D3.1 - Defining the current baseline and the target circular design methodologies

Project acronym:	ReCiPSS
Project full title:	Resource-efficient Circular Product-Service Systems — ReCiPSS
Grant agreement no.:	776577-2
Author/s:	Nina Boorsma Conny Bakker
Reviewed:	C-ECO, KTH, Bosch, Gorenje, Fraunhofer, SIVECO
Approved:	Amir Rashid
Document Reference:	D3.1
Dissemination Level:	PU
Version:	1.0
Date:	12.02.2019

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

History of Changes

Version	*Date*	*Modification reason*	*Modified by*
0.1	21.01.2019	Initial Draft	Nina Boorsma
0.2	21.01.2019	Content revisions	Nina Boorsma
0.3	24.01.2019	Textual and content revisions	Nina Boorsma
0.4	01.02.2019	Textual and content revisions	Nina Boorsma
0.5	07.02.2019	Final internal revisions	Nina Boorsma
-			
0.9	12.02.2019	Quality check	Farazee Asif
1.0	12.02.2019	Final reviewed deliverable	Farazee Asif

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 776577-2

Table of contents

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

List of figures

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

List of tables

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

1. Executive Summary

This report presents an overview of the most recent design methodologies for multiple product life cycles in literature today and provides an analysis of the current design practices for the two demonstrators, white goods and automotive spare parts. The design methodologies found in literature are presented in three categories: Design for long Use, Design for extended Use and Design for recovery. A selection of more detailed examples of design methodologies is provided at the end of this overview. The analysis of the current practices for the two demonstrating companies is done through on-site observations and interviews. The results of this data collection are presented in the form of a description of the current business activities in relation to product design, as well as a description of the opportunities to improve the product or service design related aspects in terms of fit with design for multiple product life cycles. The final part of the report determines the actions for further research and the remaining requirements for the implementation of long-term design strategies supporting multiple life cycles and the development of multiple-scenario case-specific circular design methodologies

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

2. Introduction

Technological improvements have become faster than ever and our design methodologies have difficulties keeping pace. Societies have access to more information, and with that, have more awareness of human impact on the natural environment. To avert this impact, it is time to start re-evaluating the way natural resources are used, by looking at the way resources are shaped into products and the way products are used and discarded.

This document is a result from task 3.1 from work package 3: Defining the current baseline and the target circular design methodologies that focuses on the development of a more coherent design strategy for circular manufacturing systems. This task uses as input the results form tasks 2.1 work package 2 and 4.1 work package 4. The objectives for this report, as described in the grant agreement, are:

- Evaluate current design practices.

- The analysis will use currently available tools like observations, disassembly trees and assessment methods like LCA, check-lists for the evaluation of impact of design strategies from a circular perspective, resulting in required design criteria and the establishment of case-specific parameters.

- Make a comparison of various design strategies based on their relevance to multiple product life cycles, highlighting factors leading to success or failure.

- Maintain a special focus on user-interaction in the context of IoT base platforms.

- The report is executed in close collaboration with:
    - WP 2 task 2.1 concerning circular business models
    - WP 3 task 3.2 concerning user-related aspects
    - WP 4 task 4.1 concerning circular value chains.

- The outcome of this report should serve as a starting point for the development of a more coherent design strategy for circular manufacturing systems.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

2.1.1. Methodology

Two main methods for data collection are used as the basis for this report. The first is a literature review, to make an inventory of the existing methodologies and supporting design principles for design for multiple product life cycles. The second one is case-study research, in the form of interviews and observations.

2.1.1.1 Literature review

The databases Scopus and Web of Science were used for a literature review. Altogether, the paper count for both databases together yielded 238 papers, 6 of these papers were duplicates and 76 articles met the predetermined selection criteria. The most cited and most recent papers were read in detail, to generate a basic frame for the literature. The remaining papers, as well as relevant grey literature from for example the ResCoM project, were scanned to make sure relevant information was included.

2.1.1.1 Case-study research

The participating companies of both demonstrators were visited in the first half year of the project. The visits served as a way to get to know each other and to form a good basis for the full course of the four-year project. Additionally, this visit allowed the opportunity for data collection for the baseline reports of work packages 2, 3 and 4.
The data for WP 3 collection took place through interviews, company presentations and observations. The interviews were carried out by using a semi-constructed interview guide. Table 1 and Table 2 indicate the specific data collection actions.
For the analysis of the data, the audio files of the interviews were audio-coded. These codes formed the basis for the case study descriptions later on in the report.

