Improving Information Flows for Remanufacturing

A case study at Volvo Cars on implementing design for remanufacturing within R&D

Master's thesis in Product Development & Production Engineering

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Department of Industrial and Materials Science

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Cover: Information flow mind map between internal and external stakeholder.

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Abstract

Value creation in today's economy is heavily based on a linear model, thus products are discarded at their end of life. The linear approach is a strong contributor to climate change and this is no exception for the automotive industry, which is currently facing new challenges to be more sustainable. In contrast to this model, the Circular Economy represents a regenerative and restorative model, which differs in value creation and instead aims to decouple economic growth from finite resource consumption. This report will mainly address how remanufacturing can be emphasized to increase circularity. This is easier said than done.

The study aims to provide knowledge for industrial processes that support Volvo Cars in designing electric passenger car components for remanufacturing. This will further provide an action plan for the R&D unit, where in the process of remanufacturing Volvo Cars can improve to work towards a more circular mindset. More specifically, two questions will be answered: 1) What are the potential enablers and barriers to remanufacturing the electric transmission component in a circular economy context? And what aspects to take into consideration with components when designing for remanufacturing? and 2) What are the challenges Volvo Cars faces with the current remanufacturing strategy for vehicles? The findings of the study are as follows: First, internal and external enablers and barriers to remanufacture are identified and put into the context of Volvo Cars. Further, three main aspects to take into consideration when designing components for remanufacturing have been identified and been presented, which are technical, environmental, and economic aspects. Secondly, implications are presented based on each problem category for Volvo Cars and possible improvement areas identified. And third, the information between R&D and remanufacturing supplier was found to be the main barrier to overcome, thus a workshop was performed with the purpose of verifying this, as well as establish an action plan to overcome this and pave a trajectory to become circular.

Keywords: Circular Economy, Remanufacturing, Design for Remanufacturing, Information flow, Closed loop, Enablers, Barriers.

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OSKAR KADER & IDA NYKVIST
Gothenburg, June 2021

Contents

List of Figures

List of Tables

Abbreviations

CE - Circular Economy
CW - Car Weaver
DfRem - Design for Remanufacturing
DfX - Design for X
EC - European Commission
EOL - End-of-Life
EOU - End-of-Use
ERN - European Remanufacturing Network
EU - European Union
IoT - Internet of Things
OEM - Original equipment manufacturer
PA - Program Approval
PC - Program Confirmation
PS - Project Start
RFI - Request For Information
RFQ - Request For Quotation
RIFF - Remanufacturing Information Feedback Framework
VCSB - Volvo Cars Service Business
VPDS - Volvo Product Development Process

1 Introduction

The introduction encompasses the background of the project and why the topic is of interest both for society and the industry. It also covers the background of the case company Volvo Cars and a description of the underlying problem. This is followed by the aim and research question with the project and also the objectives that are to be achieved. Subsequently, the scope and limitations of the project are presented. Finally, the introduction ends with presenting the outline of the report.

1.1 Background

There is only one planet Earth, however by 2050, the world will be consuming as if there were three at this current rate. Resting on the current approach of using resources and the natural environment is continuing to have destructive impacts on our planet (The European Commission, 2020). Hence, the effects of climate change are gaining more attention in today's society. Through comprehensive data collection and thorough studies, scientists have determined that the environment is changing. Furthermore, the main contributing factor to this change is our habits and consumption behavior of materials and energy (NASA, 2021). Emphasis on the climate question and its frequent discussion and debate in society derived to new objectives and directives that are continuously being developed in order to meet the challenges of tomorrow, regarding utilization of material and energy. For instance, the Paris agreement induced new regulations and laws that governments and countries comply with, which nonetheless affects society and particularly the industry as well (UNFCCC, 2020). The impacts of this exploitative behavior are well recognized by the industry, thus industrial actors are starting to take counteractions upon this. More and more firms start to examine possible changes in their business model towards adapting it to be more sustainable, in order to stay competitive and consequently meet the continuous development of climate regulations.

Moreover, this has entailed increased attention in strategies and methods conceivable for industries to apply in order to reduce the waste and use of materials in their products (Bonsu, 2020). An emerging concept to overcome the current status in society and industrial settings is Circular Economy (CE). CE is a topic that has recently been intensified and gained traction both in academia and industry, not least the automotive industry. It is designed to develop closed loops where resource input, waste, and emissions are minimized or even eliminated from the system. Further, it is suggested to be a strategy that companies should endorse to become more sustainable, thus meeting the climate legislation and directives (Bonsu, 2020; Stahel, 2016; Geissdoerfer et al., 2017; Ellen MacArthur Foundation, 2014).

Currently, linear industrial economy is more ubiquitous than circular industrial economy (Stahel, 2016). Blomsma and Brennan (2017) explains that linear industrial economy follows the "take-make-dispose" approach, which implies that raw materials are collected from the earth and then is transformed into products until they are finally disposed of and turned into waste after fulfilling its purpose. The value is created through producing and selling as much as possible, which is highly resource-intensive and has a significant effect on the climate. In contrast to this model, circular industrial economy represents a regenerative and restorative model, which differ in value creation and instead aims to decouple economic growth from finite resource consumption (Ellen MacArthur Foundation, 2019). Circular industrial economy aims to maintain and retain value for as long as possible, at the resources highest value. The model advocates to maintain value (not create value), increase efficiency of resources used (not producing more) (Ellen MacArthur Foundation, 2019; Blomsma & Brennan, 2017). Yet, companies have not fully realized the business potential with this transition and a trajectory of circular economy and mindset (Stahel, 2016). Since both businesses and society has its roots in linear economy, it can be rather problematic making this transition from linear to circular economy and it becomes less straightforward, moreover, various of barriers may hinder firms from incorporating the principle of CE into their practices. Furthermore, Blomsma and Brennan; Geissdoerfer et al. (2017; 2017) poses that CE is an umbrella concept, making it vague and difficult for companies to interpret and work towards.

Nevertheless, there are many frameworks available that foster value retention and a circular industrial economy. For instance Potting et al. (2017) mention a strategy focusing on nine different strategies (9R) that can be of the auxiliary for companies in becoming more circular. This report will mainly address how remanufacturing can be emphasized to increase circularity. Remanufacturing is an important strategy that entails manufacturers taking back products after the end of use and restoring them into a like-new state, or even better than the original. By retaining the components and utilizing their embodied materials for several cycles instead of a shorter period of time, the energy use and emissions can become significantly lower (Lindkvist Haziri & Sundin, 2020).

Currently, the majority of Volvo Cars is still operating on linear economy principles, however, the transformation has begun towards a circular business and zero emissions by 2040. Furthermore, by 2035 Volvo Cars has set the goal of reducing carbon emissions by 2M ton annually and thereby saving one billion SEK per annum. One of the main areas to be emphasized to achieve this goal in the strategy is value retention and remanufacturing. Despite the fact that Volvo Cars have had remanufacturing operations since postwar (World Ward II), it has not yet been prominent to the desirable extent among all entities and there is not any general approach to these kinds of processes available today (Director of Sustainability, personal communication, May 5, 2021).

1.2 Aim and research questions

As previously mentioned, remanufacturing, and more specifically remanufacturing within industrial processes can help permeate companies with a circular mindset.

This would benefit both them, and society from a long-term perspective. Hence, the aim of the project is to provide knowledge for industrial processes that support Volvo Cars in designing electric passenger car components for remanufacturing. This will further provide an action plan for the R&D unit, where in the process of remanufacturing Volvo Cars can improve to work towards a more circular mindset. This entails the following research questions guided the project work.

- **RQ1 Enablers and barriers**: What are the potential enablers and barriers to remanufacture the electric transmission components in a circular economy context? And what aspect to take into consideration with components when designing for remanufacturing?
- **RQ2 Challenges at Volvo Cars**: What are the challenges Volvo Cars faces with the current remanufacturing strategy for vehicles?

1.3 Objectives

There are several specified objectives describing actions that are planned to be carried out in this project and they are derived from the aim of this project and presented below.

1. Establish the current level of knowledge on remanufacturing of components by reviewing scientific literature on circularity in the automotive industry.
2. Identify external and internal factors enabling and obstructing remanufacturing of components in the automotive industry by performing interviews with stakeholders and PESTEL-analysis.
3. Understand how these factors can be approached to create an action plan for how Volvo Cars can work towards a more circular business.

1.4 Scope and limitations

This study extends over a defined period of 22 weeks and therefore, limitations and delimitations are established in order to meet the aim of the project. Moreover, due to the simultaneously prevailing of the extraordinary global pandemic of covid-19 is taking place alongside this project, it will affect both society and industry (Folkhälsomyndigheten, 2020). Thus, it explicitly requires that restrictions provided by the Swedish public health authority need to be taken into consideration during the project. In addition, this project will be conducted accordingly to comply with both Chalmers University of Technology's own restrictions, as well as the restrictions provided by Volvo Cars.

Furthermore, the area of Circular Economy is widespread and profound in the literature. Therefore, the research phase will be limited to only obtain a holistic understanding of the circular economy. Emphasis will therefore not be addressed to juxtapose various widespread definitions. Instead, the main focus during the research phase will encompass information and concepts of circularity and more specifically remanufacturing in the setting of the automotive industry. Due to the limited time frame, only existing methods and processes within these areas will be utilized to derive from and thus no new methods or processes will be developed. Further, material selection and in-depth quantitative calculations of components will not be carried out. Moreover, the end result is generated with respect to Volvo Cars procedures and operations, thus it may not be generalisable.

As mentioned earlier, the automotive industry is currently facing new challenges to be more sustainable. Therefore, this project will focus on the automotive industry and Volvo Cars. All participants in the interviews will be limited to this industry only. The communication means will primarily be of digital nature in order to avoid infringing the pandemic guidelines. Additionally, some sensitive information from Volvo Cars and all participants involved will be anonymous, thus only approved material may be presented in the final report to avoid infringement on confidential and sensitive material.

1.5 Outline of the report

The report consists of six sections. The first section introduces the report with its limitations and aim. The second section, the Literature review presents the existing theory this report bases on. The third section is the methodology and comprises the generic process and methods that have been used in each of the phases. This chapter encompasses two different phases, which are the exploratory and explanatory phases. Subsequently, the forth section, Mapping of Volvo comprises the understanding of Volvo Cars and a workshop. The penultimate and fifth section, presents the Discussion of the findings and methodology approach, before sixth section which concludes with a Conclusion and Recommendation, highlighting the key findings and recommendations for future development.

2

Literature review

This section encompasses an introduction to different theories and concepts within the area of CE and remanufacturing in the automotive setting, consequently, it constitutes an element in the theoretical framework in this study. The study aims to examine the currently existing knowledge within these areas and what to take into consideration when taking a circular economic approach. Hence, it deems to fulfill Objective 1: *Establish the current level of knowledge on remanufacturing of components by reviewing scientific literature on circularity in the automotive industry.*

2.1 Circular economy

Circular economy (CE) is a concept that has recently gained more attention by practitioners and scholars due to environmental depletion and the public demand for more sustainable solutions to reuse and material waste. This has further been confirmed by the rapid increase of peer-reviewed articles on the topic in recent years. The concept can be attributed back to 1989 by Pearce & Turner who started investigating the relationship between natural resources and the economy. Nevertheless, various principles such as closed loops and servitization were introduced even earlier, but in an industrial ecology setting. Since then, it has been developed by several other ideas of closing resource loops e.g cradle-to-cradle and regenerative design (Geissdoerfer et al., 2017; Stahel, 2016). The concept of CE strives towards a closed loop system where leakage of resources are mitigated, input and waste and emissions to be eliminated (Geissdoerfer et al., 2017). As a result of the Ellen McArthur Foundation actions, a butterfly diagram has been established to illustrate the relationship between activities required for industrial system to closing resource loops, see Figure 2.1 below.

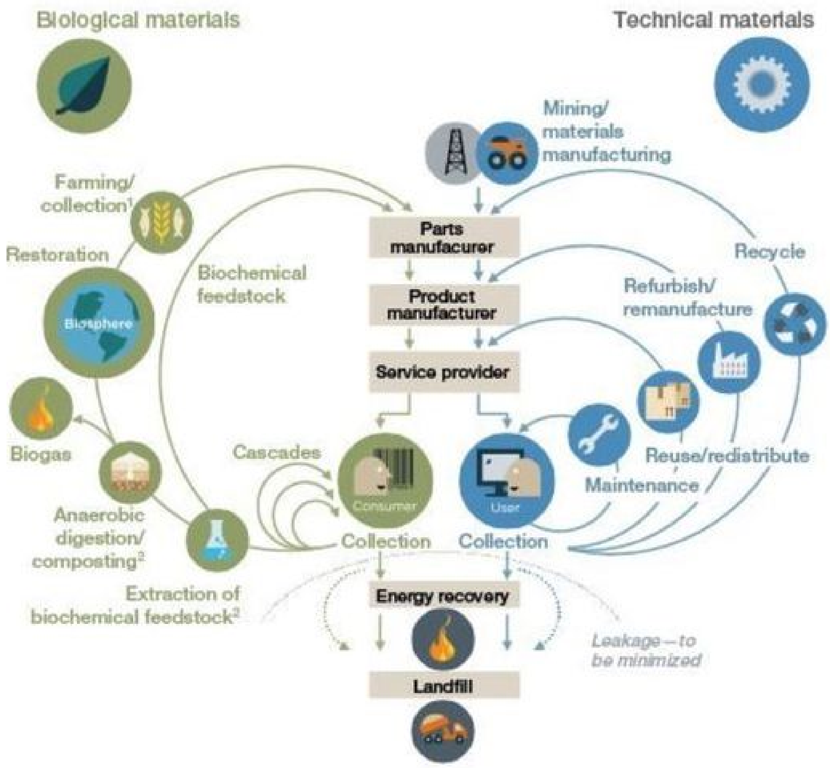

Figure 2.1: Butterfly diagram of closed loops (Ellen McArthur Foundation, 2017).

The middle part and body demonstrate the linear economic system, where raw material is transported and transformed by stakeholders until discarded to landfill. The loops on either side depict what processes can be employed to shift towards circularity. The left side loop shows the biological processes and the right side depicts the synthetic industrial system and its activities for facilitating minimization of extraction of virgin materials and waste.

Blomsma and Brennan (2017) adduce that CE can be perceived as an "*umbrella concept*", implying that it consists of a combination of already existing concepts. These concepts had previously no relation or has now been adapted with the new context. This, by aligning the concepts and emphasizing a shared characteristic. Furthermore, aligned with Kirchherr et al. (2017) findings in their extensive report, there are over 114 widespread definitions diligently utilized in academia. This has resulted in widespread definitions and diversification among industries and context. Furthermore, they highlight the fact that many authors seem to have no clue about what CE is about and distort it, leading to more ambiguity. For instance, some authors solely define and refer to CE as recycling, whilst ubiquitously CE is captured as a combination of reduction, reuse, and recycling.

The most commonly used and accepted definition of CE throughout academia and industry is the one framed by Ellen McArthur Foundation (2019): "*The circular economy (CE) represents a new type of economy that is regenerative and restorative by design, and offers a departure from the linear model. In the CE, the way products are used and designed are transformed by a shifted value creation with the aim to decouple economic growth from finite resource consumption*" (Ellen MacArthur Foundation, 2019). Despite the fact that this definition is highly reputed and used, it does not cover all parts of CE. For instance, there is ambiguity in articulation of "*regenerative*" and "*restorative*", further the definition does only take the product into consideration and not the whole business model. Moreover, Ellen MacArthur Foundation (2020) among others emphasize drivers and barriers for CE within automotive. For instance, lack of efficient processes regarding reverse logistics, difficulty combining OEM new and remanufactured spare parts procurement, and difficulties in disassembling and accessing car parts are a few barriers discussed.

Nevertheless, due to the ambiguity and widespread perception of CE, the concept entails criticism (Ghisellini, Cialani, & Ulgiati, 2016; Lieder & Rashid, 2015; Lewandowski, 2016). Potting and Kroeze (2010) argues that CE is just old concepts refined to gain new traction, thus reinventing the wheel. If the ideas that constitute CE are to be novel or not is however of less importance in juxtaposition to reassuring past failures are exploited in a proper manner for current efforts (Bocken et al., 2017). Further implications suggest that that CE initiatives have predominantly focused on recycling (Potting & Kroeze, 2010; Worrell & Reuter, 2014) and thus been misinterpreted extensively.

2.1.1 Linear versus circular economy

The CE starts at the point where ownership or liability for goods is sold from manufacturers, thus the linear industrial economy ends. After this point, users have the opportunity to optimize or not optimize the goods in the loop system of CE (Stahel, 2019).

Today most common and traditional linear economy practices induce ‘take-make-waste’ where resources are to be extracted and transformed into products which finally are discarded when their purpose is fulfilled (Ellen MacArthur Foundation, 2019). On the contrary, CE proposes a shift from this value creation approach. Instead, it opens up for an alternative approach of value creation with the purpose of decoupling economic growth from finite resources. It is based on three principles, where the first one concerns the management of renewable resources and finite stocks, as well as the preservation of natural capital (Ellen MacArthur Foundation, 2014; Linder & Williander, 2017). Hence, selection of resources should be selected mindfully and based on renewable ones. Secondly, optimize the yield of resources through creating circularity for the products at the highest utility possible. This, by implementing design principles in terms of refurbishing, remanufacturing, and recycling. The third principle refers to reduce and minimize damage to external systems through obstructing land use, toxic substances (dissipative substances), or polluting air and water.

2.1.2 Closing loop principle

As emphasized by Lüdeke-Freund, Gold, and Bocken (2019), the focus has been directed towards optimization of resource flows. The resource flows may be *slowed*, *narrowed*, and *closed* as depicted in Figure 2.2 below (Lüdeke-Freund et al., 2019; Stahel, 2016).

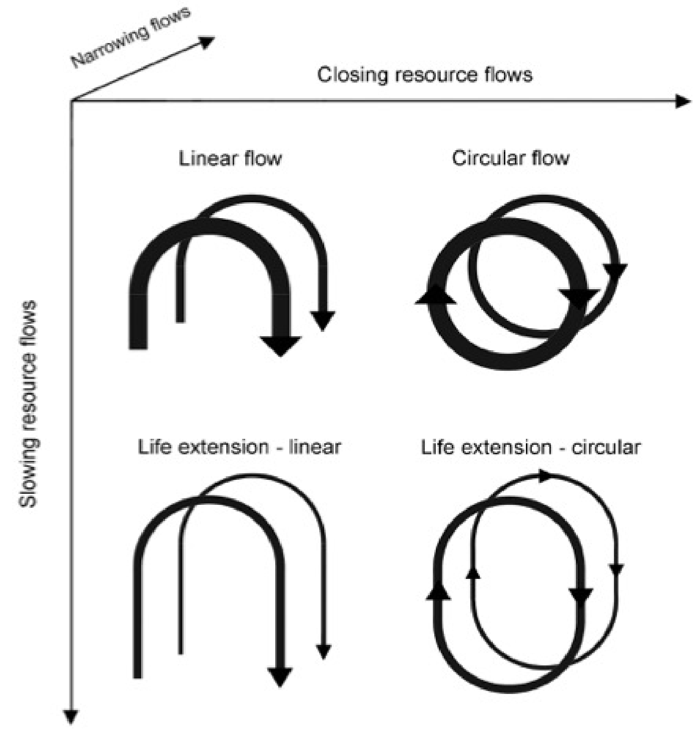

Figure 2.2: Illustrates Slowing, narrowing and closing resource loop for linear and circular flows (Bocken et al., 2016).

Slowing down the flow is about prolonging the use of resources by designing for product life extension. Narrowing the loop is about reducing the number of resources used for products and production processes, whereas closing the loop refers to the recycling of materials. Furthermore, strategies to obtain these have been enlightened. Two main strategies for reducing or slowing resource flow are *dematerialization* and *transmaterialization*. The former concerns gaining a more certain exchange of material in nature and thereby increasing the efficiency of resource use for a given function. For the latter one, it concerns the substitution of materials from hazardous/scarce to less harmful/abundant ones. Here, the resource flow can be closed and narrowed by for instance; increasing quality of material, multi-functional use, increase the recycling rate, and making the products last longer (Bocken et al., 2016).

Furthermore, as mentioned by Lüdeke-Freund et al. (2019), businesses need to be mindful in their operations resulting in the generation of excessive waste and resource depletion, looking back through the supply-chain network and how it can be managed more sustainable. However, there will always be dissipative loss in the material flow from the anthroposphere (human systems) to the biosphere (environment) making the future recovery next to impossible. For instance, dissipative losses can be the wear of rubber tires and the evaporation of chemicals and detergents (Hollander et al., 2017).

Moreover, this is connected to the reverse resource flow and as well as coordinating these. *Reverse logistics* is a strategy that may be implemented to minimize the generation of waste, reducing costs and resource consumption, and is derived on a reverse distribution, opposite to the normal resource flow. In a CE setting, reverse logistics has been adapted and the main implications concern collection and reuse of products and materials (Genovese et al., 2015). As Sundin and Dunbäck (2013) discuss in their article, reverse logistics refers to activities, stakeholders etc, associated with the distribution of products in the opposite way compared to the normal forward way, for instance from customer to suppliers (retailers), end-user and finally to a remanufacturer.

Nevertheless, previously identified challenges faced in reverse logistics by remanufacturers have been identified by Lundmark, Sundin, and Björkman (2009) and companies within the automotive industry. This refers to, for instance, uncertainties regarding demand and cumbersome ensuring core supply, hence storing large volumes of cores despite not having a concrete demand for remanufacturing projects yet. Further, Sundin and Dunbäck (2013) emphasize that the design of the reverse supply chain and how the products are collected back to remanufacturers plays a substantial role in the remanufacturing system, thus to have the cores ready right in time. The design is a delicate procedure and there is no silver bullet, consequently, each company has to find their optimum approach, taking, for instance, the number of different cores into consideration. In addition, another challenge concerns the reckless handling of cores, during any processes of remanufacturing, therefore how cores are handled and packaged is of utmost importance.

2.1.3 Value retention processes

Value-retention processes refer to retaining value in the system by performing value-adding operations to a product, for instance remanufacturing and refurbishment. It can also encompass extending the lifespan beyond the expected time a product remains useful and its expected end of use (EOU). Here EOU refers to a product's service life when it is perceived of no greater value to the user and/or not fulfilling the function it requires. Consequently, the EOU will differ and occur in various levels of obsolescence. End of life (EOL) instead refers to a point in the service life where the product can no longer fulfill the required function and there is no value-retention process available to prolonging the product, thus it becomes inevitable to recycle or dispose of it (Nasr & Russell, 2018). Further, Nasr and Russell (2018) emphasizes that value-retention processes comes with many benefits, for instance:

- Value-retention process reduction of new virgin material input
- Value-retention process reduced embodied material emissions and energy
- Value-retention process can contribute to more jobs
- Value-retention process reduces production waste

Some commonly associated processes within value-retention process and its relation to EOU and EOL can be found in Figure 2.3 below. In this paper, emphasis will be put on remanufacturing.

