value to the company and will open themselves to interesting oppurtunities	The implementation of new regulations and more real estate developers leaning towards creating a positive impact will increasing the number of reman projects in the future	Creation of a brand value for sale of remanufactured goods is vital
		Union of both fields		
Evolution rate - Legislation	What new regulations do you forsee being implemented in the future?	The regulations with respect to fire protection might become more strict in time, but	The implementation of ESG and MPG are going to drive the need for circular design of products.	The New regulations that exist now and the ones applied in the future will guide remanufacturing of EoL products
Cost Structure	Which stages of reman process will incur more cost than the other	Labour and materials are key in terms of driving the total cost of the remanufacturing process	It is an important factor that can be controlled by careful disassembly and reman plan	Labour and cost of materials will determine the impact and feasibility of reman process
Demand	How can a facade builder like you grow the demand of remanufactured products?	By remanufacturing EoL elemenst of De Satelliet, the customers will have the choice of buying products that are sustainable and require less energy than new products made from virgin materials	The increase in use of sustainble goods in the industry will drive the demand of remanufactured goods	The Environment performance, legislation and ESG will contribute to the demand of remanufactured goods in the future

Table 10-- Summary of all interviews describing the relevance of the canvas in the building industry. Source: Author

10.5 Guidelines for remanufacturing process of EoL facades (cont.)

- Phase 2: Design & Examination Phase – During this phase, components are examined, redesign concepts are made, and an expected quality level after disassembly is established. This is important for a decision to move to the next phase.

- Phase 3: Destructive and Testing Phase – During this phase remanufacturing process is carried out on a small number of disassembled products to ensure success after large scale disassembly of components.

- Phase 4: Final Disassembly Phase – During this phase, the real disassembly happens, the elements are moved to either storage or reman facility to be remanufactured.

- Phase 5: Remanufacturing process – The steps in this phase vary with every project, and is carried out with the cooperation of all stakeholders and parties involved in the cleaning, design, and assembly phase.

The figures 88-91 are flowcharts explaining the remanufacturing process of facades in detail. The guidelines also contain dialog boxes, which explain the importance of a procedure in a particular phase.

10.5 Guidelines for remanufacturing process of EoL facades (cont.)

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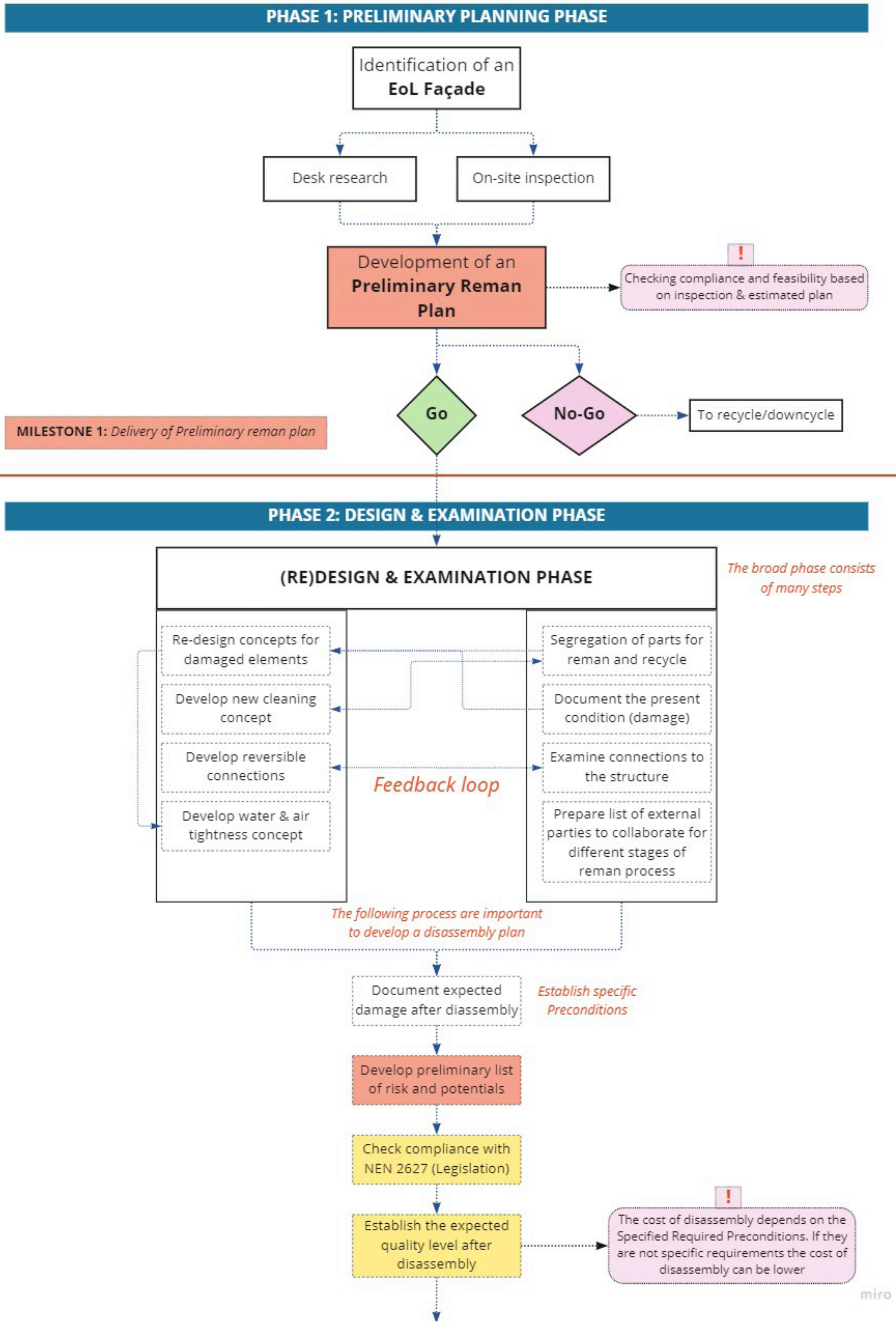


Figure 87- Part 1 of the guidelines for remanufacturing of EoL facades. Source: Author

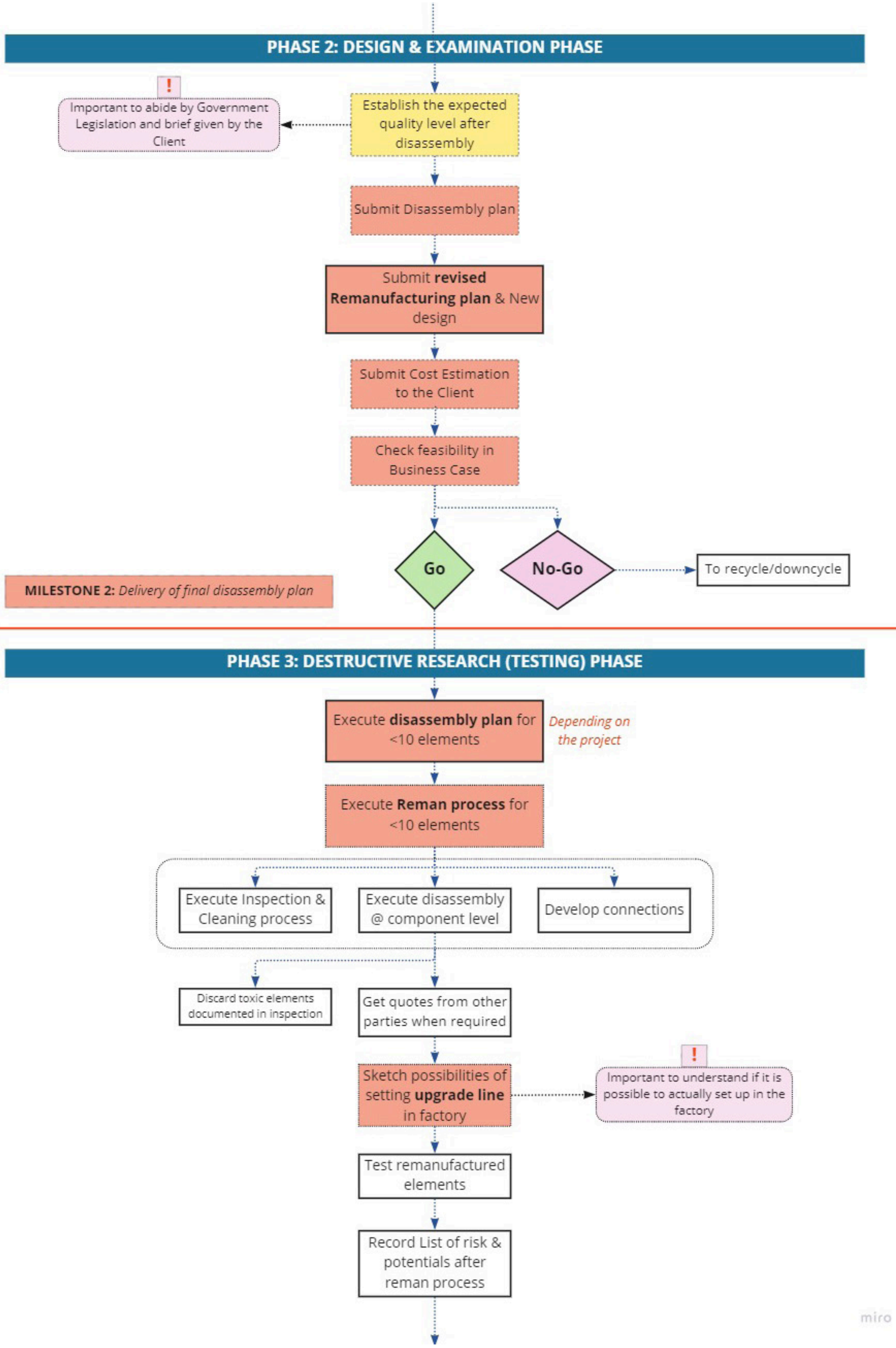


Figure 88- Part 2 of Guidelines for remanufacturing of EoL facades. Source: Author

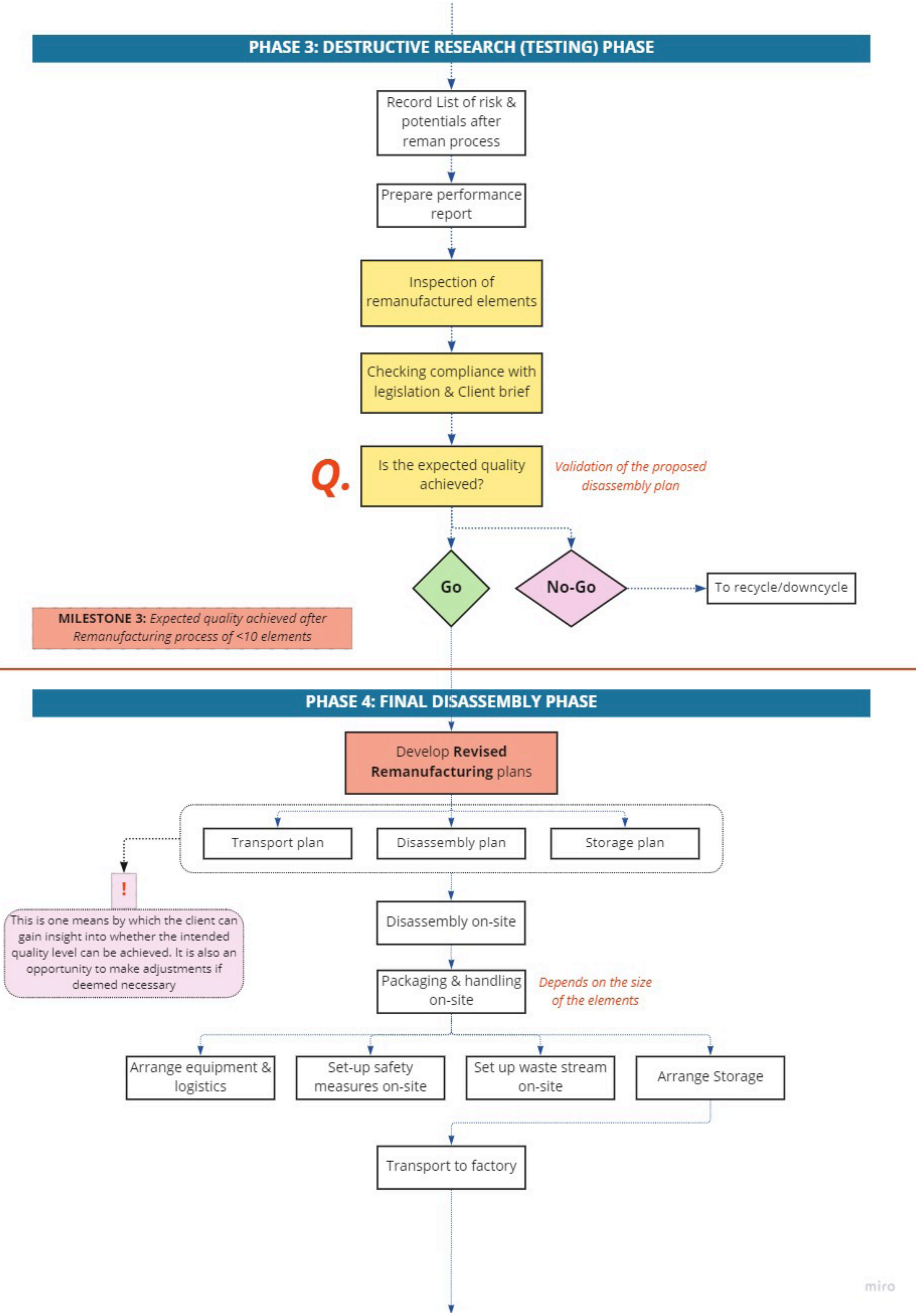


Figure 89- Part 3 of Guidelines for remanufacturing of Eol facades. Source: Author

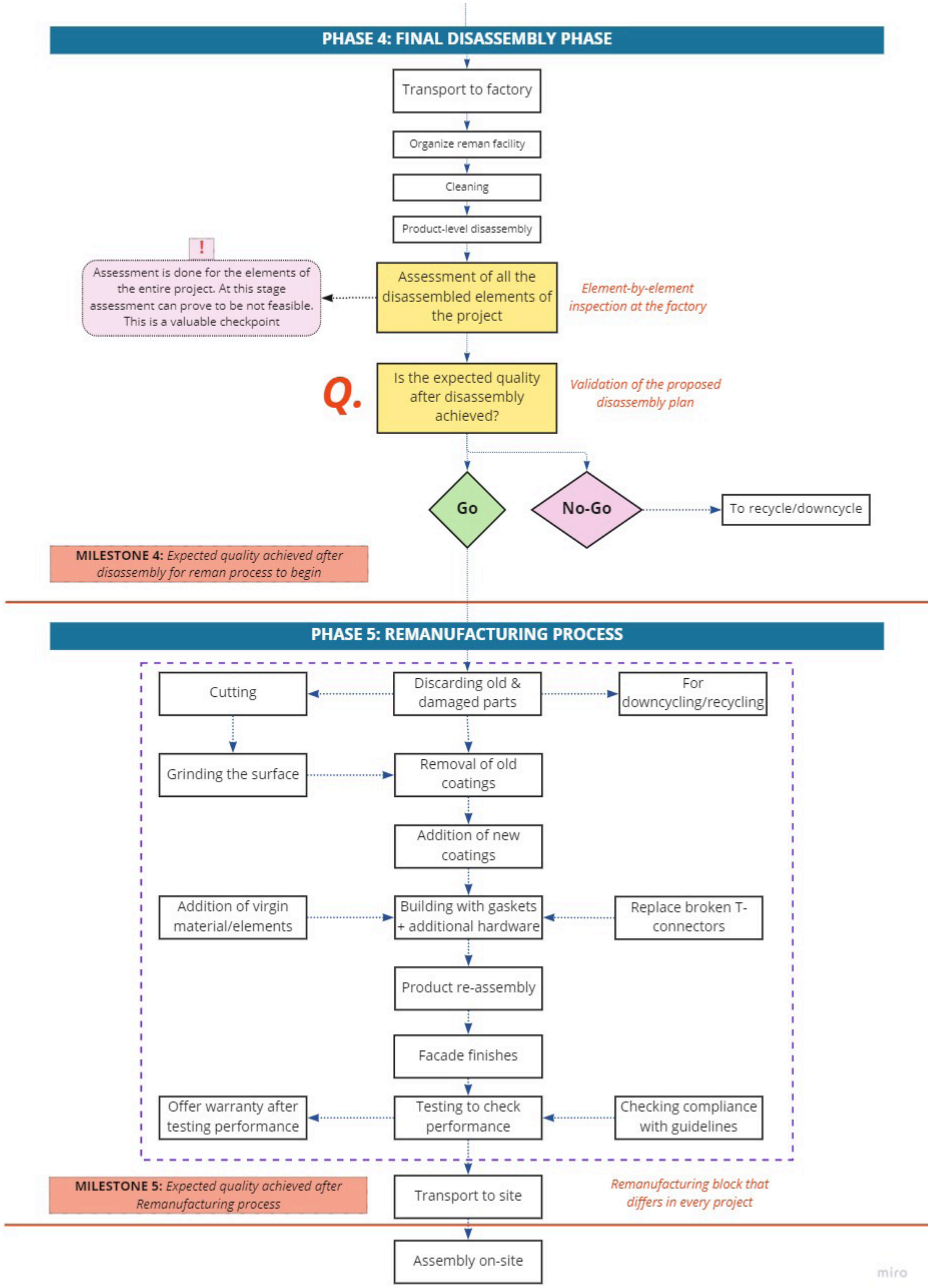


Figure 90- Part 4 of Guidelines for remanufacturing of EoL facades

10.6 *Environmental Assessment of remanufacturing process*

10.6.1 Goal & Scope

The goal is to study the environmental impacts of remanufacturing an EoL façade elements. This study aims to calculate the embodied energy result of the remanufacturing process. During the process, it has been assumed that Aluminium & Bronze will be recovered for remanufacturing. Thus, separating the single life elements such as glass, gaskets, and sealants from multiple life elements such as Aluminium & Bronze. The reman or reuse of the elements such as gaskets, thermal break and glass has not been established in the industry and is beyond the scope of the project. The author requests the reader to perceive this chapter as a hypothesis. , this section of the report is to view this section as a hypothesis and not generate conclusions through numerical values mentioned in the report.

Reman scenario: This scenario reuses the entire aluminium and bronze frame. A new water and air tightness concept is introduced which means addition of virgin materials such as gaskets, glass, and thermal break. The reman process will involve repair of broken T-joints, the profiles that have been damaged and bent due to the impact. This also includes those which contained a rubber seal.

For the purpose of this calculations, it is assumed that the reman process will involve,

- Inserting of a turn-tilt module, cleaning of bronze profiles, replacing a new sheet material
- Upgrade of new glass panes and gaskets
- Replacement of glass panels

10.6.2 Methodology

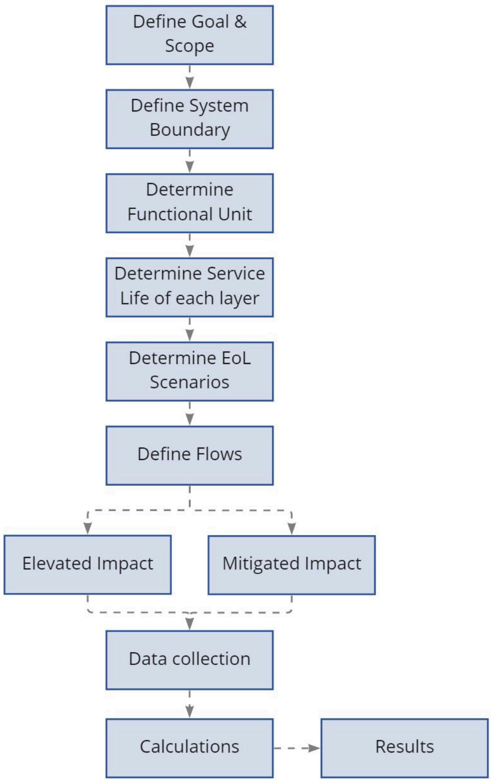


Figure 91- Methodology followed for the calculation of embodied carbon. Source: Author

10.6.3 Life Cycle Impact Assessment

This section is dedicated to the Life Cycle Impact Assessment. The research focuses on discovering opportunities to avoid waste through an assessment focused on the EoL stage and evaluate the potential of recovering aluminium and bronze profiles. The LCIA assessment differs because it relates to many input and output flows in terms of energy used throughout the life cycle, known as inventory values, as compared to a smaller number of impact themes. The figure 91 highlights the life cycle stages that are included in the assessment.

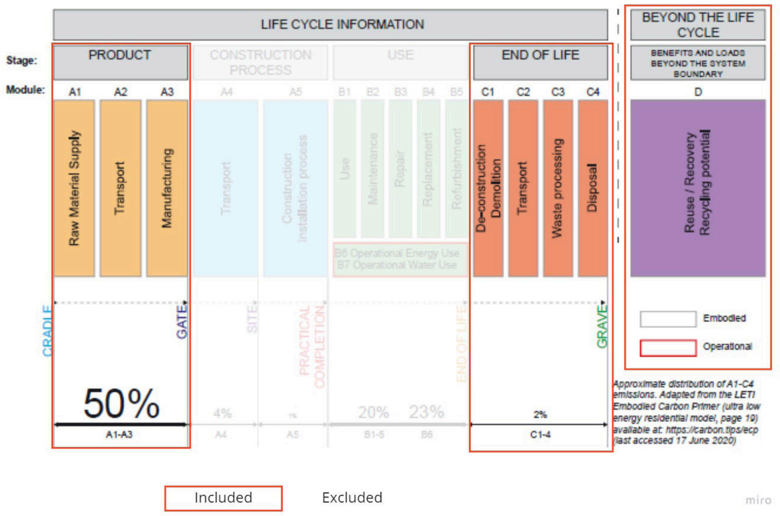


Figure 90- Part 4 of Guidelines for remanufacturing of EoL facades

10.6.4 Defining System boundary

The Authors Overend and Hartwert defined a functional unit that serves as a foundation for a fair comparison of environmental impact across different EoL scenarios. The EoL façade elements of De Satelliet are used as the functional unit for this study. It is a type of window wall system that measures 2800 X 3750 mm and is composed of Aluminium and bronze profiles together with double layer glass with a large cavity (8-75-8) / no-openable double-glazed unit in combination with a sandwich panel composed of 8mm glass followed by 100mm rockwool insulation. The material mass calculations were obtained by simple hand calculations by extracting dimensions through drawings and models.