White goods demonstrator	
Company visit: Gorenje - 28-30 August 2018, Velenje, Slovenia	
Name	**Type**
All participants	Guided tour
Aleš Mihelič, R&D Loundry, Gorenje	Presentation
Aleš Mihelič, R&D Loundry, Gorenje Maja Cvejič, Product Lead, Gorenje	Interview
Nataša Camlek, Product Manager, Gorenje	Interview
Paula Cardenas Mahne, Strategic Marketing, Gorenje	Interview
Marijan Grešovnik, Global customer care technical support, Gorenje Dušan Farčnik, Deputy director aftersales, Gorenje	Interview
Company visit: HOMIE - 8 October 2018, Delft, the Netherlands	
Name	**Type**
Colin Bom, co-founder & CEO, HOMIE	Interview

Table 1 Company visits – white goods demonstrator

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

Automotive spare part demonstrator	
Company visit: Bosch - 9-11 October 2018, Göttingen, Germany	
Name	**Type**
All participants	Guided tour
Christian Schindler, Mechanical engineer, team leader for Common Rail and Exhaust Gas Treatment Systems: new, reman and repair concepts, Bosch	Presentation
Birgit Kränzl, Business manager, responsible for Diesel Reman Products globally: reverse logistic set-up, ramp-up of reman concepts/projects of customers, Bosch Dominik Kuntz, Process Manager, C-ECO	Interview
Klaus Gohde, Market Manager, Bosch Markus Wagner, Project Manager, C-ECO Konstantinos Georgopoulos, Mechanical Engineer, Customer Insights and Reverse Logistics, C-ECO	Interview
Peter Bartel, Marketing and Engineering, C-ECO	Interview

Table 2 Company visits – automotive spare parts demonstrator

2.1.2. Document scope

This report is built of three main parts. The first part presents a concise introduction of the product innovation process as performed today. The second part contains a more elaborate overview of state-of-the-art design methodologies for multiple product life cycles. And the final part consists of an evaluation of the design practices at the demonstrators.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

3. State-of-the-art research in design for multiple product life cycles

At the core of design lies the ambition to "chang[e] existing situations into preferred ones" (Simon, 1996 p.111). Currently, most design methodologies are configurated to design 'static products'. These are products incapable of adapting to new situations. Which means that, within predetermined quality boundaries, a 'situation' can only be changed once during the lifetime of a product. This, however, does not fit with the increased demand for innovation, nor does it fit with the faster pace of life, where products are purchased and replaced at a higher pace. In other words, products nowadays require a more dynamic approach to design, to facilitate "changing existing situations into preferred ones" over a longer period of time, multiple times and at the same time minimizing the amount of energy and resources required by design.

3.1. Product innovation process

To start with, a short introduction of the product innovation process as we know it today, according to Roozenburg & Eekels (1995), later known as the Delft Innovation Method (Buijs, 2012) (Figure 1). In the middle of the figure the process of the actual 'product designing' takes places, with around it five smaller circles, represented by the design phases: analysis, synthesis, simulation, evaluation and decision. The structure of this model can be used to develop products for multiple use- cycles, however, it does require additional conditions to reach the intended end result, like an recovery scenario at end-of-life (Balkenende & Bakker, 2018). In this chapter, a selection of relevant design methodologies will be presented.