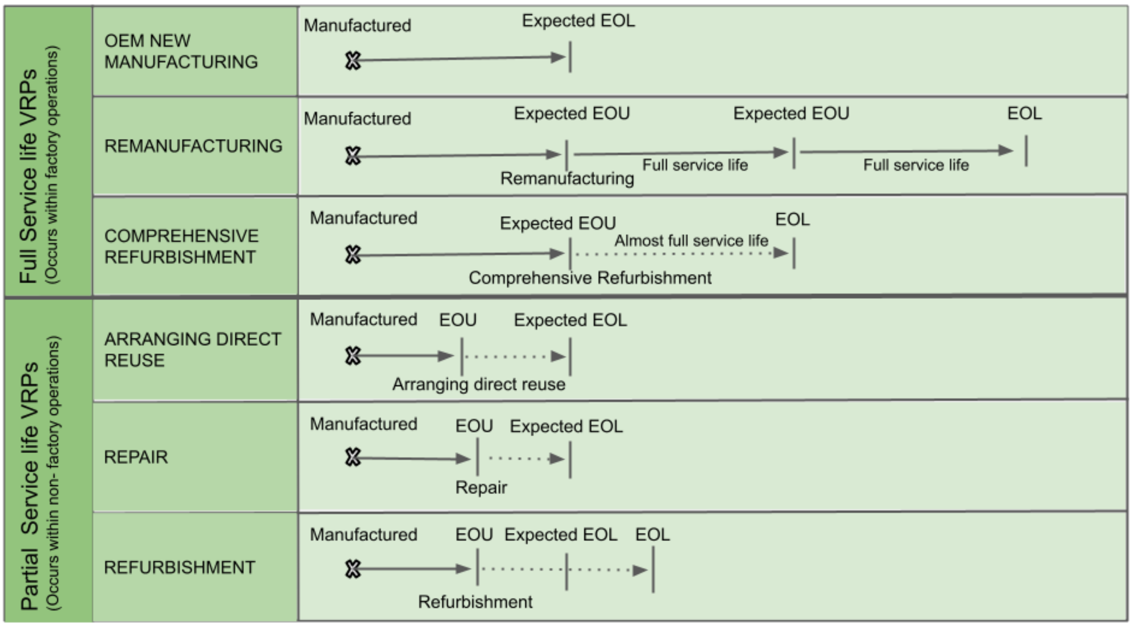

Figure 2.3: Value retention processes and how they differentiate based on EOU and EOL (Nasr & Russell, 2018).

As depicted in Figure 2.3, remanufacturing is the process that induces extending a product's expected EOU and EOL the most and also the most preferable of the above mentioned value-retention process. Consequently, it is therefore the process that could obtain and retain the highest level of value and quality out of all other strategies mentioned (Lindkvist Haziri & Sundin, 2020; Nasr & Russell, 2018; Vogtlander et al., 2017; Potting et al., 2017).

2.2 Remanufacturing

Remanufacturing is one of the value-retention process that companies can implement to reduce their environmental impact of the products. It entails taking back products after the EOU and restoring the components and the product as a whole, to a like-new or better state through industrial processes. Consequently, by keeping the parts in embodied material for a longer period of time and prolonging their usage time, the energy use and emissions can be significantly diminished (Lindkvist Haziri & Sundin, 2020). The possibility to achieve quality that exceeds the one of new parts with the support of remanufacturing, depends on processes like metallurgy and superior technology in processes (Stahel, 2016). Hollander et al. (2017) refers to remanufacturing as: *"A term for a series of industrial processes in a factory environment, whereby an OEM (original equipment manufacturer), an OEM contracted third party, or a third party licensed to carry the OEM brand name, disassembles obsolete products into components, to a level as far down as needed to bring as many of those components as considered eligible after testing back to at least OEM original performance specifications and recombines those components—generally originating from different used products—with as few as possible new parts, to manufacture new products of a similar type and specification, that result in a new product with a warranty that is identical to that of an equivalent product manufactured out of all new parts".* Further, Hollander et al. (2017) discuss a common contentious causing confusion and dichotomy with the typology of remanufacturing. In some cases it has been referred to as equivalent to refurbishment, however, the authors argue to distinguish them, as they differ in how they deal with brand and possession of intellectual properties.

Remanufacturing entails many benefits, and perhaps the most advantageous is the feasibility of developing eco-friendly products with extended service and product life (Roy, Vimal, & Jayakrishna, 2019). It has further been evidently proven that remanufacturing can reduce energy, material waste, minimize the stress of natural resources and increase the customer satisfaction. These are just few advantages highligted in the literature. According to ERN (2016b) remanufacturing can reduce new material requirement anywhere between 80-98 percent compared to new manufacturing and reduce the emission by approximately 80 percent in the appropriate industry, such as the automotive industry. Its practices within the automotive industry have been growing in importance and now almost every car manufacturer has remanufacturing projects for their components, as a new market institute. The motive behind this trend is the increased awareness of economic, legislative, and environmental issues highlighted by, for instance, Casper and Sundin (2020).

Moreover, even though remanufacturing practices have existed since the end of World War II (Vogtlander et al., 2017), environmentalists and proponents of CE have recently addressed it as one of the promising business solutions for future approaches (Vogtlander et al., 2017; Liu et al., 2014; McKinsey & Company, 2013; Prendeville S, 2015).

Despite the promising benefits and commendations, the number of OEMs pursuing remanufacturing is rather small. The approach has not gained enough traction, although it has been practiced since the end of World War II. Further, ERN (2016) elaborates on the potential drawbacks with remanufacturing prominent and known in the automotive industry today. Many products that are feasible for remanufacturing are being discarded at EOL and recycled, thus the embedded value is destroyed.

Remanufacturing requires more resources, labor intensity, and specialized knowledge than the other value-retention processes which is one of the reasons making it more complex to carry out (Vogtlander et al., 2017). A common view is that companies avoid remanufacturing their products, since it would cannibalise sale of other products, As emphasized by Guide and Li (2010), this argument has proven not to be universally valid. For instance, Caterpillar has increased the quality image of its products by performing remanufacturing and evidently shown an increased profit in sales, thus practices show there are great opportunities for remanufacturing market, yet it has shown to be difficult to obtain viable businesses.

2.2.1 The remanufacturing process

As implied by the literature, the technical remanufacturing process can differ depending on what industry and what component is considered. As emphasized by ERN (2016a) after evaluating over 105 companies across Europe, it is concluded that the different steps are sector-specific and should therefore not be generalized, see Figure 2.4 below for the different steps in an automotive setting.

Figure 2.4: The remanufacturing process and its general steps within automotive industry (adapted from ERN, 2016a).

In the two first steps the products, also referred to as cores are sorted accordingly to materials, electronics, and so forth. Further, an initial diagnostic is performed in order to determine how much of the component is damaged and if it is feasible to remanufacture at first sight. This will require experienced and competent technicians to make the evaluation (Zhang et al., 2021; ERN, 2016a; Shi et al., 2017).

In the third step, the cores are disassembled into sub-component or even completely into single parts. Disassembly is the process of dismantling a product into single parts with the help of equipment and tools. Here, parts that are not feasible or of value to remanufacture are sorted out. This step is usually performed manually due to different contaminants and degrees of corrosion (Zhang et al., 2021; ERN, 2016a; Shi et al., 2017).

Further, the next step includes cleaning which is a series of processes to obviate dirt, oil, chemicals, and corrosion from all surfaces. This is a necessity due to EOL products often occur in harsh environments and are covered by these, thus the parts need to be cleaned before entering inspection (Zhang et al., 2021; ERN, 2016a; Shi et al., 2017).

Inspection is performed to determine the status of the parts. It is an important process since it determines the status of components before issuing a warranty, which encompasses surface, internal damages, and shapes. The process is essential and it can for instance detect cracks on materials. In contrast to new production, all parts are inspected to assure it fulfills the required quality standard. Further, here the components are being classified depending on their ability to be remanufactured (Zhang et al., 2021; ERN, 2016a).

Reconditioning concerns the processing of material and operations such as; drilling, turning, grinding, and milling. This is performed to restore defective parts to their original specification, function, and performance or even better. If parts are not possible to recondition or not worth it economically, they will be replaced with new ones (Zhang et al., 2021; ERN, 2016a).

The last two steps are reassembly and final check. The reassembly is performed through a similar process as assembly lines, however solely small batches or single components at a time. The reassembly quality is highly dependent on the fasteners and methods used as well as other reassembly attributes specific to the particular product. Ultimately, after reassembly, a functional test is performed of every single part to guarantee 100 percent quality (ERN, 2016a).

2.2.2 Remanufacturability

Matsumoto, Yang, Martinsen, and Kainuma (2016) says that remanufacturability can be used to describe the ability to be remanufactured. Further, they discuss that caution needs to be addressed to remanufacturability, since due to differences in condition, quality, structure, and damage degree, sometimes the same part may hold different remanufacturability.

Further, Vogtlander et al. (2017) presents eight criterion to evaluate if products are suitable for remanufacturing regarding technical aspects. Beyond this, a comprehensive decision-making of remanufacturability has been established (Zhang et al., 2021), taking not only technical, but also economical and environmental aspects into account, see Figure 2.5 below.

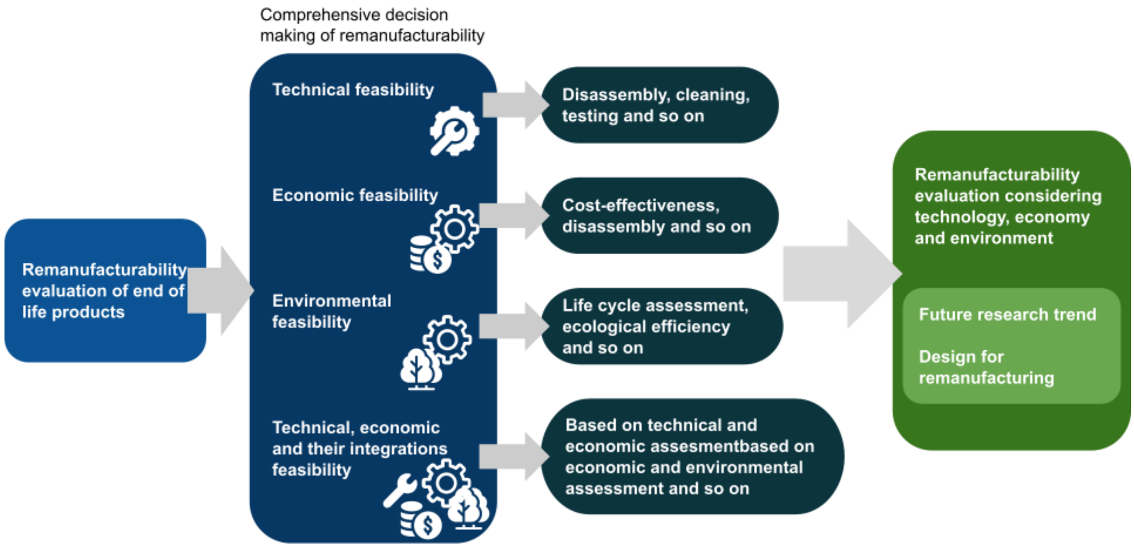

Figure 2.5: A comprehensive decision making of remanufacturability (adapted from Zhang et al., 2021).

Moreover, Linder and Williander (2017) acknowledge several factors affecting the remanufacturability. For instance, products that have a slow-paced technology development, high-quality and high demanding without being too cheap as a new component. Furthermore, Lindkvist Haziri and Sundin (2020) suggests the following aspects to be found in a product in order to facilitate remanufacturing; it has a core that can be used, functional failure rather than dissipating, value-added in the returned component has high value relative to the market value of original ones and technology is rather stable (both process and product). An important aspect to consider is that components that are to be replaced in remanufacturing, must have properties to withstand the process of remanufacturing several times, hence being inspected, disassembled, cleaned, reassembled, and tested (Sundin & Bras, 2005).

2.2.3 Remanufacturing from a product design point of view

According to The European Commission (2018), 80 percent of the environmental impact of products, are evidently determined as early as in the design phase. Due to products being designed for single-use and breaking down too quickly, they cannot be easily remanufactured, reused, or refurbished. Furthermore, products can be adapted according to Design for X (DfX) in various ways to facilitate an emphasis on sustainability aspects in product design and the life-cycle. Here the *"X"* represents the cause (Ulrich & Eppinger, 2011). For instance, there are many different engineering methods available that would result in adaptation for manufacturing, disassembly, reassembly, durability, accessibility, recycling, and remanufacturing. DfX-methodologies have been practiced and prominent within the automotive industry and been established, yet continuous improvements are pursued (Sundin, 2009).

Further, a collection of studies generating several various decision-supporting tools to support product developers obtaining a system-level approach as well as evaluating the most appropriate EOL option have been compiled (Lindkvist Haziri & Sundin, 2020; Mangun & Thurston, 2002). For instance, Sundin and Bras (2005) developed a remanufacturing matrix looking at what properties are suitable for the different remanufacturing steps. It encompasses the relationship between essential product properties and the generic remanufacturing process and entails support for DfRem. Moreover, Roy et al. (2019) has formulated three aspects to take into consideration when designing automotive products for remanufacturing. These are material orientation, manufacturing process, and finally, design orientation. Further, the compilation encompasses the aforementioned enablers, various disclosure of remanufacturability criteria, and ultimately remanufacturability attributes of each criterion are stated.

2.2.4 Design for remanufacturing

Design for remanufacturing (DfRem) is a principle that aims at facilitating the remanufacturing process through considering all the steps (e.g disassembly, cleaning, reconditioning, testing, and reassembly) when designing products. Furthermore, among many researchers, there is a consensus that DfRem consists of multiple considerations, e.g material selection/structure, joining and fastening method, durability, etc. Thus, the consensus is that DfRem includes various DfX implementations. It has also been determined by various researchers, those design guidelines are deemed to be most effective and efficiently implemented by addressing barriers of the remanufacturing process (Matsumoto et al., 2016; Shi et al., 2017; Lindkvist Haziri & Sundin, 2020).

Nevertheless, Fegade et al. (2015) has compiled several methods and tools for DfRem established by academia, as well as identified enablers and barriers. In addition, Hatcher (2013) has identified a gap in operational factors with integrating DfRem into product design. In their findings, both internal and external factors are highlighted, such as customer demand and the relationship between remanufacturer and OEM.

A prominent issue discovered is the fact that there is rarely any feedback to design from remanufacturing present. Often this depends on lack of feedback systems and communication in the supply chain since remanufacturing and design is performed isolated from one another by two different companies (Lindkvist Haziri & Sundin, 2020; Casper & Sundin, 2020). Hatcher (2013) points out that overcoming the communication barrier between remanufacturing and design could lead to products becoming more remanufacturable and suitable to implement in the design process.

2.2.5 Remanufacturing Information Feedback Framework (RIFF)

There are many existing tools and proposed actions available in the literature to address barriers, yet many of the mediating tools have evidently not been verified in practice. Nevertheless, a framework that is based on earlier literature findings and empirical findings that have been tested in automotive and large-scale industrial settings is RIFF. The proposed framework deem to strategically address and implement/improve feedback from remanufacturing to design. In addition, it also designates to identify optimum timing for feedback to be received and distributed.

The RIFF consists of four backcasting principles that are intended to continuously be revised, see Figure 2.6 below. First, the current situation and information flow are assessed, including the identification of actors and stakeholders. This is followed by step 2 where the future vision is outlined, which consists of an ideal utopian information flow from remanufacturing supplier to design. In step 3, step-wise actions are to be implemented which aim to decrease the gap between current and ideal information scenario, as well as how the actions are prioritized. The final step is an evaluation and follow-up of the effects the implemented actions had regarding DfRem and possible adjustments to target the ideal information flow. In addition, step 4 is also a revision of step 3 and thenceforth, the steps are repeated until the ideal vision is fulfilled (Lindkvist Haziri & Sundin, 2020).

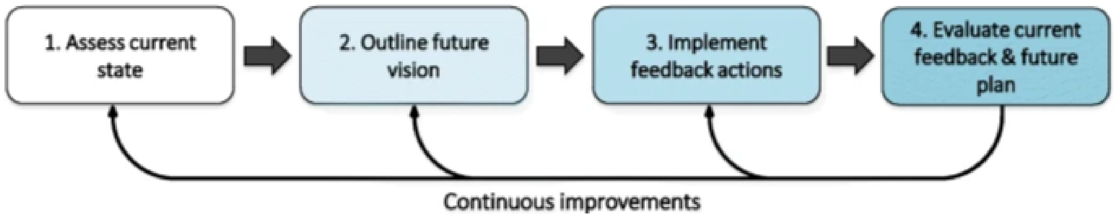

Figure 2.6: The different steps included in the RIFF (Lindkvist Haziri & Sundin, 2020).

2.3 Summary of Literature findings

During the exploratory literature review, it became apparent that there were many aspects and views to consider on different levels. Further, no literature reviewed entitled to discuss all dimensions and aspects in relation to each other. However, since the emphasis was on reputable prominent articles with a high level of cross-reference and relevance to the topics juxtaposing the articles was possible. Predefined criteria were set to eliminate literature not fulfilling the bare minimum criteria in an early stage. For instance, literature published prior to the year 2005 was immediately dismissed to target up-to-date state-of-the-art literature within the field and gain fruitful and relevant discussions.

As mentioned by Blomsma and Brennan (2017), the CE concept is not a single concept, but a combination of several pre-existing concepts. One may suggest that this is a result of the misinterpretation of the topic, discussed by Potting and Kroeze (2010) as well as the widespread nature of CE permeating academia and industry today. The research field of CE can most certainly be considered complex and ambiguous. One could argue that there is a need for reconciling the fuzzy field of CE and cultivate synergies from the various mixes of concepts. This is arguably what Ellen MacArthur Foundation intends to accomplish and has therefore initiated a common forum and digital meeting place for CE and related issues available for everyone (Ellen MacArthur Foundation, 2020). Arguably *closed-loop principle* and *Value retention processes* are considered more prominent and suitable for the automotive industry through its value it can provide to the organizations and products within the field (Casper & Sundin, 2020).

Furthermore, an important finding worth emphasizing and unanimously advocated by the authors, is that there is no silver bullet to increase the circularity, thus any general best way of applying CE practices does not exist. This will depend and vary from industry and business case, however, the main objective remains unaltered for everyone, which is to reduce the usage of virgin and scarce materials. One may argue that firms should assess their own situation thoroughly in order to find the best trajectory of CE specifically for them to increase circularity and becoming a circular business (Sundin & Dunback, 2013; Ellen MacArthur Foundation, 2019).

Further, several authors have provided some insight on remanufacturing and it is considered the most advantageous value-retention process if dealt with correctly. As mentioned by Vogtlander et al. (2017), there are immense benefits from remanufacturing such as, minimize environmental footprint, new market opportunities, less cost than new products, and many more. One may argue that the reason it has not vigorously cultivated in the automotive industry yet, may depend on the complexity of establishing such a well-functioning system. It is the most complex value-retention process and requires a lot of resources. Moreover, many components, tools, and processes are today not designed or destined for a second or third life (ERN, 2016b), thus a complete transition and reconstruction of the business landscape may be a prerequisite and necessity. This is aligned with what several other authors mentioned regarding remanufacturability. Not only do the cores need to be technically feasible as mentioned above and in addition be designed to endure the different remanufacturing processes, but also be economical and environmentally feasible (Linder & Williander, 2017; Zhang et al., 2021). As several authors emphasized, it very quickly becomes complex when measuring remanufacturability and there is not any generic approach to this, thus one may argue that it is often difficult to justify the economical and environmental benefits, it is less tangible than the technical aspect.

Several findings on the product design regarding remanufacturing have been highlighted by several authors. Since 80 percent of the environmental impact is evidently determined in the design phase (The European Commission, 2018), it can be argued that more emphasis should be addressed in this phase of the product life. Here, DfX is an ubiquitous suggested approach but may not be sufficient for implementing design for remanufacturing. In addition the authors' suggest establishing requirements and frequent communication between stakeholders concerning remanufacturing could lead to more remanufacturable products (Casper & Sundin, 2020; Lindkvist Haziri & Sundin, 2020; Hatcher, 2013; Fegade et al., 2015). It can also be argued that establishing more frequent communication would possibly lead to overcoming the internal and external barriers linked with remanufacturing. For instance, by implementing the established framework RIFF presented by Lindkvist Haziri and Sundin (2020), the information flow is revised with the purpose of including feedback from remanufacturing supplier to design team.

3

Methodology

This chapter encompasses the different project phases with associated methods and tools, with the purpose of fulfilling the objectives of the project, presented in Section 1.3. All methods used are based on existing ones with a high level of credibility and relevance, however, the overall methodology does not adhere to any given linear flow advocated by a specific author. Instead, the particular methods used are handpicked based on adequacy to the project methodology. The project flow and the different phases are presented in Figure 3.1 below.

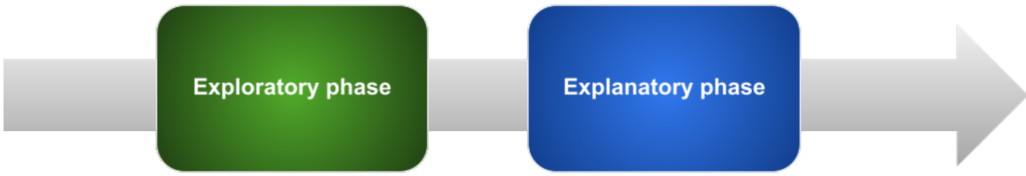

Figure 3.1: Depicting the project process.

3.1 Exploratory phase

The qualitative study was performed during the exploratory phase with the primary purpose of fulfilling Objective 1: *Establish the current level of knowledge on remanufacturing of components by reviewing scientific literature on circularity in the automotive industry.* Moreover, the exploratory phase was secondarily performed with the intention to initiate and facilitate the trajectory of Objective 2 and 3. The research phase was divided into two steps as depicted in Figure 3.2; Literature review and Mapping of Volvo Cars.