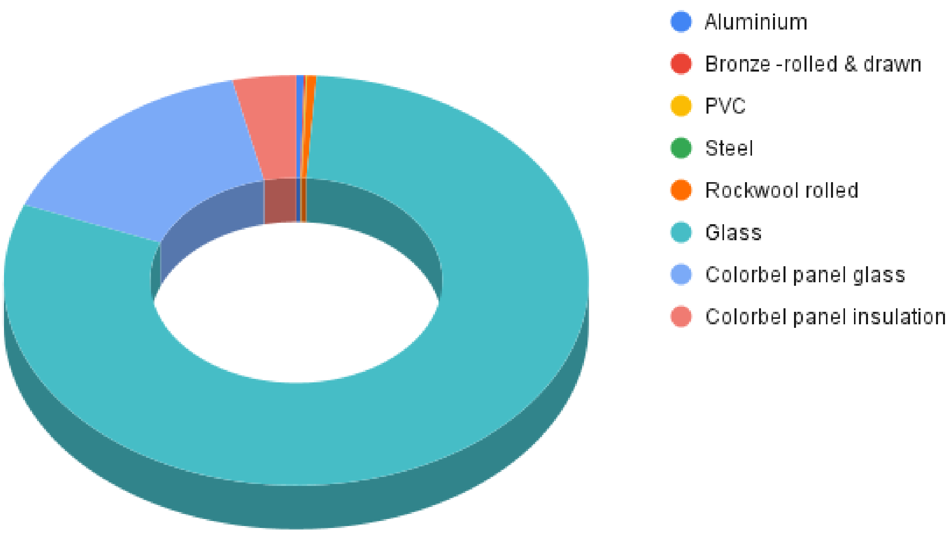


Figure 93-The material composition of the functional unit under consideration. Source:Author

10.6.5 *Defining System boundary & EoL scenario*

The scenario under consideration is the all the flows involved in the remanufacturing process. The current façade economy operates on a take-make-disposal system. The design of the façade revolves around single use and assumes that materials are disposed or find themselves in landfill. The recycle and recovery of materials have begun but are limited to Aluminium and other high value metals. The two flows are named as 'Mitigated impact' and 'Elevated impact'. A reference façade: Schüco AF UDC 80 (Aluminium Façade Unitized Dynamic Construction) is chosen as it is close to the current design of EoL façade elements. This has been chosen for a fair comparison of results of remanufacturing of EoL façade elements.

The ***Mitigated impact*** from the remanufacturing of EoL façade elements can be defined as follows:

- The savings made from avoiding disposal of EoL materials in the ecosystem are indicated in Module C – End-of-life-Disposal of the life cycle. It constitutes of on-site demolition energy (C1), transportation to recycling facility (C2), waste processing (C3) and disposal of waste from recycling stream (C4)
- The savings incurred by reusing the materials through remanufacturing process avoids energy required for extraction and production of raw materials and are indicated in the Module A of the life cycle, that entails raw material supply (A1), transportation (A2) and manufacturing (A3).

The ***Elevated impact*** from the remanufacturing of EoL façade elements can be defined as follows:

- The elevated end-of-life impact occurs as a result of careful disassembly of materials and remanufacturing to re-introduce them in the next cycle. This constitutes the disassembly energy required on-site and deconstruction energy at the factory (C1) followed by transportation energy to a reman facility (C2), processing energy (C3), and disposal of generated waste.

The assessment focuses on the A1-A3 and C1-C4. The impact of modules (A4-A5) and use module (B1-B7) is assumed to be negligible on the advantages of remanufacturing of EoL elements and as a result are not included in the system boundary.

The Scenario: The Aluminium and Bronze profiles are reused from the EoL façade and remanufactured to build a new façade. In the first use phase, the EoL evaluation of this stream had accounted for recycling of materials, Therefore, reuse of the materials from this stream can be regarded as savings from its proposed EoL recycling and production of virgin materials.

Design Scenario conditions for assessment		
Scenario	Condition	material recovered from remanufacturing
Scenario	remanufacturing of materials from disassembly	PVC profile cap
		Aluminium profiles
		Bronze profiles
		T connectors (seems possible)
		Aluminium glazing beads

Table 11 - Design scenarios for assessment. Source: Author

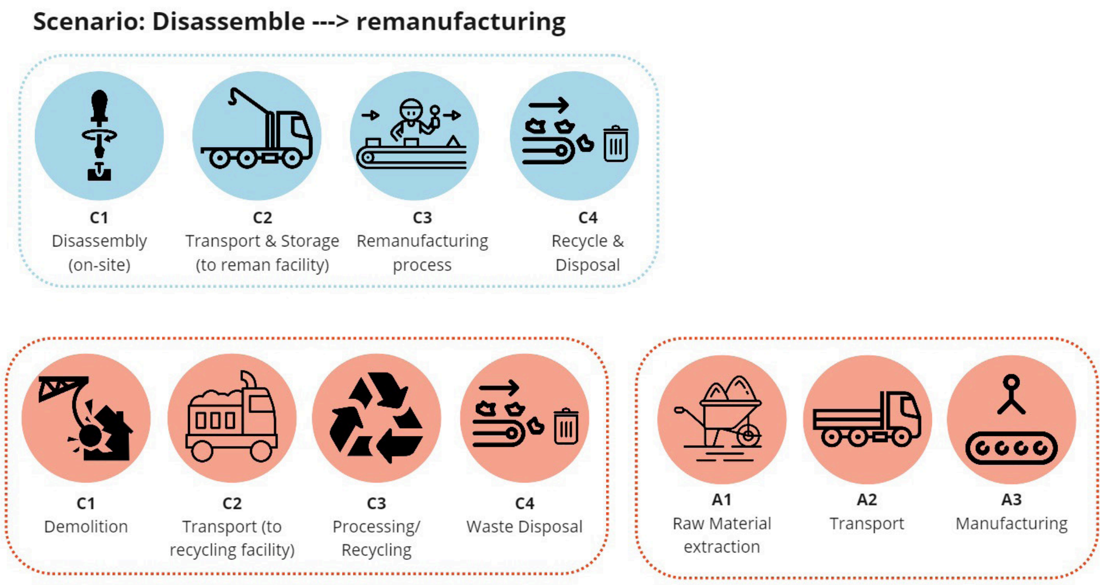


Figure 95 - Scenario 2 assessing disassembly to remanufacturing process. Source: Author

10.6.6 Gathering data

The data for the assessment is gathered from different sources like EPD's, and reports. During the calculation process, a lot of co-efficient were assumed, to obtain approximate values. This made the calculation process challenging and is the reason why the results are presented as a hypothesis and not an accurate representation of numbers and figures.

10.6.7 Discussion of results

This section elaborates the result obtained from the embodied carbon calculations that was described in the Chapter 10. Due to lack of available data and respective co-efficient at every module, the Author requests the reader to treat the results obtained from this assessment as a hypothesis, which brings awareness on the avoided and mitigated impact by adopting remanufacturing process. The first step was to calculate the percentage of materials in the functional unit shown in figure. This was done by hand calculations and the information was extracted from the drawings. The calculations map the following

1. *Mitigated impact:* The savings incurred by remanufacturing Aluminium and bronze profiles rather than demolition and recycle is mapped by C1-C4. This also calculates the amount of energy required for disassembly, transportation, and processing.

2. Avoided Module (C1-C4): Due to disassembly for remanufacturing, the energy to demolish and recycle has been avoided.

3. *Avoided Module (A1-A3):* Due to remanufacturing process, the production of new profiles has been avoided. So, the modules A1-A3 for Aluminium and Bronze has been calculated.

4. *Added Module:* The remanufacturing process includes addition of virgin materials such as gaskets, glass, and sealants to suit the demands of new project. This module is calculated by addition of impact of new materials (A1-A3) of glass, gaskets, and sealants.

As mentioned earlier, the calculations map the substituted EoL that happens due to remanufacturing. This is then followed by calculation of Avoided module (C1-C4) which begins with demolition to recycle. The avoided module (A1-A3) by reusing the Aluminium and bronze profile is calculated. The last step is the addition of a new window, EPDM gaskets, Colorbel panel and rockwool insulation. This is regarded as the added module (A1-A3). The pie chart below shows the first results. Due to lack of precedents, it was challenging to find data and the respective co-efficient for each of the steps. Therefore, the results are presented as a hypothesis, to ensure that there is a room for development in the future

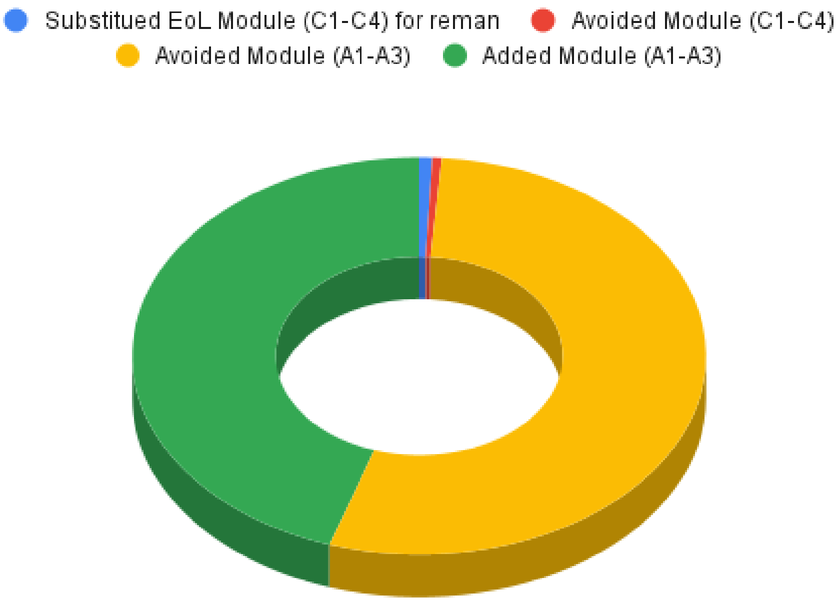


Figure 96 - The overview of added and avoided impacts of all modules. Source: Author

11 Comparison of results

The chapter presents the all the results gathered to argue the benefits of remanufacturing in terms of thermal analysis, and cost estimation.

11. Comparison of results

The previous chapters explain the concept of remanufacturing and the design for remanufacturing canvas. This is supported by the case study of De Satelliet. This study is treated as a backbone for research and gives the opportunity to apply all the theory from case studies to practice. This chapter serves as a validation of framework by testing its relevance to the building industry. This is done through analysis and comparison on three levels namely:

1. Cost
2. Thermal performance

A single façade panel of the De Satelliet is considered for the calculation of cost, thermal performance, and embodied carbon. The results from each of the are tabulated and comparison between remanufacturing process and construction of a new façade is made.

A reference façade was chosen to make a fair comparison. The criteria under consideration to choose the façade was namely,

1. Window wall façade
2. Large dimensions
3. Valuable materials (Aluminium/Bronze)

The final that closely matches the above-mentioned characters is Schucö AF UDC 80 (Aluminium Façade Unitized Dynamic Construction). In the following sections, results from each of the analysis are compared with the properties of the reference façade.

11.1 Comparison of costs

The section is dedicated to elaborating on the cost incurred during remanufacturing process. The guidelines made for remanufacturing of EoL facades were used as a basis to make an estimate of the average cost incurred at every step. The worksheets made in this process can be found in the appendix. After the costs were mapped, comparisons were made between each phase in terms of the number of materials and labour necessary at each phase. The results are represented in the form of graphs and will be explained individually in the following paragraphs.

11.1.1 Material versus Labour Cost

The first calculations were to calculate the amount of material and labour cost for each of the phases (as stated in the guidelines to remanufacturing of EoL facades). The results from the calculations were as expected. The material cost is significantly lower than Labour cost. This is described in Figure . The result is considered to be valid because in the remanufacturing process there are material savings, and a large percentage of investment is therefore in terms of labour. In other words, remanufacturing process is labour intensive and requires knowledge and skilled workforce to make it efficient and economically viable.

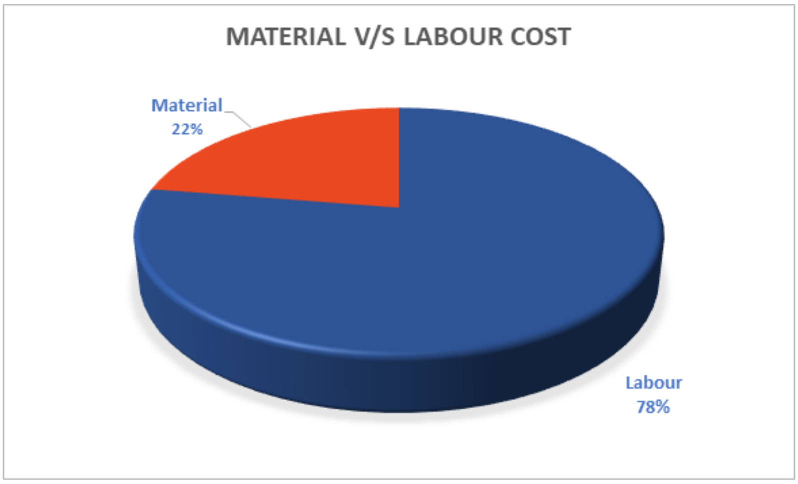


Figure 97 - The pie chart showing the comparison in terms of cost between remanufacturing process and building a new facade. Source: Author

11.1.2 Comparing the cost incurred during different phases

This section uses the different phases developed in the guidelines as a foundation to map and eventually compare the differences in cost between each of the phases (refer the guidelines in chapter 10). After the calculation, it was observed that in Phase 1 and 2, the cost incurred is only with respect to labour cost. This is because this phase entails preliminary planning followed by design and examination phase. The preliminary planning includes desk research & on-site inspection to develop a preliminary reman plan. This is the important to develop a business case. This is followed by development of redesign concept of damaged elements, assessment of risks and potentials and establishing an expected quality level after the process of disassembly.

In Phase 3 the destructive research phase begins, which involves both labour cost and a small percentage of material cost. This phase executes the reman process for a small quantity of elements to judge the feasibility of the entire project.

In Phase 4 the final disassembly begins, which is crucial as it must match the previously established quality after disassembly. Due to lack of predecessors, it is difficult to precisely estimate the amount of labour that is required for large scale disassembly, transportation, storage, and cleaning processes. Therefore, in the worksheets you can this data is absent. It is also important to note that material costs are related to packaging and handling equipment which are essential to reach the expected quality of elements.

Phase 5 is material intensive as it involves repair and replacing of EoL elements. In case of facades, it is important to note that materials such as glass, gaskets, sealants have to be replaced as they have a shorter service life in comparison to materials such as Aluminium, Bronze. Hence, the addition of former materials has a higher impact on the material costs. The bar graph in the figure gives an overview of the difference in material and labour cost over the entire remanufacturing process.

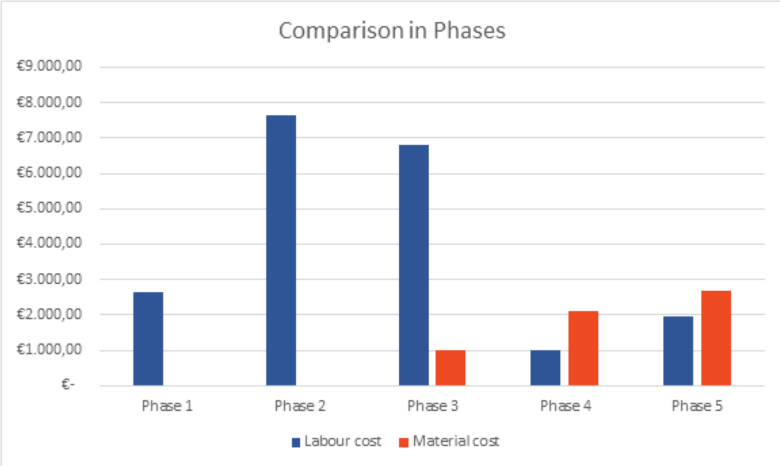


Figure 98 - Overview of the differences in material and labour cost over the entire remanufacturing process. Source: Author

11.1.2 Comparison between reman versus new facade

This section is a short note highlighting the comparison between remanufacturing and building a new façade. The sum of material and labour cost from all the phases was calculated. A rough estimate of average cost per square meter to build a new façade for a particular chosen product was gathered from Alkondor.

From the calculations and the graph, it can be concluded that by remanufacturing process costs almost half of the amount in comparison of building a new façade. It is important to note that the calculations made by the Author contain a percentage of inaccuracy. However even after incorporating this percentage of inaccuracy, it is safe to conclude that remanufacturing process is more favourable in terms of cost. This is because of savings in valuable materials such as Aluminium and Bronze, which have a longer service life than the product.

It can also be concluded that remanufacturing process can prove to be feasible and incur savings in case of building products such as facades. This is because they are also built with valuable materials that can be retrieved at EoL. The same might not be true for other building products that experience large amount of wear and tear during their service life and may not have materials or components that can be reused without damage at EoL. Therefore, care must be taken during interpretation of these results.

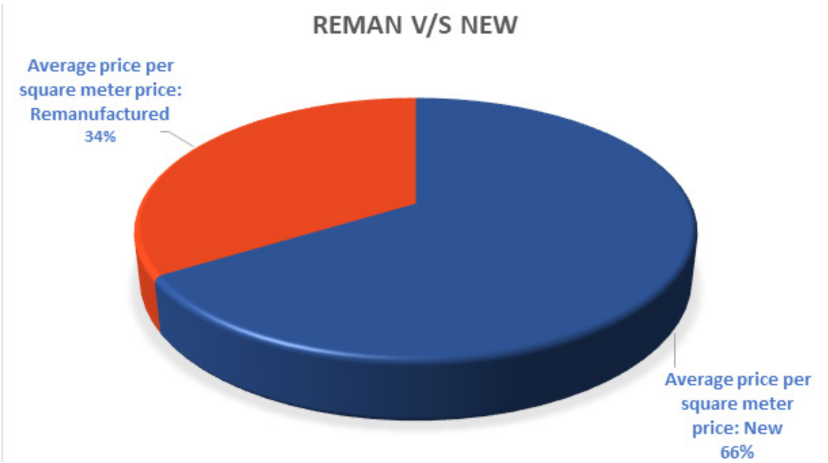
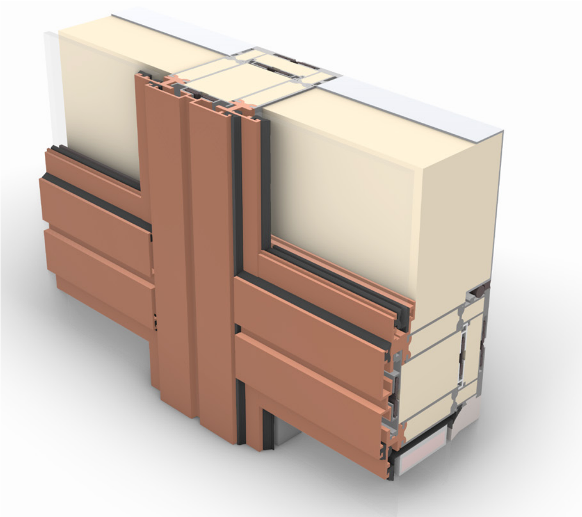


Figure 99 -The pie chart showing the comparison in terms of cost between remanufacturing process and building a new facade. Source: Author

11.2 Comparison of thermal performance with a new facade

The chapter 10 describes the methodology that was followed in the calculation of thermal performance. The results obtained from the calculations were discussed and it was concluded that the thermal performance of the façade fits in the standards by the building regulations. The table shows the exact values obtained after calculations. Therefore, it can be concluded that the façade is made from high value materials, and it has the potential to be remanufactured.



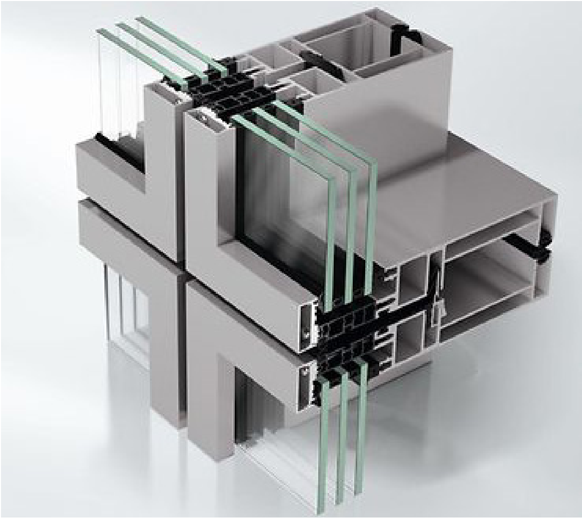


Figure 100- left shows the EoL elements of De Satelliet, Right-Schucö AF UDC 80 (Aluminium Façade Unitized Dynamic Construction). Source: Left-Author & Right Schucö

Comparison of properties		
Property	De Satelliet	Schucö
Uf value of frame		1.7
System U value	1.61	
Dimensions	2.8 X 3.75	3.0 X 4.0

Table 12- Comparison of Physical properties. Source: Author, data gathered from hand calculations and Schucö. Source: Author

12 Conclusion

The chapter answers all the research questions, discussion & final thoughts on all the deliverables that are presented in the report. It reflects on the limitations and addresses them which pave the way for future work that can be developed from the thesis project.

12. Conclusion

The presented research sought to investigate the potential of re manufacturing of building products. After the preparation of the preliminary framework, the project meets a live case study, which eventually becomes a backbone and assists in assessing the relevance of framework to building product. Additionally defining guidelines for remanufacturing of EoL facade in the building industry. In Chapter 1 - Research Framework, a series of research and design questions were framed to structure the research. This chapter that follows answers these questions and discusses the research limitations as well as the scope of future work.

The answer to this central question is structured in a series of sub questions and are answered in the chronological order. The sub question 1 opens the research to introduce the concept of remanufacturing. It further marks the difference between reman and other “re” strategies. The sub question 2 identifies and maps the criteria important for a successful remanufacturing process. The sub question 3 wraps around the case study of De Satelliet to map guidelines for remanufacturing of EoL facades. As a follow up to the case study, the sub question 4 identifies the barriers to remanufacturing of building products. Lastly, sub question 5 zooms out to focus on the larger picture on how architects, engineers and product designers can play a role in implementation of remanufacturing in the building industry.

12.1 Answering the main research question

“How can remanufacturing of building products be implemented as a strategy to accelerate the progress towards a Circular Built Environment?”

The answer to this question is gathered from the observations obtained from each step of the methodology designed for the project. This is explained in figure 101 as a flowchart. The first step towards introducing remanufacturing in the building industry is to promote design for remanufacture - which is a combination of product design and strategy. This is explained in detail in the design for remanufacture canvas made by the author.

To assist the process and begin conversation on remanufacturing, a criteria list has been made. The Author believes that application of a combination of criteria’s from the list can be done to achieve a circular building product. One of the simple ways to introduce remanufacturing of building products is through creation of product portfolios illustrated in figure 102. They should be designed with a strong concept to enhance, optimize and trade-in building products at EoL. This ensures that the product developer is close it its assets, understands the flaws in design with respect to reman. It has the chance to be developed as new revenue streams through maintenance during the life cycle.