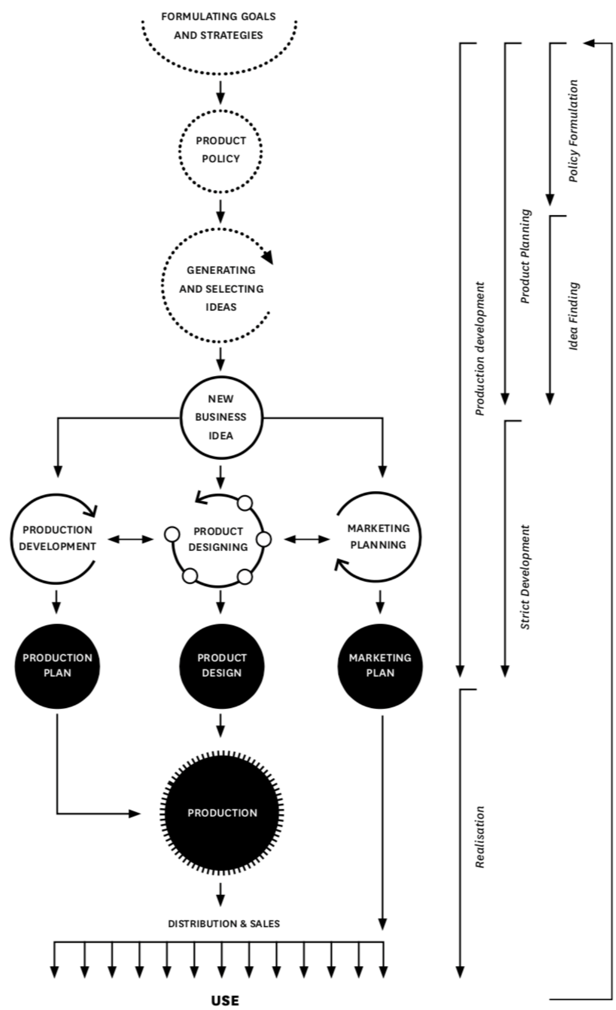


Figure 1 "Entire process of one innovation loop from company strategy to market introduction." Van Boeijen et al. (2013) p. 21, adopted from Roozenburg & Eekels (1995).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

3.2. Concepts of design for multiple lifecycles

The academic field of design for multiple product life cycles is practically non-existent. When entering the search term “design for multiple product life cycles” in the search engines of Scopus and Web of Science, the outcome is zero hits. A total number of 5 unique hits is reached when entering “design” AND “multiple product life cycles”. This means that a combination of different academic fields together constitute the knowledge needed to find the required methodologies for design for multiple product life cycles, for example Design for Long Use, Design for Extended Use and Design for Recovery.

3.2.1. Formative concepts for design for multiple product life cycles

To gain better understanding of the differences between design methodologies as they are now, and design methodologies for multiple product life cycles, a list of relevant concepts was discussed.

Business model – OEMs with the intention to design products for multiple product life cycles are likely to have business models other than classical sales models for these products. Examples of different business model are access or performance models, for which the use of functions become the offer, instead of ownership of a product (Bakker et al. 2014). Since in these cases the products will remain in the ownership of the company, more strategic design investments can be made for the longer term.

Value propositions – In conventional design methodologies, designing a single value proposition was sufficient to support sales of products. However, when designing products serving several product life cycles, different types of needs should be considered, as well as how these needs might change over time as the product cycles through the economy. This adds a time component to the offer of the OEM.

Use – A wider range of use scenarios become applicable for products designed to have multiple product life cycles. Examples are short use-cycles or shared use-cycles. Additionally, the transition from one use-cycle to the next should be addressed during the design phase.

Reverse logistics – In an access model it becomes the responsibility of the OEM to transport the product from one user to another or to take back a product to a distribution point or factory. Having some level of control over the timing, quality and volume of return flows is vital. Plus, it becomes economically interesting to look at the transportability of a product.

Recovery options – Multiple product life cycles can be facilitated through different recovery options. Besides conventional materials recycling, there are the options of repair, maintenance, redistribution, refurbishment or remanufacturing. In case the OEM is responsible for product or part recovery, it may become economically interesting to design products which facilitate these activities.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 776577-2

Lifetime extension – Once it becomes the interest of OEMs to prolong, improve or increase the amount of product life cycles, investing in design methodologies to increase a product's lifetime is likely to pay off. The lifetime of a product is the period starting from the moment a product is ready for use after initial production, and ends at the moment the product has reached end-of-life and cannot be recovered at product level (den Hollander, 2018; Murakami et al., 2010).

Recyclability – If a business model is used where products return to the OEM at the end-of-life, it can become advantageous to consider the recyclability of a product.

3.2.2. The circular economy

The concepts described above are largely covered by the, likewise nascent field of research, design for a circular economy. In 2010 the Ellen McArthur Foundation (EMF) was launched to accelerate the transition towards a circular economy. The concept of a circular economy is based on several schools of thought, for example on the ideas of McDonough and Braungart (2002) and their dichotomy of natural and technical materials, to keep materials in a loop. The concept of circular economy opposes the so-called linear economy which refers to the way we currently make use of natural resources (take-make-dispose). The best way to explain the circular economy is by using an image created by the Ellen McArthur Foundation, showing the dichotomy of McDonough and Braungart by two main loops and a range of additional loops of different sizes, corresponding to the different associated strategies. The loop on the left-hand side represents the biosphere, while the ones on the right-hand side represents the technosphere (Figure 2). The technosphere, which is the focus for product design, constitutes of the following loops: share, maintain/ prolong, reuse/ redistribute, refurbish/ remanufacture and recycle.