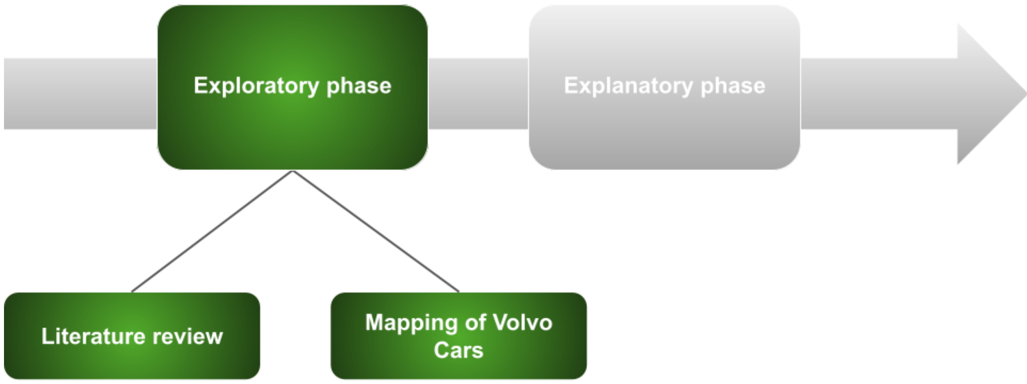

Figure 3.2: Phase one, the Exploratory phase.

3.1.1 Literature review

The literature review was conducted through four different steps; reviewing of literature, analysis of the literature, documentation, final analysis and a summary of the literature.

The literature review mainly encompassed a collection of relevant articles, reports, and conferences regarding Circular Economy and Remanufacturing within the automotive industry. The purpose of the review was to generate theories related to the relevant topic. To gather relevant literature, Chalmers library was utilized in order to grant access to various databases such as Scopus and Science Direct. In addition, Google Scholar was utilized to avoid bias publishers. To achieve the objectives, the literature review initiated with a broad funnel by identifying a number of various highly reputable articles within the topic of CE. By identifying a seminal and highly cited paper it was deemed as a good start set. Thereafter, it proceeded to branch out into in-depth topics such as remanufacturing in an automotive setting and thereby contracting the funnel.

To ensure the trustworthiness and target of relevant literature and authors, the snowballing method was applied (Wohlin, 2014). Figure 3.3 below illustrates how the snowballing procedure was applied and the various steps included. Since the literature review had an exploratory nature, the snowballing procedure was deemed as a suitable approach to establish sufficient content. Furthermore, during the process, internal brainstorming and snowballing of tentative keywords were conducted in order to generate fruitful search terms to find even more literature of relevance. This was made to ensure a wide perspective and to be more serendipitous in the findings (Wohlin, 2014). A few examples of the keywords included in the search term used was; "*Circular economy*", "*Circular automotive processes*", "*Remanufacturing*" and "*Value retention processes*".

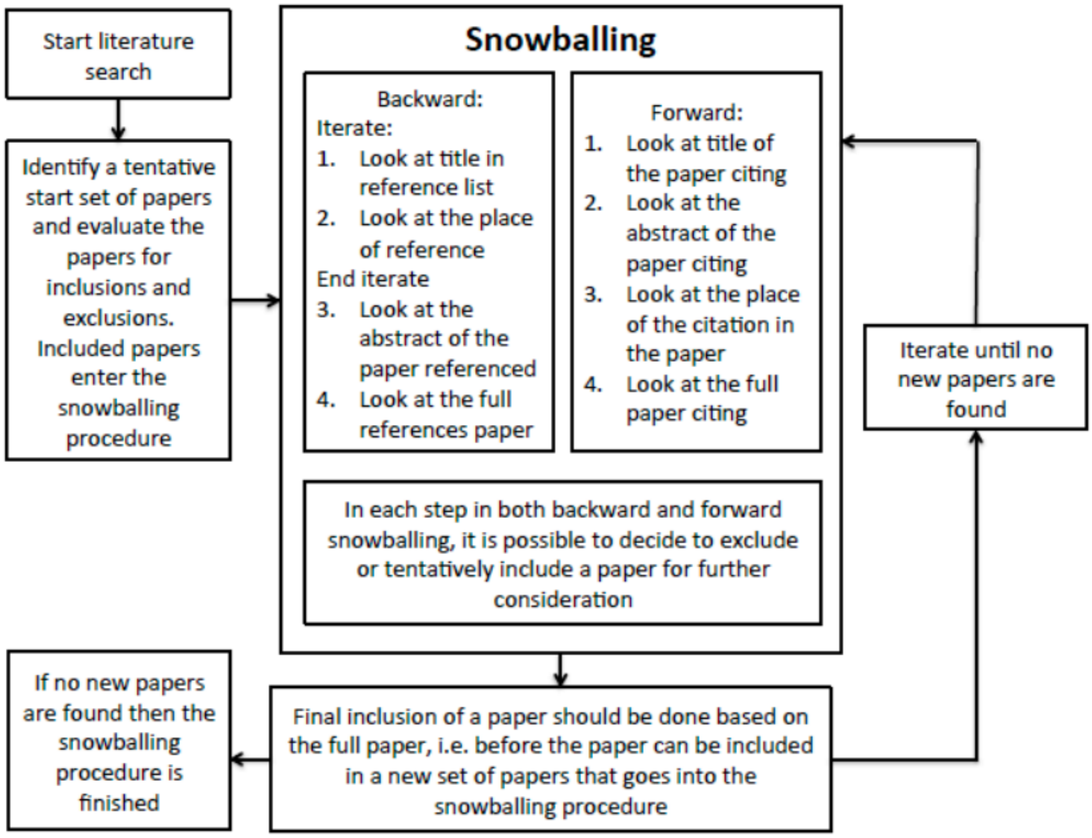

Figure 3.3: The snowballing procedure (Wohlin, 2014).

Once the start set was decided, the first iteration took place, and which articles to include were decided. In the first iteration, both backward and forward snowballing were performed. When the former was performed, the reference list was examined to identify new relevant papers to include. The decision to exclude papers in the reference list was based on a list of basic criteria, such as relevance in the title, publication year, type of publication, and authors. To ensure relevant selection of papers, questions such as these below were discussed.

- Is the title implying tentative content to include?

- Have the authors' published relevant papers in the area before?
- Is the article published in a relevant setting and place where it may be published?

If the paper still was a candidate for inclusion after these steps, the abstract was examined to evaluate the amount of relevance and if a definitive decision could be made. Thereafter, the full paper was examined to decide whether to use the paper or not. In the latter snowballing, identification of new papers was conducted based on papers citing the studied paper. The first screening was here based on information provided by the database. Thereafter, the ditto procedure as backward snowballing the abstract and full paper was examined.

Iterations were ongoing continuously during the course of the project and simultaneously as new information appeared to be justified. This, until the project team considered sufficient literature was gathered and that several perspectives had been taken into consideration, or no new papers were found, thus the loop is ended.

Documentation of literature

Due to the extensive systematic literature study, a large amount of literature was gathered (over 50 articles were retrieved), thus to ensure the traceability was not compromised, it was important to have a clear strategy of saving the material. Therefore, a literature data spreadsheet was utilized to save and assort the selected literature, see Appendix A for a draft. To ease tracking of the literature in the data spreadsheet, the following associated information was documented; authors, title, year, journal, paper type, source, summary, read by, and web link. In total, over 55 articles and books were included, summarized, and discussed. Furthermore, subtopics were established to distinguish and cluster relevant literature and provide a holistic view to visualize the distribution of each topic, hence indicate which part needed more emphasis.

Summary of literature review

The theory gathered regarding CE was extensive, thus it was divided into categories and branched down into; Concepts within CE, remanufacturing and remanufacturing from a product design point of view. The summarized data collected gave an understanding of CE and remanufacturing within the automotive industry, as well as the currently existing knowledge within these areas.

3.1.2 Mapping of Volvo Cars

To identify possibilities and challenges, an analysis of the company's current situation was conducted. The analysis encompassed qualitative methods such as semi-structured interviews with employees and data gathering by the company's internal database. Additionally, three unstructured meetings were arranged with the aim to get a deeper understanding of the development/design process, components, and remanufacturing process. By mapping Volvo Cars it was deemed to fulfill Objective 2 *Identify external and internal factors enabling and obstructing remanufacturing of components in the automotive industry by performing interviews with stakeholders and PESTEL-analysis.*

Research of Volvo Cars' intranet

Research of Volvo Cars' internal database was continuously made throughout the mapping process. Initially, broader research of Volvo Cars' intranet was conducted, in order to get a more holistic view of the company's business and get an overview of goals, vision, products, strategies, stakeholders, and processes. Thereafter research was continuously performed in parallel with the interviews with the purpose to find more specific data on a lower level.

Seminars at Volvo Cars

To get a better understanding of the development- and remanufacturing processes seminars with experts within these fields were performed. The experts were contacted beforehand by email with information including the purpose of the meeting and what information was asked for. This, in order to ensure that the right people with the right expertise were selected for the seminar. The data gathering from the seminars was sent out to the experts before it was included in the report in order to get their consent to publish the information. The seminars were also recorded with the participants' consent. The purpose of the seminar was to get a holistic view and identify areas to investigate further, no specific questions were going to be addressed. The experts were therefore free to form the structure of the meeting.

Focus group interviews

During the project, focus group interviews were conducted with employees from the Aftermarket and R&D departments. This with the aim of identifying and understanding the different tools and programs that the company currently uses in the development phase. But also to comprehend the components that the department: Electric drive transmission is responsible for.

The focus group interviews were conducted with a group of two and three participants. The industrial experts were informed in advance via e-mail with information including the purpose of the meeting and the topic to be addressed to ensure that the right people with the right knowledge were selected. The focus group interviews were also recorded with the participants' consent. The moderators did not follow a strict interview guide because the goal was to create as open a discussion climate as possible, where the participants felt free to share their knowledge and ideas on the chosen topic. This is aligned with what Denscombe (2014) advocates regarding the performance of focus groups, to make it as well-grounded as possible.

Interviews during Exploratory phase

To gain a deeper knowledge about how Volvo Cars works today with circular economy and remanufacturing, a qualitative study was conducted in the format of semi-structured interviews with different stakeholders of the company. The purpose of the interviews was partly to understand the organizational structure, remanufacturing process but above all understand what knowledge of the circular economy and remanufacturing already exists within the company and how knowledge is exchanged between departments and remanufacturers, see Table 3.1 below. The aim of the interviews was also to further investigate a number of topics identified in the literature study and seminars. The semi-structured interview method was therefore considered to be most appropriate and effective in obtaining as useful information as possible. In semi-structured interviews, the researcher uses the recipient's answers to a number of prepared questions as to their source of data. *"The interviewer has still formulated a number of questions to be answered but is at the same time very flexible when it comes to letting the interviewee elaborate the answer"* (Denscombe, 2014). In this way, the areas identified as interesting in previous methods can be investigated further by adapting questions around them. At the same time, there is still room for new undiscovered areas to emerge, as the method allows the interviewee to speak more broadly about the topics as opposed to structured interviews where the researcher must carefully control the interview (Denscombe, 2014).

Table 3.1: Compilation of personal communication performed during the Exploratory phase.

Characteristic	Date of interview	Department	Interviewee	Area
Semi-structured	2021-02-21	STS AB	Remanufacturing supplier	Mapping of Volvo Cars
Semi-structured	2021-03-23	BORG Automotive AB	Remanufacturing supplier	Mapping of Volvo Cars
Semi-structured	2021-03-05	Sustainability center at Volvo Cars	Director of Sustainability	Mapping of Volvo Cars
Seminar	2021-02-16	Remanufacturing strategy at Volvo Cars	Strategy and program manager	Mapping of Volvo Cars/Remanufacturing
Semi-structured	2021-02-11	Professor	Professor at Linköping University	Circular Economy/Remanufacturing
Semi-structured	2021-03-15	Service department at Volvo Cars	Service Propulsion	Mapping of Volvo Cars
Semi-structured	2021-03-15	Aftermarket department at Volvo Cars	Product business manager	Mapping of Volvo Cars
Semi-structured	2021-03-15	Electric drive transmission R&D at Volvo Cars	Propulsion system architect	Mapping of Volvo Cars
Semi-structured	2020	Sustainability center at Volvo Cars	Head of Sustainability center	Mapping of Volvo Cars
Focus group ***	2021-03-12	Electric Drive Transmission R&D at Volvo Cars	Design engineers	Mapping of Volvo Cars
Focus group **	2021-03-23	Aftermarket department at Volvo Cars	Product business managers	Mapping of Volvo Cars

Two different interview guides were created, one with questions that addressed the company's current knowledge of the circular economy and one with questions about the company's remanufacturing process. Both interview guides also included questions about information exchange. The interview guide was broken down into different topics and questions were categorized thereafter. The questions were formulated as open-ended questions due to the semi-structured form chosen. To confirm that the questions were formulated in a good way, a test interview was conducted before the real interview where the questions were asked to two other students at Chalmers.

The interviewees were contacted and informed about the purpose of the project by email a few days before the interview session, this was to ensure that the participant gave their consent to participate in the research. The interviewees' consent is also very important for the researcher when it comes to research ethics (Denscombe, 2014). The interview questions were also sent at least one day before the session, to give the participants a chance for preparations.

Due to the pandemic of Covid-19, the interviews were conducted online through Microsoft Teams, which also was a platform all participants were already familiar with. Online interviews are advantageous in terms of cost and time, no time-consuming or costly travel needs to be done (Denscombe, 2014). The interviews were recorded which according to Denscombe (2014) is a more reliable way of capturing the discussion. The recording was only made with the consent of the participants.

PESTEL-analysis
Furthermore, in order to attain a holistic view of the current situation, a PESTEL (Political, Economic, Social, Technological, Environmental and Legislation) analysis was conducted. This will elucidate the external macro factors related to the company and the topic. For instance determine drivers and barriers concerning aspects such as Political, Environmental, and Technological (İhsan Yüksel, 2012). Further, a patent analysis could be useful to determine the maturity of the technology, the trends, estimating the level of depth explored within the topic previously to this thesis and prohibit eventual infringement. By investigating the number of search results, and amount of patents available, this can be analyzed. By performing a PESTEL analysis, Objective 2 will be treated.

3.2 Explanatory phase

The purpose of the Explanatory phase was partly to fulfill Objective 2. Moreover, it was also performed with the aim of fulfilling Objective 3, *Understand how these factors (external and internal) can be approached to create an action plan for how Volvo Cars can work towards a more circular business.* Here, the findings from the Exploratory phase were discussed to create something useful to advance knowledge and possibly improve the practices at Volvo Cars. Moreover, a workshop was conducted to identify potential barriers and challenges with Volvo Cars' current information flow regarding remanufacturing and create an action plan. The project phase can be shown in Figure 3.4 below.

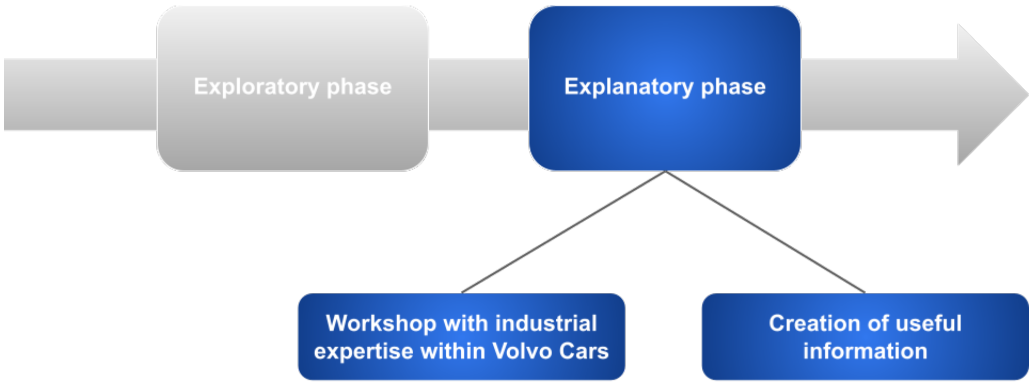

Figure 3.4: Phase two, the Explanatory phase.

3.2.1 Creation of useful information

With the information analyzed and internal and external factors affecting remanufacturing discovered, the intention was to apply it and advance knowledge to possibly improve current practices at Volvo Cars. Further, cultivating and adapting the result was made to create something useful to implement in terms of an action plan for stakeholders involved with remanufacturing at Volvo Cars. This resulted in a workshop which was performed, see Section 4.6 for the result.

3.2.2 Workshop with industrial expertise within Volvo Cars

A workshop with stakeholders involved in the process of design for remanufacturing within Volvo Cars was conducted. This with the purpose to evaluate and test whether the implementation of the proposed "Remanufacturing Information Feedback Framework", developed by Haziri and Sundin (2020), can help Volvo Cars overcome a potential barrier identified in the information flow. The aim of the workshop was to increase the awareness of a potential barrier to remanufacturing of components at Volvo Cars and understand how it can be addressed to overcome this together, through changes in the information flow.

In order to make the workshop as realistic as possible, the workshop was designed based on a case, where two selected components from Electric drive transmission are going to be developed and designed for remanufacturing. The proposed framework is based on four different steps (Haziri and Sundin, 2020):

1. Assess the current state
2. Outline future vision
3. Implement feedback actions
4. Evaluate current feedback & future plan

According to the limited time frame of the project, steps 1 and 2 were considered to be feasible in time. Step 1 was chosen to be carried out before the workshop was realized and step 2 was carried out during the workshop execution. Further, the setup of the workshop will be described in the following section as consisting of three different main phases: Before, During, and After, see Figure 3.5.

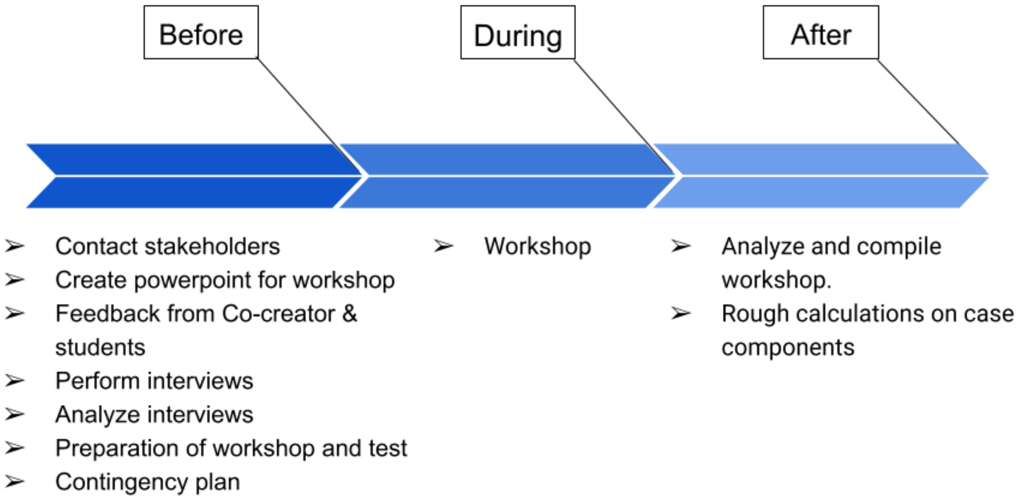

Figure 3.5: The methodology before, during and after the workshop.

Before the workshop

This phase is based on Step 1 in the *"Remanufacturing Information Feedback Framework"* and includes the following activities:

- Identify and interview stakeholders involved
- Elucidate information flow
- Analysis of the interviews

Identify stakeholders involved

Based on information obtained from interviews with employees in the exploratory phase and together with the recommendations in the RIFF framework, a number of different stakeholders were identified to be involved in the information flow between design engineers and remanufacturers. The selected stakeholders that was seen as important to involve in the workshop come from the following departments: Aftermarket, Sustainability, Procurement, Remanufacturing, Service, Design, and Manufacturing departments. All these stakeholders were contacted by email and received information regarding the purpose of the workshop and also a brief description of the upcoming steps.

Interviews of stakeholders

In order to map the current information flow and understand what information, between who and when the information is transferred, interviews with employees from the different selected departments were performed before the workshop occasion. The role of the selected interviewee varied and could range from specialists at the technical level to specialists at a more strategic level. What was required was that all respondents had a good knowledge of the department to which they belong, reasonably good technical knowledge of the selected components, and a close relationship to the Electric Drive Transmission department. In order to perform interviews as targeted as possible, a structured interview form was selected. This was also preferable since the issues to be addressed were very clear for the project team (Denscombe, 2014).

An interview guide was created to consist of a number of questions with the aim of addressing what information is transferred, between which stakeholders the information is communicated and when in the design process is the information transferred, See Appendix B for the interview guide. Most of the interviews were performed by email, however, an exception was made if the interviewee preferably felt more comfortable answering the questions through a meeting on Microsoft Teams. The stakeholders were asked to answer the questions based on the case that had been specified and therefore also received a brief description of the properties of the components selected to the case. Additionally, stakeholders were also asked in the interview to depict a rough estimation of the current information flow using PowerPoint tools.

Analysis and compiling of interviews and information flows from respective stakeholders

A common information flow was created by compiling collected data from interviews together with the painted information flow from each stakeholder. The answers gathered from interviews were compiled and compared in an excel file. Data related to how information flows between the different stakeholders were then visualized through a flow chart. The design of the flow chart was adapted from an example of actors map from Lindahl, Sundin, and Östlin (2014), which also states the importance of classifying stakeholders by using different colors when information flows are going to be demonstrated. The internal stakeholders were therefore painted in a common color and the external ones in another color. The information flowing between the various stakeholders was illustrated with drawn arrows, directed at the direction the information is transferred, see Figure 3.6.

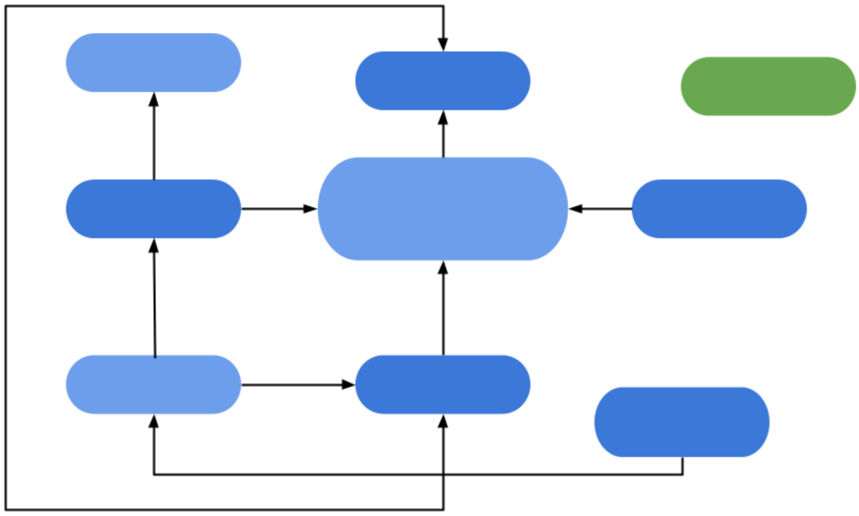

Figure 3.6: Example of an information flow map. (Adapted from Lindahl et.al 2014).

Workshop preparations

Due to the ongoing pandemic, the decision was made to conduct the workshop online through Microsoft Teams. A PowerPoint template was therefore created for the workshop as a meditating tool in order to ease the communication between the participants during the workshop.