At a product level, the building products must indicate the presence of an embedded core made of high value materials that can be recovered at EoL and reintroduced in multiple lifecycles. Additionally, by designing the product for easy inspection & disassembly, the core can be recovered without damage and reintroduced in the subsequent lifecycles. The introduction of new rules and regulations in the near future will drive the need for circular products. The business model should further be crafted to complement the design and ensure return of cores at EoL.

However, in the current scenario, buildings products are generally designed for single use . The reverse logistics channels are not established to take back the product to reman at EoL. Additionally, the concept of remanufacturing is not fully understood by all professionals in the industry. An understanding of it is important to promote its application. This can be achieved through trainings & workshops.

It is observed that service life of a building product being longer than the ownership period, the manufacturer or contractor is no longer in control of the product. Additionally, there are several stakeholders involved in the value chain and the ownership changes with time. Thus making it all difficult to keep track of changes over its life cycle, and make information accessible to all. The implementation of advanced digital workflows can assist in overcoming the current barriers to remanufacturing and transitioning towards a circular built environment.

Lastly, it is important to note that remanufacturing of building produts leads to raw material savings, reduction in landfill and pollution. In the building industry remanufacturing is favourable because it has the chance to reduce the cost of the project. Due to its condition being as good as new, it abides all the building regulations and is generally profitable for the project.

The following sub research questions provide more insight into understanding the concept of remanufacturing to explaining the challenges to reman and role of architects, designers, and engineers in promoting the reman as a circular strategy in the built environment.

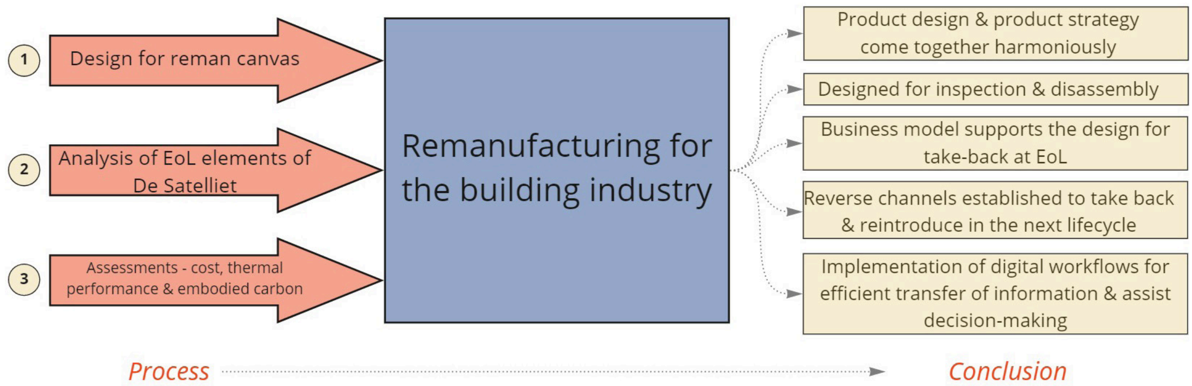


Figure 101 - Flowchart showing the overall process followed to answer the research question. Source: Author

Figure 102 - Example of a product portfolio that is suitable for remanufacturing. Source: Author

12.1.1 Sub research Question

1. What is remanufacturing, and how is it different from the other 're' strategies of the circular economy?

The Authors Charter & Gray (2006) define remanufacturing as a process of returning a used product back into the supply chain to its original performance by restoring its valuable core component and addition of virgin materials to assemble the product, with a warranty that is equivalent or better than new manufactured product. This way you cannot tell the difference between the two!

It can also be perceived as recapturing the value of a product to the match the quality it had when it was manufactured the first time. The other industry specific synonyms of remanufacture are, rebuilt, recharged, remoulded, rewound and overhaul (Gray & Charter, n.d.). Remanufacturing is different from the "re" in the following ways: -

- Recondition/refurbish: It does not always come with warranty, it is restored only functionally
- Repair: The analysis of root cause is generally not performed, and it generally does not come with a warranty.
- Reuse: The object is restored functionally, and it will generally retain problems that it had in the previous lifecycle
- Recycle: It returns a product to its raw material form, loses all the embodied energy when it loses its physical characteristics

"However, remanufactured goods mean that condition is better than or as new & warranty-comparable or equal to new product". It is advantageous to remanufacture building products because it leads to raw material savings, reduction in landfill and pollution. In the building industry remanufacturing is favourable because it has the chance to reduce the cost of the project, due to its condition being as good as new, it abides all the building regulations and is generally profitable for the client. The figure 103 gives an overview of all "re" strategies.

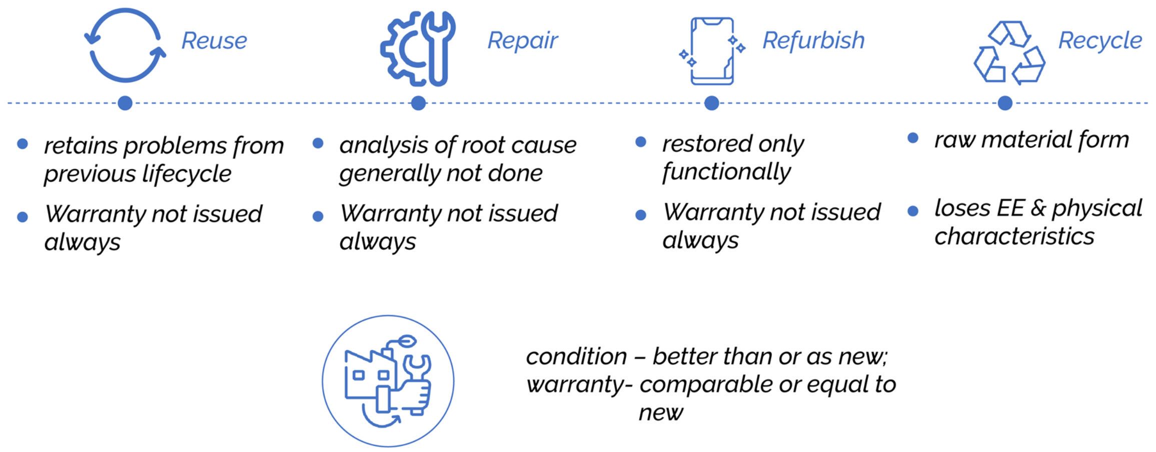


Figure 103 - Overview of the different "re" strategies and their difference between remanufacturing. Source: Author

2. ***What are the conditions and criteria for successful remanufacturing and how can these be applied to the building industry?***

Through case studies it can be established that detailed product design and business model & product strategy are two important domains that need to complement each other for a remanufacturing process to be successful. A thorough analysis of case study and conversation with experts in the building industry, revealed that the following criteria are valuable for the success of remanufacturing process. The results are summarized and formulated into a "design for remanufacture" canvas. The canvas is not an exhaustive list but is valuable piece to start conversation on implementation of remanufacturing in the building industry.

From the comparison of list of criteria with the case studies, it is also established that the list of criteria must not be viewed as a checklist but rather as a series of options through which combinations can be generated to achieve a successful remanufacturing concept. This can eventually be termed as a circular product.

Building products must be made from high value materials and should be ***designed for upgradeability*** (modular design) and ***designed for disassembly***. Every product must have a high value ***core*** that can be ***reintroduced*** into ***multiple lifecycles***. The product design must be supported by a ***business model*** that ensures ***return of core at EoL*** of a product.

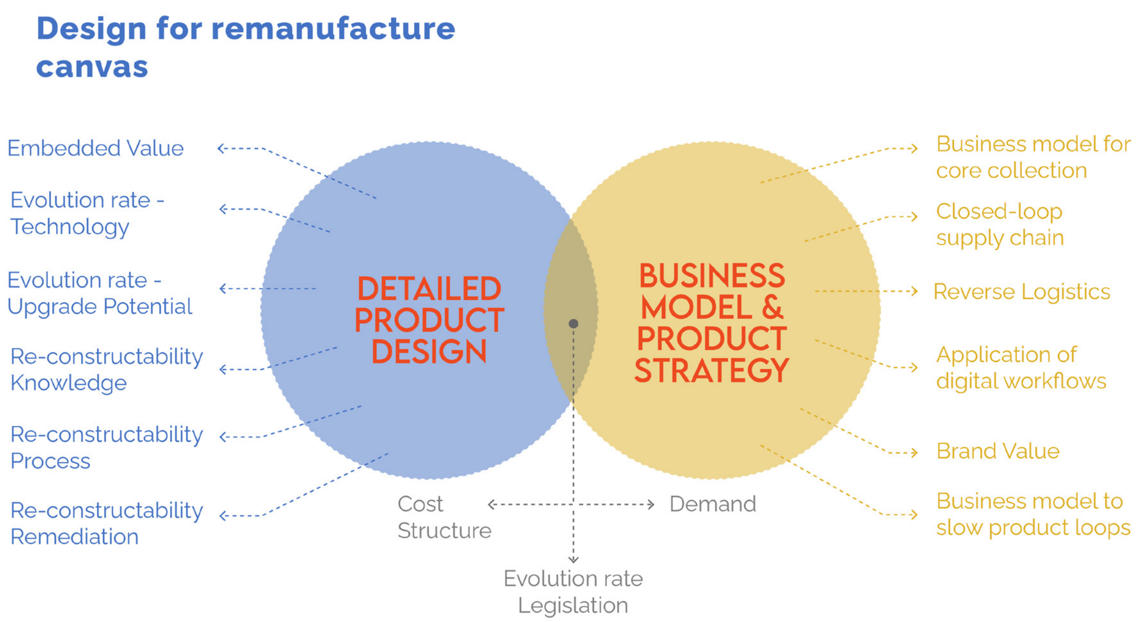


Figure 104 - The design for remanufacture canvas. Source: Author

3. *What guidelines must be followed to begin the process of remanufacturing of an EoL Façade product?*

To answer this question, the first step was to study the case of De Satelliet to analyse the limitation and drawbacks of the current process. It is established that buildings are an assemblage of products; manufactured and maintained by numerous stakeholders. Therefore, it is essential to collaborate with all the stakeholders responsible for all the building products. This collaboration ensures inflow of knowledge and skill that is important for decision-making at every step of the reman process.

It was observed that this collaboration was missing in the disassembly of De Satelliet. The façade builder was involved much later in the project. Due to lack of knowledge on process of disassembly, a large number of façade elements have been damaged. This increases the pressure on remanufacturing making it a labour-intensive process.

The answer to this question has been elaborated by making a guideline map that can be applied in the remanufacturing of EoL façades for future projects. For the remanufacturing process of an EoL façade of an old structure, with little to no information available, the guidelines (in chapter 10) can be applied. They are categorized in five phases.

- *Phase 1*: Preliminary Planning Phase -This is important to gather all the data and establish a business case.

- *Phase 2:* Design & Examination Phase – During this phase, components are examined, redesign concepts are made, and an expected quality level after disassembly is established which is important for a decision to move to the next phase.

- *Phase 3:* Destructive and Testing Phase – During this phase remanufacturing process is carried out for a small number of disassembled products to ensure success after large scale disassembly.

- *Phase 4:* Final Disassembly Phase – During this phase, the real disassembly happens, the elements are moved to either storage or reman facility to be remanufactured.

- *Phase 5:* Remanufacturing process – This varies with every project, and is carried out with the cooperation of all stakeholders and parties involved in the cleaning, design and assembly phase.

4. What are the challenges involved in the remanufacturing of EoL façade products and what are the potential methods to solve them?

The construction industry can be thought of as dynamic and highly fragmented in nature. There are many stakeholders involved right from the inception to the EoL of a building. To answer this question, the challenges are written with respect to the case study of De Satelliet but in general are also applicable to all building products in the current scenario.

- *Lack of product data:* The ownership period is shorter than the service life of the product. Therefore, the manufacturers & contractors lose control over the building product after installation. Additionally, the repairs are generally carried out by a third party who is not a manufacturer. Thus, a knowledge gap is created, and the manufacturer is sometimes unaware of the drawbacks of the product. At its EoL, a third party is introduced to recover and remanufacture the product. At this stage, in the current scenario, there is absence of information about the following:

1. Packaging and handling instructions
2. Disassembly
3. Remanufacturing
4. Knowledge on its construction & recovery.

This lack of communication, followed by challenge of disassembly and inspection makes it unfavourable to remanufacture building products. The first step towards solving this problem is to integrate material passports in BIM models (digital twin). This way buildings are viewed as material banks. The Author has identified a valuable addition to the overall scope of a materials passport – a remanufacturing product profile. It is a subset of materials passport and is defined by (Barker & King, 2006) as; *"a strategic architecture of common and parametric components that forms the basis for a product family – aimed at meeting either the objective of increased commonality or increased variability"*

The reman product profile contains valuable information on packaging and handling instructions, disassembly plan, remanufacturing plan, life cycle analysis et,al. The digital technologies such as Laser scanning and Photogrammetry, can be adopted and integrated with product data to eventually serve as a decision-making tool to every stakeholder in the chain who wants to receive information or make changes to the product. This assists in separation of single and multiple life components followed by providing knowledge on possible methods of recovering valuable materials. This also helps in critically evaluating the reman process for its environmental and economic viability.

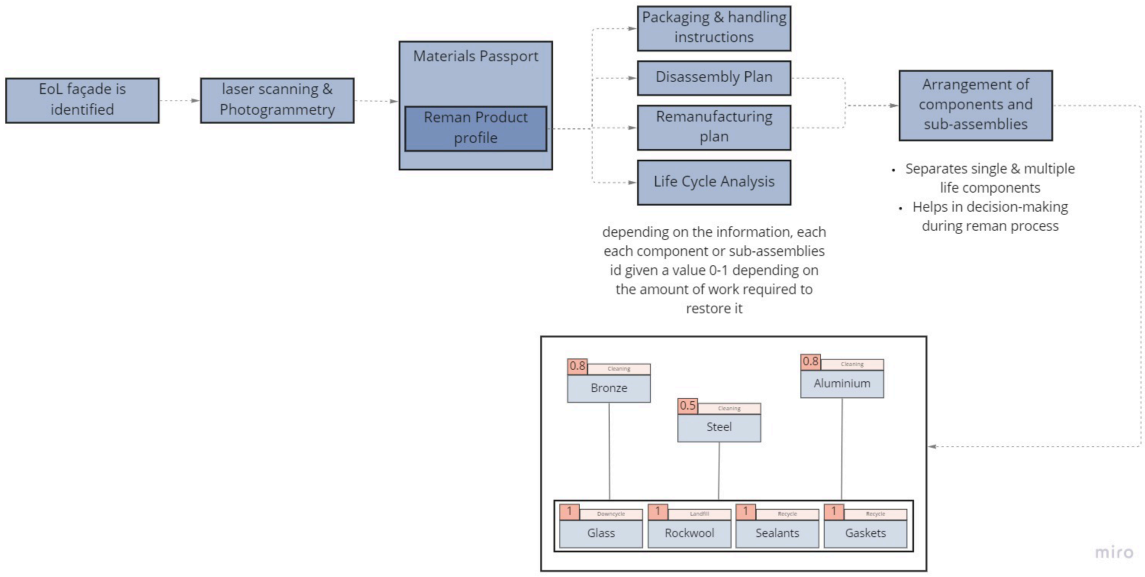


Figure 105 - The overall scheme of a reman product profile. Source: Author

The introduction of digital workflows have the potential to revolutionize and change the entire landscape of remanufacturing. To overcome the challenge of lack of communication between all the stakeholders in the value chain and staying close to the company assets. The statical and dynamic performance of a building product can be monitored through RFID tracking. For efficient transfer of information between all stakeholders, IoT and block chain technology can be applied to track changes made to the product at all levels. Further it updates the information and monitors financial flows to ensure transparency between all the stakeholders in a project. The other challenges to remanufacturing include:

- Designed for single use:
- Lack of Building Rules and Regulations to support reman of products. The only Quality requirements and advice found was by VMRG, which limits itself to technical and aesthetic maintenance.
- The challenge of disassembly: Most building products at least the ones that have completed half of their first life cycle are not designed for disassembly
- Demand is unknown: Inventory analysis is key to understand the changing market demand and value of products.
- Reverse logistics not established to take back the product at EoL and reman to reintroduce in the next life cycle
- Current business model focused on selling of new products
- Warranty and Liability
- Corrosion and contamination
- Risk of cannibalization

It is important to note that one of the biggest risks with remanufacturing process is that in the absence of evaluation, there is always a risk of creating more impact than virgin production. Secondly, by adopting remanufacturing practices, there is a transfer of enormous responsibility which was previously customers imposed on the manufacturer.

5. What is the role of architects and designers to enable and promote products to be designed for remanufacturing?

Through research, it has been established that a building must be viewed as an assemblage of products with each of them having different life spans and different EoL scenarios. The building products are standardized, mass produced and high value materials available at fixed locations. These conditions make it favourable to remanufacture them. However, the building industry is always lagging in terms of accepting new advancements, due to its dynamic and fragmented nature, which poses challenges to remanufacturing.

- As Architects and engineers, it is vital to be careful on the *choice of material* and the design of the building product.
- As product designers it is important to adopt strategies such as design for disassembly and upgradability. For building products, the degradation due to external environmental conditions should also be considered, this makes it challenging to apply "re" strategies at EoL
- As product designers, it is important to *communicate with all the stakeholders* and consider the EoL use during the design stage.
- For sales, advertising, and product strategy team it is important to shape the business model to ensure return of core at EoL.

12.2 Answering the design question

"How can the air and water permeability concept be developed for an EoL façade such as De Satelliet to extend its lifecycle"

The façade of De Satelliet was built around 30 years ago, when the legislation for thermal and fire protection standards were not as thoroughly developed as they are today. Therefore, there is a pressure on remanufacturing process to develop the EoL façade to match the current regulations and standards. One of the crucial parts is to develop the water tightness and air permeability concept.

The junction where the profiles meet is regarded as the weakest link that must be designed carefully to avoid problems of leakage.

In the current scenario, the old seals were done manually are damaged after disassembly. The mullion extends the transom by a few centimetres. Care must be taken to bridge this extension where it meets the next profile.

A conceptual solution to achieve water tightness was developed together with Alkondor. The idea is to insert new aluminium profiles (see A, B & C) to hold and secure new gaskets that serve as lines of defence. They are designed to be slender and fit in the interstitial gaps of the existing profiles.

In the horizontal section, the new aluminium profiles insert stop at the point where they meet the existing mullion. Whereas the horizontal rubber continues throughout the length of the building to serve as a continuous barrier against the outside moisture and air.

In the vertical section, the same aluminium profiles (see C) are repeated to match the horizontal and maintain the lines of defence. At the junction where the horizontal and vertical rubbers meet, the ones in the vertical direction are adjusted to align and wrap (see top figure) the rubber in the horizontal direction.

To hold the cover caps in both directions, small aluminium extrusions (see D) have been designed which can be inserted and tilted to lock the cover cap and serve as a bridge to connect the new aluminium profile and the cover caps.

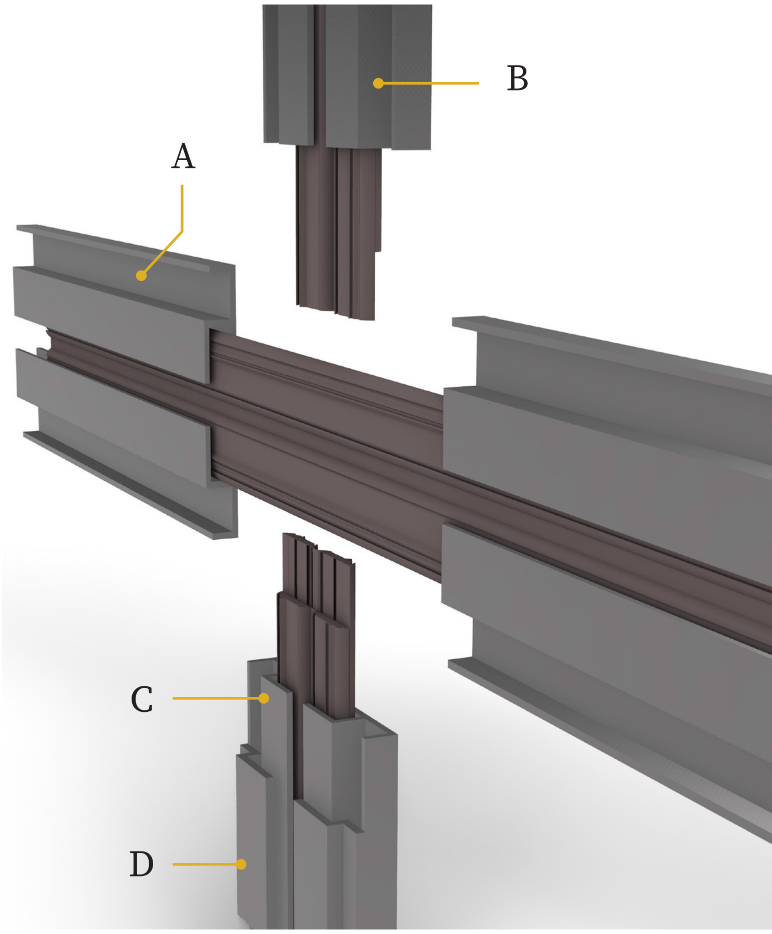


Figure 106- Showing the junction where the horizontal and vertical rubbers meet. Source: Author

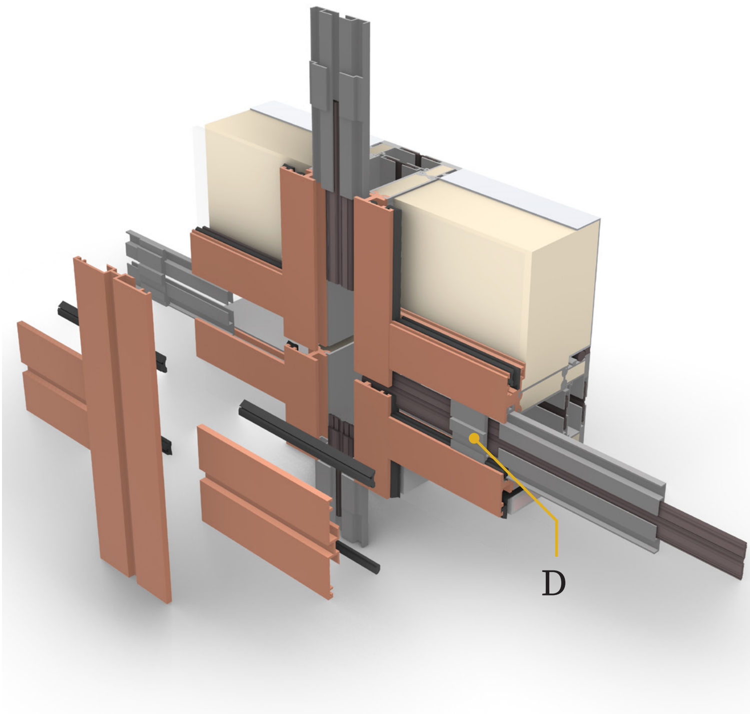


Figure 107- Exploded isometric view showing the crucial junction of four profiles. Source: Author

Important pointers

1. The continuation of the rubber in the horizontal direction is crucial to serve as a barrier from floor-to-floor level.
2. The vertical rubbers to meet the horizontal in a way that they completely wrap around the horizontal gasket. This is important to lock the moisture and air in the environment from entering the inside.