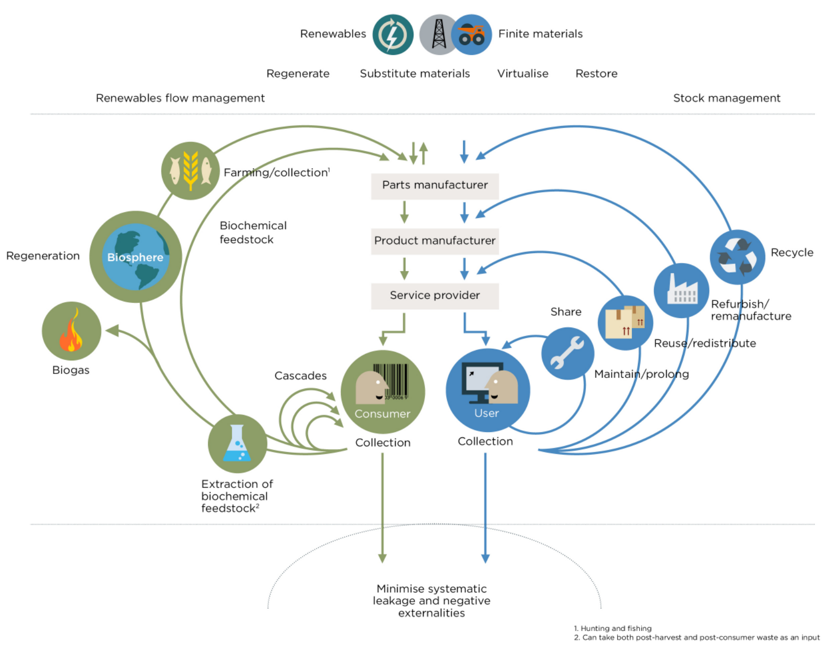


Figure 2 The Butterfly Diagram (EMF, 2018a)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

3.2.3. Design for a circular economy

The methods and principles supporting design for a circular economy can be built in a similar way to the Butterfly Diagram, which can be seen in Figure 3. Two main branches can be distinguished, one being 'design for product integrity', covering the inner circles of the Butterfly Diagram, and the other 'design for recycling', covering the outer circle of the Butterfly Diagram. Design for product integrity is further divided into: long use, extended use and recovery, with a list of associated design approaches beneath them (den Hollander et al. 2017).