Testing and verification of planned workshop

To verify the layout and content of the planned workshop, a meeting with the co-founder of the framework was arranged. The aim of the meeting was to get feedback on interview questions and the layout of the workshop. Moreover, a pilot test workshop was conducted together with two students at Chalmers. The pilot was performed in the same way as the real workshop intended to be. During the test, the two students came up with feedback on the workshop as an overview and also more specific feedback regarding the meditating tool (PowerPoint), time, and facilitators 'performance.

During the workshop

During the workshop itself, the goal was to execute step 2 in the proposed framework, outline future vision by performing the following steps:

- Create ideal information flow between designers and remanufacturers.
- Address the current gap between current and ideal information flow.
- Create an action plan in order to achieve the ideal information flow and prioritization of proposed actions.

To state the ideal information flow and identify how the current information flow can be improved in an effective way, a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis was performed by the participants during the workshop.

After the SWOT analysis executed by participants was finished, a concluded SWOT was performed by adding proposals made by the facilitators. Further, an action plan was created by analyzing the outcome of the concluded SWOT. Moreover, prioritization of proposed actions was made by using an impact & feasibility chart. Where four actions were selected and distinguished from the other generated action by a red circle placed on the chart according to their impact and ease of implementation. Finally, three actions in the chart were selected after discussion to proceed with and are also the actions to be focused on at first hand.

The time frame for the workshop was two hours. The selected stakeholders from phase one to participate in the workshop were interviewees from aftermarket, service, and design. To evaluate the participants' experience of the workshop and obtain feedback, an evaluation questionnaire was created in the Google forms tool.

SWOT-analysis

To compile and compare the possibilities and challenges from theory and experts, a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis was conducted (Ulrich & Eppinger, 2011). SWOT-analysis is an ubiquitous way to obtain an understanding of external and internal opportunities and challenges an organization can face. The analysis is composed of four different elements to be assessed within the organization. These are; strengths, weaknesses, opportunities, and threats. Two elements analyze the internal aspects, which are strengths and weaknesses, whilst opportunities and threats cover the external aspects. The purpose of performing a SWOT-analysis is mainly to evaluate the current standpoint. Further, possible competitive advantages can be identified, as well as proactive measures against possible threats. Although the company can control the internal surrounding and environment, the external environment is beyond any control (Sammut-Bonnici & Galea, 2015). The SWOT-analysis was used during the workshop as a mediating tool for the participants, in order to assess the current information flow and support the identification of the gap between current and ideal information flow. Here the advantages and disadvantages were possible to be identified while obtaining a holistic view.

After the workshop

After the workshop, the results were compiled to be further analyzed and discussed in whether the results can help Volvo Cars in designing components for remanufacturing. Additionally, rough calculations were also made in the form of cost estimation and CO_2-footprint to specify what savings the implementation of the framework could entail.

Practical implication of case components in Granta EduPack
In order to check the rough cost and CO_2-footprint estimations of the chosen components (bushing and linking rod), the Granta EduPack program was utilized. It consists of a database with a unique set of materials and process information, materials selection tools, and a range of supporting resources. Moreover, EduPack includes the possibility to compare different scenarios of the product life (manufacturing, production, use-phase, etc) in terms of cost, energy, and CO_2-footprint (Ansys, 2020). All the necessary information regarding material properties, processes and manufacturing site were retrieved from Volvo Cars. The additional data, such as transportation distance was instead estimated. See Table 3.2 below for data included in the cost calculation.

Table 3.2: Information regarding the bushing and linking rod (VOLVO).

Part	**Material**	**Process**	**weight (g)**	**recycle content (%)**
Big bush	Natural rubber	injection moulding	114	0
Inner core	EN AW 6082 E-T6 [AlSi1MgMn}	Extrusion chemical pretreatment	251	0
Housing	Aluminium- EN AC 44300 DF HPDC	Grit-blasting 345	345	49%
Linking rod	EN AB 46000	Extrusion	470	99%
			TOT weight: 1180	

Further, the components were known to be dimensions for the longevity of 15 years and manufactured in China, then transported to France to finally be arriving at Gothenburg, Sweden by ship. This distance was estimated to 24109 km. For the remanufactured part, it was known that Volvo Cars has local remanufacturing suppliers at Gothenburg, however, the components are stored in Maastricht, Netherlands, before sent to a supplier, therefore the cores will be transported to Maastricht and then back to Gothenburg. This distance was estimated to 2250 km in total. Moreover, to make it more realistic and trustworthy, the calculations were based on a batch of 1000 parts and a longevity of 15 years on both cases, since remanufacturing is supposed to be as good as new or better. When all data was retrieved, it was inserted in EduPack and the Eco-audit program, see Appendix F for inserted values.

4
Mapping of Volvo Cars

In this section, the mapping of Volvo Cars will be presented. Among other things, the company's product development process and the remanufacturing process will be explained. In addition, a general business description of the agile department: Electric drive transmission will be presented.

4.1 The 2040 vision - A climate-neutral company

Today Volvo Cars is still largely a company operating on linear economic principles, where take-make-dispose is a predominant way of doing business. The company is aware of the need to continue working towards being a more circular business, where materials and resources are used more efficiently. Volvo Cars sees enormous potential to become even more resource-efficient and has therefore a strong vision to become a circular business by 2040 (Head of Sustainability center, personal communication, 2020).

The exact path to get there is still under development but the company is aware that they need to start somewhere, continuously evaluate, and move the approach when needed. Volvo Cars have realized that having a vision is not enough, there must also be clear goals to work towards. Therefore, targets have been set for 2025, 2030, and 2035 (Director of Sustainability, personal communication, Mars 5, 2021).

The company believes that sustainability should be perceived as important as safety is considered at the moment, an area Volvo Cars has long been a leading player in (Head of Sustainability center, personal communication, 2020). According to Volvo Cars' sustainability director, there is no specific definition of Circular Economy in the company. Instead, the company has chosen to describe what they want to do in different settings and how they want to address all aspects of Circular Economy in how to design, produce and use, see Appendix for interview guide C (Director of Sustainability, personal communication, Mars 5, 2021). Today, Volvo Cars use Ellen MacArthur's measurement tool: Circulytics to measure the company's circularity, which is divided into the following two parts:

- Enablers: What has been systematized within the company? Are there roles that work against circularity and is it imbued with the operations?
- Result: How does the material flow in and out of the company? How does it change over time?

Volvo Cars' main goal within sustainability is to become a circular business and a climate-neutral company by 2040. They also strive to reduce their carbon footprint by 40 percent per vehicle. To achieve these goals, Volvo Cars have chosen to focus on eliminating waste and use more recycled materials. They have developed circular business models such as car-sharing concepts and also retain components and materials, through working with developing the following four different value retain processes: Remanufacturing, Refurbish, Repair and Reuse. As mentioned above, these are examples of processes that Volvo Cars has chosen to focus on in their business model (Head of Sustainability, personal communication, 2020). The four value-retention processes of Volvo Cars were created with the purpose of achieving the 2040-vision and the various goals set within it (Director of Sustainability, personal communication, Mars 5, 2021).

One of the major challenges identified in Volvo Cars' work towards the 2040 vision is the lack of control. The company today includes a large and extensive network of supply chains and is dependent on various partners who need to be convinced. In addition, there is a challenge in convincing internally to change the business model (Director of Sustainability, personal communication, Mars 5, 2021).

Moreover, a business model shift that has become more apparent in Volvo Cars, is the growing consumer trend of mobility sharing. Consumers are becoming more and more interested in just having access to a car rather than tying up capital by owning it. Therefore Volvo Cars strives for greater ownership of its cars and focuses on finding more flexible mobility solutions for the customer. For example, the new car subscription service, Care by Volvo, was released in 2021. Care by Volvo is a subscription service where the customer has the opportunity to drive cars without a fixed commitment period. The change means that the company itself will own a larger part of its products, which aims to own 50 percent of the cars by 2025 (Volvo Cars, 2020). This also means that the company will be increasingly responsible for the service and maintenance of the cars (Product business manager, personal communication, Mars 15, 2021). In addition, the company launched the M brand as well as a mobility solution, which offers the customer easy access to cars by booking in an app (Volvo Cars, 2020).

4.2 Electric drive transmission

In 2017, Volvo Cars started the journey for an agile transformation of the organization. Before that, Volvo had a mindset, where the hardware was developed first and then the software was developed at a later stage. The company understood that they needed to start working according to a "computer on wheels" mindset. Where software and hardware are developed simultaneously. Therefore, Volvo Cars decided to apply Agile methodology in the development (Denning, 2020). The implementation of agile development resulted in a re-organization that today consists of a number of different product streams. One of the product streams is called Electric Propulsion and which includes the agile department: Electric drive transmission.

The vision of Electric drive transmission is to develop the most desirable electric axle drives-offers for electric vehicles. The scope of the agile team is as follows:

- Develop transmission mechatronics modules/system for electric axle drive sys-

tems.
- Develop and verify transmission mechanical components.
- Responsible for system solution, integration, and verification of the electric axle drive system as a delivery unit (Design engineers, personal communication, Mars 12, 2021).

4.2.1 Components within Electric drive transmission

In this project, data from the Compact Modular Architecture (CMA) has been used, the selection of Compact Modular Architecture as a platform, was made based on Volvo Cars' approval for publication of images and data. Compact Modular Architecture is the platform in Volvo Cars' model XC40 battery electrical vehicle. Figure 4.1 below depicts the front axle drive system and its associated components for which the Mounts team in Electric drive transmission is responsible for. The main function is to hold the E-machine in place and minimize any vibrations as well as behave a specific way if impact occurs to protect the driver. Further, bushing and linking rod were selected for the workshop case, see Table 3.2 for a detailed description of properties. Both bushing and linking rod are so-called full-service supplier components which means that an external supplier is responsible for providing engineering activities including access to design, research, and development (Design engineers, personal communication, Mars 12, 2021).

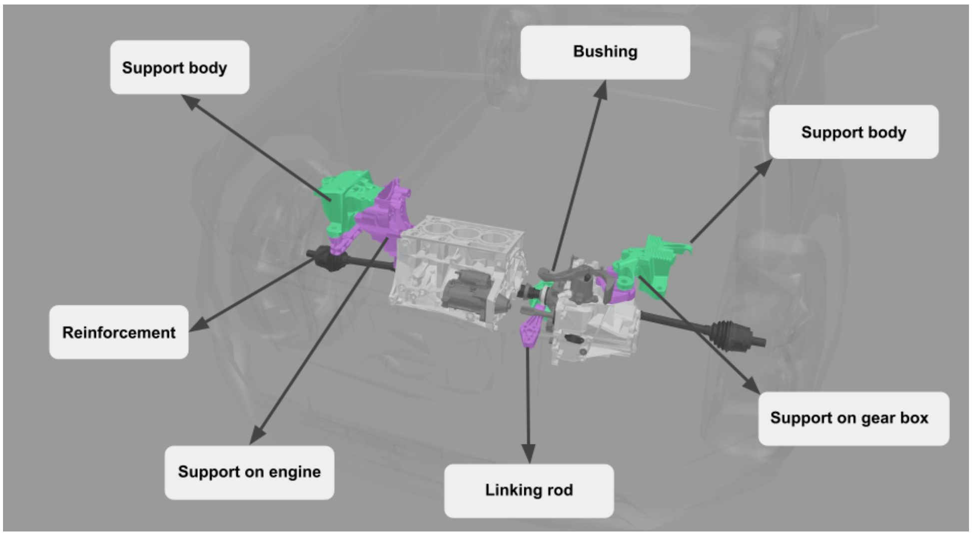

Figure 4.1: The various components associated with Electric drive transmission, and more specifically the engine mount (A2Mac1, 2021).

4.2.2 Product development process

Volvo Cars have developed their own product development process adapted to their business, Volvo Product Development Process (VPDS). The process for how Volvo Cars develop new products can be described as a flow consisting of four different phases: Strategy, Concept, Technology, and Industrialization. Each phase includes a number of important milestones and gates, which indicate, among others, the time when and what important decisions must be taken and different activities that must be carried out. To make it easier for the reader to understand the process, a scaled-down version of the process has been created, see Figure 4.2. The down-scaling version only consists of the concept and engineering phases, as it is the two phases that are seen as most relevant with regard to the dissertation. In addition, the relevant milestones and gates for these two phases will be further explained.

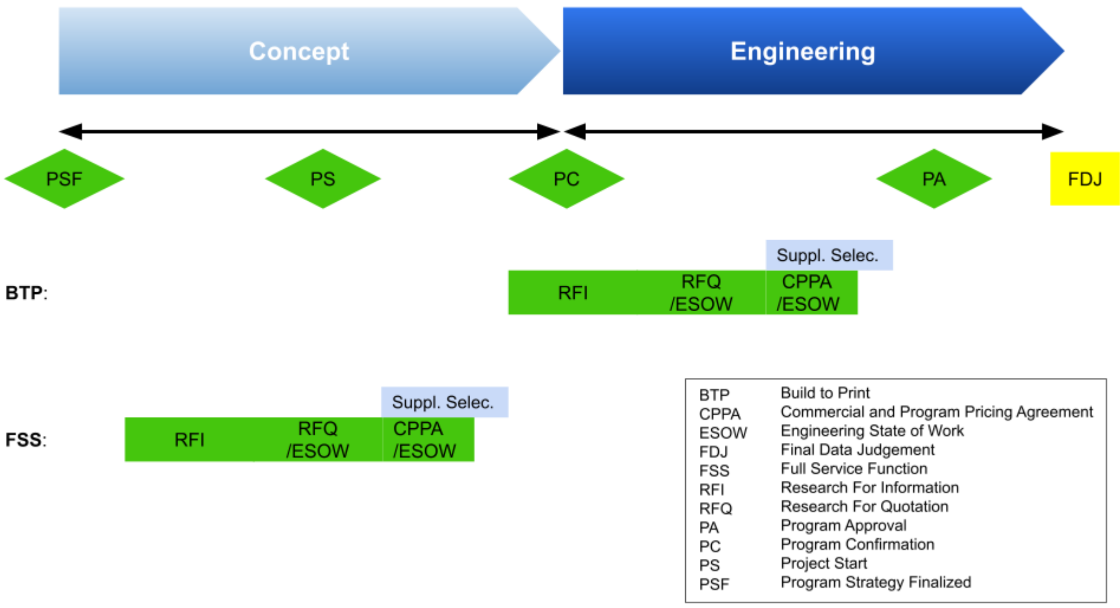

Figure 4.2: Simplification of Volvo Cars' product development process.

The concept phase begins when a strategic plan for the program has been confirmed and completed. The start of the concept phase is where the milestone "Program strategy finalized" has been marked out in Figure 4.2 . In program start, decisions are made about assignments, goals, and financing of the program. Examples of these decisions can be simply described as which car should be developed, how to develop the car, when the car should be developed, costs for the program, volume to produce, and so on. Once a number of generated concepts have been presented and looped, a concept is selected to continue with. Figure 4.2 also shows the milestones for program confirmation and program approval. In these steps, it is ensured that all selected solutions are confirmed and compatible. As well as final approval for the selected program is taken(Propulsion system architect, personal communication, Mars 15, 2021).

There are two different types of purchases that are mainly used in Volvo Cars' products when components are developed, build to print and full-service supplier. When a build to print component is developed, Volvo Cars are more or less responsible for all design and development. The supplier then manufactures the parts according to Volvo Cars' specifications. While when an full-service supplier component is developed, the responsibility for design and development is outsourced to an external supplier(Propulsion system architect, personal communication, Mars 15, 2021).

The time when the choice of suppliers is made varies depending on whether Volvo Cars chooses to use the build to print or full-service supplier component. When full-service supplier components are developed, sourcing supplier activities take place early within the concept phase. While with build to print components, the sourcing activities take place at a later stage(Propulsion system architect, personal communication, Mars 15, 2021).

The actual process for selecting suppliers can be described as follows: First, a Request for Information (RFI) is sent out to a number of potential suppliers in an early concept/design phase. This is done in the form of a document that contains comprehensive information about the component to be developed. A request for quotation (RFQ) is then sent out to the suppliers, which includes more detailed information regarding the component. Then the suppliers has to confirm and decide if they have the ability to deliver what Volvo Cars demand (Propulsion system architect, personal communication, Mars 15, 2021).

The RFQ consists of information regarding the article number, volumes and location of manufacturing, etc. Along with the RFQ, a contractual document called Engineering statement of work (ESOW) is also sent out. Engineering statement of work is a contract defining the technical scope of the new part and states the work and responsibilities between the company and suppliers. Lastly, a commercial and program pricing agreement is made and can simply be described as a contract signed by Volvo Cars and the selected supplier (Propulsion system architect, personal communication, Mars 15, 2021).

The engineering phase ends with the Final Data Judgment gateway and at this stage all development and technical activities should be complete and ready for tools to be ordered (Propulsion system architect, personal communication, Mars 15, 2021).

To reduce the complexity of developing a car, Volvo Cars today uses a development platform called Car Weaver. Which is a system where, among others, requirements for the various systems that the car consists of are gathered and woven together. A car's development process is very complex because it is a product that consists of many different parts/systems that are controlled by electronics, which in turn are run by small computers. The responsibility for the development and design of all these systems is divided between different teams. Therefore, Car Weaver is a very important tool for gaining control over and gathering all the important information related to the car (Product business managers, personal communication, Mars 23, 2021).

4.3 Remanufacturing process at Volvo Cars

Volvo Cars have been working with remanufacturing for over 70 years. As early as 1945, the company began to renovate gearboxes due to the prevailing shortage of raw materials that arose after the World War II, which also paved the way for Volvo Cars' exchange system (Volvo Cars, 2021).

Volvo Cars strive for renovating products "as good as new or better". They only cooperate with suppliers that remanufacture according to Volvo Cars' requirements, through specifications. Products are always remanufactured to the latest specification which means that the remanufactured part can correspond to a later and better update than the original part that was mounted in the car from the beginning (Strategy and program manager, personal communication, February 16, 2021). An enabler for Volvo Cars' remanufacturing process is the large environmental and financial savings that it entails. A remanufactured part requires up to 85 percent less raw materials and 80 percent less energy compared to a new part. In 2019, the program saved approximately 341 tons of steel and 144 tons of aluminum. The energy saved corresponds to a carbon dioxide emission reduction of 3,321 tonnes per year. Volvo Cars' exchange system accounts for 15 percent of its spare parts sales (Ellen MacArthur Foundation, 2019).

Currently, Volvo Cars do not have any remanufacturing processes in-house, but instead, as mentioned above, they cooperate with a number of selected suppliers. Scandinavian Transmission AB (STS AB) is today the remanufacturer of Volvo Cars' gearboxes. Volvo Cars procure gearboxes from Aisin AW, which is the parent company to STS AB. Aisin Aw is the owner of the design and also the one from who STS AB receives all technical information and spare parts, thus it is the OEM.

According to STS AB (2021), reassembly is considered to be the most costly and difficult step in the remanufacturing process itself. This is because it consists of many different time-consuming elements and necessarily requires very skilled assemblers, see Appendix D for interview guide. Further, BORG Automotive, which is another major remanufacturer of automotive parts in Europe, assent that, see Appendix E for the interview guide.

In the interviews with the various remanufacturing companies, it also became clear that design for disassembly should be highly prioritized. Today, there is an increasing trend in buying kits from a set of components that are already assembled by the supplier. The issue that arises is that the different parts are usually assembled using welding or rivets. This complicates the remanufacturing process and results in more material than necessary must be scrapped, since it obstructs the disassembly step. When too much material is wasted, it is not economically sustainable to renovate the product. Although the environmental aspect is a high incentive for the remanufacturers, profits and revenues are obviously more important because they are a profit-driven company. Even from a customer perspective, financial incentives are more important than the environmental savings that are made, see Appendix D.

Furthermore, the remanufacturers highlight the importance of standardizing parts and fasteners in order to make it easier to remove the parts without breaking them. The ideal scenario would be if remanufacturing aspects were taken into account already in the concept/design phase. In general, the choice of surfaces and materials does not affect the remanufacturability as much as the construction itself. Above all, welded components are obviously considered the most challenging to renovate. In addition, heavy components can be challenging to renovate from an ergonomic perspective and often require more help devices.

4.3.1 Volvo Cars' exchange system

An important factor and link between Volvo Cars and the various remanufacturing companies is their so-called exchange system which offers one of the most extensive ranges of remanufactured exchange parts in the automotive industry. The system is created to retain the components within the control of Volvo Cars after EOU/EOL. The reasons why Volvo Cars take back components is partly to enable remanufacturing of components but also to ensure that their products are managed according to their requirements and protect the brand. This means that products do not fall out of their control and are misused by other retailers in the market. The flow of the remanufacturing process can be described as follow: The remanufacturing process is initiated with a customer/dealer who buys an exchange part from Volvo Cars. The customer/dealer can choose between two offers: Alternative A: pay 20 000 SEK + pay a deposit fee of 20 000 SEK, which will be returned when the old part has been collected by Volvo Cars and retrieved by the exchange center in Maastricht, Netherlands from the dealer. Alternative B: Pay 35,000 SEK and keep the core parts. (Strategy and program manager, personal communication, February 16, 2021).

If a customer/dealer chooses alternative A, the remanufacturing process can be described as follows, see Figure 4.3. A new exchange part is sent from the distribution center at Volvo Cars located in Gothenburg to a dealer or customer, for example, Bilia (1). The customer/dealer replaces the broken part with the new one. The broken part also called the core part is then sent to the exchange terminal located in Maastricht (2). In Maastricht, a decision is made whether the component can be remanufactured or not. If not, the component is scraped (3). Otherwise, it is put in stock until a remanufacturing project is being started (4). When a remanufacturing project has been launched, the broken part is sent to a remanufacturing company that renovates the component to the latest specification (5). The remanufactured component is then sent back to the distribution center in Gothenburg (6), which is then distributed to a new customer or dealer again (7) (Strategy and program manager, personal communication, February 16, 2021).