The proposed solution lacks testing. To ensure that it actually works, it must be physically tested in a model to evaluate the drawbacks and unforeseen challenges it might pose. At this point, the author can foresee a challenge in accomodating the tolerances and movements in the newly added aluminium profiles. Due to lack of time, this remains beyond the scope of the thesis project. However, it is a positive step towards crafting a practical for the future.

12.2 Discussion

12.2.1 On remanufacturing for the building industry

As we realize the challenges with linear economy for a material-intensive sector such as the building industry, strategies that allow savings in raw material, reduction of waste and conserve embodied energy of a material should be implemented. Remanufacturing is one such strategy that returns a used product to its original specifications with a warranty that is equal to or better than a newly manufactured product. It follows the principle of thinking in systems, designing out waste and thinking in cascades which are core principles of circular economy. Remanufacturing is particularly favourable for building products as it leads to savings in cost and in theory remanufactured goods are acceptable and follow building regulations. However, for remanufacturing to be successful, products must be designed for remanufacture.

This means that product design and product strategy must come together harmoniously. One possible solution is creation of product portfolios that aim to enhance, optimize and trade-in building products at EoL. This means that business model complements the design thereby giving the product developer a chance to understand the behaviour of the building product throughout the lifecycle. This assessment with time, gives freedom to change and upgrade the design. They also become new channels to generate revenue by intervening in during the life cycle.

The new regulations such as MPG and ESG are driving the demand for remanufactured goods. It can be assumed that with time, the more specific regulations will be developed which is crucial in driving the demand of remanufactured goods. Two new laws are identified and explained in the following paragraphs.

Environment Performance Buildings – MPG (Milieu Prestatie Gebouwen)
The MPG is an important indicator of a building's sustainability. The lower the MPG, the more environmentally friendly the material use. The environmental performance of building materials will become an increasingly important factor in determining a building's overall environmental impact. The MPG is an objective tool in the design process that can be used to record the outcome of a design process in a Schedule of Requirements (EnvironmentPerformance Buildings - MPG, n.d.).

It is further explained by with an example of Recycled floor coverings which give a building a sustainable appearance while also serving as an important means of communication. An MPG calculation, on the other hand, shows that the durability of the floor beneath the carpet has a much greater impact on the environmental impact.

The implementation of similar building rules and regulations will drive the demand of circular building products. This promotes the need for building products to be designed for remanufacture. However, the current barriers to design for remanufacture (DfRem) of building products are:

- There is a lack of DfRem guidelines based on Life cycle thinking.
- Design for reman aims at facilitating reman process, but most often, this information is not available during the design phase.
- Although there exist guidelines for design for remanufacture, there is a gap in the research on operational factors influencing the integration of DfRem into the design process.
- It is important to note when products must be taken back as well as the most appropriate component end-of-life options.
- Many EoL issues prevent products and material from being salvaged stem from design. This implies that it is effective to incorporate the EoU management consideration into the early product design stages.
- (Lindkvist Haziri & Sundin, 2020) highlight that communication between design and remanufacturing has the potential to lead products that are more remanufacturable and a more efficient design process. An important criterion in the reman is that the parts that are to be replaced in reman and repair must withstand the reman process of being inspected, disassembled, cleaned, reprocessed, reassembled, and tested several times.

12.2.2 On Remanufacturing Information Feedback Framework

The remanufacturing feedback framework developed by (Lindkvist Haziri & Sundin, 2020) is a method for strategical planning and implementation of feedback in the reverse order that is from remanufacturing to design. This framework is developed as a flowchart with four simple steps that outlines the strategy. The current design process of building products is linear. In most cases, the product owner does not have a clear picture on the reasons of failure or how it behaves during the lifecycle. It is important to note that in the absence of this information, it is not possible to design for remanufacturing. Therefore, transfer of this information is vital. The flowchart is a framework that supports the implementation of feedback from remanufacturing to product design in 4 successive steps, while leaving enough room for continuous improvements.

12.2.3 Notes on future design of facades

After a thorough understanding of concept of remanufacturing and analysis of EoL elements of De Satelliet, the author concludes the following: -

- There must be a presence of a core; that can be recovered at EoL and remanufactured to be reintroduced in next life cycle. The core in case of a façade for instance can be the high value profiles (the entire frame)
- The design must be supported by a business model that ensures return of core at EoL. The ownership-based model of core collection where the product is owned by the manufacturer and operated by the customer, as for example in a rental, lease or product-service offer can be applicable for the façade industry.

- The design should include features such as designed for disassembly, standardised construction of parts, and durable and valuable core that can be upgraded to match the market.
- The other product properties include -
  - Use of robust materials, that are also easy to clean and resistant to corrosion
  - Assembly methods that allow non-destructive disassembly & reassembly
  - Minimal number of connectors and chance to reuse them
  - Easy access to parts that wear and tear
- To implement digital workflows to monitor the product and support portfolios that aim to enhance and upgrade during a product's lifecycle and facilitate take-back at EoL
- To follow guidelines developed in this thesis project for remanufacturing of EoL facades.

12.2.4 On remanufacturing of other building products

Facades are extremely complex building products made up of many building materials with varying life spans. This is a challenge for remanufacturing as it increases the pressure on labour and increases the risk of producing more environmental impact than virgin production. Therefore, building products such as HVAC systems and raised floor systems which have fewer layers and are made of materials with similar life spans must be considered.

12.2.5 On De Satelliet

De Satelliet is a special façade that was engineered very well 30 years ago, using high value materials, making them very easy to reuse. Thus, making the reman process more favorable as it is valuable to recover the materials in the current state compared to recycling. Therefore, it can be regarded as a special case, and might not be the case for for every building built 30 years ago.

12.2.6 On Design for reman canvas and list of criteria

The design for remanufacture canvas developed by the Author is supported by a list of criteria. The following include a short note on a few important criteria that are crucial to the success of remanufacturing of building products.

- Embedded value: Building products must possess an embedded core that is made of high value materials and can be upgraded.
- Business model for core collection: ownership and service-based models of core collection are applicable to building products
- Legislation: The introduction of new rules and regulations in the industry such as MPG will drive the demand for circular building products
- Application of digital workflows: This is crucial in transfer of information and has the potential to assist in decision making. It is indispensable and will be introduced in the building industry in the near future.
- Reverse Logistics: To establish channels to take back products at EoL is crucial for remanufacturing
- Creating brand value: It is considered as a popular topic in the industry and is crucial to increasing consumer awareness on remanufactured products, thereby promoting its use.

12.2.7 On Design for reman canvas and list of criteria

The Author has designed a remanufacturing product canvas that can be implemented by a Façade builder like Alkondor. The reman product canvas, however, is in its nascent stage and has the potential to be developed further.

Table

Product canvas - Alkondor

Key Partners	Key Activities	Value propositions	Customer relationships	Customer Segments
Wicona	Product design and development	High quality facade product		
Nirokomp	Reverse logistics through a simple database	Maintainance and surface treatment services		
		Buy back of EoL facade for reman operations		
Key Resouces	**Channels**	**Cost structure**	**Revenue Streams**	**Social & Environmental**
	Direct sales and account management with contractor and client	Remanufacturing operations		Reduction in carbon footprint
		Labour		Raw material savings
		Raw material cost		

Figure 108- The Proposed remanufacturing product canvas for Alkondor. Source: Author

12.4 Conclusion

The concept of circular economy is well established theoretically but lacks methodology to be implemented in practice. Therefore, the research project focuses on "how" remanufacturing can be introduced in the building industry. The methodology was designed to create a canvas and list of criteria to answer this question followed by validating the same with a case study of De Satelliet. The literature review and case study contributed to shaping the preliminary canvas. The case study of De Satelliet opened new possibilities to refine the canvas further by incorporating inputs from professionals. Thus, it served as a backbone to validate the relevance of criteria to the building industry.

It can be concluded that the canvas developed covers the broad spectrum of remanufacturing. It has the potential to begin the conversation and craft a methodology to design for a certain building product for remanufacturing. The guidelines made for the remanufacturing for EoL facades is practically applicable as it incorporates feedback from stakeholders (such as urban miner, façade builder and client).

The barriers to remanufacturing were mapped during the process of making guidelines. The solutions to each of them were proposed through the integration of digital workflows. One of the potential solutions was elaborated in depth through introduction of remanufacturing product profile as a subset of materials passport. The assessments on cost, embodied carbon, and thermal performance were critical in evaluating and comparing remanufacturing versus building a new product. The results from the assessments conducted for De Satelliet are promising and encourage remanufacturing. This way the thesis has achieved all the end products that was initially intended to by the methodology. Therefore, it can be concluded that the adopted methodology was successful in answering all the research & design questions.

Looking at the building industry at large, it has been noticed that there are other examples of disassembly with an intention of giving a second life like the De Satelliet. For instance, Gelders office building in the province of Gelderland is also an example of circular demolition. A sports hall and a circular knowledge hub is proposed to be built using the EoL elements of Gelders office, thereby giving it a second life (Gelders Office Building Circularly Demolished, n.d.). This shows that there is exist scope of similar projects aimed at disassembly for second life in the future.

12.5 Limitations & Future work

The research project started on a very ambitious note with an intention to start from developing the canvas to have a proof of concept of a portion of a computational workflow implemented to display the potential of digitalisation. However, due to the constraints in time, it had been redefined to match the timeline of the project.

The thesis explains the potential of implementing digital workflows right from material passports to IoT. The project can be considered as a foundation to develop these concepts as they are undoubtedly valuable inputs to the industry.

The design for remanufacturing canvas is not an exhaustive list but a valuable source to begin conversation on remanufacturing of building products. Additionally, each of the criteria present in the canvas have the potential to be explored and elaborated further.

The assessments that the Author has carried out in terms of Thermal analysis and embodied carbon can also be extended to all the life cycle modules to carefully analyse the impact at every stage and draw meaningful conclusions that can then be traced back to improve the product design and strategy.

The project maps only one lifecycle of a product. By using the canvas and application of digital workflows, multiple life cycles can be assessed to make conclusions on how the impact of reman process changes at every life cycle and until how long it remains feasible in terms of economic and environmental impact.

12.6 Reflection

Since history the extraction and utilization of resources has been the bedrock of societal advancement and generation of wealth. One of the most significant challenges with linear economy are related to resource availability and environmental pressure caused by waste generated by production and consumption. The Circular economy can be seen as a possible method to overcome the challenge of utilization of raw materials by increasing the efficiency. Remanufacturing is regarded as one of the strategies of the circular economy that has been successfully implemented in Automobile, Electrical and Aerospace Industries. However, the building industry can be described as laid back as it remains one of the last industries to accept change due it its dynamic and fragmented nature.

The research project draws its motivation from the vision for 2050 of the Dutch Government for the Construction Sector. It aims to transition to Circular Economy by adopting sustainable construction by implementing principles of reuse, maintenance, and remanufacturing by encouraging disassembly of materials. The objective of the research was to first develop a framework to guide the remanufacturing process of end-of-service/life building products and secondly evaluate if the disassembled elements of De Satelliet can be remanufactured in a sustainable manner. Therefore, the thesis aims to conclude by presenting the results in terms of calculations on environmental impact and cost that is comparable to a new façade. This is supported by creation of guidelines for the remanufacturing of EoL facades through learnings from the case study

“The graduation thesis has been immensely valuable in broadening my understanding of the entire lifecycle of building materials and products. Furthermore, it made me realize that product design and product strategy as a union can shape building products and extend their service life to reduce their environmental impact”

Aspect 1: Explanation of research methodology and findings

Due to absence of examples of remanufacturing of building products on a large scale, the first phase of the research was to deep dive into understanding what makes remanufacturing successful in other industries. This method was chosen over picking a product and exploring remanufacturing of the same. Extensive Case study literature review was to understand the context of the This exercise was done to extract criteria’s, which were then assessed for relevance to the building industry.

In the second phase of the project, the disassembled De-Satelliet from the DNB complex was chosen as a case study. This choice became the backbone of the project and presented the opportunity to discuss and shape my canvas. A detailed analysis of the De Satelliet also helped in understanding the nature of EoL facades.

The last phase was to evaluate the reman process in aspects of cost and environmental impact. The calculations for environmental impact were a challenge due difficulty in finding co-efficient for each stage of the C & D Modules. To overcome this challenge a self-derived methodology was developed for the assessment by deriving inputs from previous graduation reports from Rahul Grover (Towards Buildings That Thrive, 2020) Neha Gupta (Materials & Approach, n.d.) and research papers (Hartwell & Overend, 2019) Materials that did not have EPD’s were assessed using existing literature.

The drawings of the project were provided by Alkondor, which helped in performing hand calculations and analysis to test the thermal performance of the façade. This process was valuable to understand the challenges with remanufacturing of EoL facades that are constructed >30 years ago. The investment on valuable materials at the design phase made façade of De Satelliet one of its kind and therefore easy to use. Eventually the methodology led to reliable results and assisted in drawing meaningful conclusions.

Aspect 2: Relationship between research and live case study of De Satelliet

The case study was found to be immensely valuable in validating all the canvas and its relevance to building industry. Further it provided a structure to all the theory I had absorbed in the Literature review and data collection phase. Through collection of learnings from the case study of De Satelliet, the graduation thesis was able to craft general guidelines for remanufacturing process of EoL facades.

The thesis presents a remanufacturing product canvas that can be adopted by façade builders such as Alkondor. They could also apply the guidelines and all the learnings from the graduation thesis in future remanufacturing projects. The presented outcome also highlights the importance of implementing remanufacturing of EoL façade to transition to Circular Built Environment.

Aspect 3: Relationship between the graduation topic in Building Technology Track (BT) and track of the Master program (MSc AUBS)

The Building Technology track has five interconnected arms namely, Façade, Climate, Structure, Computational and Circular design. The Graduation topic finds itself between Façade & Products and Circular Design domain.

Therefore, it gives multiple learning opportunities across different fields. However, a knowledge that I missed during the electives phase was to lean calculation of Life Cycle Analysis and Embodied Carbon.

Through graduation thesis, I got a chance to self-explore and understand how valuable it was in evaluating design proposals. I find it as a valuable addition to future courses.

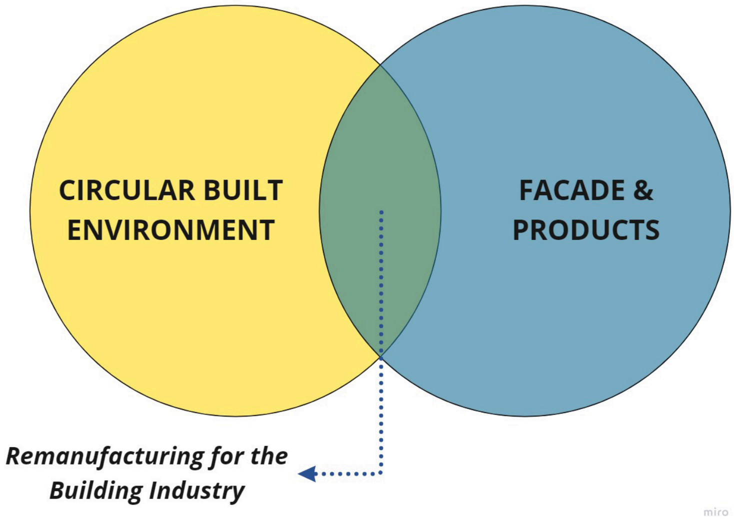


Figure 109- The placement of the graduation topic. Source: Author

It was noticed that the concept of remanufacturing was misunderstood with other "re" strategies. This knowledge is valuable and has now been made accessible through courses such as Circular Building Products that has now been introduced in the track. I was able to audit the class along with and found it relevant and applicable to my on-going research. In future, if graduation projects on this subject are expected from future students of BT track, it is valuable to also introduce the role of a sustainability consultant in the electives such as MEGA to integrate it in the academic curriculum.

Aspect 4: Relationship between the graduation project and the broader societal, professional, and scientific framework, with focus on applicability of methodology

The topic finds itself under the broad realm of Circular Economy and aims to explore the potential of remanufacturing for the building industry. According to a study on Lifecycle stages and modules by Orr, Gibbons, and Arnold (2020), the extraction, processing, manufacturing, and transport of materials up to the point where they leave the factory gate to be taken to site contribute to roughly half of the carbon emissions calculated throughout the lifecycle of a building.

The concept of remanufacturing is very valuable for the building industry because it offers advantages in terms of cost savings and most importantly a remanufactured product is designed to generally pass all the inspections and check, as it is considered to be "as good as new" products. The technical drawings serve as a foundation to prove this. Additionally it follows the three key principals of Circular Economy namely (Macarthur, n.d.) "think in systems", "design out waste", "think in cascades".

The methodology starting from development of canvas to gathering results are valuable and have the potential to be applied in future projects (live and graduation thesis projects) The canvas has the potential to start conversations for remanufacturing of other EoL building products. There is a future for incorporating computational workflows which can be the focus of other projects, as they are valuable and necessary inputs for the building industry.

Aspect 5: Looking back, Looking forward

Strengths: The remanufacturing canvas, list of criteria was guidelines for reman of EoL facades were developed after intensive research, conversation with experts and understanding on latest discussions on circularity.

Weaknesses: Due to limited time, the work on developing the canvas further was not possible and the focus shifted towards the live case study of De Satelliet.

Opportunities: through development of guidelines for remanufacturing of EoL facades, all the important stages have been mentioned and relevant computational workflows have been identified. This part of the thesis has immense opportunity to be developed further.

13

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The chapter presents the bibliography

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13A. List of figures

14 Appendix

The chapter presents the appendix

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Case study	Party responsible for reman	Method of core collection | Core sourcing	Location of reman plants across the globe	Materials /parts recovered during reman process	Lifecycle period / warranty offered	Numbers to measure success of reman process	Initiatives by the remanufacturer to raise consumer awareness	Priority areas in PLC	Related DfX Strategies	Integration of digital technologies	links to papers	Cite aut all pape
Caterpillar	OEM- Original Equipment manufacturer	Product life extension *Refurbish & upgrade* Deposit based method of core sourcing policy	Mississippi Reman facility in Corinth Shrewsbury, UK- Center for reman in EU America - Piracicaba,Brazil | Nuevo Laredo, Mexico | Franklin (Indiana) |Mississippi, Corinth, Prentiss County | North Dakota, West Fargo, Asia - Shanghai, China |	Engine block in the Cylindrical bore - This has a removable sleeve.	12 month warranty on all remaufactured process		Core deposit - customers pay for the core, shipped to them in a reusable container. While returning a core part, this container is used, to portect it from being damaged. As new warranty for all the reman products is offered.	Manufacture, sales, Use, upgrade, refurbish and EOL	Design for Disassembly	Addition og a product link service to the units, to enable the manufacturer monitor a number of criteria related to the general status of the item, - fuel levels, potential risks	https://ellenmacarthurfoundation.org/circular-examples/design-and-business-model-considerations-for-heavy-machinery-remanufacturing	
BMW (Steering wheel)	OEM- Original Equipment manufacturer & Independent remanufacturer		Many locations in South Africa, Zimbabwe, Namibia, Botswana, Eswatini et.al BMW steering gears are imported from germany	steering gear - core componenet of the system (gone throuigh three generations of products - mechanical,hydraulic to electric			BMW i3 high-voltage retrofit program including a technology upgrade of the battery.	Use, upgrade, refurbish and EOL	Modular Vehicle Design	A special software helps read data on production & usage process datastored in the steering gearECU, and detects high usage kilometers and old parts that do not meet the technical requirements of reman will be directly discarded	https://inf.news/en/auto/6e0ec8dd1ad3e4e294e90b5a8c1ea9f5.html https://www.bmw.co.za/en/fastlane/bmw-retailer-locator.html#/dlo/ZA/en/BMW_BMWM	
Autoelectro In reman since 1986	Independent remanufacturer & supplier of Rotating Electrics in the UK	Direct order & Deposit based. The cores are retrieved from automotive part wholesalers across UK through service exchange scheme where surcharge is involved.	Bradford, UK	starter motors & alternators are first diagnosed as economically remanufacturable and un-remanufacturable. The ones without benefit are scrapped and sold to recycling company. Aluminium, copper, iron & other metals in he components are seperated for reuse and/or recycling	reman products are issued with a 24 months (2 year) warranty, which is longer than the OE equipment		need to understand the difference between remanufactured and cloned products although reman are higher in quality contributed from strict manufacturing and testing processes. The customer has the choice between new products by OEM and same quality reman products at a lower price by Autoelectro, or cloned products with interior quality and a lower life span	upgrade, refurbish and EOL				
SCM Turbomotive Ltd In reman since 1980s	Independent remanufacturer	Direct-order, Deposit-based, Buy-back and Voluntary-based	Huddersfield, UK	form remanufacturing a turbocharger, the alloys aluminim, cast iron, titanium can be recovered.	warranty offered for reman products is larger than OEM, 24 months warranty and 12 months no quibble guarantee		SCM remanufactured products are 70% priced compared to newly manufactured products. SCM reman products are cost effective, and also easy to sell to their customers			SCM has internal developed tools to measure the economic performance such as availability of tubochargers, cost savings, pricing, stock, etc.		
Xerox	OEM- Original Equipment manufacturer	Product leasing. The customer is offered a mixture of new and remanufactured products to suit the particular operating conditions and budget Buy back & ownership based	Venray(NL), - mid sized multifunction product is fully remanufactured Mitcheldean (UK) - the Fuser Manufacture Centre remanufactures high value fuser roll components Dundalk(IRL) - both large industrial printers (the Docutech range) & smaller DC12 machines are also remanufactured	Plastics, copper wire are recycled	15 years- with multiple reman cycles	At Venray remanufactured production is approximately 1000 units per annum. At Mitcheldean remanufactured production is approximately 400,000 units per annum. At Dundalk reman production is approximately 650 units per annum. In addition, 400 smaller DC12 machines are also remanufactured at the Dundalk site.	Asser recovery operation (ARO) aims were one: remove old copying machines from the waste stream & two: process the old machines for resale. Before original sale they are customised to suit the final destination country (in terms of language & software settings etc) and then shipped for first life use. A team of 50 people manage this operation. This sale is managed through a network of Xerox Operating Companies (OpCos) who deal directly with the customers.	Manufacture, Sales, Use, Upgrade, EOL	Design for disassembly Design for Multiple lifecycles Design for upgrade Modular design of subassemblies **Use of reman Design Platforms**		https://www.xerox.com/corporate-social-responsibility/2018/environment/circular-economy.html	
Refrigerator display cabinet manufacturer The Bond Group (TBG) 12ft RDc with a display area of 6.5m2	3rd party remanufacturer	Product service oriented Direct order based	Sheerness on the Isle of Sheppey, Kent	Materials like Mild Steel, copper, aluminium, plastic and foam are recovered and remanufacturing by adding small % of new material	Average lifecycle is 5-8 years before reman	In 2009, it was known to remanufacture approximately 4000 RDC's	The ability to mix and match old functional store cases with remanufactured cases when performing a partial retrofit. The whole process takes between 2-4 weeks. The purchaser saves twice-reduced cost of reman unit, & reusing serviceable RDC;s from refit	Sales, Upgrade, EOL	Design for upgradability	Need to develop an extensive knowledge base, to trade RDC's between retail companies to fill a large order		
Inrego AB	Independent Remanufacturer	Buy back based | Product leasing or Products as service	Sweden	copper, tin, plastics & rare earth metals etc ae avoided to end up early in the waste stream. As reuse makes use of all embedded materials in the product		In 2014 around 700 schools utilized reconditioned computers through Inrego. It reconditioned 260000 units which saved 2800 tons of CO2 equivalent emissions	Around 90% of all received equipment is reused, the remaning is downcycled at an external recycling partner. At reception all core inits are bar code labeled with unique ID tied to its serial number, which is scanned to track and register specifications and test results throughout the reconditioning process. Data is wiped out using professional software that renders a data wiping certificate	Sales, Upgrade, EOL				
APD International	3rd party/Independent remanufacturer	Direct order based. The cores are obtained from OEMs via direct order, the reman products are directly returned to OEM's	Gloucestershire, UK & Mikulov, Czech Republic	Advanced materials such as alloys, rare earth metals etc will be reused within the reman process or recovered for recycling and reuse		produces 15000 remanufactured units annually to support the service within the printing industry	the reman product is atleast 40% cheaper then new , at the same time reducing waste stream disposal costs.	Sales, Upgrade, refurbish & EOL				
Canon	OEM- Original Equipment manufacturer	Ownership based - lease contracts typically running for 4-6 years. Buy basck based Voluntary based	Giessesn in Germany is the reman facility for EU Following a second life, reman products will be returned to NSOs if they are under a leasing contract	91% of the parts by weight are reused in the reman process.	3-5 years is an avergae life of a MFP (Laser Multifunctional Printers) before it is replaced.	By the end of 2017, Canon reports to have collected 394,000 tonnes of cartridges globally	In EU, customers can return their used cartridges free of charge, and they are reused or recycled into new cartridges using closed-loop process	Sales, Use, Upgrade, EOL	Design for disassembly Design for multiple lifecycles Modular design Design for durability	Managed Print Service - customers can outsource print management to Canon EMEA, who analyses printing habits and customer needs to find a cost-effective solution. They suggest appropriate equipment and cost-eefective solution		
Scandi-Toner AB in reman in 1993	Independant remanufacturer	Direct order & Buy back based. Around 90% of the used toner cartrideges are collected through Scandi-Toner's own return systems and rest 10% is bought from partners in Europe.	Karlstad, Sweden	materials recovered by the toner cartridges reman process are aluminium and steel	the reman cartridge has a warranty of 24 months, which is equal to the newly manufactured cartridges. However, it is not a big deal as they are mostly used within the 24 months		price-worthy reman are sold at 40% lower price of a new toner cartridge . The reman cartridges use 80% less oil when compared to new produced toner which uses 3-5 litres of oil oer cartridge		Design for disassembly			
Sony (SCEE) Original Playstation	OEM -Original Equipment manufacturer & 3rd party remanufacturer	Direct order based | Service exchange system	Two in European Union and 2 in Australia and NZ respectively	expensive processing units & mother boards		SCEE estimates that around 40% of returns towards the end of a product life cycle, were attributed to out of warranty. Without the current option from SCEE, over the period of 2004-2006, this prevented 3000 tonnes of CO2 entering the atmosphere and 13000 due to UK operations over the rest of Europe	Service replacement scheme -customers are without a console for a mimimum amount of time (only 24-48 hours in UK). Console collected from choice of address and new one is delivered at door step	Sales, marketing, distribution & software development				