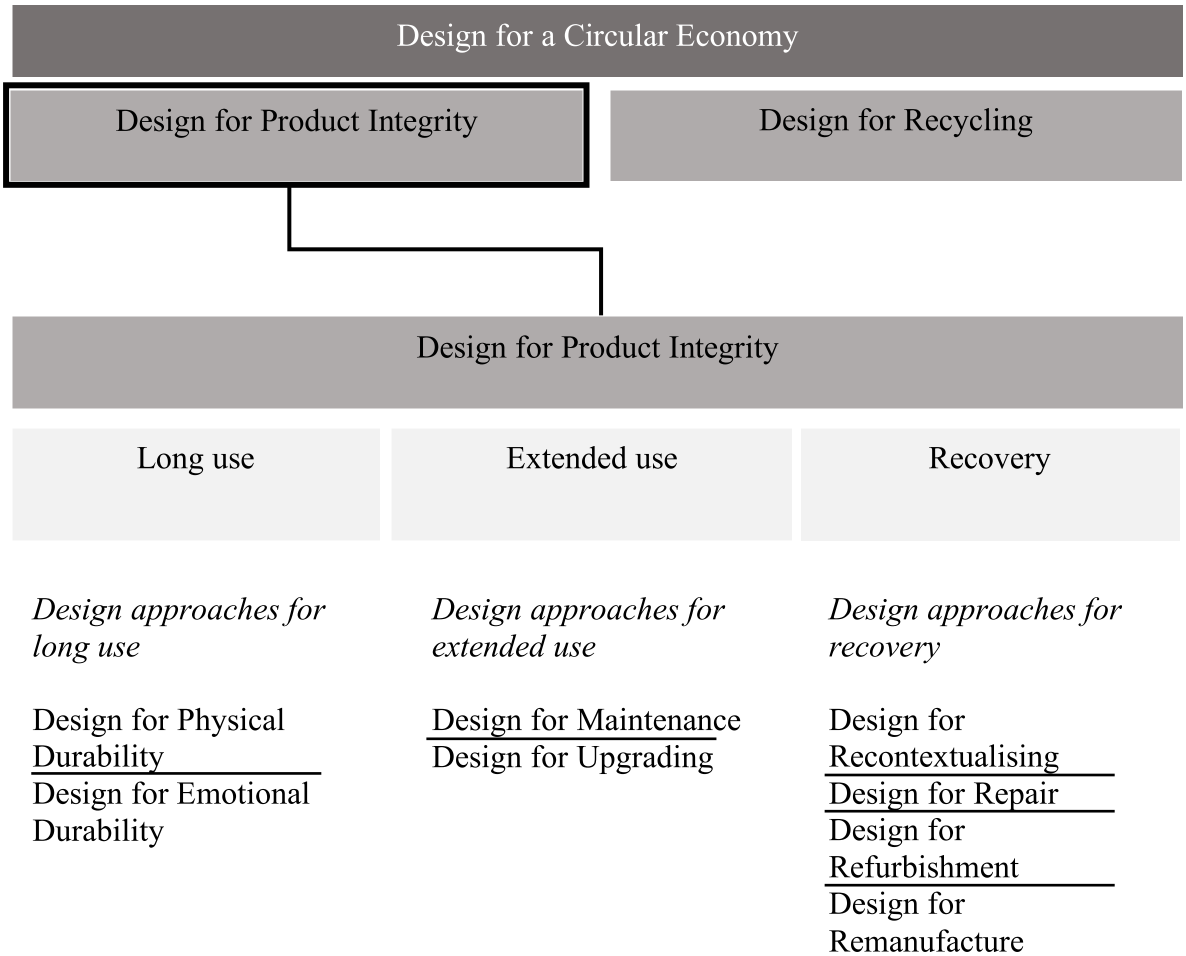


Figure 3 Methods and principles supporting design for a circular economy, adapted from den Hollander et al. (2017)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

3.3. Methods for design for multiple product life cycles

3.3.1. Design methods for Long Use

Product design methods for long use aim to prolong the useful lifetime of a product over the longest possible period. Thereby products are kept in use for longer than average products of same category. To manage the design decisions which facilitate this, both the physical lifetime of the product and the durability of the emotional relationship between user and product need to be taken into account. Table 3 describes the methods supporting long use in more detail.

Methods for Long Use		
Title	**Description**	**Characteristics**
Design for Physical Durability	Methods for designing physically durable products aims to design products with long lifetimes. Not only should their function be accessible for as long as possible, they should also be socially relevant. Den Hollander (2018) mentions three main pointers to keep in mind for designing durable products. The first is to keep the number of moving parts at a minimum, since these parts are most prone to damage and wear. The second is to make the operating mechanism wear resistant and keep stress resulting from load during use within acceptable boundaries. And thirdly, during material selection the effect of the use context and conditions should be taken into account. The final note is that the design solution should always be weighed against the required resource input (Keoleian & Menerey, 1993).	Numerous methods for durability are available, depending on the specific company objective.
Design for attachment and trust	This method aims to design products with emotional durable designs, where the relation between product and user stir emotions affecting the way a product is perceived, resulting in emotional attachment (Chapman, 2005). Chapman proposes a 6-point framework for designers to structure their interventions. The six points are: Narrative, Detachment, Surface, Attachment, Fiction and Consciousness (ibid.).	

Table 3 An overview of design methodologies for long use

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

3.3.2. Design methods for extended use

There are scenarios in which designing for long use is only limitedly possible. For these scenarios it is worth considering design methodologies for extended use. These methods often manage design decisions at the early phases of the design stage, where, for example, architecture decisions are made in order to upgrade, change or refurbish a product at a later point in time. Table 5 presents an overview of the methods.

Methods for Extended Use		
Title	**Description**	**Characteristics**
Design for Maintenance	This design methodology aims to optimally facilitate an expert to perform recurrent restorative actions on a regular basis, most of the time on location, to guarantee functioning of a product (Linton & Jayaraman, 2005). This method is often applied to complex products containing parts with varying life expectancies. Three approaches for maintenance are: preventative maintenance, predictive maintenance and reactive maintenance (Flores-Colen & de Brito, 2010).	Target phase: Early design phase. Enabler: Designing sensor embedded products, which allow smart data collection by Machine-to-Machine (M2M) communication and Internet-of-Things (IoT) connections (Höller et al., 2014).
Design for upgrading	This method aims to extend the lifetime of a products, by providing a service of hardware and software updates during the use phase, in order to allow continuous improvements, even after initial production (Matsuda et al., 2003; Vezzoli & Manzini, 2008; Xing & Belusko, 2008).	Approach: Product roadmap
Platform design	This approach is based on the idea of having a standardized product base, containing high-value parts and standardized connection points, which is constant for an entire product family. This strategy can be of use in two ways. Firstly, by standardizing a high number of parts throughout a product family, saving production costs (King & Burgess, 2005). And secondly, by	Target phase: Early design phase

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

	allowing the flexibility of the design to allow broad market coverage.	
Design for Modularity	This method aims to organise a product by dividing it into building blocks with standardized interfaces, supporting a company's strategy (Ericsson & Erixon 1999). This enables for example ease-of-repair or accelerated implementation of innovations. And, more importantly, postpones product obsolescence (Ma & Kremer, 2016).	Target phase: Early design phase

Table 4 An overview of design methodologies for extended use

3.3.3. Design methods for Recovery

At the point a product reaches end-of-life, a product can, whether or not by design intent, still have remaining useful life. The design of a product can be optimized according to a preferred recovery strategy, by using the methodologies presented in Table 5.