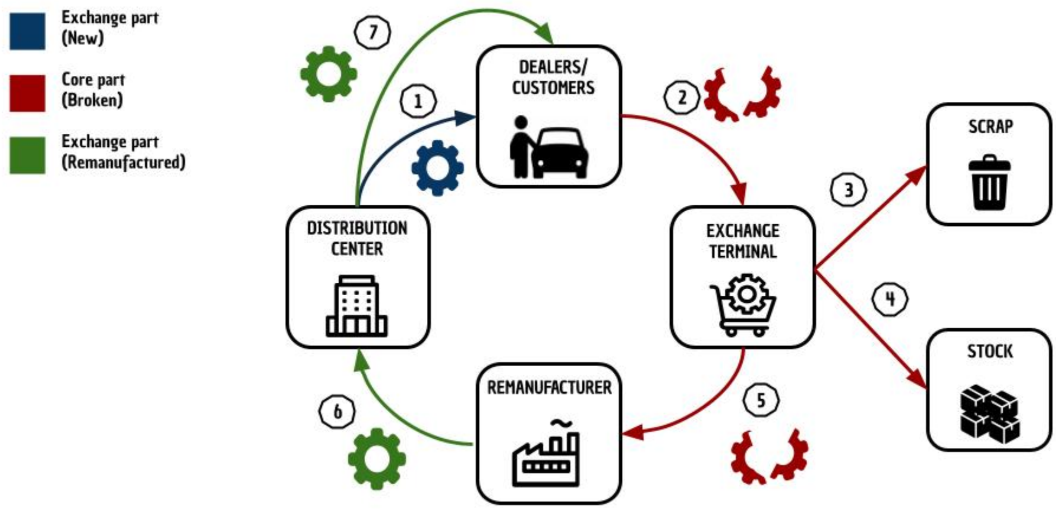

Figure 4.3: Volvo Cars' exchange system (adapted from Strategy and program manager, personal communication, February 16, 2021).

4.4 PESTEL-analysis

PESTEL-analysis has been conducted to identify external macro-factors that could potentially affect Volvo Cars in a CE context. Analyzing the external factors and identifying trends is why this broader scope was chosen (İhsan Yüksel, 2012). Here, data are extrapolated from the broader European level. Furthermore, some macroeconomic and macro-political trends (such as unemployment rate predictions and likely political change) are largely exempted from due to CE is unlikely to be sensitive to these factors. The objective of the analysis is to identify prerequisites, enablers, and barriers, as well as trends on the macro-level, affecting CE and remanufacturing of components at Volvo Cars.

4.4.1 Political

Sweden is currently a politically stable country and not likely to have any radical political changes in the near future. As the corporate tax rates are rather low for companies but have high regulatory compliance demands in regard to the environment compared to other countries, hence Sweden is perceived as a friendly environment for private enterprises (Forbes, 2018).

The European Commission (EC) and global business leaders have initiated programs and plans for CE, which are turning into key factors in creating sustainable futures. The new action plan encompasses initiatives regarding the whole life cycle of products, focusing on their design, promoting CE processes, fostering consumption of environmental nature, and much more (The European Commission, 2018).

The actions implemented in 2020 consist of two main blocks, sustainable products and empower consumers. EC has proposed legislation on sustainable products, ensuring that newly produced products within the EU market are designed for longevity, easier to repair, reuse and consist of as much recycled material as possible, instead of raw material. Further, single-use will become highly restricted. Furthermore, the actions entail that consumers must get access to reliable information to support them in making environmentally sustainable purchases, thus information concerning, for instance, reparability, remanufacturability, and durability are required (The European Commission, 2018).

Moreover, to pave the way for CE globally, the EU and China signed a memorandum of Understanding on CE collaboration back in 2018. This trade commitment concerns aligning policies to ease the transition to a CE and taking synergies from each other to entail new sources of innovation and economic growth (The European Commission, 2020).

4.4.2 Environmental

The environmental aspect with regards to CE is how much CO_2-emissions can be avoided by substituting and reducing raw material and energy consumption. The EC induces to propound businesses to pursue value-retention process, for instance remanufacturing retains much material, thus less raw material is utilized for the manufacturing of new products, and thereby the energy is reduced. By reducing energy consumption, it is usually apparent and leads to a reduction of CO_2-emissions (ERN, 2016b).

4.4.3 Socio-cultural

According to Ellen MacArthur Foundation (2020) sustainability and CE has without a doubt boomed and gained more interest recently, not solely in academia but in the entire society. Evidently, 80 percent want sustainable products and chooses that over the less environmental-friendly option. What we see now is a change in the behavior and attitude of customers, putting more pressure on policymakers and corporations.

Between the years 2012 and 2018, jobs linked to CE grew by more than 5 percent and reached around 4 million within the EU. Furthermore, it is estimated that the new CE action plan put forward by the EU would entail 700 000 new jobs and avoiding emissions by 600 million tonnes of CO2 by 2035. These amendments would increase the competitiveness and dependencies of the EU and beyond this, it is estimated to increase the total GPD in the EU by an additional 0,8 percent (Ellen MacArthur Foundation, 2020; The European Commission, 2018).

4.4.4 Technological

The development of technology within the Circular Economy seems to play an increasingly important role in the future. The increased number of patent applications progressed in the field of the circular economy over the years attest to this. New technologies are also developed in different research phase fields enabling circular models. In Table 4.1 some of the technologies developed and their potential applications presented. Today also the state-of-the-art remanufacturers invest in developing new manufacturing techniques in their processes (ERN, 2016b).

Table 4.1: Key technologies enabling the circular economy (Rematec, 2020).

Technology	**Potential applications**
Life and material sciences	- New raw materials - Replacement of non-renewable inputs with renewable feedstock - New usage of industries' by-products
Sensors and internet of things (IoT)	Measurable, recordable and verifiable asset location makes it easier to maintain, monitor and replace components
Block-chain	Supply-chain visualization
Machine learning	- Optimized production flows and processes - Coupled with IoT it can enhance supply streams and reduce energy consumption - Effective transportation routes

A shift from mechanical parts to electronic parts is becoming increasingly apparent in the automotive industry (Casper & Sundin, 2020). The increase in environmental policy actions has contributed to a growing market for hybrids and electric vehicles and has thus also contributed to the fact that remanufacturing of electrical and hybrid drives has become increasingly important. Remanufacturing of electrical and hybrid units also looks to play an important role in the future, which is expected to grow from 3 percent to 16 percent. Moreover, remanufacturing of electronic components and electronic control units is expected to increase from 8 percent to 12 percent, and when it comes to batteries, a growth from 1 percent to 8 percent is expected (Rematec, 2020).

4.4.5 Economical

The implementation of circular models in technology can contribute to a net benefit of € 1.8 billion per year by 2030. Which corresponds to € 0.9 trillion more per year if linear models are being applied (McKinsey & Company, 2015). On the other hand, the transition from linear models to circular models requires costly structural changes as a new value chain must be organized. Today, unfortunately, there is a lack of financial incentives in Europe to motivate companies to undergo the structural changes required for the implementation of circular models.

Something that can motivate companies to invest more in remanufacturing is the fact that remanufactured parts generally result in higher profit margins compared to original manufactured parts (ERN, 2016b). The automotive remanufacturing sector in Europe is also expected to have an increasing annual growth of 18 percent until 2030 according to ERN (2016b). Moreover, the increased consumer demand for remanufactured parts in Europe is expected to open up new growth opportunities for OEMs.

4.4.6 Legislation

In December 2015, the first action plan for the CE was presented by the EC. In 2019, a new action plan for the CE was presented. The action plan contains a number of actions that need to be taken in order to achieve a climate-neutral Europe by 2050. The action plan contains various initiatives to regulate production, design, consumption, waste management, and the market for recycled materials. Among others, it contains directives on how products should be taken care of in a sustainable way and proposed actions for how to achieve more sustainable product design (The European Commission, 2018).

4.5 Summary of Volvo Cars

Today, Volvo Cars have a strong vision to be a climate-neutral company by 2040 and have also begun its journey to achieve a more circular business. The company is aware that they still work according to linear principles but have started working more on how they can move to a circular business model (Head of Sustainability center, personal communication, 2020). Among others, goals have been set and the company is increasingly investing in finding solutions for how to achieve this. The company has also found a measurement tool that helps them measure their success at a strategic level (Director of Sustainability, personal communication, Mars 5, 2021). On the other hand, today's goals and measuring tools do not seem to be adapted to a lower level. The fact that the goals are not translated at a more specific component level can make it difficult for a design engineer, for example, to understand how he or she can contribute to achieving the goals.

One of the current challenges that the company seems to face is the lack of control over processes and components. This is mainly due to their broad network of external suppliers both in the early development phase of new components and in the remanufacturing of existing components (Strategy and program manager, personal communication, February 24, 2021). This can also result in insufficient access to important detailed information about component properties and processes. There can also be uncertainty whether the business model, goals, and vision are in line with the suppliers' way of working. Even internally, there seem to be great challenges in succeeding in reaching out and translating the vision and goals at all levels. Also, the fact that it is a very profit-driven business with customers prioritizing lower prices over environmental savings can also be a barrier for the company to overcome (STS AB, personal communication, February 22, 2021). In addition to this, there are no financial incentives in Europe to motivate companies to adopt circular business models. On the other hand, the PESTEL analysis shows that there are also a lot of external driving forces for motivating Volvo Cars' in circular investments.

Volvo Cars have many years of experience in remanufacturing and a well-established system for collecting and sending components to dealers (Volvo Cars, 2021). Coupled with the fact mentioned by (ERN, 2016b) that the remanufactured part generally provides higher profit margins compared to the original mounted part can be seen as an incentive for the company to focus even more on remanufacturing. Involving remanufacturing aspects in an early design phase is something that remanufacturing suppliers consider necessary in order to benefit the process even more. Some of the challenges that can be identified in the current remanufacturing process are the growing trend of buying kit solutions and the lack of control over the remanufacturing process (STS AB, personal communication, February 22, 2021).

Today Volvo Cars only renovate according to the latest specifications and guarantee that the remanufactured part must meet quality "as good as new or better" (Strategy and program manager, personal communication, February 24, 2021). This means that Volvo Cars have no second lines or second offers. Compared to other companies that have a system where the customer can choose between a component with properties "as good as a new one" and a component with lower quality at a lower price. This may mean that Volvo Cars does not have the ability to shift its market according to customer needs. Where, among others, it can be difficult to meet the customers who own an older car and do not think it is worth investing in a completely new part. Introducing second offers could mean that the company achieves a more segmented market where the needs of a broader customer group are met.

There are several external factors affecting the progression of CE and remanufacturing at Volvo Cars. A compilation of the PESTEL (Political, Economical, Sociocultural, Technical and Legal) macro factors showed that on the EU level there is much that speaks on the behalf of CE. See Figure 4.4 below. The initiatives such as the circular Action plan and Horizon 2020 will be auspicious for Volvo Cars to keep implementing CE in their business and shift to a circular business (ERN, 2016b; The European Commission, 2020). However, some obstacles are apparent, such as the technology and environmental impact rate is much higher than the legal facet can handle. Beyond this, there is a lot of ambiguity in the current legislation inducted (The European Commission, 2020).

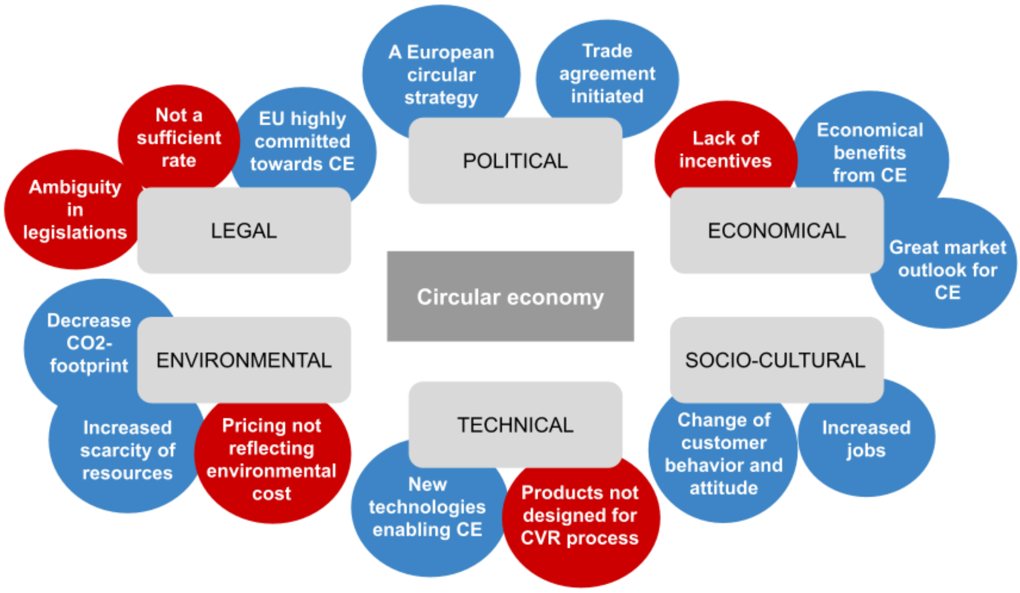

Figure 4.4: Summary of the PESTEL-analysis. Red color represents barriers and blue color the enablers.

4.6 Workshop with industrial expertise within Volvo Cars

Lack of communication was a reoccurring issue that several interviewees pointed out and something that was emphasized in the literature. Together with the theory raised by, among others, Hatcher (2013): That overcoming the communication barrier between remanufacturing and design could lead to products becoming more remanufacturable and suitable to implement in the design process. The Remanufacturing information feedback framework (RIFF) developed by Lindkvist Haziri and Sundin (2020) was considered as a solution to successfully overcoming the potential communications barrier, which has been identified both in the interviews and in the literature. Moreover, it has been suggested that by overcoming the communication barrier, many other related barriers will also be easier to solve (Lindkvist Haziri & Sundin, 2020). Therefore, a workshop together with a number of stakeholders from Volvo Cars was chosen to be conducted. This is to verify whether the aforementioned theoretical framework from the literature could be feasible to implement at Volvo Cars.

4.6.1 Step 1: Mapping of current information flow

This step is the first one in the framework and includes an assessment of the current state with the support of interviews with stakeholders and mapping a rough estimation of current information flow. This was performed prior to executing the workshop and constitute the basis when performing it.

Interviews with stakeholders

Through the interviews, it was confirmed that several stakeholders take part in communication regarding remanufacturing. When the bushing and linking rods are designed, there is no communication and feedback from remanufacturing suppliers to provide fruitful input to R&D whatsoever. Instead, remanufacturing suppliers are involved later in the product life, thus when regarding EOL issues. Here, they communicate with Aftermarket, Service, Remanufacturing, and Procurement at Volvo Cars. The most common issues discussed are price changes, spare part exchange, and delivery information. The development process has been well established and it is defined as an integrated process, including feedback from Manufacturing, Service, Procurement, Full-service supplier, and in the near future Sustainability as well. The most common communication channel is meetings and through various internal programs such as, Car weaver and VPC, which are used to deliver requirements and demands on various aspects of the product. Despite this, information regarding remanufacturing does not reach R&D in time to make adaptions to concepts and design. Knowledge about remanufacturing in the departments of the company is often poor and stays isolated. Currently, there is little structured interaction with remanufacturing suppliers.

The Service department receives information about problems with the machines and malfunctions from manufacturing. Mainly, they have established great contact and relationship with the end customer, retrieving continuous feedback.

Furthermore, the external stakeholders except for the customer/retailer, emphasize the fact that they want to be included more and earlier. They see tremendous benefits for both parts by doing so and believe that it can result in synergies, making remanufacturing aspects more prominent in the products. As pointed out by the majority of stakeholders, the external stakeholders are variables and will change depending on component and platform entailing difficulties to retain a thorough relationship, instead of an arm-length one.

Creation of existing information flow

From the prior mapping of Volvo Cars and the interviews with stakeholders, it was possible to create an overview of the existing information flow at Volvo Cars, as depicted in Figure 4.5 below. This flow was later presented with more in-depth details and verified by involved parties. To make the flow straightforward and avoid cumbersome details, *what* and *when* is being communicated has been deliberately excluded. The blue boxes deem to represent internal stakeholders, and the green boxes the external ones. Further, the thicker arrows are to demonstrate direct communication between key stakeholders, R&D, and Remanufacturing supplier. In addition, Sustainability has been excluded from the figure, due to it permeates all internal stakeholders and it is currently under reconstruction, thus it can not be included with exact precision.

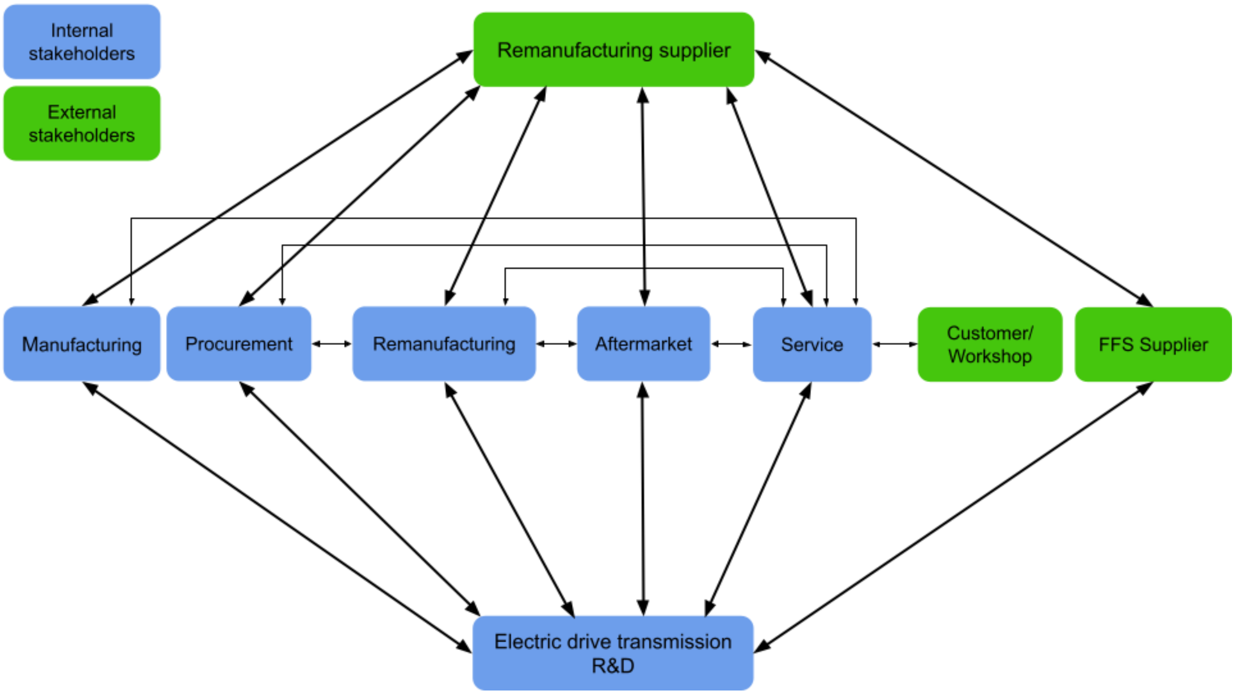

Figure 4.5: Rough estimation of current information flow.

4.6.2 Step 2 - Outlining the future vision

The ten participants in the workshop consisted of design engineers, product owners from design, service representatives, as well as representatives from aftermarket and sustainability. Everyone in the workshop demonstrated an interesting and open-minded approach to the topic and elements presented. The participants contributed well to the workshop and were committed to discussing ideas regarding the topic. All parties got a chance to briefly examine the current information flow depicted in Figure 4.5 and unanimously agreed with the outline.

SWOT-analysis of current information flow

Through compiling the strength, weaknesses, opportunities, and threats of current flow, it will facilitate the discussion and identification of the potential ideal information scenario. During the workshop, the participants concluded in the following SWOT-analysis shown in Figure 4.6 below.

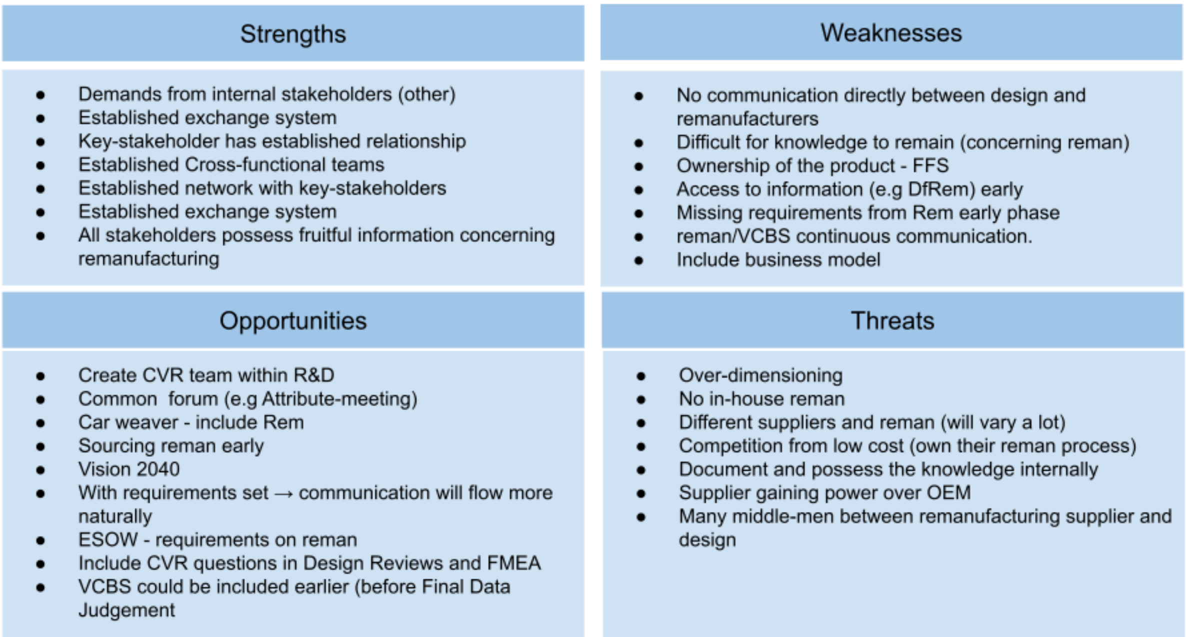

Figure 4.6: Compilation of concluded SWOT-analysis during the workshop.

As shown it resulted in strengths such as there is an established cross-functional team within Volvo Cars with the current flow. Moreover, key stakeholders and networks have been established where communication is currently present, even if it perhaps is not distributed when needed and late in the process.

Further, some of the weaknesses brought up was that there is no direct communication between design and remanufacturing suppliers. An issue with communication is also that the components are of full function service characteristic, implying that access to drawings, bill of material, and other specifications is not necessarily available, instead of in possession of the supplier. It has also been pointed out that the information concerning DfRem is not available early for designers when making harsh rigorous decisions that are irreversible. It is also mentioned that there is a lack of business cases for remanufacturing and it is not included in the current business model, making it difficult to justify the benefits in transitioning towards remanufacturing in design.

The participants concluded in many opportunities. An important opportunity identified was to source remanufacturing suppliers in the early conceptual phase to captivate input from start. Also, a strong driving force is the vision 2040 set by Volvo Cars, and therefore the urgent and interest in changing towards the better is of higher priority than ever before. Moreover, all parties were in concordant that if feedback regarding remanufacturing was retrieved and institutionalized into existing requirement channels, it would evidently naturally streamline the communication.