Criteria	Definition	Observed in the case study of	Author	
Method employed for collection of cores	The process of remanufacturing fundamentally relies on the collection of core. Cores are generally collected through a specifically designed business model. Detailed product design informed by conventional reman process, carefully considers core collection.	Applicable in all case studies		
Adaptive remanufacturing	It is defined as the use of an EOL product core to create a similar but non identical product whose function and use characteristics are effectively equivalent to the original new product.	Daves furniture	(Krystofik et al., 2018)	
Indexing	It is defined as the process of upgrading a product to suit the current market, compared to a new product and thus more competitive with virgin products	Daves furniture	(Krystofik et al., 2018)	
Market Adaptability	Market preferences and demand change swifty, therefore a remanufactured product must be "designed for upgradability""and assert that an optimal strategy must maintain effective functional equivalence with current virgin product to preserve economic viability of remanufacturing	Daves furniture	(Krystofik et al., 2018)	
Closed-loop supply chain	The logistic channels of a product must be structured to simultaineously minimize waste oppurtunites and maintain both a viable resource stream and consistent customer base.	Daves furniture	(Krystofik et al., 2018)	
Evolution rate - Technology change	The technology under consideration should be capable of restoring the product and remaining stable over multiple lifecycles.	Canon, Philips, Xerox	(Charter & Gray, 2008), (Mfps, n.d.), (Economy & Model, 2020)	
Evolution rate - legislation	Evoluton rate i guided by the Rules and Regualtion that are released by higher authorities and Government Institutions. They impact the remanufacturing of products in terms of colletion of cores, material recovery and resale of remanufactured products into the market	Canon, Philips, Xerox	(Charter & Gray, 2008), (Mfps, n.d.), (Economy & Model, 2020)	
Evolution rate - Upgrade Potential	The product must have features that make it upgradable	Applicable in all case studies		
Reconstuctability - Construction	The component should be made of standard interchangable parts.The construction procedure during a reman operation should be set by standardized protocols, to make the process efficient	Canon, Xerox, Daves	(Krystofik et al., 2018), (Mfps, n.d.)	
Reconstructability - Remediation	Reamnuafacturing over multiple lifecycles should be enivronmentally feasible and economically viable. This ensures that the process is not impratical and expensive compared to remanufacturing of new products.	Daves furniture, Philips	(Economy & Model, 2020), (Krystofik et al., 2018)	
Reconstructability - Knowledge	The skilled labour for the remanufactured process should be made avilable on a single remanufacturing facility with standard protocols to prevent creation of new remanufacturing channels which may not be cost-effective.	Philips	(Economy & Model, 2020)	
Value - Embedded Value	The core product must be durable and should contain a high value	Philips, Canon, Xerox	(Charter & Gray, 2008), (Mfps, n.d.), (Economy & Model, 2020)	
Value - labour-v-materials	The availabililty of skilled workforce is important in remanufacturing process of products with a low EOL value (applied vice-versa)	Daves furniture	(Krystofik et al., 2018)	
Value - Specilaities	Offering additonal incentives such as digital support system and policies can help in promoting sale of remanufactured products.	Canon	(Mfps, n.d.)	
Remanufacturing cost structure	The overall cost of procurement and reprocessing the core should be low, when compared to the residual value-added,	Canon	(Mfps, n.d.)	
Reverse Logistics/channels	Channels for the reverse flow of returned products must exist. These are related to revenue streams as well.	Applicable in all case studies		
Role of ICT	Digitisation is a key component of upgradebility. This is valuable for sales and management team to continuosly monitor the company's assets while offering the customer latest upgrades and incentives to turn-in the products at/or before EOL	Philips, Canon	(Mfps, n.d.), (Economy & Model, 2020)	
Design for remanufacture - Detailed product design / product parts	It is an integral part of the product devlopment process, to achieve complete benefits of remanufacturing with respect to reduced energy, waste and material consumption	Applicable in all case studies		
Remanufacturing design platform	Creation of a remanufacturing design platform which is a strategic architecture of components that forms a platform of components with dedicated values remanufactured for multiple lives into which a series of high ebergy using components are added.	Xerox	(Charter & Gray, 2008	
Creating a brand value	To make the remanufactured product well-known in the market helps customers understand what they are getting in terms of quality. This also allows sales teams to better understand and communicate the proposition.	Philips, Caterpillar	(Sakao et al., 2010), (Economy & Model, 2020)	
Demand	There should exsit sufficent demand for the remanufatured product	Applicable to all case studies		

Table

Observations from all case studies

Circular Business Model & Strategy	Philips	Xerox	Canon	Caterpillar	Daves Furniture
DfX Product life extenstion strategy	Design for long life by design for diassembly & upragability	Design for diassembly & upgradability	Design for diassembly & upgradability	Design for diassembly & upgradability	Most parts of office furniture retrived through circular sourcing are designed for disassembly & upgradability
Technical Design Concept		Remanufacturing design platform	Managed Print Service		
Material Choice					
Circular Sourcing	Harvesting parts & components from traded MR systems	Xerox retrives EOL products through direct channels or buys back for third party leasing companies	EOL products are either retuned to Canon through direct channels or are bought by Canon from third party leasing companies	Customer return the equipment at EOL in a sustainable box which carries a small core deposit	Harvesting EOL Office furniture considered as waste to transform into "as new" products
Re-make & upgrade	Machines were upgraded until upgrades were available and then refurbished	Machines are remanufactured and upgraded to match the customers specifications	Machines are remanufactured and rebranded as Eq80, which denotes that atleast 80% of the machine has been develped with reused parts	The returned equipement is remanufactured and upgraded to the specifications of a new product available in the current market	The machines were indexed and remanufactured to suit the current market demands
Reverse Channels	The MR equiments were leased to customers on ownership-based contract. The same channels were used for resale	The machines are leased on Ownership-based contract, wherein Xerox reatins authority of the machines to make decisions at EOL	Canon takes back machines as part of the same transaction when it delivers new units.	The equioment is sold on a deposit based model. The end user is expected to return the product at EOL to recieve a new remanufactured product with warranty and as new condition.	The customers who provided EOL furniture are promising customers who buy-back remanufactured products. Incentives in price and demand makes ithe remaufactured product favourable.
Access & Performance	Enhances performance and functionality of MRI equipment throughout its lifetime	A majority of printers are leased rather than owned by customers.	A majority of printers are leased rather than owned by customers. The Managed Print Service value proposition focuses on delivering mproved performance to customers.		
Extending producer value				The Caterpillar machines are designed for durability and the cores are designed to work for mulitple life cycles	
Classic long life					
Encourage Sufficiency					The remanufactured products encourage sufficiency and are esxpected to be returned to Daves at EOL
Resource recovery	Incentivises return and take back of MRI equipment	Excercises buy back or take back equipment from customers and third party	Excercises buy back or take back equipment reaching EOC from customer lease	Incentivises return of products	Incentivises return and take back of all EOL office furniture
Role of ICT	SmartPath Portfolio, that enhances optimise during the servie life, transform and trade-in of MRI equipment at end of service life or contract		Machines in Field and Managed Print Service helps the sales and management team to offer upgrades and incentivise return of equioment		

Facade remanufactured with EoL elements															
No	Material	Source	Quantity	Cross section [m2]	Length [m]	Volume [m3]	Density [Kg/m3]	Mass [Kg]	% of share by mass	% of share by Volume	Disassembly [MJ]	Transport to reman facility [MJ]	Deconstruction [MJ]	Processing [MJ]	Recycle & Disposal [MJ]
1	Aluminium mullion														
2	Aluminium transom														
3	Bronze mullion														
5	Bronze transom														
6	PVC														
7	Glass (8-75-8)														
8	Glazing beads														
9	Rubber Gaskets								0,03195	Transport			energy		CO2
10	Rockwool Insulation rolled								3,4	Deconstruction			transport		
11	Rockwool insulation (100mm)								0,013	Disposal		0,239	Disassembly		
12	Glass (8)								0,01	processing		0,0437	Deconstruct		
				0,001261712	6,536	0,008454878072							processing	0,01	processing
				0,012262249	16,674	0,03404135138									

Facade remanufactured with EoL elements											Substituted EoL				
No	Material	Source	Quantity	Cross section [m2]	Length [m]	Volume [m3]	Density [Kg/m3]	Mass [Kg]	% of share by mass	% of share by Volume	Disassembly [MJ]	Transport to reman facility [MJ]	Deconstruction[MJ]	Processing [MJ]	Waste processing [MJ]
1	Aluminium mullion		3	0,005664597	8,28	0,01558112108	7900	123,0908566	11,06429837	2,279753495	29,41871472		5,379070432		-
2	Aluminium transom		3	0,006597652	8,394	0,0184602303	7900	145,8358193	13,10878048	2,701010685	34,85476082		6,373025305		-
3	Bronze mullion		2	0,000741669	3,738	0,005544717444	8500	47,13009827	4,23639484	0,8112759605	11,26409349		2,059585295		-
4	Bronze transom		2	0,000520043	2,798	0,002910160628	8500	24,73636534	2,22348381	0,4258004817	5,911991316		1,080979165		-
	PVC			0,002531776	4,684	0,005929419392	1300	7,70824521	0,6928729501	0,8675636695					
5	Glass (8-75-8)		2	0,021408	3,736	0,159960576	2500	399,90144	35,94603998	23,40464978					
6	Glass (8)		1	0,021408	3,236	0,138552576	2500	346,38144	31,13527446	20,27233584					
7	Rockwool Insulation rolled		6	0,009051408	12,018	0,04187229381	60	0,04187229381	0,00376378526	6,126549408					
8	Rockwool insulation (100mm)			0,2070677858	7,836	0,2946453017	60	17,6787181	1,589091321	43,11106067					
9															

Facade remanufactured with EoL elements											Substituted EoL				
No	Material	Source	Quantity	Cross section [m2]	Length [m]	Volume [m3]	Density [Kg/m3]	Mass [Kg]	% of share by mass	% of share by Volume	Disassembly [CO2/kg]	Transport to reman facility [CO2/kg]	Deconstruction [CO2/kg]	Processing [CO2/kg]	Waste processing [CO2/kg]
1	Aluminium mullion		3	0,005664597	8,28	0,01558112108	7900	123,0908566	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-
2	Aluminium transom		3	0,006597652	8,394	0,0184602303	7900	145,8358193	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-
3	Bronze mullion		2	0,000741669	3,738	0,005544717444	8500	47,13009827	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-
4	Bronze transom		2	0,000520043	2,798	0,002910160628	8500	24,73636534	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-
	PVC			0,002531776	4,684	0,005929419392	1300	[illegible]	[illegible]	[illegible]	[illegible]				
5	Glass (8-75-8)		2	[illegible]	[illegible]	[illegible]	2500	[illegible]	[illegible]	[illegible]	[illegible]				
6	Glass (8)		1	[illegible]	[illegible]	[illegible]	2500	[illegible]	[illegible]	[illegible]	[illegible]				
7	Rockwool Insulation rolled		2	[illegible]	[illegible]	[illegible]	60	[illegible]	[illegible]	[illegible]	[illegible]				
8	Rockwool insulation (100mm)			[illegible]	[illegible]	[illegible]	60	[illegible]	[illegible]	[illegible]					
9															
				[illegible]		[illegible]		[illegible]							

Facade remanufactured with EoL elements											Avoided Module C			
No	Material	Source	Quantity	Cross section [m2]	Length [m]	Volume [m3]	Density [Kg/m3]	Mass [Kg]	% of share by mass	% of share by Volume	Demolition [MJ]	Transport to reman facility [MJ]	Waste processing for recycling [MJ]	Disposal [MJ]
1	Aluminium mullion		3	0,005664597	8,28	0,01558112108	7900	123,0908566	[illegible]	[illegible]	[illegible]	[illegible]		
2	Aluminium transom		3	0,006597652	8,394	0,0184602303	7900	145,8358193	[illegible]	[illegible]	[illegible]	[illegible]		
3	Bronze mullion		2	0,000741669	3,738	0,005544717444	8500	47,13009827	[illegible]	[illegible]	[illegible]	[illegible]		
4	Bronze transom		2	0,000520043	2,798	0,002910160628	8500	24,73636534	[illegible]	[illegible]	[illegible]	[illegible]		
	PVC			0,002531776	4,684	0,005929419392	1300	[illegible]	[illegible]	[illegible]				
5	Glass (8-75-8)		2	[illegible]	[illegible]	[illegible]	2500	[illegible]	[illegible]	[illegible]				
6	Glass (8)		1	[illegible]	[illegible]	[illegible]	2500	[illegible]	[illegible]	[illegible]				
7	Rockwool Insulation rolled		2	[illegible]	[illegible]	[illegible]	60	[illegible]	[illegible]	[illegible]				
8	Rockwool insulation (100mm)			[illegible]	[illegible]	[illegible]	60	[illegible]	[illegible]	[illegible]				
9														
				[illegible]		[illegible]		[illegible]						

[illegible]

Facade remanufactured with EoL elements											Avoided Module C			
No	Material	Source	Quantity	Cross section [m2]	Length [m]	Volume [m3]	Density [Kg/m3]	Mass [Kg]	% of share by mass	% of share by Volume	Demolition [CO2/kg]	Transport to reman facility [CO2/kg]	Deconstruction [CO2/kg]	Disposal [CO2/kg]
1	Aluminium mullion		3	0,005664597	8,28	0,01558112108	7900	123,0908566	[illegible]	[illegible]	[illegible]			
2	Aluminium transom		3	0,006597652	8,394	0,0184602303	7900	145,8358193	[illegible]	[illegible]	[illegible]			
3	Bronze mullion		2	0,000741669	3,738	0,005544717444	8500	47,13009827	[illegible]	[illegible]	[illegible]			
4	Bronze transom		2	0,000520043	2,798	0,002910160628	8500	24,73636534	[illegible]	[illegible]	[illegible]			
	PVC			0,002531776	4,684	0,005929419392	1300	[illegible]	[illegible]	[illegible]				
5	Glass (8-75-8)		2	[illegible]	[illegible]	[illegible]	2500	[illegible]	[illegible]	[illegible]				
6	Glass (8)		2	[illegible]	[illegible]	[illegible]	2500	[illegible]	[illegible]	[illegible]				
7	Rockwool Insulation rolled		2	[illegible]	[illegible]	[illegible]	60	[illegible]	[illegible]	[illegible]				
8	Rockwool insulation (100mm)			[illegible]	[illegible]	[illegible]	60	[illegible]	[illegible]	[illegible]				
9														
				[illegible]		[illegible]		[illegible]						

Facade remanufactured with EoL elements											Avoided Module A		
No	Material	Source	Quantity	Cross section [m2]	Length [m]	Volume [m3]	Density [Kg/m3]	Mass [Kg]	% of share by mass	% of share by Volume	Extraction [MJ]	Transportation [MJ]	Production [MJ]
1	Aluminium mullion			[illegible]			7900	0	0	0			
2	Aluminium transom			[illegible]			7900	0	0	0			
3	Bronze mullion		2	0,000741669	3,738	0,005544717444	8500	47,13009827	[illegible]	[illegible]	[illegible]	[illegible]	
4	Bronze transom		2	0,000520043	2,798	0,002910160628	8500	24,73636534	[illegible]	[illegible]	[illegible]	[illegible]	
	PVC								0	0			
5	Glass (8-75-8)		2						0	0			
6	Glass (8)		2						0	0			
7	Rockwool Insulation rolled						60	0	0	0			
8	Rockwool insulation (100mm)					0	60	0	0	0			
9													
				[illegible]		[illegible]		[illegible]					

Facade remanufactured with EoL elements											Avoided Module A		
No	Material	Source	Quantity	Cross section [m2]	Length [m]	Volume [m3]	Density [Kg/m3]	Mass [Kg]	% of share by mass	% of share by Volume	Extraction [CO2/kg]	Transportation [CO2/kg]	Production [CO2/kg]
1	Aluminium mullion		3	0,005664597	8,28	0,01558112108	7900	123,0908566	[illegible]	[illegible]	0	0	0
2	Aluminium transom		3	0,006597652	8,394	0,0184602303	7900	145,8358193	[illegible]	[illegible]	0	0	0
3	Bronze mullion		2	[illegible]	3,738	[illegible]	8500	[illegible]	[illegible]	[illegible]	0	0	0
4	Bronze transom		2	0,000520043	2,798	0,002910160628	8500	24,73636534	[illegible]	[illegible]	0	0	0
	PVC			0,002531776	4,684	0,005929419392	1300	[illegible]	[illegible]	[illegible]			
5	Glass (8-75-8)		2	[illegible]	[illegible]	[illegible]	2500	[illegible]	[illegible]	[illegible]			
6	Glass (8)		2	[illegible]	[illegible]	[illegible]	2500	[illegible]	[illegible]	[illegible]			
7	Rockwool Insulation rolled		2	[illegible]	[illegible]	[illegible]	60	[illegible]	[illegible]	[illegible]			
8	Rockwool insulation (100mm)			[illegible]	[illegible]	[illegible]	60	[illegible]	[illegible]	[illegible]			
9													
				[illegible]		[illegible]		[illegible]					

Design Scenario conditions for assessment		
Scenario	Condition	material recovered from remanufacturing
Scenario	remanufacturing of materials from disassembly	PVC profile cap
		Aluminium profiles
		Bronze profiles
		T connectors (seems possible)
		Aluminium glazing beads

	1,868	1,338	
	L	W	D
Glass	1,868	1,338	0,008
Glass p	1,618	1,338	0,008
Steel box			0,002
Al			
Bronze			
rockwool	1,618	1,338	0,1
PVC	1,868	1,338	0,00136543

ALUMINIUM PROFILES					
A	0,002354573	2,684	2		0,01263934786
B	0,002281642	2,798	1		0,006384034316
C	0,001961437	2,798	1		0,005488100726
D	0,001655012	2,798	2		0,009261447152
	0,008252664	11,078	6		0,03377293006
BRONZE PROFILES					
E	0,000520043	2,798	2		0,002910160628
F	0,000741669	3,738	2		0,005544717444
	0,001261712	6,536	4		0,008454878072
ROCKWOOL FILLING					
G	0,00218541	2,684	2		0,01173128088
H	0,00226477	2,798	1		0,00633682646
I	0,00226477	2,798	1		0,00633682646
J	0,002336458	3,738			0,01746736001
			2		
	0,009051408	12,018		6	0,04187229381
ROCKWOOL					
K	0,0082890868	2,798	1		0,02319286487
L	0,19343	1.3	1.682		0,251459
M	0,005348699	3,738	1		0,01999343686
	0,2070677858	7,836		3,682	0,2946453017
D	W	H			
0,115	1,3	1,682			
STEEL					
EPDM					
		3,738	2		1261,9488
Q	168,8				
R	103,5	2,798	2		579,186
S	123,655	2,798	2		691,97338
	395,955	9,334			2533,10818
	8289,086	1			
	221.03				
	115				
	1,922				