Methodologies for Recovery		
Title	**Description**	**Characteristics**
Ease-of-disassembly	Developing products that are easy to disassemble, allows taking (selected) parts out of a product unscathed, requiring limited amount of actions, costs and time investment (Brennan et al. 1994, p. 59). Core to this methodology is to design the connectors such that reassembly is possible, the parts can be disassembled damage-free, the connectors are highly standardized and limited tools are required (de Aguiar et al., 2017).	Ease-of-disassembly is an essential part of all methods for extended use, recovery and recycling
Design for Repair	This methodology aims to design products which facilitate the act of reaching and restoring broken or worn out parts in a product. Based on five papers, Flipsen et al. (2016) define repairability as: "reparability is the ability to bring a product back to working condition after failure, in a reasonable amount of time and for a reasonable price.'	Enabler: Designing sensor embedded products, see 'Design for Maintenance'.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

	This goal can be achieved by making parts prone to damage or wear easy to access, test and/ or replace.	
Design for Remanufacturing	For this recovery strategy a used product is brought back to, at least, original performance specification with a warranty to match, through a standardized industrial process, often including steps like disassembly, testing, part replacement, cleaning and reassembly (Ijomah et al. 2007; Nasr & Thurston, 2006; Parker & Butler, 2007). Design for remanufacturing is supported by design for ease of identification, ease of handling, ease of separation and ease of securing (Sundin & Bras, 2005).	Numerous design tools and methods are available for remanufacturing, depending on the specific company objective. Enabler: Designing sensor embedded products, see 'Design for Maintenance'.
Accessibility	Structural arrangements of (selected) parts in products, which allow ease-of-disassembly and ease-of-access of (selected) parts (Moss, 1985, p. 37). Besides assembly order and configuration, the selected connectors and placement of product in its context are of influence.	Accessibility is an essential part of all methods for extended use, recovery and recycling
Material selection	Selection of the material(s) for constructing a product, based on best fit with a product's function, throughout its entire lifecycle, including possible recovery strategies (Castro, et al., 2004).	Material selection is an essential part of all methods
Value Hill Tool	This methodology aims to develop circular strategies and enable successful positioning of those strategies. The starting point for the value hill tool exists of two main challenges. The first has to do with management of resources; tracking products and making sure they are returned after use. The second challenge is to make use of the remaining value in those products, at the highest quality possible. (Achterberg et al. 2016) Authors: Elisa Achterberg, Circle Economy & Sustainable Finance Lab; Jeroen Hinfelaar, Nuovalente; Nancy Bocken, TU Delft.	Recently developed (2016), early design phase method.
Circularity Calculator	This methodology aims to support circular decision making, by determining the degree of circularity of resource flows in an early stage of product development. The	Recently developed (2017) digital tool. Target phase: Early

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

	circularity calculator, developed for the H2020 ResCoM project, is a digital tool, which allows to enter case-specific parameters to calculate the degree of circularity of any company's resource flows. Authors: Ingrid de Pauw & Bram van der Grinten, IDEAL&CO	design phase
Service design	The methodology of service design makes use of explorative, generative and evaluative techniques, to develop a plan for the way of structuring and designing touchpoints (the points in time when interaction between service and user takes place) and customer journeys, messages and experiences (Halvorsrud et al, 2016, Mager, 2007).	
Customer journey mapping	In a more general sense a journey map attempts to generate a schematic representation of an existing or envisioned product or service related journey, as a means to form the basis for a product or service (re)design (Halvorsrud et al., 2016). The map is often divided into several phases, like an introduction, use and end phase. The best-known journey map, is the customer journey map, in which the touchpoints of user with a product/ service are mapped over different phases in a scheme, in a chronological order.	
Product journey mapping	This specific form of journey mapping assists in designing series of circular offers for a single product with meaningful start and end of the use phase. (Ellen MacArthur Foundation, IDEO, 2018, December 13). Authors: Ellen MacArthur Foundation, IDEO	Recently developed (2018), unvalidated method

Table 5 An overview of the design methodologies for recovery

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

3.4. Demonstrator-specific target design methodologies

After providing an overview of the methodologies found in literature, and analyzing current design practices of both demonstrators (see section 4. Demonstrators), a conclusion can be drawn regarding the target design methodologies for the demonstrators. Table 7 evaluates two indicators, the priority level of the design methodologies and the related current skill level of the demonstrators. The methodologies with a difference between these two have learning potential for the demonstrators, therefore, are target methodologies (Table 6).