An aspect brought up was that Volvo Cars does not perform remanufacturing processes in-house, which makes the communication to that facet more complex and difficult to develop a firm relationship, since it depends on suppliers and components. Moreover, an issue brought up in the competitive landscape with other competitors becoming auspicious through already performing in-house remanufacturing. It was also discussed that today there are perhaps too many middle-hands in the communication flow and reconstruction could be necessary to eliminate waste and possible abundances.

Determination of ideal information flow

The ideal scenario was generated with the SWOT-analysis as a basis, through discussion of *what*, *when*, *how* and between *who* the information regarding remanufacturing should be distributed to be optimal. See Table 4.2 below.

Table 4.2: Conclusion on how, what, when and who the information regarding remanufacturing should be distributed in the ideal scenario.

What	How	When	Who
Requirement list and demands	Involve remanufacturing supplier in sourcing process	Early	Design, procurement suppliers and aftermarket
Remanufacturing related issues	Include remanufacturing supplier in existing communication flow	Weekly	Design & Remanufacturing supplier
Knowledge and information exchange regarding remanufacturing process	Conduct Workshops/meet-up regarding remanufacturing	Continuously	Design and Remanufacturing supplier
Documents, files, reports & drawings	Grant access to files and documents	Continuously	All stakeholders
Component value retention related information	Create component value retention team within R&D	Continuously	Design & Volvo Cars Service Business

The new information that was decided included all stakeholders, but the main focus was to increase the communication directly between Design and Remanufacturing supplier, which should be induced early in the concept phase and continuously since it is here the integration of remanufacturing aspects in the design are possible.

With these new conclusions in mind, a few adaptions have proceeded from the previous flow as shown in Figure 4.5. Some flows were considered redundant and were instead merged with other flows. For instance, Service, Aftermarket, and Remanufacturing were clustered and merged together to Volvo Cars Business Service (VCBS), since it became apparent that they work closely together regarding to all issues related to remanufacturing.

Moreover, the ideal information flow can be advanced from what was concluded and has been depicted in Figure 4.7 below. Here, the new information distributed and decided upon is visualized with a light yellow color and the orange box represents when the information is distributed. The letter C refers to continuous feedback, E represents Early feedback in the design process and W refers to weekly communication.

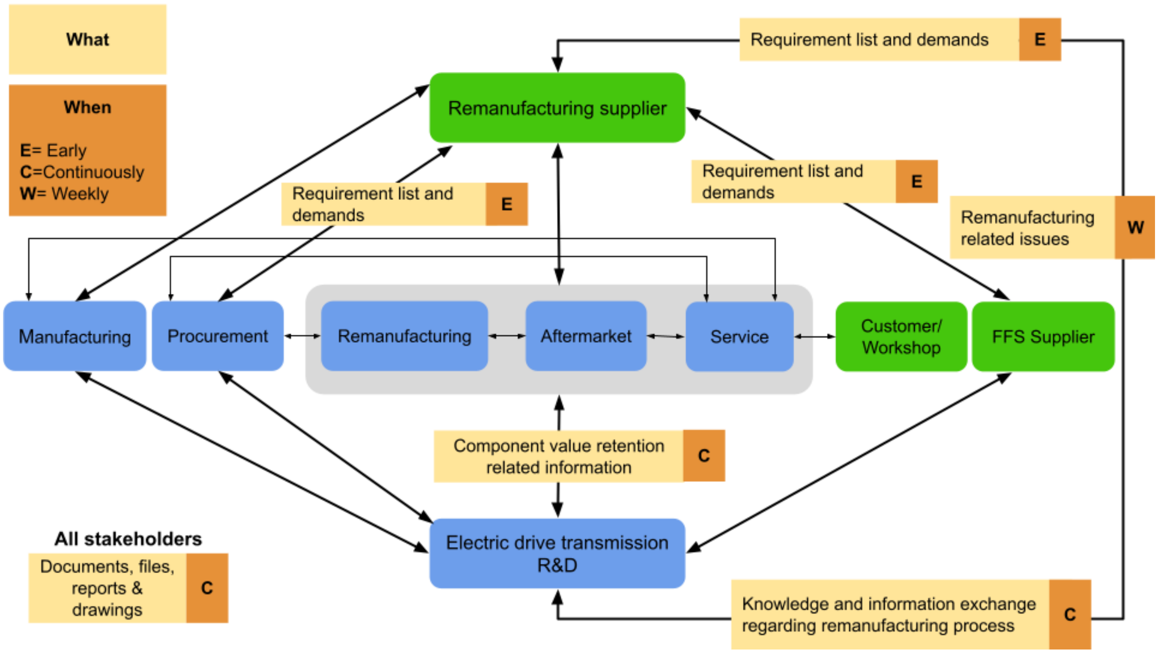

Figure 4.7: The ideal information flow visualizing what and when the information is distributed.

Creation of action plan and prioritization

With the ideal scenario determined, actions to pursue in order to minimize the current gap was generated through discussion, resulting in the following actions:

- Go see and visit the remanufacturing supplier
- Increase knowledge internally and perform workshops
- Guidelines in R&D for component value retention
- Feedback from remanufacturing
- Source remanufacturing supplier early
- Include DfRem in specifications
- Create business cases for remanufacturing
- Remanufacturing representative
- Remanufacturing process in-house

From first sight and in the first selection process, only four actions were chosen to discuss further. These were further investigated regarding dependencies and entered into a feasibility-impact chart to determine the prioritization order to implement the actions, as shown in Figure 4.8 below. To distinguish the selected actions, a red circle is used, further, the eliminated actions are depicted with grayscale color.

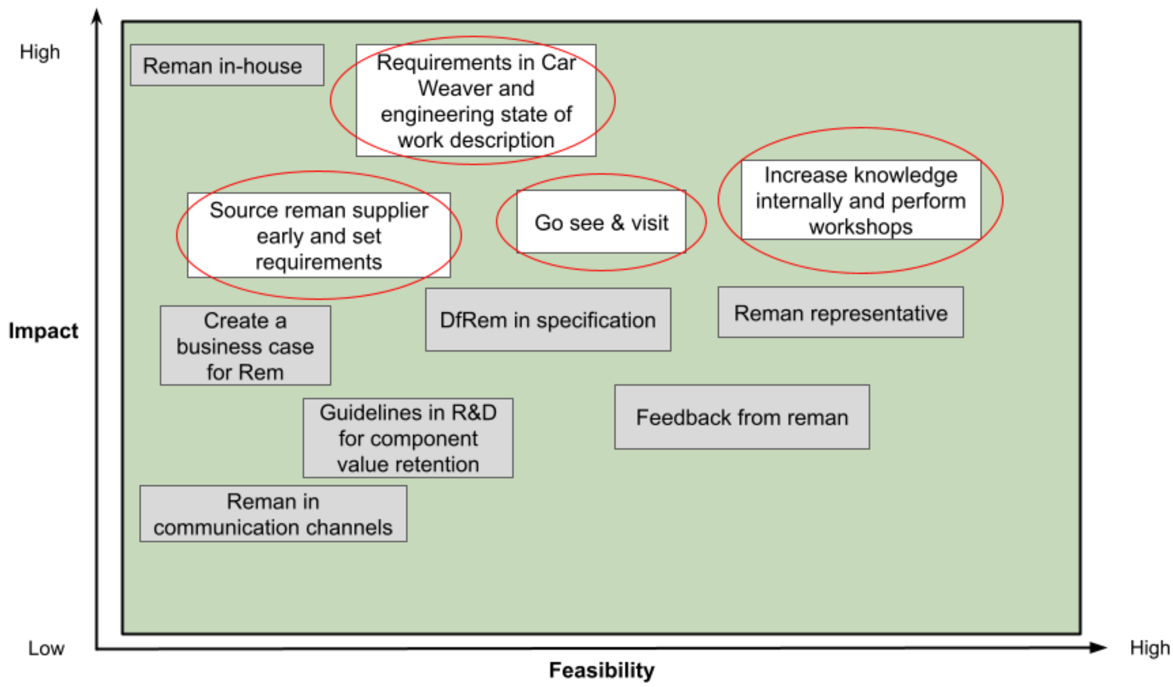

Figure 4.8: The four remaining actions distinguished by red circles and the actions position on the feasibility-impact chart. Y-axis represents impact and x-axis the feasibility.

Based on the positioning in the chart, three actions were picked and prioritized accordingly:

- Increase knowledge internally and perform workshops
- Go see and visit
- Implement requirements in Car weaver and generic engineering state of work descriptions

4.6.3 Feedback on workshop execution from participants

The overall experience in perception of the participants was excellent and exemplary, see Appendix G for detailed extraction of feedback. The vast majority enjoyed the workshop and thought it was a great learning experience. Further, the disposition of time was perceived to be ideal as well as the support from us (the facilitators) perceived to be sufficient. Moreover, after the workshop, several stakeholders explicitly expressed they learned more regarding the internal stakeholders' point of view and what their work encompasses. On the question, if they believe the framework can be useful to implement, the foremost answer was yes.

4.6.4 Practical implications of case component

When the workshop was finalized, a rough comparison of cost and environmental impact was performed in CES EduPack on the case components, encompassing bushing and linking rod. The comparison is between a newly manufactured component and a remanufactured component. With all the necessary data embedded in EduPack, the result showed that remanufacturing decreases cost by 79 percent compared to a completely new product, as shown in Figure 4.9. The yellow bar represents newly produced and the green bar refers to the remanufactured components.

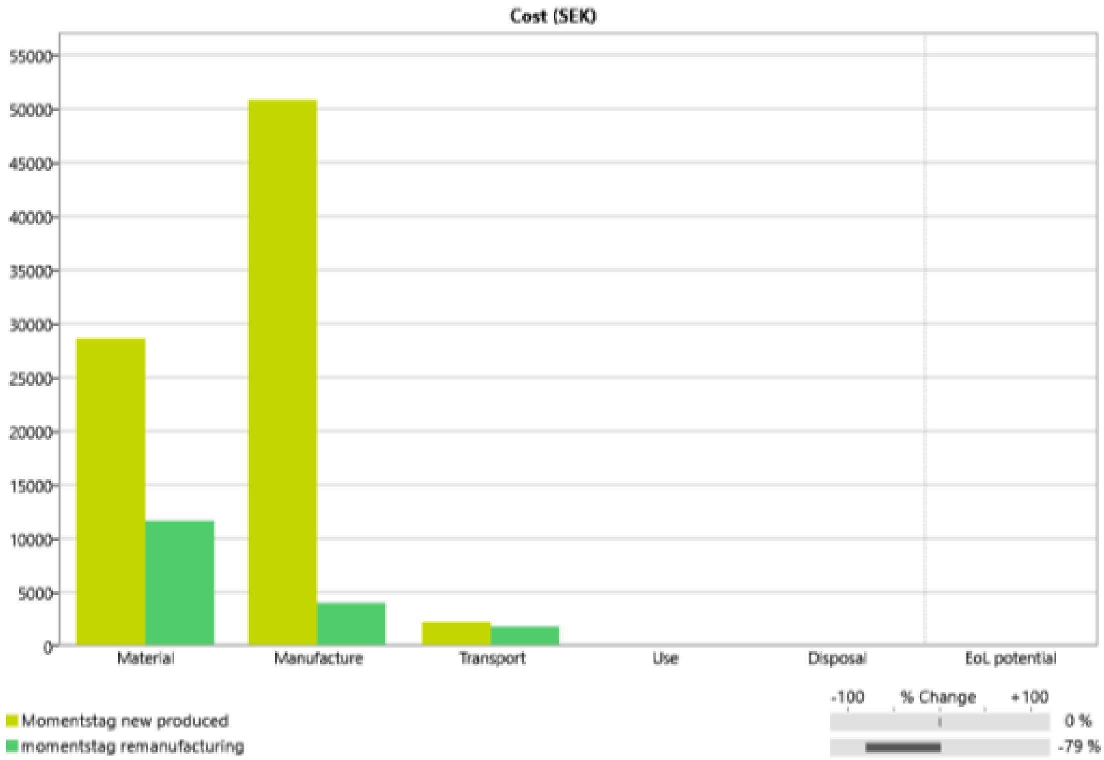

Figure 4.9: Rough comparison of cost between remanufactured and new product of bushing and linking rod.

Further, it showed that remanufactured components will decrease the CO_2-footprint (kg) by 94 percent compared with newly produced products, as depicted in the Figure 4.10 below. The largest difference comes to CO_2-footprint related to material, thus it concerns the early phase of the product life, the extraction of material.

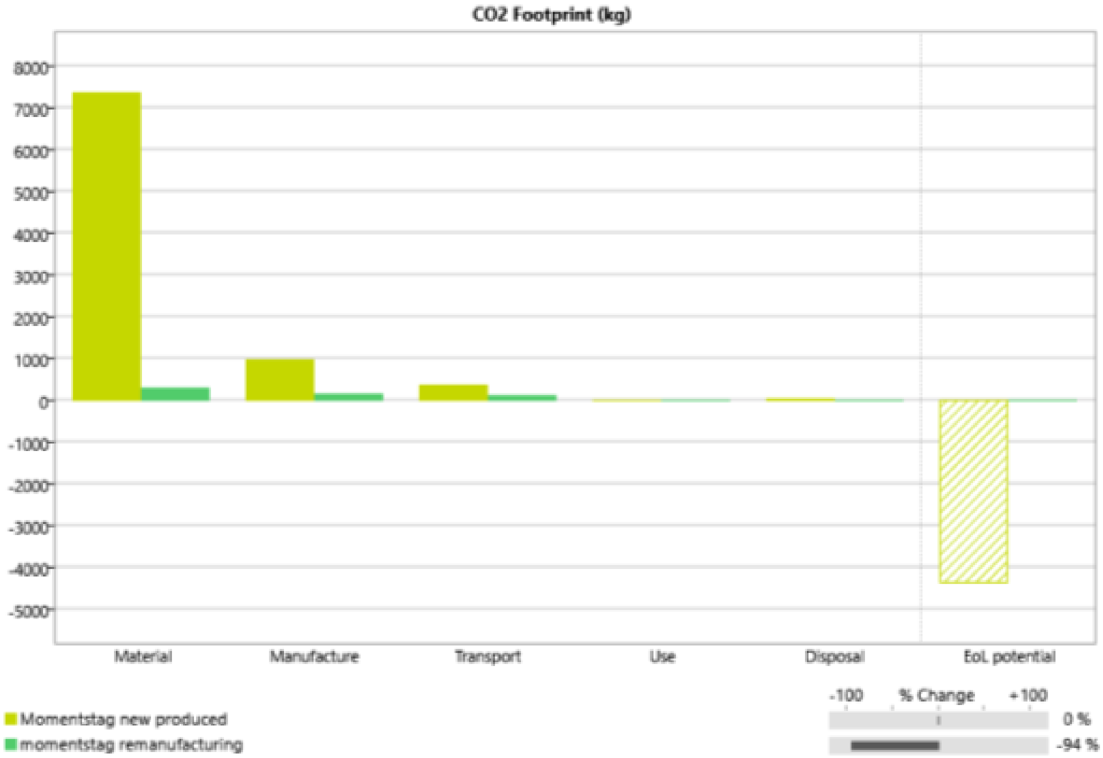

Figure 4.10: Rough comparison of CO_2-footprint between remanufactured and new product of bushing and linking rod.

Nevertheless, the practical implications and rough cost and environmental estimation should be considered with great carefulness, since it is a rough estimation and can be highly deviating from reality. Nevertheless, it can be argued that indication may be somewhat accurate. The most costly phase is evidently to be the manufacturing phase and material phase, as here the greatest difference can be found between newly produced and remanufactured components. In addition, the potential saving of cost and CO_2-footprint, 79 percent respectively 94 percent, are numbers in correlation and within the interval implied from the literature (ERN, 2016b).

5 Discussion

Here, the analysis and overall discussion concerning the project is presented. The general project process and its nature, Circular economy and more specifically remanufacturing and its issue of identifying knowledge gaps are further discussed. Finally, the research questions are addressed and discussed in relation to the findings of this report.

5.1 Discussion of research questions

In this section **RQ1: Enablers and barriers** and **RQ2: Challenges at Volvo Cars** will be discussed. More specifically, potential enablers and barriers to remanufacturing electric transmission components highlighted by the literature and Volvo Cars are being analyzed and discussed. Further, aspects to take into consideration when DfRem is discussed. Beyond this, challenges that may arise with the current remanufacturing strategy at Volvo Cars are also treated.

5.1.1 Closed-loop system

Volvo Cars have a well-established closed-loop system for collecting and retrieving components that are to be remanufactured. This is something that Sundin and Dunback (2013) especially emphasizes and highlights that how the products are collected back to remanufacturers plays a substantial role in the remanufacturing system. The process of collecting the cores is not perceived as a major problem. Instead, the fact that Volvo Cars only remanufacture components to a quality equivalent of *"as good as new or better"* and offer no other alternative, may arguably imply that they lose potentially important customers. By not covering the entire spectrum of customers, they lose those customers who see no point in investing in new components with a lifespan equivalent to a new one in an old car. One may suggest that introducing a second offer, where the customer has the opportunity to choose between a more expensive component but with quality corresponding to a new and a cheaper one with slightly lower quality, would lead to higher demand.

Nevertheless, as of now, Volvo Cars is not willing to compromise their quality assurance to a slightly lower level, since it is correlated with lower safety assurance. One may suggest that Volvo Cars faces a dilemma. Making a trade-off to lower the quality and perhaps jeopardizing the safety perception of the brand and being able to compete for greater market shares with the competitors (Ellen MacArthur Foundation, 2019). Or stay with their current strategy of as good as new or better and only target a specific part of the possible market, but without compromising any perception of the brand. This among others, can be linked to the previously identified challenges in reverse logistics from retailers identified by Lundmark et al. (2009) and companies in the automotive industry. For instance, the uncertainty regarding demand and cumbersome insurance of the core supply, thus storage of large volumes of cores despite the fact that there is still no concrete demand for remanufacturing projects.

On the other hand, Volvo Cars seem to have developed a great deal for suppliers, in order to ensure returning of cores. The deal makes it more profitable for suppliers to return the cores to Volvo Cars when exchanging it for a new part, than if they would not do it (Strategy and program manager, personal communication, February 16, 2021). Furthermore, even though remanufacturing of automotive parts has been carried out for a long time, there still seems to be a great opportunity for companies to increase their market and business growth within it. The remanufacturing market is rather unexplored and there is great opportunity to pioneer and penetrate the market. The forecast is that remanufacturing will be an attractive market with high demand and thus it is not close to saturated (Strategy and program manager, personal communication, February 16, 2021) (Professor at Linköping University, personal communication, February 11, 2021) (Ellen MacArthur Foundation, 2020; ERN, 2016b). Therefore, we believe that the idea mentioned by among others, the strategy and program managers at Volvo cars, to expand remanufacturing processes in-house would be a great opportunity for Volvo Cars to grow even more in the market. In addition, the growing mobility service trend is also a reason for Volvo Cars to focus more on streamlining their remanufacturing processes. As this business shift will entail greater ownership of maintenance services and the company must therefore find a sustainable way of retaining their products mindfully.

A challenge identified within the remanufacturing process is, however, the difficulties in disassembling and accessing parts (Ellen MacArthur Foundation, 2020). The two interviewed remanufacturing suppliers also insisted that disassembling and reassembling are seen as the most difficult and costly operations in the processes. These steps require highly skilled and educated assemblers. This may imply that there is a great challenge to realize an in-house remanufacturing process for Volvo Cars and to find the right staff. In addition to this, it is regarded as a very complex and resource-demanding issue to implement, not done overnight.

Furthermore, the remanufacturing supplier, STS AB (2021), also mentioned that personnel is above all their biggest investment. Who also strongly believe in the integration of remanufacturing aspects in an earlier stage in order to facilitate these steps. The interviewee from the service department at Volvo Cars also highlighted the requirements of technology expertise of remanufacturing within the company as an important factor for improving current work within remanufacturing.

Another challenge identified in the mapping of Volvo Cars is to succeed in motivating and convincing people to a change in the current business model. Above all, one of the difficulties that underlie this is the large and extensive network of suppliers that Volvo Cars has built today (Director of Sustainability, personal communication, May 15, 2021). Today, Volvo Cars collaborate with several external suppliers both in the early concept/design phase and in remanufacturing. One consequence of this is that they lose control of certain parts of their business. The lack of ownership and control over all processes and products can be argued to negatively affect the company's work towards a more circular business. As a result of this, Volvo Cars may lack access to important information regarding the components and products that could support the company to be auspicious in various value-retention processes that exist today. Moreover, in the literature and in the conducted interviews with remanufacturing companies, the integration of remanufacturing aspects in the early design phase was considered to be a crucial factor for a company to be able to achieve a higher level of remanufacturability (BORG Automotive AB, personal communication, May 23, 2021; STS AB, personal communication, February 21, 2021).

Furthermore, today Volvo Cars uses a lot of full-service supplier components, it can therefore be argued that Volvo Cars' ability to integrate remanufacturing at an early design stage is negatively affected. This is due to a lack of important information regarding product design as touched upon earlier. Therefore, we believe that ownership of all products and processes would mean that Volvo Cars can control and influence their business model to become even more circular. In addition, the choice to move more engineering activities and processes internally could have saved the company time. By managing this internally, would imply that the extensive network of suppliers that Volvo Cars has today had decreased and perhaps also reduced some of the administrative work that is performed today. The sharing of information could also be made more transparent, since in that case information only needs to be shared within the company.

It can be argued that this will require immense resources to possess everything within the firm. A different trajectory to pursue is to change the requirements in the sourcing process of suppliers. By emphasizing the importance of suppliers to be aligned with the same vision as Volvo Cars when it comes to sustainability and putting pressure on the suppliers, it can perhaps be solved, without adding more resources to the process.

5.1.2 Communication

As mentioned before, a clear definition of the concept of CE does not exist. In the literature, it is presented as a collection of widespread definitions that vary depending on the industry and its context. Even within Volvo Cars, there does not seem to be a clear definition of CE, but instead, the company chooses to describe it in a number of goals and actions to be pursued within the company (Director of Sustainability, personal communication, Mars 5, 2021). The goals that Volvo Cars has set within CE are described at an overall level but not translated and applied at all levels. One may argue that this can make it difficult for many employees to understand how they can contribute to the company's vision of becoming a more circular business in practice. Further, Volvo Cars' measurement tools of CE appear to be of more strategic and generic level. They utilize the Circulytics measurement tool presented by Ellen MacArthur Foundation to measure circularity (Ellen MacArthur Foundation, 2020). The company has begun greater work in trying to concretize and adapt the goals at lower levels. However, this work will not be instituted overnight or be easy to implement, given the size and complexity of the company. Instead, it is suggested that this should be approached mindfully and be a long-term installation and reform.