Mullion	A	0,002354573	2,684	1	0,00631967	0,03195	Transport
	D	0,001655012	2,798	1	0,00463072	3,4	Deconstruction
	D	0,001655012	2,798	1	0,00463072	0,013	Disposal
	SUM	0,005664597	8,28	3	0,01558112	0,01	processing
Transom	A	0,002354573	2,798	1	0,00658809		
	B	0,002281642	2,798	1	0,00638403		
	C	0,001961437	2,798	1	0,00548810		
	SUM	0,006597652	8,394	3	0,01846023		

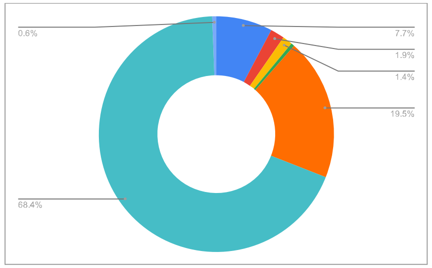
	No	Material	Quantity	Cross section [m2]	Length [m]	Volume [m3]	Density [Kg/m3]	Mass [Kg]
	1	Aluminium mullions	6					
	2	Bronze	4					
	3	PVC	4	0,00730778136				
	4	Steel						
	5	Rockwool	2					
	6	Glass glazing	2	0,021408	3,736	0,159960576	2500	399,90144
	7	EPDM						
	8	Glass sandwich	2	0,021408	3,236	0,138552576	2500	346,38144
	9	Rockwool rolled	6					
	10	Chrome steel						

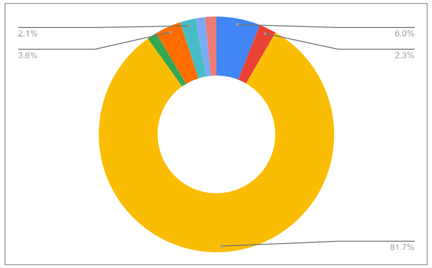
% of mass of constituent material							
No	Material	Cross section [m2]	Length [m]	Volume [m3]	Density [Kg/m3]	Mass [Kg]	%
1	Aluminium -1100	0,008252664	11,078	0,03377293006	2720	91,8623697	0,00133290133
2	Bronze -rolled & drawn	0,001261712	6,536	0,008454878072	8500	71,8664636	0,0003336849
3	PVC	0,001265888	2,684	0,003397643392	1300	4,41693641	0,00013409329
4	Steel	0,001431929	1,3	0,0018615077	7860	14,6314505	0,0000734673
5	Rockwool	0,2161191938	19,854	0,3365175955	60	20,1910557	0,01328119153
6	Glass	0,042816	6,972	0,298513152	2500	746,28288	0,01178128692
	EPDM	395,955	9,334	2533,10818			99,97306337
							0,0269366253
			total volume	2533,790698			
							100,0269366
		0,001265888	2	0,002531776	1300	3,2913088	
	PVC final	0,002531776	4,684	0,005929419392	1300	7,70824521	

Design Scenario conditions for assessment			
Scenario	Condition	material recovered from recycle	material recovered from remanufacturing
Scenario 1	recycle of materials from demolition	Bronze from profiles	
		Aluminium from profiles	
Scenario 2	remanufacturing of materials from disassembly		PVC profile cap
			Aluminium profiles
			Bronze profiles
			T connectors - ?
			Aluminium glazing beads

No	Material	Cross section [m2]	Length [m]	Volume [m3]
1	Aluminium -1100	0.008252664	11.078	0.03377293006
2	Bronze -rolled & drawn	0.001261712	6.536	0.008454878072
3	PVC	0.002531776	4.684	0.005929419
4	Steel	0.001431929	1.3	0.0018615077
5	Rockwool	0.0226891938	18.554	0.08505859554
6	Glass	0.042816	6.972	0.298513152
7	EPDM	0.000395955	9.334	0.00255310818

No	Material	Cross section [m2]	Length [m]	Volume [m3]
1	Aluminium mullion	0.00062	3	0.00372
2	Bronze -rolled & drawn	0.00062	1.16	0.0014384
3	PVC	3.0 X 1.2		0.0504
4	Steel	0.000103	7.9	0.0008137
5	Rockwool	0.000286	4.16	0.00221312
6	Glass	0.000157	4.16	0.00130624
7	EPDM	0.000098	4.16	0.00081536
8	Aluminium pressure plate	0.000114	4.16	0.00094848





No	Material	Cross section [m2]	Length [m]	Volume [m3]
1	Aluminium	0.012262249	16.674	0.03404135138
2	Bronze -rolled & drawn	0.001261712	6.536	0.008454878072
3	PVC	0.002531776	4.684	0.005929419
4	Steel	0.001431929	1.3	0.0018615077
5	Rockwool rolled	0.009051408	12.018	0.04187229381
6	Glass	0.3365175955	19.854	6.681220341
7	Colorbel panel glass	0.138552576	9.334	1.293249744
8	Colorbel panel insulation	0.2070677858	7.836	0.2946453017

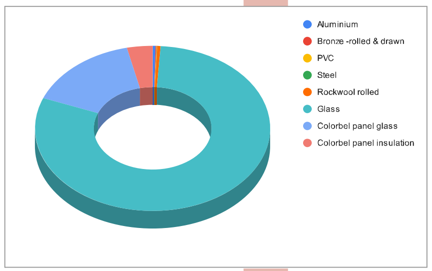
	0.012262249	16.674	0.03404135138
	0.001261712	6.536	0.008454878072

ALUMINIUM PROFILES				
A	0.002354573	2.684	2	0.01263934786
B	0.002281642	2.798	1	0.006384034316
C	0.001961437	2.798	1	0.005488100726
D	0.001655012	2.798	2	0.009261447152
Sum	0.008252664	11.078	6	0.03377293006

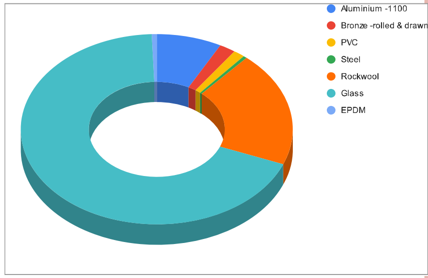
BRONZE PROFILES				
E	0.000520043	2.798	2	0.002910160628
F	0.000741669	3.738	2	0.005544717444
Sum	0.001261712	6.536	4	0.008454878072

ROCKWOOL FILLING				
G	0.00218541	2.684	2	0.01173128088
H	0.00226477	2.798	1	0.00633682646
I	0.00226477	2.798	1	0.00633682646
J	0.002336458	3.738	2	0.01746736001
Sum	0.009051408	12.018	6	0.04187229381

ROCKWOOL				
K	0.0082890868	2.798	1	0.02319286487
L	0			0
M	0.005348699	3.738	1	0.01999343686
Sum	0.0136377858	6.536	2	0.04318630173



Design Scenario conditions for assessment			
Scenario	Condition	material recovered from recycle	material recovered from remanufacturing
Scenario 1	remanufacturing of materials recovered from disassembly	Bronze from profiles	
		Aluminium from profiles	
Scenario 2	reycling of materials after dismantling/demolition on-site		PVC profile cap
			Aluminium profiles
			Bronze profiles
			steel box?
			T connectors - ?
			Aluminium glazing beads



EoL Scenario	Means of transportation	Site to storage facility [Km]	Storage to processing facility [Km]	Processing to reman facilty [Km]
Remanufacturing	Electric - Boat	50	100	150
Recycling	14 Tonne 2 Axle truck	50	50	

Transport
CO2

ECF	TD	TEF	TD X TEF
0.03195	50	0.1065	0.005325
	100	0.1065	0.01065
	150	0.1065	0.015975

Deconstruction CO2
EC c1 3.4 KgCO2e/,2 use this for deconstru

Disassmembly for reuse
The research assumes 74.3 kg carbon emissions per GJ of energy

	recyc	reman
E demolition	0.239	0.432

Processing the waste factor for Al frames is 0.010

ECF	TD	TEF	TD X TEF
0.01065	50	0.1065	0.005325
	50	0.1065	0.005325

No	Material	Source	Quantity	Cross section [m2]	Length [m]	Volume [m3]	Density [Kg/m3]	Mass [Kg]	% of share by mass	% of share by Volume	Disassembly [CO2/kg]	Transport to reman facility [CO2/kg]	Deconstruction [CO2/kg]	Processing of residual waste [CO2/kg]
1	Aluminium Mullion	secondary	3	0.005664597	8.28	0.01558112108	7900	123.0908566	11.06429837	2.279753495	3.088235294	2.959719647	1.544117647	1.600181136
2	Aluminium Transom	secondary	3	0.006597652	8.394	0.0184602303	7900	145.8358193	13.1087048	2.701010685	3.088235294	3.506622275	1.544117647	1.895865651
3	Bronze Mullion	secondary	2	0.000741669	3.738	0.005544717444	8500	47.13009827	4.23639484	0.8112759605	3.088235294	1.133243213	1.544117647	0.6126912775
4	Bronze Transom	secondary	2	0.000520043	2.798	0.002910160628	8500	24.73636534	2.22348381	0.4258004817	3.088235294	0.5947859046	1.544117647	0.3215727494
5	PVC Mullion (inside)	secondary	2	0.002531776	2.342	0.002964709696	1300	7.70824521	0.6928729501	0.8675636695				
6	PVC Transom (inside)	secondary	2	19.854	2.342	0.002964709696	1300	399.90144	35.94603998	23.40464978				
7	Glass (8-75-8)	Primary	2	9.334	3.736	0.159960576	2500	346.38144	31.13527446	20.27233584				
8	Glass (8)	Primary	2	103.4	3.236	0.138552576	2500	0.04187229381	0.0037637852	6.126549408				
9	Rockwool panel insulation (100)	secondary		221.03	12.018	0.04187229381	60	17.6787181	1.589091321	43.11106067				
10	Rockwool insulation rolled	Primary			7.836	0.2946453017	60							
11	EPDM	Primary												
							Percentage of components recovered for reman process		30.63288182	6.217840622	12.35294118	8.19437104	6.176470588	4.430310814
									Total					31.15409362

^=3.4×10−6/

Recovering materials from EoL facade for Remanufacturing process — Avoided Module C

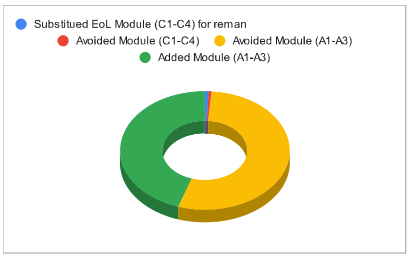
No	Material	Source	Quantity	Cross section [m2]	Length [m]	Volume [m3]	Density [Kg/m3]	Mass [Kg]	% of share by mass	% of share by Volume	Demolition [CO2/kg]	Transport to waste processing facility [CO2/kg]	Waste processing for recycling [CO2/kg]	Disposal [CO2/kg]
1	Aluminium Mullion	secondary	3	0.005664597	8.28	0.01558112108	7900	123.0908566	11.06429837	2.279753495	3.088235294	1.966376434	1.600181136	
2	Aluminium Transom	secondary	3	0.006597652	8.394	0.0184602303	7900	145.8358193	13.1087048	2.701010685	3.088235294	2.329727213	1.895865651	
3	Bronze Mullion	secondary	2	0.000741669	3.738	0.005544717444	8500	47.13009827	4.23639484	0.8112759605	3.088235294	0.7529033199	0.6126912775	
4	Bronze Transom	secondary	2	0.000520043	2.798	0.002910160628	8500	24.73636534	2.22348381	0.4258004817	3.088235294	0.3951634363	0.3215727494	
5	PVC Mullion (inside)	secondary	2	0.001265888	2.342	0.002964709696	1300	7.70824521	0.6928729501	0.8675636695				
6	PVC Transom (inside)	secondary	2	0.001265888	2.342	0.002964709696	1300	399.90144	35.94603998	23.40464978				
7	Glass (8-75-8)	Primary	2	19.854	3.736	0.159960576	2500	346.38144	31.13527446	20.27233584				
8	Glass (8)	Primary	2	9.334	3.236	0.138552576	2500	0.04187229381	0.0037637852	6.126549408				
9	Rockwool panel insulation (100)	secondary		103.4	12.018	0.04187229381	60	17.6787181	1.589091321	43.11106067				
10	Rockwool insulation rolled	Primary		221.03	7.836	0.2946453017	60							
11	EPDM	Primary									12.35294118	5.444170404	4.430310814	
														22.22742239

Recovering materials from EoL facade for Remanufacturing process — Avoided Module A

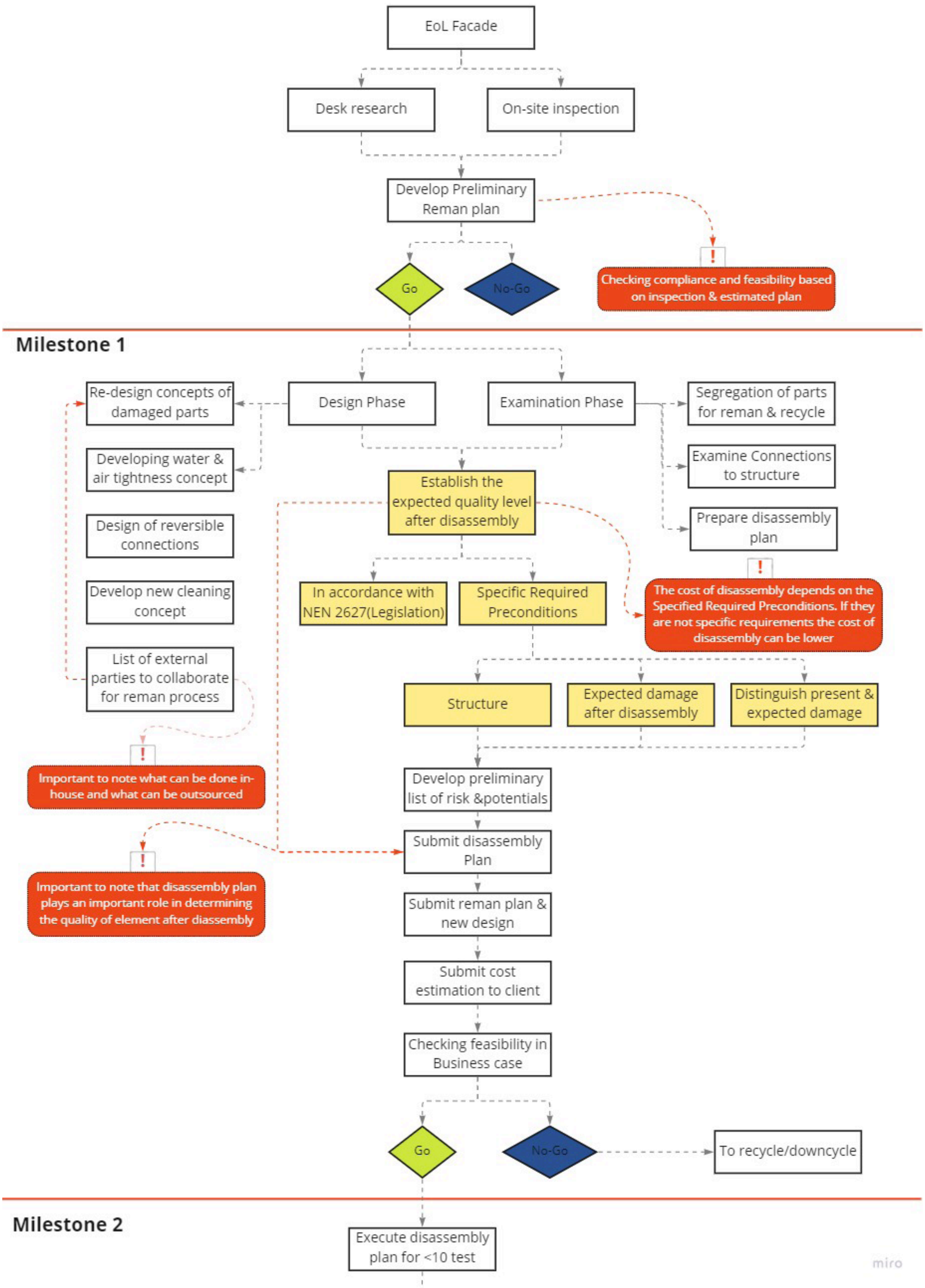
No	Material	Source	Quantity	Cross section [m2]	Length [m]	Volume [m3]	Density [Kg/m3]	Mass [Kg]	% of share by mass	% of share by Volume	A1 Extraction [CO2/kg]	A2 Transportation [CO2/kg]	A3 Production [CO2/kg]
1	Aluminium Mullion	secondary	3	0.005664597	8.28	0.01558112108	7900	123.0908566	11.06429837	2.279753495		822.6161947	
2	Aluminium Transom	secondary	3	0.006597652	8.394	0.0184602303	7900	145.8358193	13.1087048	2.701010685		974.6207804	
3	Bronze Mullion	secondary	2	0.000741669	3.738	0.005544717444	8500	47.13009827	4.23639484	0.8112759605		314.9704467	
4	Bronze Transom	secondary	2	0.000520043	2.798	0.002910160628	8500	24.73636534	2.22348381	0.4258004817		165.3131296	
5	PVC Mullion (inside)	secondary	2	0.001265888	2.342	0.002964709696	1300	7.70824521	0.6928729501	0.8675636695			
6	PVC Transom (inside)	secondary	2	0.001265888	2.342	0.002964709696	1300	399.90144	35.94603998	23.40464978			
7	Glass (8-75-8)	Primary	2	19.854	3.736	0.159960576	2500	346.38144	31.13527446	20.27233584			
8	Glass (8)	Primary	2	9.334	3.236	0.138552576	2500	0.04187229381	0.0037637852	6.126549408			
9	Rockwool panel insulation (100)	secondary		103.4	12.018	0.04187229381	60	17.6787181	1.589091321	43.11106067			
10	Rockwool insulation rolled	Primary		221.03	7.836	0.2946453017	60						
11	EPDM	Primary		0.000395955			100						
													2277.520551

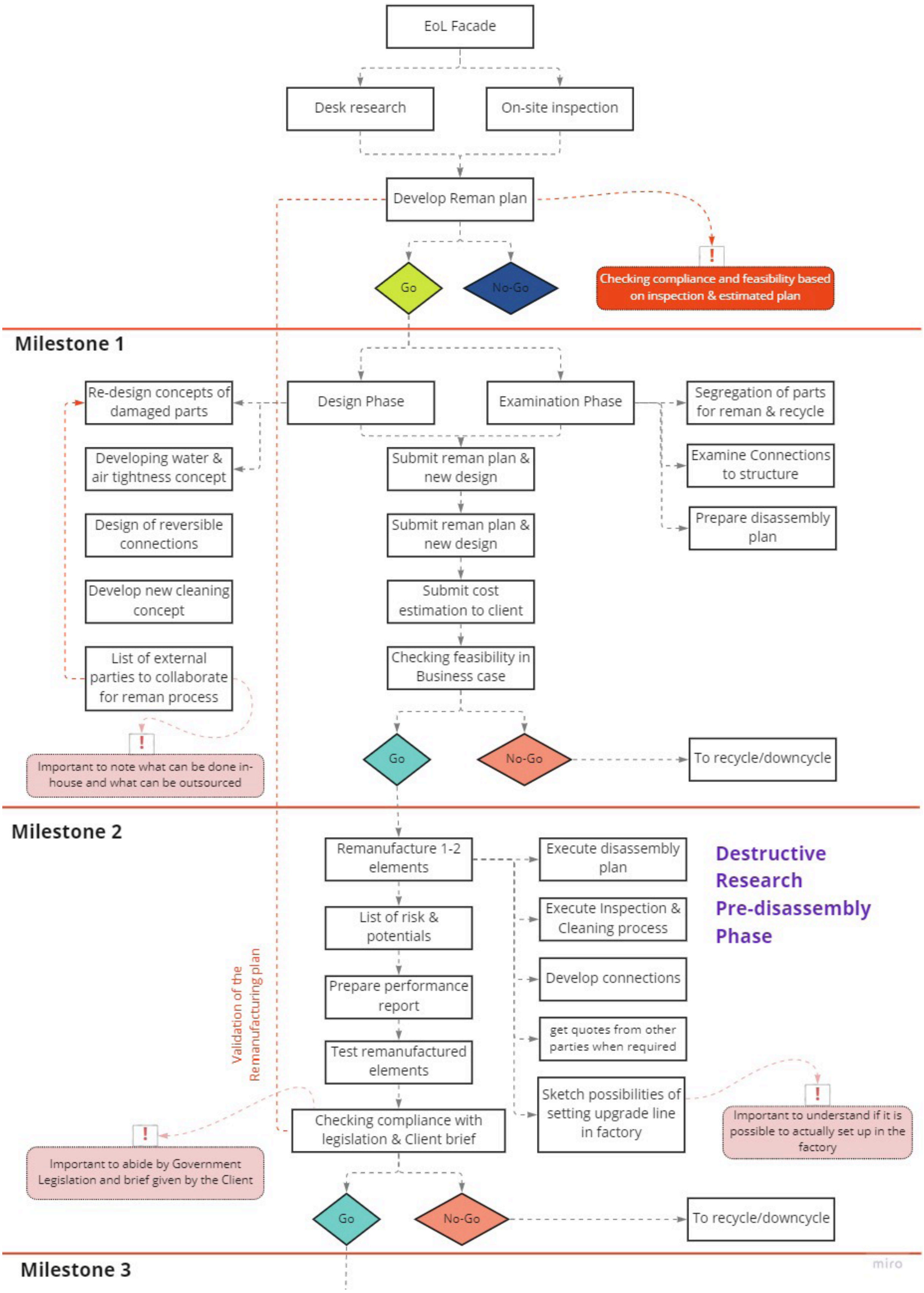
Adding new virgin materials to the EoL facade for Remanufacturing process — Added Module A