Target methodologies	
White goods demonstrator	**Automotive spare part demonstrator**
High learning potential	**High learning potential**
- Design for upgrading - Design for remanufacturing - Accessibility - Service design - Customer journey map - Product journey map	- Design for attachment and trust - Service design - Customer journey map
Medium learning potential	**Medium learning potential**
- Design for attachment and trust - Design for maintenance - Platform design - Ease-of-disassembly - Design for repair	- Design for upgrading - Design for remanufacturing - Product journey map

Table 6 Company-specific target design methodologies

3.4.1. Long use

Making products long lasting and physically durable is the very basis for design for multiple use-cycles. Both demonstrators have high skill levels when it comes to designing physically durable products, especially regarding the material selection, construction, engineering and reliability of the products.

On the other hand, a product's durability is also influenced by its emotional durability. This is particularly important in Business to Consumer markets, since products in these markets are often located in people their home, and are interacted with on a day-to-day basis. Gorenje is familiar with the ins and outs of designing for emotional durability, however, this might need to be rethought when moving to access models and offering mainly services.

In the case of the automotive demonstrator, a similar transition is taking place. For car parts, the image of reliable engineering essentially generates the required trust. However, with the development of an ICT platform design for emotional durability needs to be applied in a whole different way, since it facilitates the exchange of

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

valuable data between value chain parties. For example, a wholesaler can now make use of the possibility to outsource his core-management, supported via the ICT-platform, and will not get hold of the physical cores as he is does today. That might generate the feeling of intransparency or loss of control. These aspects must be addressed in the development of the platform. Techniques to collect and process data need to be highly reliable and trustworthy not only in terms of technical performance but also according to the experience of the user. Moreover, the ambition of C-ECO is to introduce a new service to its users. The users of this service should be fully confident in the platform.

3.4.2. Extended use

Bosch is highly skilled when it comes to extending the lifetime of products. Their business model of remanufacturing spare parts is based on extending the lifetime of cars. Therefore, Bosch excels in platform design, design for maintenance and modular design. Using ICT solutions can be a way of increasing the efficiency of the current practices of Bosch.

In the case of Gorenje, platform design offers the possibility of extending the lifetime of the products, by exploring possibilities for upgrades and ease-of-maintenance, offering added value to the market. The focus for platform design in Gorenje's business case currently is standardization for cost reduction. This, however, might provide opportunities regarding upgrades or ease-of-maintenance when considered for decision making during the strategic product design phase.

3.4.3. Recovery

Both OEMs can profit from putting design for remanufacturing on the agenda for early stage product development, or better yet, for the compilation of the product design brief. Bosch has incorporated numerous design aspects supporting remanufacturing, like ease-of-maintenance, repair and disassembly. Nonetheless, additional opportunities can be provided by constructing a product according to the lifetime and value of parts, designing for cleanability, and designing for easy and fast identification and testing, e.g. by designing labels for the parts which will be able to stay attached to the core after the very demanding lifetime (high engine temperatures, water, oil and other impurities etc.) would be very beneficial for all the following processes till remanufacturing.

Gorenje designs its products in order to be easy to repair and easy to disassemble. Therefore, it would be beneficial if the structure of the product allows parts to be easily accessible too. At this point remanufacturing is not core priority of the company, but keeping a potential remanufacturing process in mind, can be beneficial on the long term, in case the strategy changes.

The objective for both demonstrators is to develop a new service, by making use of service design and journey maps.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

Target design methodologies						
Methodology	**Whitegoods demonstrator**			**Automotive demonstrator**		
	Priority level	*Current skill level*	*Learning potential*	*Priority level*	*Current skill level*	*Learning potential*
Long use						
Design for Physical Durability	High	High	Low	High	High	Low
Design for attachment and trust	High	Med./ High	Med.	High	Low	High
Extended use						
Design for Maintenance	High	Med.	Med.	High	High	Low
Design for upgrading	High	Low	High	Med.	Low	Med.
Platform design	High	Med./ High	Med.	High	High	Low
Design for Modularity	Med.	Med.	Low	High	High	Low
Recovery						
Ease-of-disassembly	High	Med.	Med.	High	High	Low
Design for Repair	High	Med.	Med.	High	High	Low
Design for Remanufacturing	High	Low	High	High	Med./ High	Med.
Accessibility	High	Low	High	High	High	Low
Material selection	High	High	Low	High	High	Low
Value Hill Tool	Low	Low	Low	Low	Low	Low
Circularity Calculator	Low	Low	Low	Low	Low	Low
Service design	High	Low	High	High	Low	High
Customer journey map	High	Med.	High	High	Low	High
Product journey map	High	Low	High	Med.	Low	Med.