Furthermore, both in the interviews conducted and in the literature, a prominent issue has been identified. The fact that there is a lack of feedback between design and the remanufacturing supplier. According to the literature, this often originates from the lack of feedback systems and communication in the supply chain, since remanufacturing and design are carried out in isolation from each other by two different companies (Lindkvist Haziri & Sundin, 2020; Casper & Sundin, 2020). This underpins the theory that Volvo Cars would have benefited positively from greater ownership of products and processes.

On the other hand, there is no clear evidence that greater ownership of components and processes would mean that the communication barrier between designers and manufacturers would be completely overcome. Volvo Cars are still in itself a large company with a large complex flow of information. However, we considered that testing RIFF would help the company identify potential improvements in the flow of information both internally and externally. Therefore, it could have been auxiliary no matter how the ownership of processes and products is designed. See Section 5.2, for a deeper discussion about the workshop and testing of the framework.

5.1.3 Product design

Today Volvo Cars' electric transmission components are for the most part designed with a linear economy approach. Yet, the components at Volvo Cars have been regarded as compatible for remanufacturing in several aspects. Aligned with the literature, the components possess properties such as high-quality, slow-paced technology development which indicates a high level of remanufacturability (Linder & Williander, 2017; Vogtlander et al., 2017). Further, there is room for improvement in the design of the products. To obtain more DfRem influencing the products Zhang et al. (2021) refers to technical, economical, and environmental aspects to include in the design. These aspects become useful for the technical complexity level of Volvo Cars' transmission components, making it feasible to evaluate and increase the remanufacturability. The technical aspects refer to aspects such as compatibility to go through the various steps in remanufacturing process. For instance, disassembly (no welded or riveted parts), durable material selection, and accessibility of components. The economic feasibility and aspect concerns that it must be cost-efficient and profitable to perform a remanufacturing project, thus a business case to verify this is a necessity. Last but not least, the environmental aspect refers to a life cycle assessment which should result in decreased environmental impact for remanufacturing than newly produced components.

However, currently, it appears to be difficult to evaluate economic and environmental feasibility with high accuracy. Moreover, with increasing the remanufacturability of the components, a risk of interfering with the functionality of the components occurs. Hence, a trade-off between functionality and remanufacturability is *de facto*. For instance, the behavior of the various parts in case of collision must not be manipulated and thereof, caution with design changes need to be taken, thus the safety of passengers may be compromised (Propulsion system architect, personal contact, May 15, 2021). It can therefore be assumed that there are limitations with current design and complexity when it comes to constraints that can not be manipulated in order to change the current design features.

Nevertheless, it has been adduced that there is room in the product development process to make changes as well as include more circular processes in all the departments at Volvo Cars, facilitating circular prominence in the components. In addition, the remanufacturing supplier STS AB highlights the same conclusion and it has been hallmarked by all parties as well (STS AB, personal communication, February 21, 2021).

5.1.4 Business norm

Even though Volvo Cars is currently working in a linear economic model, CE has recently become of greater interest and priority (Director of Sustainability, personal communication, May 6, 2021). The transition from linear to circular business has certainly begun and it can be hallmarked by increased engagement shown internally from all levels in the company. Nevertheless, as mentioned in the literature it is resource-demanding to make a transition of this magnitude. One obstacle that has been identified is the fact that the knowledge level of CE varies a lot in the company and in some cases missing. This is further suggested to be regarded with high priority and ensure the knowledge to be distributed and easily accessible for everyone. Since employees tend to change positions it can be suggested to be of utmost importance to ensure the information stays and is documented, instead of dispersed. This to ensure everyone is moving in the same direction, which is vital for the change to take place (Ghisellini et al., 2016; Lüdeke-Freund et al., 2019). Moreover, it can be argued to overcome these obstacles, a direct benefit for remanufacturing and

CE should be presented and calculated, to have more momentum and convincing arguments to emphasize the issue more than previously.

5.2 Discussion of workshop

In this section the overall performance and result of the various steps are discussed as well as reflected upon.

5.2.1 Workshop results

The interviewees whom also participated in the workshop were employees of various technical level, hence the discussions and information retrieved from the interviews fluctuated in a technical level. Therefore, some stakeholders were easier to grasp and elucidate than others. Some stakeholders had a more holistic point of view, however, with several different stakeholders combined, the rough estimation of information was perceived as accurate enough, see Figure 4.5 in Section 4.5. This was also confirmed and verified by the participants. Furthermore, the intention was to illustrate the flow in a straightforward manner, thus everyone should understand it and thereof, ease the identification of improvement areas.

When the SWOT-analysis of current information flow were performed, the participants generated many fruitful propositions. Some of them were overlapping with the propositions mentioned in the literature and suggested by the authors as well. One may argue that there are general aspects and obvious ones which may be ubiquitous and prominent in almost every information flow, no matter what setting. For instance, a proposition that was overlapping was *access to information early* as well as *difficult for knowledge to remain or be documented*. These are generic well-recognized issues related to information flow (Lindkvist Haziri & Sundin, 2020). Beyond this, issues specifically connected to this flow and the company Volvo Cars were generated by the participants and did not get addressed in the literature nor by the authors. These propositions generated solely by the participants can be found in Figure 5.1 below.

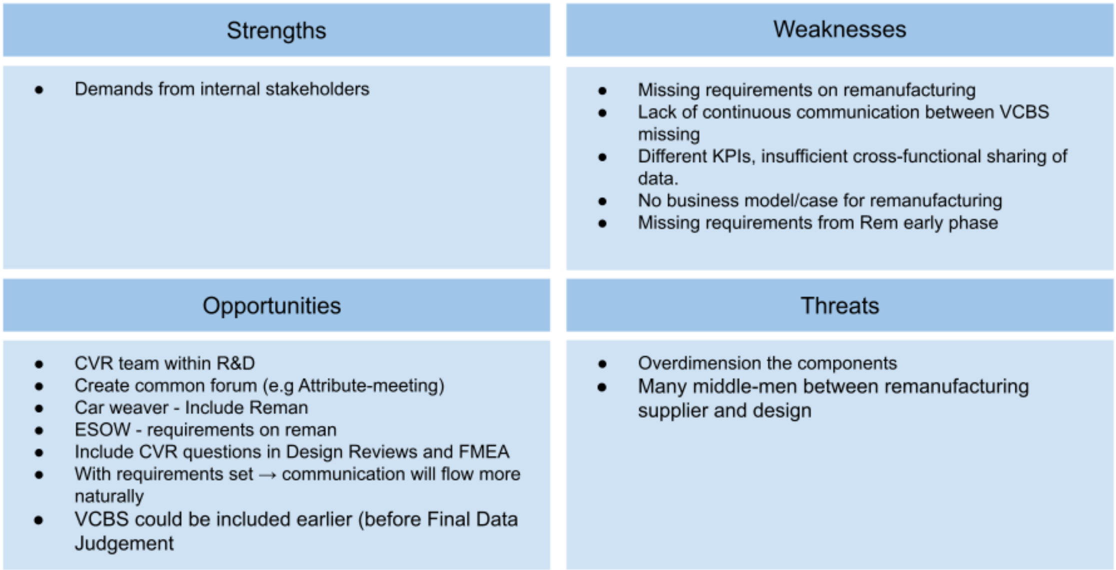

Figure 5.1: The propositions solely generated by the participants during the workshop.

Further, the result of how, what, when, and to who the information should be distributed in an ideal scenario were based on the SWOT-analysis and thorough discussion. One may argue that the result from this step should be regarded with prudence since it was concluded upon within a short period of time. Moreover, some of the propositions are highly dependent on another before it could be possible to proceed with. For instance, *Involve remanufacturing supplier in the sourcing process* is a prerequisite step to *Include remanufacturing supplier in the existing communication flow*. It can be argued that these propositions are highly relevant to overcome the identified issues and are linked to the main barrier, which in this case is direct and early communication between design and remanufacturing supplier. This indicates that the participants have understood the main issue and thereof emphasizing appropriate information flow in the ideal scenario, as shown in Figure 4.7 in Section 4.6.2.

The actions generated to advance on and decrease the current gap to the ideal scenario were aligned with what the participants have concluded upon from the ideal scenario. See Table 5.1 below for how the actions are connected to what was concluded upon earlier. In addition, some actions were generated in further discussion during the workshop, these are:

- Requirements in Car Weaver and engineering state of work description
- Create a business case for remanufacturing
- DfRem in specifications
- Guidelines in R&D for component value retention

Table 5.1: Derived actions and their link to what, how, when and to who the information regarding remanufacturing was concluded to be distributed in the ideal scenario.

What	How	When	Who	Actions
Requirement list and demands	Consider remanufacturing supplier in sourcing process	Early	Design, procurement suppliers and aftermarket	Source Remanufacturing supplier early
Remanufacturing related issues	Include remanufacturing supplier in existing communication flow	Weekly	Design & Remanufacturing supplier	Include Remanufacturing supplier in communication channels
Knowledge and information exchange regarding remanufacturing process	Conduct Workshops/meet-up regarding remanufacturing	Continuously	Design and Remanufacturing supplier	Increase knowledge internally by performing workshops & Go see and visit
Documents, files, reports & drawings	Grant access to files and documents	Continuously	All stakeholders	Remanufacturing in-house
Component value retention related information	Designated team within R&D	Continuously	Design & Volvo Cars Service Business	Remanufacturing representative & Component value retention team within R&D

To be noted is that towards the end of the workshop, time was running out, hence the final steps of prioritizing and picking actions were accelerated and may or may not have affected the outcome. Nevertheless, the three actions proceeded with can arguably be perceived as valuable and aligned with what the authors had in mind. These actions are also considered to be feasible to implement and follows the intended trajectory to increase feedback from remanufacturing supplier to design. Two of the actions, the *workshop session* and *Go see and visit* are overlapping with actions suggested from the literature (Lindkvist Haziri & Sundin, 2020). This further implies that Volvo Cars' information flow regarding remanufacturing faces similar challenges to automotive companies addressed in the literature. The last action decided upon *Implement requirements in Cars Weaver and engineering state of work description* is depending on the other two actions, hence it would not be possible to initiate before the other two have been fully implemented and evaluated. It should be taken into consideration that whether these actions will increase DfRem and improve the feedback will not be possible to determine at this stage. Instead, it can only be evaluated during and after completion of all the following steps presented in the framework RIFF.

5.3 Discussion of methodology

The scope of this project has been revised as the project progressed, mainly due to the access of data has been limited. The authors noticed quite early in the project the difficulty of accessing information from competing companies, which made it difficult to conduct a high-quality competitor analysis. Therefore, objectives and research questions have been adapted accordingly.

Additionally, the way to tackle this project has changed as the project progressed. The initial idea of this project was to develop a guideline aimed at helping engineers designing components more adapted for remanufacturing. This idea has been revised because areas of improvement were found on an overall level, considered as a basic prerequisite for being able to improve on a lower level. This ultimately led to the project's results being directed at a more general level than what was originally intended.

Moreover, the major challenges faced in this project have been mainly the ongoing pandemic, where we have been unable to conduct interviews and workshops on-site to a greater extent. As previously mentioned in section 5.2 we believe that the workshop would have given a more fruitful result if it could have been carried out on site.

In addition, the time frame for the project has been very limited in terms of how extensive the subject of CE is and how complex the company structure of Volvo Cars is. This resulted in a time-consuming process of collecting data in the exploratory phase, limiting the scope of the project. A major obstacle for this project was to reach out and find the right people in the extremely large complex organization. Many employees have shown a great interest in this project and in the subject of Circular Economy, but it has been very difficult to identify which stakeholders possess the information we requested to complete this project.

5.3.1 The legitimacy of the Exploratory phase

In this section, the legitimacy of gathered data during the Exploratory phase is being discussed. This was mainly performed by the literature review and performed interviews and intranet during the mapping of Volvo Cars.

Legitimacy of literature review

Patel and Davidson (2011) adduces the importance of source criticism. Further, they argue that it is of utmost importance to ask questions such as; "under what circumstances was the paper done?" and "what purpose did the author have when releasing the paper?" when evaluating literature.

Aligned with Patel and Davidson (2011), the used literature was carefully reviewed and had a source-critical and objective approach through thorough discussions. Since several authors shared the same conclusions and due to the authors' level of expertise and experience within the subject, the literature was evidently considered to obtain a sufficient level of trustworthiness. Nevertheless, due to limited time as mentioned in the delimitation, see Chapter 1.2, this will impact the legitimacy of the literature (Patel & Davidson, 2011). Further, this may also affect the amount of information gathered in this study. Therefore, emphasis was on reputable prominent articles with a high level of cross-reference and relevance to the topics. Beyond this, predefined criteria were set to eliminate literature in an early stage. For instance, literature published prior to the year 2005 was immediately dismissed to target up-to-date state-of-the-art literature within the field.

Legitimacy of Mapping of Volvo Cars
To ensure that the information examined at the Volvo Cars intranet was trustworthy, the authors were contacted to understand more about the information in its context and to identify the first-hand source. Furthermore, we aimed to find several sources of information to gain a diverse and holistic view taking several standpoints into consideration. This was evidently not always the case, thus the authors' background was instead taken into consideration. Moreover, some sensitive information was difficult to be accessed and thereof, other parts of the intranet were examined to find similar information. It should be taken into account that the majority of the sources were second-hand sources interpreted by Volvo Cars employees and created on such a basis. Therefore, the information was approached with caution to avoid bias statements.

Since the interviews were performed mostly of semi-structured characters, it was possible to capture some of the recipients' personal thoughts (Denscombe, 2014). One may argue that this gives an implication if underlying information exists that may not be documented or found at first sight. Further, the interviewees had various technical backgrounds and belonged to different departments across Volvo Cars. This with the purpose to find similarities and differences in their perception. To ensure the information was not lost or lose fruitful insight, the interviews were recorded. This allowed for focus entirely on the discussion and smooth execution. In addition, the interviewee always retrieved the interview guide beforehand to avoid misinterpretations and have the opportunity to prepare. In retrospect, it can be suggested that this resulted in the information being more accurate and streamlining the performance and transcription.

5.3.2 Workshop performance

All the participants in the workshop demonstrated great interest in the topics and elements presented. Everyone was committed before and during the session, providing fruitful insight from their perspective, leading to interesting discussions in breakout rooms and the main session. The flow of the workshop was considered to be well-balanced in terms of logic, also the participants did not express any issues of comprehending the different steps. Each task was considered to be understandable and easy to grasp, however, this can be difficult to determine since we, the authors will most likely have a greater understanding of each elements included. Nevertheless, the workshop was tested on two students to test perform each task to evaluate the difficulty prior to the actual workshop. The visualization tools and mediating tools were concluded to make it considerably easy to visualize and conduct each task to solve the issues at hand.

The case components used in the workshop were considered to be suitable in terms of information available, complexity, and its being acquaintance with the stakeholders. The participants are in contact with the bushing and linking rod on a daily basis, thus they were considered to have ease of relating to issues regarding the components. One may argue that having more time would perhaps give the opportunity to make a more thorough analysis of the components and more effort put into including a business case. Instead within the set time frame, a rough estimation of cost and environmental comparison was deemed to be sufficient and still valid.

Due to the ongoing pandemic, the workshop had to be performed remotely. Despite the fact that the mediating tools were useful and the workshop went well, the result may or may not have been different if it had been conducted in person. In hindsight, some difficulties arise with performing the workshop on a digital platform. For instance, the body language of the participants is not possible to detect and understand, the threshold of reaching out if something is unclear gets higher, as well as increased chance of misinterpretations. Moreover, performing the workshop physically, could ease the use of the backcasting method and go back in the various steps obtaining a more holistic view than during a digital live session.

In retrospect, to make the workshop more reliable and in-depth, more stakeholders could have been involved, taking more diverse aspects into account. Furthermore, the participants had a variety of technical backgrounds and including more diverse employees, it could have led to discussions of higher quality. One may also wonder how the workshop outcome would have been if it included the whole RIFF framework and thereof, the last two steps as well. Due to limited time, this was not possible to include and should therefore be recommended for future development and verification. Moreover, in this case, the workshop was conducted with the prospect of full-service supplier components. One may argue that the overall discussion would have differed if it was performed from the point of view of build to print instead of full-service supplier. The information flow would conceivably have been different, likewise the outcome and action plans. Thus, this would be interesting to compare the different cases to find similarities and differences to conclude on the most favorable option.

5.3.3 Ethical dilemma

First, since the master's thesis was conducted with an industrial company, Volvo Cars, the thesis was written with the premise of a confidentiality agreement signed by the authors. Consequently, not all the information gathered could potentially be published and included, thus it deems to limit what this paper contributes for the public to access.

Secondly, a possible conflict emerges with the objectives between the authors and the industrial company, where requirements need to be satisfactory at the university simultaneously. One may argue that this could affect the authors' capability of remaining unbiased in their thinking and approach. Nevertheless, the authors' were granted the freedom of choice within the field of CE and decide upon the research path to pursue, hence great freedom was the nature in conducting the study.

Thirdly, another ethical dilemma arises with this topic approached in the study. Claiming to introduce new more environmentally friendly components feasible to remanufacture and becoming the leader in sustainability within its industry. This may be argued that it can not be certain how much the company will initiate on CE and remanufacturing in the future prospect work, thus how this information in this study will be used is yet to be determined. One may suggest that the lucrative nature of Volvo Cars' business today may be interfering and limiting incentives to improve the environmental aspects. Further, it may also affect the current function and values, such as safety, thus a trade-off and stagnation point might been reached.

6

Conclusion and recommendations

In this chapter, the aim, objectives, and research questions are answered, presenting the outcome and overall conclusion. Further, this is followed and concluded with recommendations for future work and development is presented.

6.1 Conclusion

This thesis aimed to provide knowledge for industrial processes that support Volvo Cars in designing electric passenger car components for remanufacturing. This will further provide an action plan for the R&D unit, wherein the process of remanufacturing Volvo Cars can improve to work towards a more circular mindset. There were a lot of viewpoints to take into consideration. The conclusion of the thesis will be in correlation to what degree the objectives of the report have been fulfilled. Objective 1 "Establish the current level of knowledge on remanufacturing of components by reviewing scientific literature on circularity in the automotive industry" was achieved with the Literature review in Chapter 2. Secondly, the Objective 2 "Identify external and internal factors enabling and obstructing remanufacturing of components in the automotive industry by performing interviews with stakeholders and PESTEL-analysis." was fulfilled in Chapter 5 which derived from a combination of Chapter 2 and Chapter 4. Finally, the Objective 3 "Understand how these factors can be approached to create an action plan for how Volvo Cars can work towards a more circular business." which builds on Objective 2, is deemed to be fulfilled through the outcome of the performed workshop in Chapter 5. This was based on a conclusion of Chapter 2 and Chapter 4. However, it requires extensive validation to definite determine if the Objective 3 has been properly fulfilled, which is beyond the time frame of this paper.

As a result of answering **RQ1 Enablers and barriers**: "*What are the potential enablers and barriers to remanufacturing the electric transmission components in a circular economy context? And what aspect to take into consideration with components when designing for remanufacturing?*" the main enablers and barriers concluded upon are presented in Figure 6.1below. In addition, the three main aspects to be taken into consideration when designing for remanufacturing were concluded to be technical, economical, and environmental, see Section 5.2 for in-depth discussion.

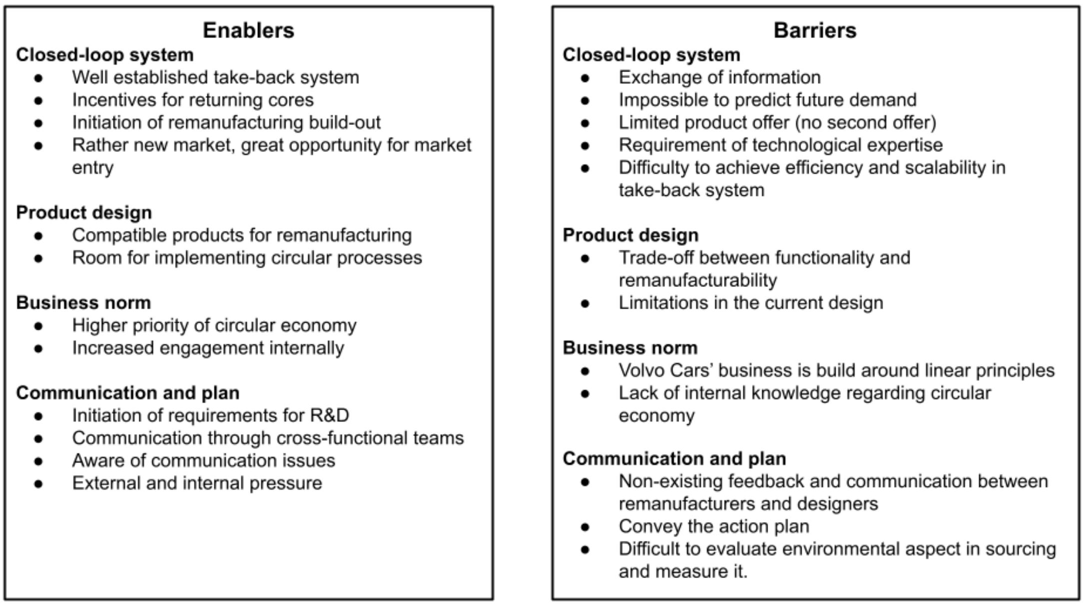

Figure 6.1: The main concluded enablers and barriers to remanufacture electric transmission components.

By answering **RQ2 Challenges at Volvo Cars:** *What are the challenges Volvo Cars faces with the current remanufacturing strategy for vehicles?* it was possible to conclude upon challenges. Firstly, the remanufacturing process at Volvo Cars, mainly performed with the help of external stakeholders is regarded as a challenge. This due to ownership of the products are neglected from Volvo Cars' possession, hence control and knowledge are decreased. Further, the issue with not pursuing a second offer, thus adhere to "as good as new or better" may be an unfavorable trajectory, since a lot of market shares are forfeited.

Secondly, it was concluded that the information flow regarding remanufacturing was one of the most complex and important challenges the company faces. In conclusion, by overcoming this challenge, many other ones would also evidently be solved. Therefore, an action plan was concluded to support Volvo Cars and the R&D unit, wherein the process to improve. These actions to be pursued first are:

1. Increase knowledge internally and perform workshops
2. Go see and visit remanufacturing suppliers
3. Implement requirements in Car Weaver and generic engineering state of work descriptions.

Thirdly, today Volvo Cars is still operating on linear processes, thus their products are of linear nature. This transition towards a circular business is of great magnitude and complexity to accomplish. Further, a sub-goal in this reconstruction is to find a sustainable way of measuring circularity and remanufacturing on the sub-level, which is not available today. Further, in this transition that has initiated towards a circular business, one must ensure not to compromise the safety and functionality, thus be prepared for trade-offs, since it is evident inevitable.