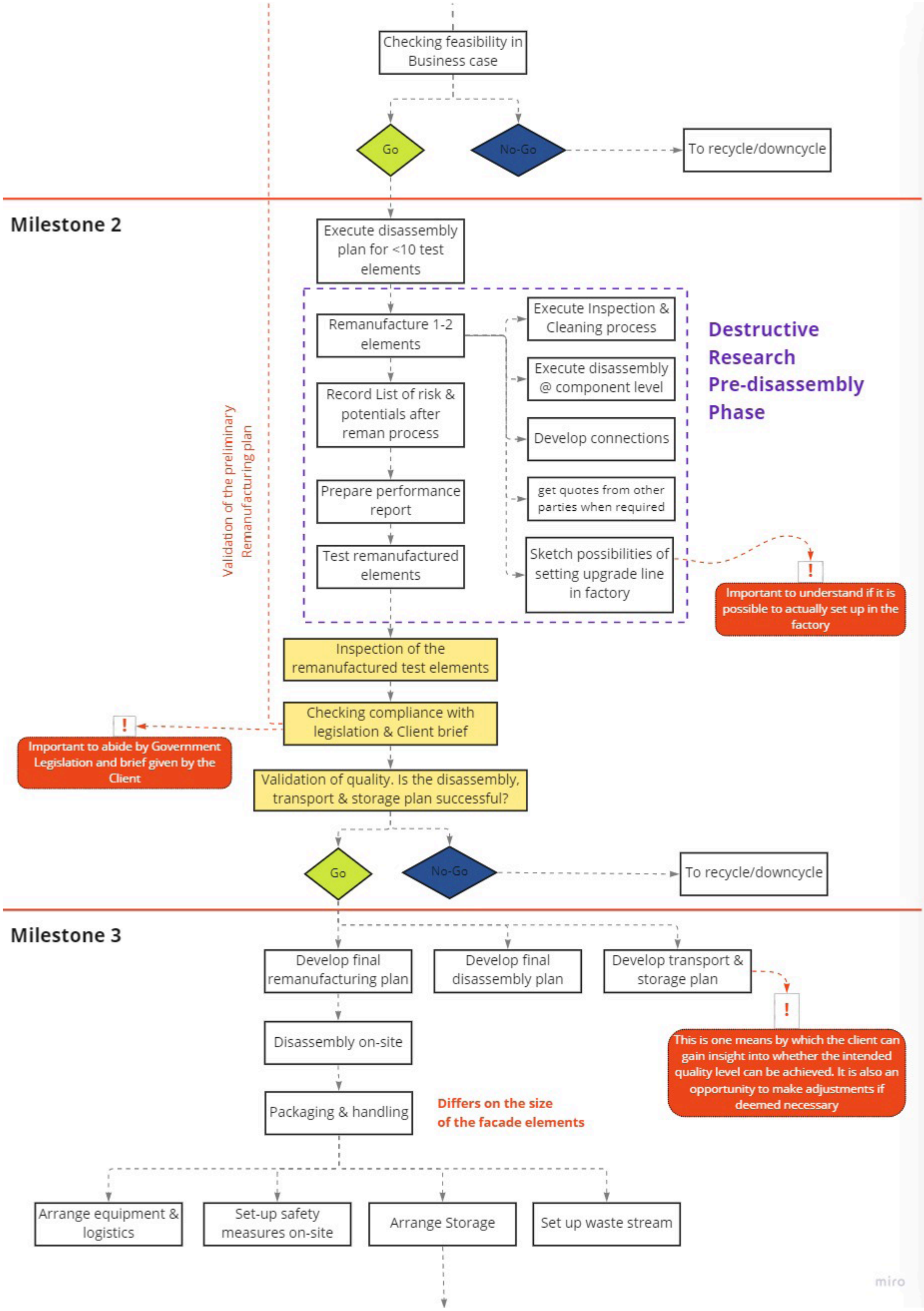
No	Material	Source	Quantity	Cross section [m2]	Length [m]	Volume [m3]	Density [Kg/m3]	Mass [Kg]	% of share by mass	% of share by Volume	A1 Extraction [CO2/kg]	A2 Transportation [CO2/kg]	A3 Production [CO2/kg]
1	Triple Glazing unit Schucö	Primary	1									948.57	
2	Rockwool Insulation	Primary		103.4	12.018							5.099626663	
3	EPDM	Primary		0.000395955	3.736	0.00147928788	100	0.147928788				0.4748514095	
6	Colorbel panels	Primary										948.57	
													1902.714478

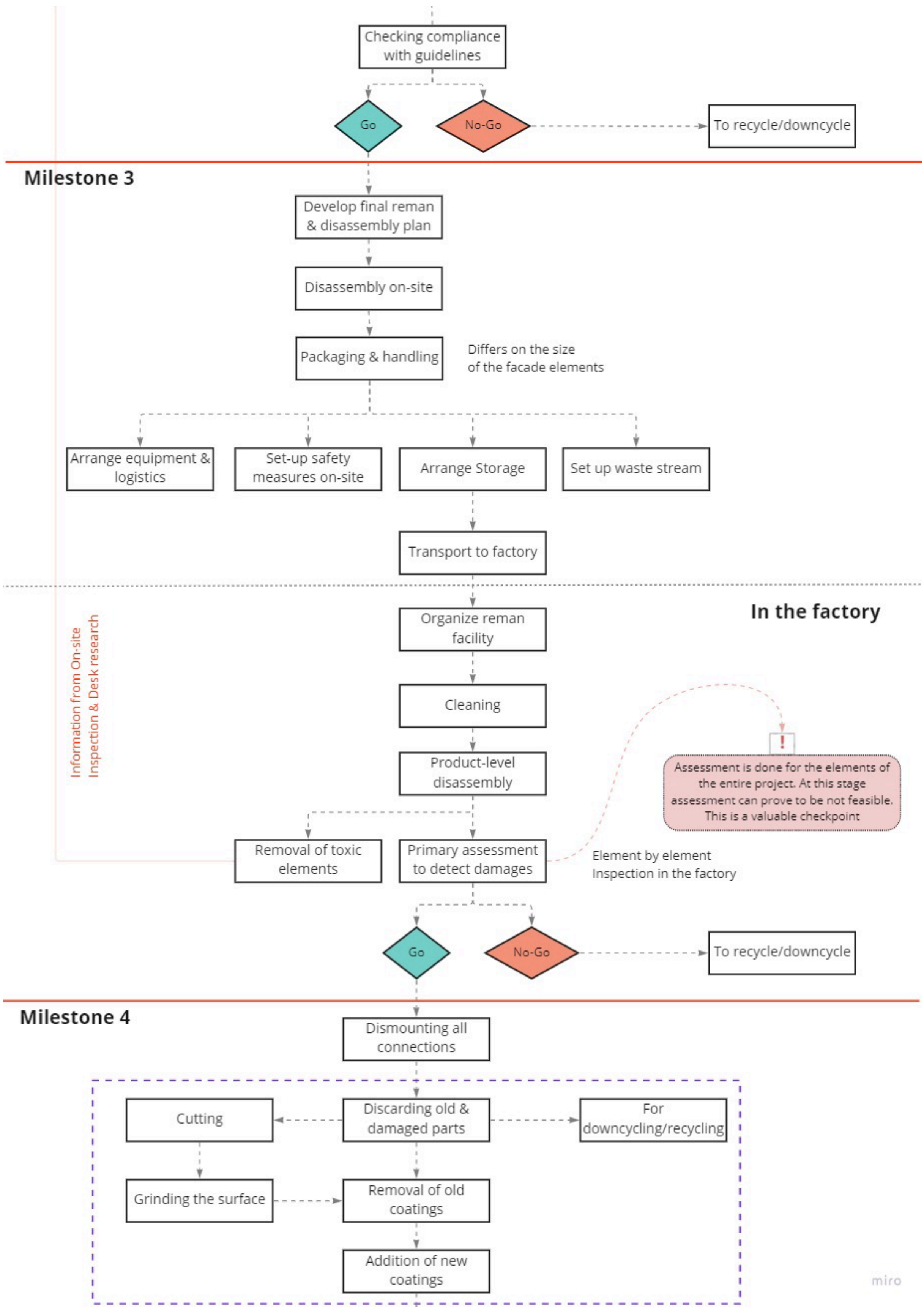


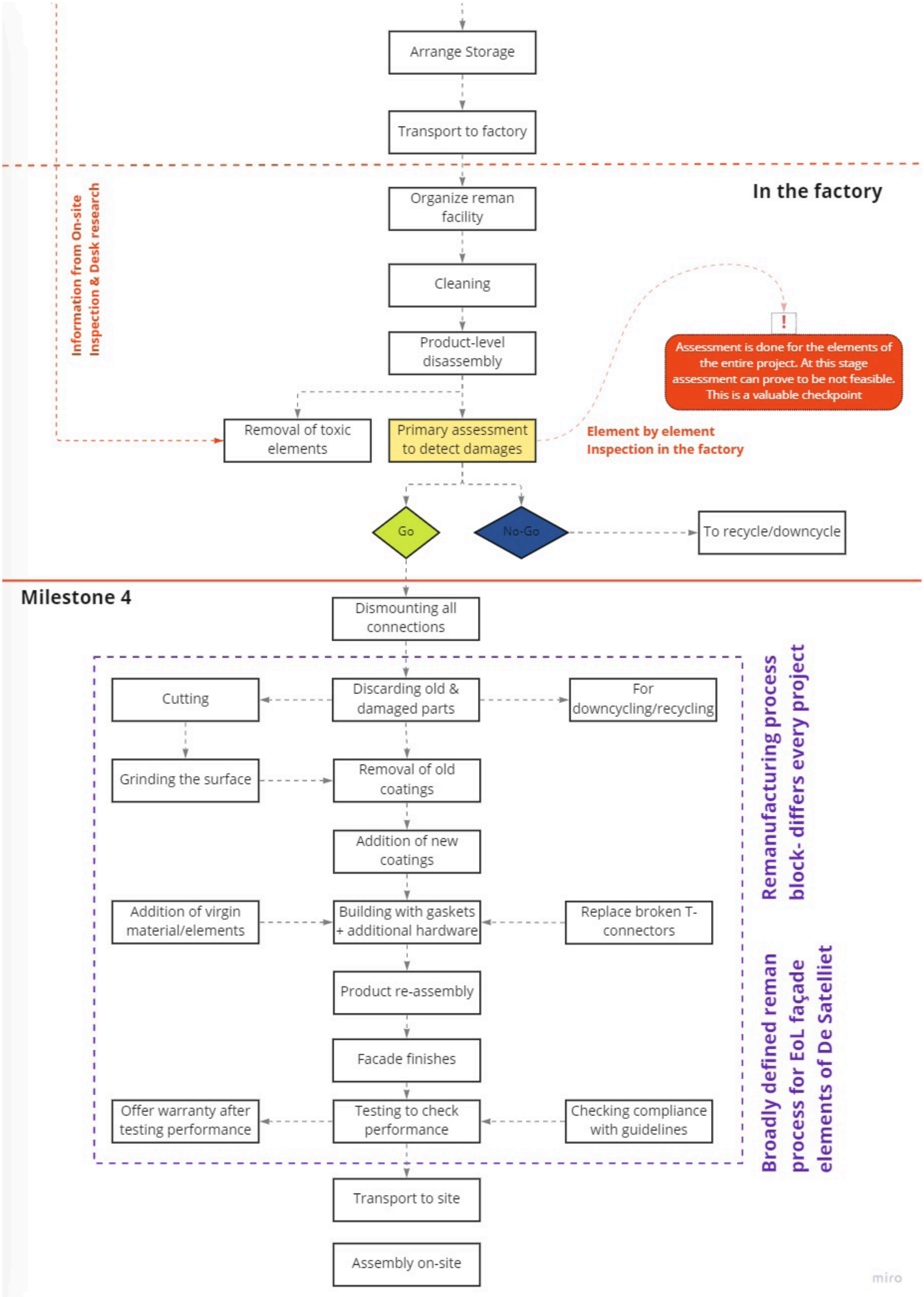
2,52E+2
121.79
1.382


EoL Facade
Desk research
On-site inspection
Develop Preliminary Reman plan
Go
No-Go
!
Checking compliance and feasibility based on inspection & estimated plan
Milestone 1
Re-design concepts of damaged parts
Design Phase
Examination Phase
Segregation of parts for reman & recycle
Developing water & air tightness concept
Examine Connections to structure
Establish the expected quality level after disassembly
Design of reversible connections
Prepare disassembly plan
Develop new cleaning concept
In accordance with NEN 2627(Legislation)
Specific Required Preconditions
!
The cost of disassembly depends on the Specified Required Preconditions. If they are not specific requirements the cost of disassembly can be lower
List of external parties to collaborate for reman process
Structure
Expected damage after disassembly
Distinguish present & expected damage
!
Important to note what can be done in-house and what can be outsourced
Develop preliminary list of risk &potentials
!
Submit disassembly Plan
Important to note that disassembly plan plays an important role in determining the quality of element after diassembly
Submit reman plan & new design
Submit cost estimation to client
Checking feasibility in Business case
Go
No-Go
To recycle/downcycle
Milestone 2
Execute disassembly plan for <10 test
miro


EoL Facade
Desk research
On-site inspection
Develop Reman plan
Go
No-Go
Checking compliance and feasibility based on inspection & estimated plan
Milestone 1
Design Phase
Examination Phase
Re-design concepts of damaged parts
Developing water & air tightness concept
Design of reversible connections
Develop new cleaning concept
List of external parties to collaborate for reman process
Important to note what can be done in-house and what can be outsourced
Submit reman plan & new design
Submit reman plan & new design
Submit cost estimation to client
Checking feasibility in Business case
Segregation of parts for reman & recycle
Examine Connections to structure
Prepare disassembly plan
Go
No-Go
To recycle/downcycle
Milestone 2
Validation of the Remanufacturing plan
Remanufacture 1-2 elements
List of risk & potentials
Prepare performance report
Test remanufactured elements
Checking compliance with legislation & Client brief
Execute disassembly plan
Execute Inspection & Cleaning process
Develop connections
get quotes from other parties when required
Sketch possibilities of setting upgrade line in factory
Destructive Research Pre-disassembly Phase
Important to understand if it is possible to actually set up in the factory
Important to abide by Government Legislation and brief given by the Client
Go
No-Go
To recycle/downcycle
Milestone 3
miro


Checking feasibility in Business case
Go
No-Go
To recycle/downcycle
Milestone 2
Execute disassembly plan for <10 test elements
Remanufacture 1-2 elements
Record List of risk & potentials after reman process
Prepare performance report
Test remanufactured elements
Execute Inspection & Cleaning process
Execute disassembly @ component level
Develop connections
get quotes from other parties when required
Sketch possibilities of setting upgrade line in factory
Destructive Research Pre-disassembly Phase
Important to understand if it is possible to actually set up in the factory
Validation of the preliminary Remanufacturing plan
Inspection of the remanufactured test elements
Checking compliance with legislation & Client brief
Important to abide by Government Legislation and brief given by the Client
Validation of quality. Is the disassembly, transport & storage plan successful?
Go
No-Go
To recycle/downcycle
Milestone 3
Develop final remanufacturing plan
Develop final disassembly plan
Develop transport & storage plan
This is one means by which the client can gain insight into whether the intended quality level can be achieved. It is also an opportunity to make adjustments if deemed necessary
Disassembly on-site
Packaging & handling
Differs on the size of the facade elements
Arrange equipment & logistics
Set-up safety measures on-site
Arrange Storage
Set up waste stream
miro


Checking compliance with guidelines
Go
No-Go
To recycle/downcycle
Milestone 3
Develop final reman & disassembly plan
Disassembly on-site
Packaging & handling
Differs on the size of the facade elements
Arrange equipment & logistics
Set-up safety measures on-site
Arrange Storage
Set up waste stream
Transport to factory
In the factory
Organize reman facility
Cleaning
Product-level disassembly
Information from On-site Inspection & Desk research
Assessment is done for the elements of the entire project. At this stage assessment can prove to be not feasible. This is a valuable checkpoint
Removal of toxic elements
Primary assessment to detect damages
Element by element Inspection in the factory
Go
No-Go
To recycle/downcycle
Milestone 4
Dismounting all connections
Cutting
Discarding old & damaged parts
For downcycling/recycling
Grinding the surface
Removal of old coatings
Addition of new coatings
miro



Arrange Storage
Transport to factory
In the factory
Information from On-site Inspection & Desk research
Organize reman facility
Cleaning
Product-level disassembly
Assessment is done for the elements of the entire project. At this stage assessment can prove to be not feasible. This is a valuable checkpoint
Removal of toxic elements
Primary assessment to detect damages
Element by element Inspection in the factory
Go
No-Go
To recycle/downcycle
Milestone 4
Dismounting all connections
Cutting
Discarding old & damaged parts
For downcycling/recycling
Grinding the surface
Removal of old coatings
Addition of new coatings
Addition of virgin material/elements
Building with gaskets + additional hardware
Replace broken T-connectors
Product re-assembly
Facade finishes
Offer warranty after testing performance
Testing to check performance
Checking compliance with guidelines
Remanufacturing process block- differs every project
Broadly defined reman process for EoL façade elements of De Satelliet
Transport to site
Assembly on-site
miro

11.04_Interview with Martijn Veerman
The discussion on the Reman canvas and list of criteria
Interviewee: Martijn Veerman, Circular façade specialist, Alkondor
Present in the discussion were: Tillmann Klein & Juan Azcarate-Aguerre
Date: 11.04.2022
Purpose of the interview: To identify if the list of criteria gathered from case study are applicable and valid for the building industry

1. Re-constructability
The disassembly of the façade elements they said When you mount the façade element, everything came is exactly in place, with not too much pressure without too much Geveld force. But if you get it lose then its already being fixed the joints have rusts on it, the corrosion is there. So, to get it loose you have to and there the joints can sometimes be broken so that's a different approach. So if you want to design products then you have to take that into account that the connections can more tight because of the corrosion and stuff, the question of the weather or water tightness so then you don't really have always in your mind when you design products that there is also a possibility which makes the re-construability is less interesting.
That is also something different from household elements, because during the nice weather it is outside, so the screw connection is it still okay after 30 years.
2. DFX Strategies: This spills a little bit on the design side. How valuable do you think these are and how relevant they are for the design of building products.
That's a good one. DO you mean the functional strategy, the first function as a building and the second building as I think the design for disassembly, design for remanufacture?
T: I think it refers to when you make a new product, you already have in mind remanufacture, so the design will be made for that. From my point of view. I think it's extremely important especially for design of facades from now on we must basically deal with they are made so you can exchange glass, because it can break, so it already has a certain amount of disassembly potential. But its never thought radically for the whole façade. To upgrade components, you could even change some of the parts, like cover cap, this type of things, glass and the gaskets but not more
MV: Yes, that is very important
3. RI: Knowledge and skillset. For the case study that we have now, does your workforce already have the knowledge to remanufacture the product or do you need to train them?
MV: Knowledge and Skillset that's very important because for the existing facades for example you need to know how the systems work. The DNB façade is 30 years old, and I think its not a very common project, but for the common project we make at the time, it doesn't even have a thermal break. You need the knowledge about the product on how it was made 30 years or long ago as a first step. Then the knowledge about how to disassemble then you need to know how it was built. So that's important and how we see it now with your new façade products like we designed for disassembly is that we always have a link to the product via BIM 360, where we have the manual on how to disassemble the façade elements products. So, then you can realize like the digital system hopefully over 30 years people can open the documents and see oh there we must unscrew the element to get it loose this is how it works, so very important if you don't know this, then there is no chance to survive the products
TK: When we look at the façade that is there now, it was done by unqualified people in a way,

so its needs specialists for that. Do you think the average façade builder like in your company the people that really build the facade would be able to dismount this mount, probably would have done a better job, but do they know how to reuse the façade that you think would be optimal?
MV: yes, I think they can do the opposite way of working, definitely! We do it sometimes which is more surface based. For example, a door is damaged after 10 years, and we replace it with a new one. It is already happening but, on a very small scale. There are some basic rules how attach a façade element to the building. It is same with curtain wall system. When you have a facade specialist, they know how to do this. The important thing is the connection to the building surface. In the case of DNB Bank. How that element is attached to the building structure is always special system, a special product, its not standardised, and there you see a lot of things going on, which you don't know. On the facade you have the anchors, then floor coming out of the anchors, the people are using the building seal the façade, sometimes we don't do it ourselves, the contractors do it. Later in the process of use of the building things have changed people seal it without knowledge and then its difficult to know how it get it out because we have no idea what happened.
TK: the skills of your people is fine but, you need a good documentation to be efficient, you need to understand the system beforehand so you can basically make a good disassembly plan.
MV: The focus on how it is attached to the structure of the building. The element itself is not really the problem, but the attachment to the structure, the anchors, the systems are the most important thing.
4. RI: Evolution of technology. The technology is fast evolving, and this also determines if can take back and improve it to the same standard. The façade we have now was built a long time ago, this also plays a major role in remanufacturing. So, what are your thoughts on that
TK: 30 years is a long-time span, the technology has moved ahead from double to triple glazing systems, so I think systems should be able to accommodate evolution for a long-time frame. This means that we see the systems from 80's is very difficult to do, so a future façade, its essential. The question is what type of technology evolution do we expect?
MV: I want to turn it upside down, like we develop the façade concept, our new Cis-skin façade concept in collaboration with these new technology parties, developing new technology for the future like new glass insulation, glass products we have to develop then that fits to our system, instead of waiting and then there's a new piece of glass and then finding out that will not fit in our system, we need to grip on the market and that's also the reason why we had the collaboration with Vicona by //// to make sure we have a world wide view on what the developments are, could turn the developments also into our development in to our new façade products and then seeing oh it will not fit and we can just demolish a façade because its no way how to develop this new technology.
TK: So, you want to look at what is the development of the future, you want to control it
MV: Maybe yes
TK: or do you talk about the past?
MV: The future. From now on, we want to what we see now id the vacuum is coming out, we have glass packages of almost 6 cm wide but the future is that we have technologies wit glass 10mm then you have 2X better insulation than triple glazing, so we said okay we have to develop our system further together with these parties to fit into our systems , maybe we need an adapter to get the product in our system, something like that. The same with energy

generation of PV and solar panels in our façade. We think of collaboration s with clients of these product, to get it in our façade to make it suitable in our façade.
TK: Yes, its good, if you look at the past, the most development in glazing sealing and u value of systems. The latter one is I think is going to develop anymore, we see a plateau in the last years. The u value has improved, and its also getting increasingly difficult to do that, just physically because you have reached a maximum, indeed other components could be getting on the market that will have an influence on facades in 30 years. So, you just be able to predict what those could look like right and steer the development in a way.
MV: Yeah, I think in one of the ways we see it so far so that we try to control now innovation so b there to do subsidy projects European projects so we know what's coming out and we just can steer it a=that they don't fit in our systems.
TK: you can also turn around, you can also Talk to these parties and say, in the future we will just nit build new facade, but upgrade ones, and if you build systems, façade integrated system, his is hat the system of the future will look like, beware that you are flexible enough to fit
MV: to be concrete on that, we developed a BIM library with modules, and these are modules architects can use in the facades, they can make. Maybe in the future we do upgrade modules, we in the module library okay we have a module where you can upgrade your collar panels its already prepare its existing in them library, you can order it, something like that, to make it more concrete.
The world will change!
TK: you have to see what the system is, of you see that PV technologies will last 20-25 years, maybe oner you have to renew them. The facade can make 70 years. This means you must change the module 3 times most likely, 5years you have different types of technologies
5. RI: Embedded value In Automobile industries, when the product comes back, they would have a small part of the product that was designed to move for multiple lifecycles, a that could be reuse. Is the same is with façade, are there parts of the faced that can move to the next life cycle without having much done, can it be reused, which parts have the most value?
MV: It's a very good question because New Horizon also asked I, can we in DNB case. can we make one new façade out of two damaged facades? Can we reuse some little components from the façade? My opinion is that it is very difficult then you see the product as a saamstelling out of more articles. To get the profile loose from each other you need a lot of labour cost. So probably yes, but is it economically feasible, I have my questions about that. And regarding which kinds of companies, you see on a facade. I see the hinges the handles to open the window, I see glass piece, glazing beads, the gaskets, panels and like the infill the glass panel or the sandwich panel you can easily get it out and reuse it somewhere but after 30 years glass panels for reuse, is not possible, the performance id like 0 after 30 years of glass panel. Insulation s not there anymore which we ha 30nyears ago. But reusing the profile itself, in the case of DNB bank is the s
Disassembly the profile and to reuse it. No, the same for he anchors is all broken you have seen it when you were there its all, not reusable. Maybe if we do it in a more attention to it, probably you could use anchors as a product as a new façade, but I think the most value and economically feasible thing of reuse of products in the façade industry is to use them complete elements.
TK: as a complete
MV: Then you have less labour cost, and the material cost anymore, only you upgrade with

new air sealing and water tightness systems and you adda new anchor system to attach to the structure and that's it. Then you have a feasible economical product. In our new system for Cis-skin system façade system, there we tried to get a mullion separated from the transom so you can reuse them but it's designed for reuse that is possible
TK: So basically, the past ones, its really difficult the reuse profiles are very specific but, in the future, the part with the highest value is the aluminium the gaskets not really, maybe
JU: Hinges and handles mechanisms
MV: The hardware is valuable
TK: ///told me that a window handle is about 9 euros so the question is it should be very easy if you want to reuse it. I think MV is right, if you are able to keep the whole system in a way then you can keep all the other parts as well. If you can rese the frames, you can change the gaskets for example. Why not the hinges could stay, but you see the milled to the frame, you cannot just exchange it to a new one, its really made integrally, so you cannot take out an old hinge and put a new one because geometry and other things.
So, for future façade I think id you look at most the panels maybe could look at the panels separately for remanufacture, the glass panes. Or panels and the frame the aluminium frame if you can keep that if you treat it well. 70 yeas, 100 years, it could survive 2 cycles,
JU- the ///might also change right? Material prices are going up faster than labour prices already for some time in the last few crises one after the other
TK: Its all a matter of price right if you have nothing you cannot get nothing. You can collect all the old windows that you can get and build a
JU: Or in other countries you can justify, in Mexico or India probably you can justify the labour cost of remanufacturing
TK: yes, we can also afford lower u values
MV: yea exactly
6. RI: Legislation: The case studies lot of new regulations are being given out by the government like EPR and other things where the manufacturer is responsible for the further product ta EoL and he/she mut take it back and do you that in the future how do you see that the regulations we have right now will change for BP, and do you think there will also come a time when you have to take back the product and do something with it. Which way are they going to?
MV: The regulations regarding the insulation sound insulation, fire I think regarding fire yes the regulations will be getting tight and tight insulation and stuff I don't know if that will go on a specific item that will move to more tight more higher standards. I think the regulation will go more in the scope in the building needs energy neutral in energy use. Then you have to see it holistic, like ion the total concept. The total amount of product making a building should form a zero-energy performance. And same for the environment standard, like in the future we see that its not possible anymore to only make a building to make virgin materials, it definitely needs reused materials complete as a product or recycled content in buildings. So that's a different legislation, building regulations, but it is regulation based on the environment, yes that is how I see it more in depth.
Tk: I also think in terms of safety if you want to reman a façade, you have to deliver some of product safety protocols, that will also definitely happen.
RI: But do you see anting at product level. I understand ta the building level. But at a product level you mentioned there might come a time, you mentioned the building might be built out of reused parts. So does that also not influence at a product level?

MV: Yeah definitely! Yes, there could be at the product level, asked for changes. But you see it already like in insulation. M<y question is insulation of products is developed to an end I think I mean, what do you want more?
TK: Profiles I think are almost on the limit, the u values are 0.1 and 0.2 but that's not delivering much so I don't think there will be.
MV: Fire safety I imagine that could be something challenging. Fire but also safety burglar safety and all the buildings like energy in the total like we have to add solar panels in buildings in facades That ends up in new products.
JA: What about EPR? Are there any actual steps being taken on that, when the company is responsible for taking it back or responsible for making it work for a longer time.
TK: Not yet, but that might come.
MV: We have the/..... a new law the producers for 10 years, need to guarantee the performance of the product. Like main constructors have to make sure that that will happen. There's a system quality system which has to make sure that the product is delivered.
TK: What do you call it?
MV: /////
MV: Ye, that's a new law.
JU: /////
MV:///// 1 july 2022.
JU: Carbon taxation and even more is the taxing of labour which
MV: yeah
7. RI: Cost structure; is about for reman process to be established there are a How can you as a faced builder intervene within the lifecycle, collect revenue that can support your reman process?
MV: that's very interesting, the process the development of project is very unforesee it, you don't know how that goes so to very difficult
TK: what we cab say though, the cost structure is the most competitive in terms of cost, otherwise it wont really fly right? The question is what makes this cost structure. I think its labour, material cost but also new regulations, if people are forced to do certain things, they might pay more factors that make it affordable to do it.
8. TK: Brand value. Do you think its interesting for you guys because you have the brand name and the resources?
MV: At this moment, yes branding is a very hot topic. They like it when you do it is kind of a trend probably to reuse product into buildings to places.
For the case of DNB bank, it gives some extra value to say on a different place where we reuse the façade elements, oh this is the facade elements used for 30 years for DNB bank
TK: In the sense that your really. Do you have to do this now, be working on things like this because don't get jobs anymore? Does it pay off? Or is it because in the future it could be done, if you, do it?
MV; in 20 years probably.
TK: If this type of brand value thinking evolves as a hot topic.
MV: yeah that's also a law n that side that is the //////// gebouw and that is we have the shadow cost for the product we use in the building sector and it has impact on the environment and negative impact and they in Holland they get it back to shadow cost in euros and other countries in Europe they use 3 points or whatever points that as a system to compare products, In holland we do it with euro, and there is a performance maximum boundary of 1.0 and

that means 1.0 shallow euros per /// in a building. And the one so getting lower and lower, the impact to the environment will be lower and lower in the future. Now it's already from secretly its already 0.8 and it will go down until 2030 and to get it half like 0.5 then you have to be half better than you are in 2021, on the negative impact of the environment. When you have half impact then, reuse or recycling of materials and products is getting more and more important. At a certain point in 2050 they want to have it 0. So, no impact anymore no co2 in the environment or whatever impact on the environment, then you can make materials from recycled or recused products.
TK: What you say is once thar comes, the brand value will be very important.
MV: in the direction of 2030, its already half of what we had in 2021, and its 2050 it needs to be 0. No impact anymore only circular products can be used. That is very important.
TK: We are already at the demand, so you predict that the demand will rise, so you see that it will rise.
9. RI: Demand what do you think the demand will be for the remanufactured units?
MV: Already mentioned that the environment performance, the legislation and we also have the ESG law in the ISO standard that is coming up, when you inverse in real estate, with an amount of 100 million or more, you have to be sure you invest in positive ESG. The real-estate that's also a trigger for investors to only deal with developers which can give a positive ESG
We make in hoofdorp we make a renovation 18000 sq.m facade at a certain point the developer and investor called us because he wanted to know what the environmental value of the faced and I asked them why they need it
One of the investors from USA, New York he needed the information because he invested in the real estate, and he want to have this certificate. And because there are no rules on it yet, no real standard, he was okay with just typing the story, like environmental low impact, recycled hinges made this whole story, and this was okay. You need certificate to make it real that you have to certain sustainable products. That's on a worldwide on the real state and investment of big real estate firms is already changing policies.
Ju; market
MV: yeah
TK: that's the argument for legislation, demand and brand value
10. RI: Reverse logistics: how important do you think it is for a façade builder like you to invest at the beginning of the project itself in order to collect the product at the ned of life. Like do you see value in investing in this process?
MV: As we just discussed before, the value we invested is the future, when we do it proactive, we are the first ones saying how to make circular façade, instead of how the whole market is telling us how to do it! We are telling everyone now! We see that market demand is accepting that and that is interesting, and we have developed together with the market with real estate partners, contractor, suppliers, so we are strong we have a whole team under us as ambassadors, how say that this is the façade system of the future and existing all these circular aspects. What we have in a system, new systems also coming with circular approach. But we are the first ones telling ho. People are just following us, how we do it. To follow our standard. We have a newsletter you can sign in to our newsletter on our website we see all our competitive façade builders, the system suppliers and other have already registered. Now everyone is following us, how we do it, have no idea but they probably can copy it. Definitely!
11. RI: Business model. There should be a business model established to make this happen so what er your thoughts on that, coming up with a business model that can help this thing

MV: That is difficult to say. Our business model is still based on selling of new façade products, but we see with the leasing project it will change, but we still don't know yet. We are still starting with it; the finance is not on the real estate side. That will change then the whole financial money streams will be different. So yeah, and same for the aluminium produce, its like when we come at a point where we only want to reuse products, they nor have the raw materials anymore, but how it exactly works, is very difficult to say now. But we see a new business model that we can make money for it that Civil building at TU Delft and I hope we will expand this with more projects where we can monitor the façade, so we have data, and to create a new solid new business model for the future, together with the projects where we try to finance also the .... The contractor.
RI: ICT and customer support to monitor all the assets and products in buildings to see how they are performing to see how they are performing and connect it
MV: yeah
12. RI: Construction process: In case of large projects, where you must reman huge facades, you will need a factory line for the workforce to be trained in that's aspect
MV: That's also still to be developed and for the existing façade like the DNB bank, we are starting to develop a factory like to develop the work, with the .... last week. But for the Cis-skin faced we don't know yet, but we definitely will set up something hat is not really at this moment, but we have a reverse factory line. Now we have a factory line.
RI: Will it also influence your construction process? Do you have any more points for that?
TK: It is interesting to see that the criteria that come form all the other examples, you have already encountered those, in the same way.
RI: First attempt at mapping the detail reman process

3.4.4 Interview with Martijn Veerman

3.4.5 (14.04) Interview with Martijn Veerman

14.04_Interview with Martijn Veerman

On the way we find we are missing a step, or one step is not needed and ideally, we can define it in such a way that we can write cost to it.
MV: yeah yeah
TK: then we have a virtual cost estimation of the façade. For now, I can imagine you would have been involved in the project form the beginning and you would have probably gone to the project and make an assessment from the existing facade.
Ri: Even ia disassembly plan for instance
TK: So, inspection I think as I imagine that was before you have the job you just send someone to inspect and make some basic measurements. You probably going to see if you can find plans,
MV: Yes, and do a desk research. I think together with all these processes would take 2 days. One person to days for the inspection
TK: Exactly and two people to measure and look. So, one day of desk research and one day of trip basically. You have seen it and then I think you have to make the disassembly plan or concept. That would need a bit of time. You need to calculate how many façade elements right?

MV: Maybe we forgot a step like after the inspection you actually want to know id its feasible to in the business case can we use the facade. There you can point the possibilities to reuse it or if it should you be recycled?
TK: yeah exactly! You will have to evaluate that in the beginning! So basically, two things, you have to state the situation I think you have to make a disassembly plan and you have to develop the remanufacturing plan basically. Find a new purpose in what you change so basically let's call remanufacturing as reman planning and that would include shipment of parts and the new parts and for that you need sometime. I think that's going to cost you, if you are experienced with that lets say 3 days right?
Basically, you make an offer for your client.
MV: Yeah exactly! And based on that offer the cline twill makes his business case, if it's worth or not to invest in disassemble, clean store and everything? So, there would be a key point, a milestone
Ri: yeah, a Go – No- Go moment
Tk: So, then the following steps would be a part of the plan. So okay let's say this is the plan making. Something like a yes or no option or say maybe only the parts will be remanufactured or things will be recycled or
MV: Yes, that is possible. Maybe you can have different lines, like one line is recycle chain and then reuse as it is also a possibility or using parts of it. Or just going to disassembly for reuse. These three lines. Reuse, reman and recycling.
TK: So, three lines reuse reman and recycle. Because I think with facades any remanufacturing at least they need new gaskets. Okay then there would be disassembly itself.
MV: When you disassemble the façade elements what we have seen in the case of DNB bank! that we were called to kind of a test. To test one façade element together with all the specialized parties like the facade builder the demolition party, the client to do one test and see what is coming up, how it's getting loose, which risks do we see and which risks we had not foreseen all this steps. It's a check or mock-up
RI: So basically, like ta list of risks and potentials
MV: yeah, and thus by doing on element or one-two parts
TK: Would you do already that already in the first phase after the inspection can you make the plan and after you make the plan so basically when you can already that the business case could be positive then you make a test
MV: Maybe there is a part in between after the test, the demolition and new go and Go-NO Go moment will pop. Sometimes you don't know if
TK: yeah you will get to know the details, oh the gaskets are much worse than we thought but just to be okay that's a good one
MV: we call this destructive research, where we destruct the element and test the performance
TK: That's the validation of your plan, then you start the real disassembly.
MV: like the logistics. The material equipment, the cranes and trucks then you have the people transport and safety. Safety is very important. The waste stream and the next part is packaging, you need to put in cradles.
TK: For each façade it might be different. For one it might be easy and for the other it might be different and complicated boxing and cradling stuff before you can ship it. So that's it I think.
MV:
TK: then you have storage and cleaning.
MV: First storage and that is where the products will wait before they get out to, definitely be

reused and then the next step is indeed cleaning. Because there is dust, rainwater coming in. So you have to first clean it and then start the disassembly of the product and simultaneously build an upgrading line for the product.

TK: the primary assessment to detect damages. That is then to be done indidvidaully piece by piece right? Before you. I think I like the one with removal of hazardous substances. For example the old facades might have some asbestos in it
MV: From 6. When façade elements existed around 6 surface treatment you remember the cITG building, then you have to handle it with care. The asbestos
TK: that is also a part of the inspection. You should write it down in the inspection report about the type of materials present. SO the material analysis to identify hazardous substances is important and then indeed you probably would do something on site eventually already and some of it really in the facory
MV: when you see in the first phase, oh there is a hazardous substances then you must handle it with care, with special machines and tools so then you have a different process with the cleaning because you have to remove everything and very strict control conditions. So then the removal hazardous substances. That can be a very complicated ta the moment.
What do you mean with primary assessment to detect damages?
RI: if assessment happens at element level. Like profiles, maybe the extent of damage that has occurred due to disassembly can be detected and then you can really see what percentage can be reused?
TK: but basically, that's the phase when your really start reman process right? But reman process can be really different from just removing gaskets and for other projects maybe even new cover caps, new glass panes, so it could be mimimal and could also be very extensive to reman parts and for the reman you need to take it apart and assess it in detail
And then the reman process I think the following steps would be including so the discarding of damaged parts, removal of coatings new coatings re-engineering of parts development of water tightness concepts, design of reversible connections that is all a prt of whole reman sequence.
RI: Is there anything that could be missin
TK: the cutting and grinding has been mentioned and it already makes it very specific. It could be pull out gaskets and to basically put it in some kind of bath for soaking or cleaning. You need it to take it apart to such a level that you can start remanufacturing. For example. Does this façade for operable windows Martijn?
MV: the case no
TK: For example, if you had that and if you wanted to bring the whole façade back, then you probably had to revisit the whole mechanics, clean it oil it. But it is then rally individually from project to project. I don't know in your graph, maybe if you could one block for remanufacturing, probably the other things could as examples to it, removal of coatings, the special sequence which is a very detailed planning depending on what it is. What we can say basically even in the next meeting when you think about ht gaskets and things then we could fill in this in, okay what about this facade, we take one elemet which we think is okay, the best one. The ideal case. So, what do we need to do, first cleaning, take out the gaskets the glass beads, and you could be very detailed what that would really mean for this façade theoretically and in this case, do they need any special treatment for bronze to bring it back,

I don't know.
MV: there is a special treatment ofcourse, in this case the Nirokon is the party who did the cleaning, if you like to know more about the cleaning process which is very specific, I can get you in touch with Ruben stom but in this case what he did is, first removed the wax layers, kind of the protection layers to get on the material layer. Next, he polished the material and waxed it again
That is roughly the process
MV: yeah you see it if you operate it with a rough paper, you can see it polidh it and then you see the different layer
TK: But is there still wax on it after such a long time?
MV: yeah you can see it? If you go operate it with a rough paper to polish it, then you can see it.
TK: is it still from the original time from 35 years?
MV: No in the time, with some staff they must have first you reomove that then you come to the official bronze layer and you can build it again, You cannot do something over it again its too long ago.
TK: yeah okay that is really good, as we ca get theoretical costs for that
MV: Do you like to get in contact with Ruben from Nirokomp.
TK: I think first really think about all the processes. If we say we would bring this element back, can you already say that or does it need oter people from your other factory like Jon Oudekamp?
MV: yeah we still don't have the facade in our factory. Re-born promised it would come and Nirokomp, but there is no date yet. I think soon it will be there and then we do the step of introducing and then we are at the step. From the next time we should do what we are doing now, the pre-disassembky phase. The test, we are too late as everything is disassembled already but we actually don't know really how that element can be refurbished and make it working or not.
That's some learning. Actually we don't have the idea yet.
TK: let's say we would have taken the element from the building as a test, its in the factory and then you really start doing it. I think what would be really good to say is first we remove the glass probably, the gaskets. I don't know, do they clean it as one element or do they take it apart and clean it separately.
MV: yeah that is done, already too late but we have done the ///// Niromkomp did a test before they started to disassemble all the facade. They had already one element with little piece where they did the surface treatment and cleaning, so we knew already that it was possible and I sent a photo of the piece which we got in the first process, when they did the test then we saw the little mullion from the element and the cleaning test. But that is the only test we have done at the moment and by learning now we should have done the whole test, like checking the statica glass how you get it out, the connections how it is made but cleaning already we did already in preliminary phase.
Nirokomp can tell you more about how they did, what they did and how they see it to do it on a bigger scale than to do it on a single piece

TK: So probably needs new glass panes right? In remanufacturing glass panes is a whole new story. I will now assume that we just get new glass panes in it are they thicker Martijn.
MV: Probably you will not get the same glass, because with the glass you really take. I think in most situations commonly have smaller glass than what we have right now, like we go from double glazing to triple glazing so the glazing beads are no having the same depth, so you less

depth, but in this case we need more depth so we have to definitely make new glass beads.
TK: they are on the inside, right? What colour do they have?
MV: yes, they are on the inside, and they are white. Yes, they are aluminium you don't want to do that in bronze again, it will be too expensive. We have 200 kilograms of bronze per element, which when you recycle you get 5 Euros per kilogram!
TK: 1000 euros bronze per sq.m?
MV: No per kilogram you get 5 Euros
Tk: yeah so you can build a new façade for that!
MV: yeah we have 10 sq.m. This kind of façade will cost between 700-800 euros and 900 euros. But it's still a lot of money! The value of this material is very high The façade elements are 1250 gelds? And if you calculate what it should cost now with all the inflation and stuff, 2500 per sq.m instead of 1250 per gelde. Massive amount! Its really expensive if you recycle only the bronze, it's already gives you 1000 euros for the whole element! Its crazy!
Tk: How big is the element?
RI: 2.8M X 3.75M
TK: its 2.8M wide? Really? Its so wide?!
MV: The height is 3750 so that's really high!
TK: Its really almost 10 Sq.m then!
MV: haha Tillmann,
TK: But that means you already have 100 euros per sq.m which is already a lot! With new elements would be probably atleast be 5000-7000 euros.
MV: yeah
TK: For that you can do a lot of remanufacturing.
MV: This kind of façade as an element façade we should do again we make out of element façade. Then you with the high performance to aound 800 euros per sq.m
TK: yes, without sunshading
MV: without sun-shading yes! So, around 800o euros per element.
TK: 8000 Euros you can do a lot of work on the existing
MV: Exactly, so that's the reason why Re-born belong is like interest is to reuse as much as possible, because in the business case, every single element you can reuse saves them for the client they will not build a façade of 800 euro per sq.m compared to the traditional ways of today building a new façade. They should o diifrtently. But still you pay 500-600 eure per sq.m So that's still a bit okay. Its crazy!
TK: Which is good for the project?
MV: Ofcourse! Specific as a project like there are no other buildings. I think there are no building like this! It is the only case! You can learn a lot from this building probably in this system. This will not happen again!
TK: I don't know yeah probably in Germany there are a few!
MV: DO you know more buildings like this?
TK: yeah In Germany there are a lot of bank buildings with a lot of bronze façade. We once did a project where we basically upgraded the insulation from the outside, we let the old façade in place. No actually we didn't! the deal was to leave the old façade. I can show you next time, we did a double façade of it. It was a special case. So basically we covered the old façade and made a new weather screen from the outside which means the inner part was weather protected then and we has special cover caps. Insulation cover caps to put on top of it, for the u-value. In

the end they didn't do it, they removed ...because it was cheaper but you don't believe it I think okay they were afraid of doing it! But its also a possibility of a weather screen around it, if you don't have operable windows. You can make a double façade that you can really improve the u value and you don't wanna have problems with water tightness anymore!
MV: We can list the parameters that influence the cost to the areas we don't know how much the cost will be, or its dependanmt on the project
TK: I think once you have the project in your factory, the façade you can atkleast estimate what you would like to do. So you can do all sorts of things in the reman block, so in the reman block varies you add to add new glass, new gaskets, cleaning the profile inside and outside. I think you have to see that, and you make sure if you it
So lets see once you have finished reman process and you have an element that is new, you bring it back to the same or different building doesn't matter. I think what you have to do is look at new brackets for fixing it, you need to think of all he connections between the floor and façade, fire protection which is kind of standard things you do but. You have to think of dividing walls and fire walls for staircases an have to deal with. Maybe you have to think of a new cleaning concept, if you can use an old one or develop a new one! Maybe you need new machinery for cleaning for the new project, but that really depends. If the project would similar, for example if they would put up the building on a different location again, you could work on new brackets and get it there again hoping the tolerances are not bigger or smaller than before.
MV: you have to always take into account the tolerances!
TK: but that's it then basically you followed all the steps of a new building!
MV: The testing at the last is also very important to see what the performances are after you installed it. You can just not. You will test and see if its okay and have to achieve the performance criteria
Maybe remanufacturing façade element, assemble one façade element, do the testing and then go further because when you last and then you have problems, and then you have serious problems, and that's a good step to add to the list.
TK: You have to have one vocabular on this step, which is risk assessment to see what could go wrong! Could it be that other elements are different, we cannot do it as planned? What if the water tightness is not working, what if something breaks, and what what what.....
But it could really depend from project to project. After assembly on site then I think you have it!
MV: yeah this process I agree

REMANUFACTURING AS A STRATEGY FOR A CIRCULAR BUILT ENVIRONMENT

An investigation into the potential of remanufacturing of disassembled façade elements of De Satelliet. DNB Complex