Research contribution

Through the insights gained within this master's thesis, there is an opportunity for new studies to be conducted within the company. It can be concluded that the information flow is the fundamentally underlying factor to overcome barriers within remanufacturing, consequently, it must be taken into account with the highest priority. Parameters within the information flow which was concluded to be of significant importance was **how**, **what**, **when** and to/from **who** the information is distributed, and should therefore be inquired into, see Table 5.1. Ultimately, a conclusion worth emphasizing, is that there is no silver bullet and generally applicable best way of improving the information flow for remanufacturing. Too many variables and circumstances needs to be taken into account. Therefore, the approach should be adapted to each company's situation and circumstances, thus finding the best way specifically for their case. However, the overall goal remains the same, to reduce the complexity and obtain direct communication at the right time. How this is achieved will vary greatly for companies.

Recommendations for future development

There are four avenues worthy of further exploration. Firstly, to carry out the remaining steps of the Remanufacturing Information Feedback Framework (RIFF) and evaluate if it resulted in increased DfRem.

Secondly, Explore the opportunities to implement in-house remanufacturing processes. This can suggestively be initiated by test the framework for a case where build-to-print is regarded instead of full-service supplier and evaluate the outcome.

Thirdly, develop a business case for remanufacturing components to support the work towards reaching the stated sustainability goals and visions at Volvo Cars.

Fourthly, and last, create guidelines regarding remanufacturing for different work layers within the company, to facilitate the work of designing and developing components for remanufacturing.

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Appendix

A Compiled literature data spreadsheet

A draft of the compiled literature data spreadsheet.

Author 1	Author 2	Author 3	Publication title	Year	Type	Type
Circular economy						
Michael Sadani	Bernard Yannou	Yann Leroy	Heavy vehicles on the road towards the circular economy: Analysis and comparison with the automotive industry	2018	Journal	Article
A. Buruzs	A. Torma		A review on the Outlook of the Circular Econoy in the Automotive Industry	2017	Journal	Article
Julian Kirchherr	Denise Reike	Marko Hekkert	Conceptializing the circular economy: An analysis of 114 definitons	2017	Journal	Article
Fenna Blomsma	Geraldine Brennen		The Emergence of Circular Economy: A New Framing Around Prolonging Resource Productivity	2017	Journal	Article
Walter R.Stahel			The circular economy	2016	Journal	Article
Jouni Korhonen	Antero Honkasalo	Jyri Seppälä	Circular Economy: The concept and its Limitations	2018	Journal	Article
European Commission			Circular Economy Action Plan:For a cöeaner and more competitive Europe	2020	Report	Report
Walter R. Stahel	Ellen MacArthur		The Circular Economy: A User's Guide	2019	E-book	E-book
Fuli Zhou	Panpan Ma		End-of-Life Vehicle (ELV) Recycling Management Practice Based on 4R Procedure	2019	Journal	Conference pape
Laura C.	Aguilar Esteva	Akshat Kasliwal	Circular economy framework for automobiles: Closing energy and material loops	2020	Journal	Article
Jihong Yan	Chunhoa Feng		Sustainable design-oriented product modularity combined with 6R concept: a case study of rotor laboratory bench	2013	Journal	Article
Bocken, N. M. P	C. Bakker	I. de Pauw	Product design and business model strategies for a circular economy	2015	Conference	Article
den Hollander, M.C.,	Bakker, C.A	Hultink, E.J.	Product Design in a Circular Economy: Development of a Typology of Key Concepts and Terms.	2017	Journal	Article
Lüdeke-Freund, F.	Gold, S	Bocken, N.M.P	A Review and Typology of Circular Economy Business Model Patterns	2019	Journal	Article
Nancy M. P. Bocken	Elsa A. Olivetti	Jonathan M. Cullen	Taking the Circularity to the Next Level: A Special Issue on the Circular Economy	2017	Journal	Article
Peter Hopkinson	Markus Zils	Philip Hawkins	Managing a Complex Global Circular Economy Business Model: Opportunities and Challenges	2018	Journal	Research article
Linder, M.,	Williander, M		Circular Business Model Innovation: Inherent Uncertainties. Business Strategy and the Environmen	2017	Journal	Article
Ellen MacArthur Foundation			Circular economy	2020	Web page	Article
Geissdoerfer, Martin	Paulo Savaget	Nancy M.P. Bocken	The Circular Economy – A New Sustainability Paradigm?	2017	Journal	Article
Remanufacturing						
Erik Sundin	Casper		Electrification in the automotive industry: effects in remanufacturing	2020	Journal	Article
Vogtlander, J.G.	Scheepens, A.E	Bocken, N.M.P.,	Combined analyses of costs, market value and eco-costs in circular business models: eco-efficient value creation in remanufacturing.	2017	Journal	Article
Lindkvist Haziri, L.	Sundin, E.		Supporting design for remanufacturing - A framework for implementing information feedback from remanufacturing to product design.	2019	Journal	Article
Nancy M. P. Bocken			Remanufacturability evaluation of end-of-life products considering technology, economy and environment: A review	2021	Journal	Article
J. Groenewald	James Marco	Nicholas Higgins	In-Service EV Battery Life Extension Through Feasible Remanufacturing	2016	Exhibition	Article
Xiufen zhang	Shuyou Zhang	Lichun Zhang	Identification of product's design characteristics for remanufacturing using failure modes feedback	2019	Journal	Article
Xiufen zhang	Shuyou Zhang	Lichun Zhang	Product design characteristics for remanufacturing in automotive industry.	2018	Journal	Article
Fabrice matheuix	Daniel Forelich	Pierre Moszkowicz	ReSICLED: a new recovery-conscious design method for complex products based on a multicriter	2009	Journal	Article
Peter Hopkinson	Markus Zils	Philip Hawkins	Managing a Complex Global Circular Economy Business Model: Opportunities and Challenges	2018	Journal	Article
N.Z. Nasr			Redefining Value- The remanufacturing revolution	2019	Journal	Article
Ramyani Roy	K. E. K. Vimal		Development of a Framework Model to Explore the Remanufacturing Feasibility of Automotive Components	2019	Journal	Article
Vishal Fegade	AV Kale	R.L Shrivatsava	Design for Remanufacturing: Methods and their Approaches	2015	Journal	Article
Casper Grey			Remanufacturing and product design - Designing for seventh generation	2007	Journal	Article
Patricia Van Loon			Assessing the economic and environmental impact of remanufacturing: a decision support tool for	2018	Journal	Article

Figure A.1: Phase two, the Explanatory phase.

B Interview guide regarding information flow

To what departments/stakeholders do you communicate within Volvo Cars regarding design and remanufacturing?

What information does design (Electric Drive Transmission) receive from you?

What economical, technical and environmental information regarding the component do you transfer/request?

Does the information go through any other stakeholders or is it direct communication with design?

How is the information transferred?

How is the information used?

What is the most important information transferred?

What information do you retrieve regarding design and remanufacturing? and from who?

When in the process do they receive the information? (when in the design process)

In addition, what information could be useful for designers to receive from you?

What are the most important requirements design has to include regarding purchasing?

C Interview guide for Sustainability center at Volvo Cars

Vad är cirkulär ekonomi för dig?

Vad är Volvos definition på cirkulär ekonomi?

Hur cirkulära är Volvo Cars idag? Och hur mäts det?

2040-Vision, vad är strategin bakom det?

Hur jobbar ni med remanufacturing för att uppnå 2040-målet?

Hur fungerar remanufacturing processen idag och var finns det förbättringspotential?

Vad är de främsta återgärder idag som Volvo Cars görs idag som gör företaget mer cirkulärt?

Vad är det största utmaningarna Volvo Cars står inför när det gäller cirkulär ekonomi? (externa och interna)

Hur kommer kunden gynnas av att Volvo Cars blir mer Cirkulärt?

Hur ser ert samarbete ut med övriga avdelningar på Volvo Cars? Vilka har ni främst kontakt med? Vilka hade ni behövt ha mer kontakt med och varför gällande cirkulär ekonomi?

Hur ser er kontakt ut med de som sitter inom R&D och mer specifikt Electric Drive Transmission? Vilken typ av information delas?

D Interview with STS Transmission AB

What components do you remanufacture? How do you prioritize what components to remanufacture?

How to prioritize?

How have the transition from Mechanical vehicles to more Electrical vehicles affected your process?

What drivers and barriers do you have from political and legislative aspects? And do you have any incentives?

Process: How does your process of remanufacturing look like? What steps are included and does it differ with different components/material

properties?

Which operation is the most difficult and costly and why?

Can you guarantee that a remanufactured gearbox has the same quality as a newly manufactured gearbox?

How do you ensure the quality of the component/product?

Feasibility: How do you decide whether or not to remanufacture a given component/product? What are the criterias?

What happens to the material you can't REM? Do you dispose of it or what happens?

What is required for a component to be remanufacturable according to you?

Does surfaces and material selection affect the remanufacturability?

What components are most challenging to remanufacture and why?

What is difficult with remanufacturing electric transmission components? Like cogs and more delicate parts?

Volvo: How often do you communicate with Volvo's manufacturer supplierCustomer, suppliers, manufacturers? daily, weekly, monthly, etc...

Do you have any communication with the designers/R&D and have they visited to get deeper knowledge and understanding of your processes and procedures?

Do you think R&D and designers would be auspicious by visiting you and getting more insight in the field?

On average, how much time does it take to remanufacture a gear box?

Do you retrieve gearboxes globally from the entire globe?

Do you have any feedback system? if yes, how does it work?

E Interview guide for BORG automotive AB

What components within electric transmission (powertrain/gearbox) do you remanufacture? How do you prioritize which components to remanufacture?

How have the transition from Mechanical vehicles to more Electrical vehicles affected your process?

What major changes have occured in the remanufacturing industry over the past several years?

What drivers and barriers do you have from external and internal aspects?

How does your process of remanufacturing look like? What steps are Disassembly first, however there are cases where cleaning comes first due to components being dirty. Inspection of the componentes and it goes through the gate (is it good/bad, possible to repair/remanufacture?)

Which operation is the most difficult and costly and why?

What Makes Disassembly Most Difficult?

What Makes Cleaning Most Difficult?

What Makes Inspection Most Difficult?

What Makes Refurbishing Most Difficult?

What Makes Part Reassembly Most Difficult?

How do you ensure the quality of the component/product?

Feasibility How do you decide whether or not to remanufacture a given component/product? What are the criterias?

What is required for a component to be remanufacturable according to you?

How do you measure remanufacturability? What aspects to consider?

Is it worth/possible to remanufacture all parts in a vehicle? If not, when is it not worth it/possible?

Is it possible to remanufacture powertrain mounts (bushings and consoles)? Why/why not? And do you currently remanufacture it?

What components are most challenging to remanufacture and why?

What design issues affect remanufacturing the most?

What does your communication with R&D and designers look like?

F Inserted values in CES EduPack for both cases of remanufacturing and new produced product.

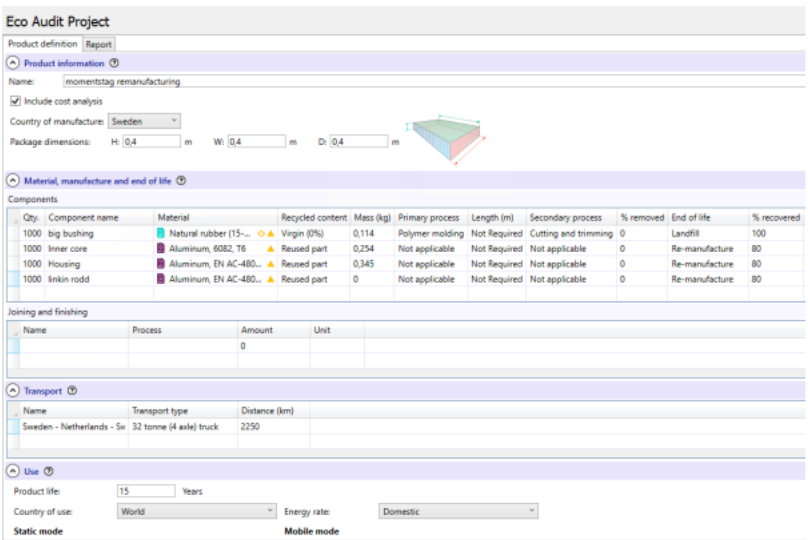

Figure F.1: Inserted values for remanufactured component.

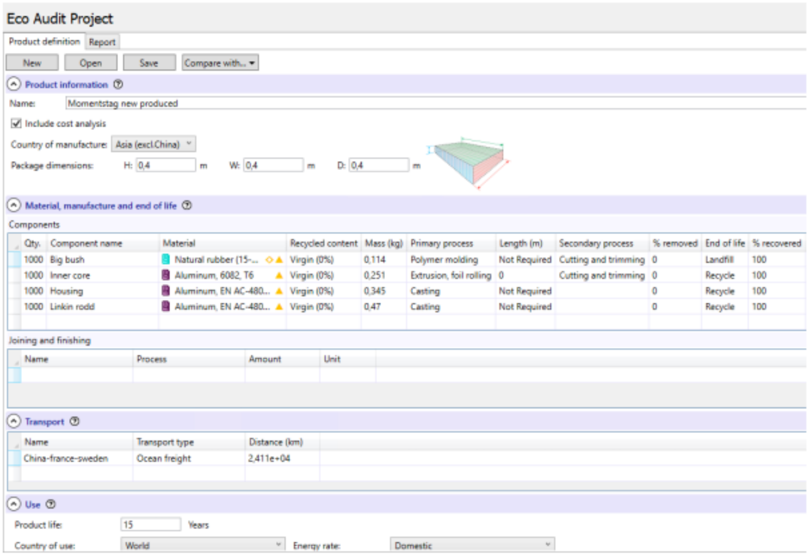

Figure F.2: Inserted values for new produced component.

G Extraction of feedback from the workshop.

Figure G.1: Rating of overall experience during the workshop

Figure G.2: Rating of the workshop according to relevance.

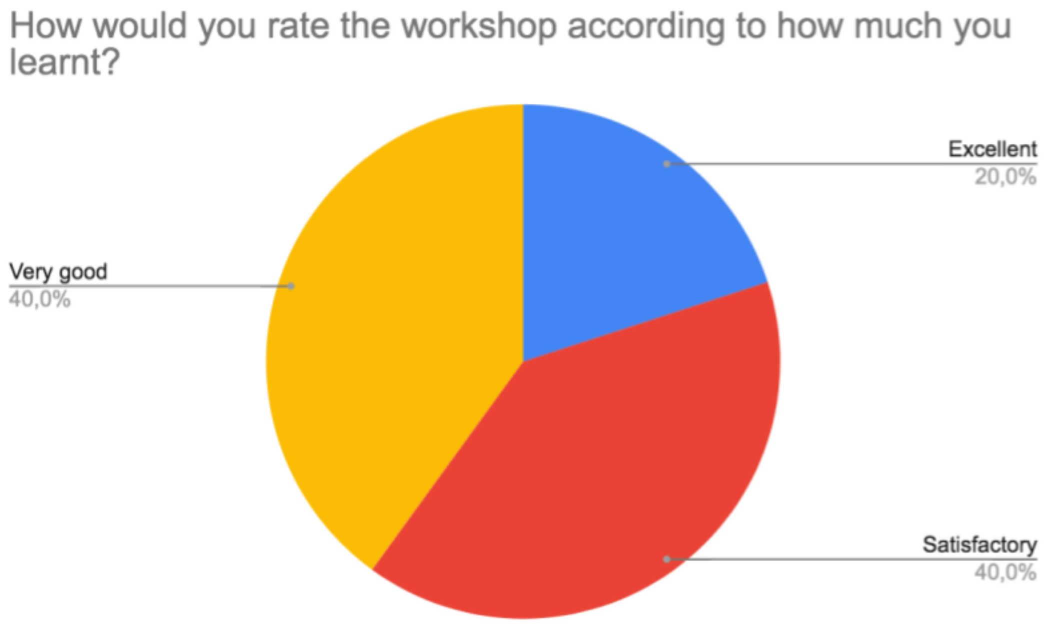

Figure G.3: Rating of the workshop according to learning outcome.

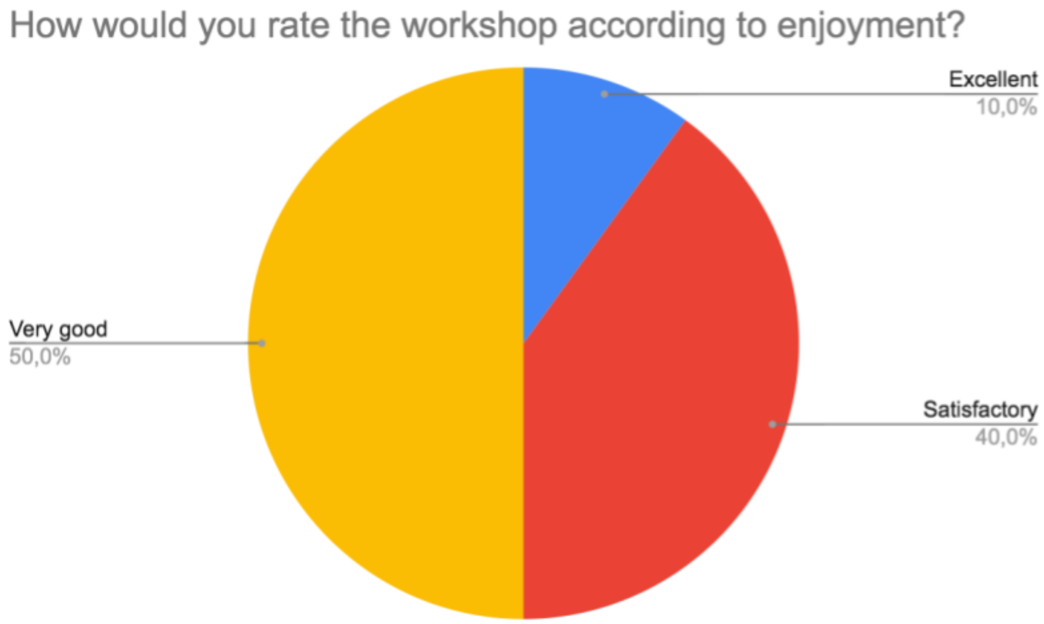

Figure G.4: Rating of the workshop according to enjoyment.

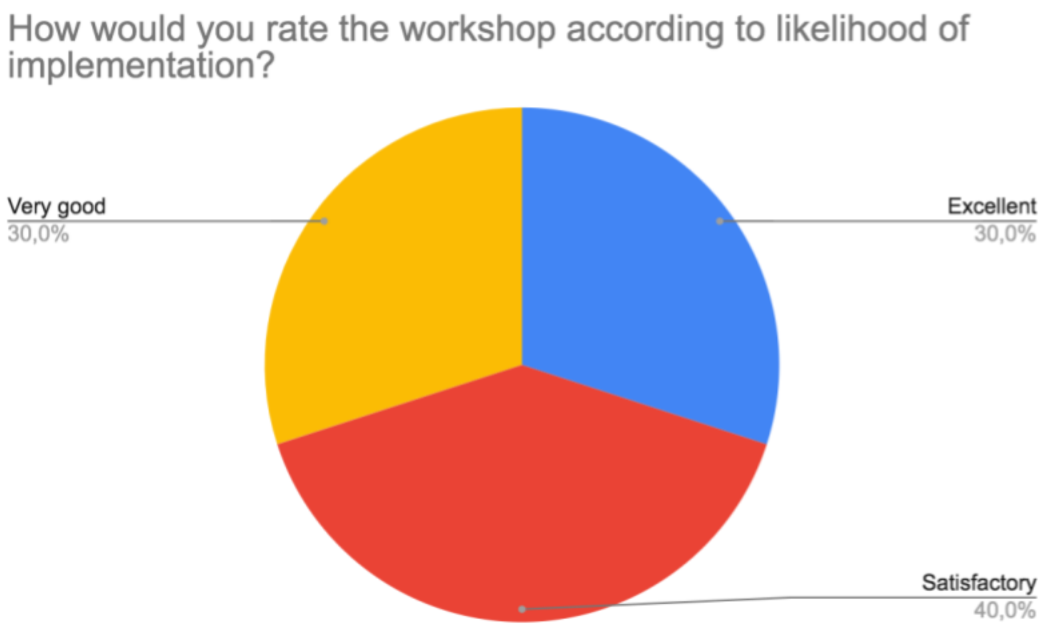

Figure G.5: Rating of the workshop according to likelihood of implementation.

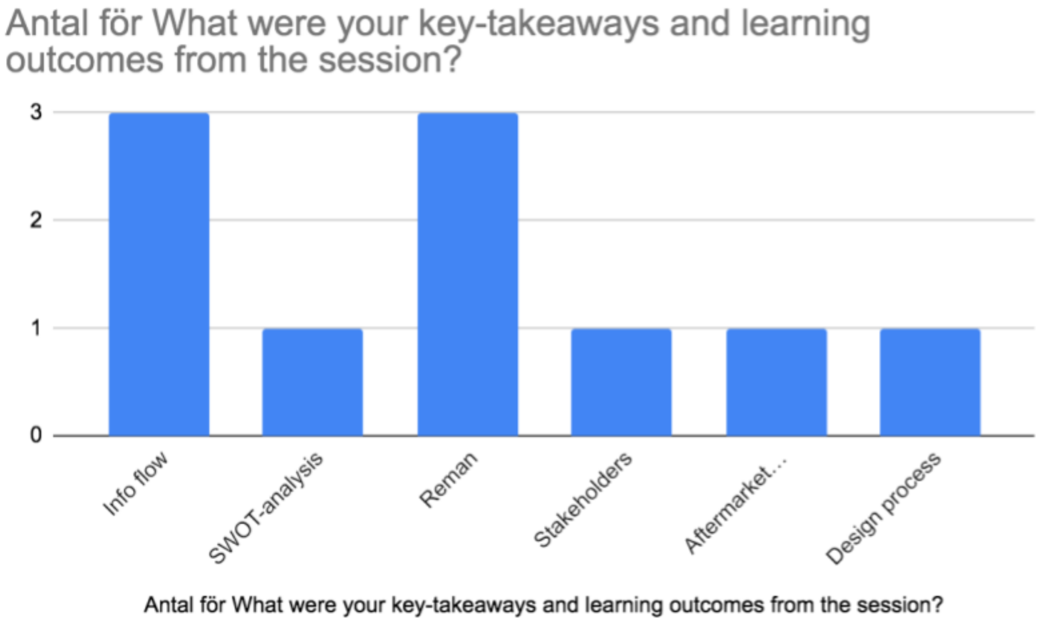

Figure G.6: Feedback of key-takeaways from the workshop.

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