Table 7 Demonstrator-specific target design methodologies

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

3.4.4. Detailed overview of a selection of design methodologies

To give an example of what a design methodology is and how it can be applied, several of the target design methodologies are explained in more detail on the following pages. The descriptions mention the aim and the basic steps the methodology follows. The selected methodologies are:

Selected methodology for long use

- Design for emotional durability

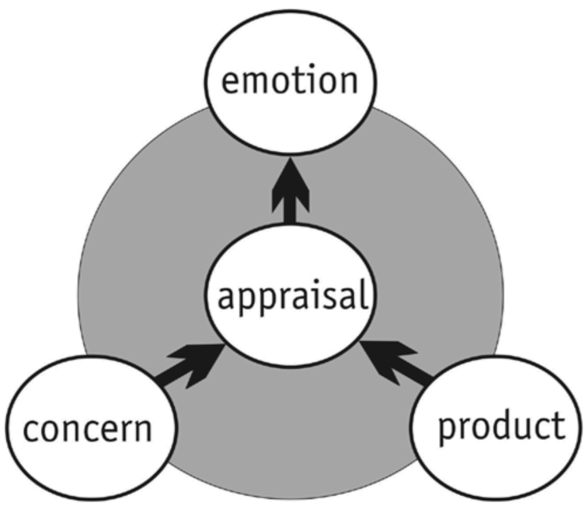
Selected methodology for extended use

- Design for upgradability

Selected methodologies for recovery

- Design for remanufacturing
- Service design
- Product journey mapping

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

Title	**Design for Emotional Durability**
Author(s)	Various
Aim	This Methodology aims to design products with emotional durable designs, where the relation between product and user stir emotions in such a way that it affects the way a product is perceived, resulting in emotional attachment (Chapman, 2005).
Method	How to design for emotional durability cannot be captured in one single methodology or technique. There is a range of methodologies to choose from. Desmet and Hekkert (2007) divide the way people experience products into three interlinked categories: Aesthetic Experience, Experience of Meaning and Emotional Experience. Where the first two have the ability to evoke the latter (Figure 4). Bearing that in mind, product experience can be described as "the entire set of effects that is elicited by the interaction between a user and a product" (Hekkert, 2006). According to Demirbilek & Sener (2003), positive experiences can be designed using the following affect programmes: 1. Senses 2. Fun 3. Cuteness 4. Familiarity 5. Metonymy (relating to something of meaning, almost methaphorically, e.g. to a figure or cultural aspect) 6. Colour  *Figure 4 Emotions and product design, adapted from Desmet (2002)*
Reported effectiveness	Mature method, widely applied.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

Title	**Design for Upgradability (DfU)**
Author(s)	Various
Aim	To extend the lifetime of a product, by providing a service of hardware and software updates during the use phase of a product, in order to allow continuous improvements, even after initial production (Aziz, 2016; Matsuda et al., 2003; Vezzoli & Manzini, 2008; Xing & Belusko, 2008).
Method	The term Design for Upgradability is often mentioned in literature, particularly in relation to product durability (Bocken et al., 2016; Charter & Gray, 2008; Fegade et al., 2015; Hatcher et al., 2011; Khan et al. 2018; Xing et al., 2013; Zafarmand et al., 2003). Matsuda et al. (2003) propose the following method, with a roadmap as the result. After defining a full generation of products and developing a market introduction plan, the final step is to generate an upgrade planning flow following 5 steps, emphasizing that careful selection of key components is crucial: 1. Choose the target product 2. Build a component database 3. Match the demand and product structure 4. Determine the design solution 5. Evaluate the upgrade product line-up The types of upgrades possible (Vezzoli & Manzini, 2008): - Software upgrades - Hardware upgrades - Upgrades tailored to surroundings - Upgrades tailored to user preferences - On-site upgradability
Reported effectiveness	Mature method, widely applied.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

Title	**Design for Remanufacturing (DfRem)**
Author(s)	Various
Aim	To facilitate product remanufacturing, a product recovery strategy, performed at end-of-use of a product. For this recovery strategy a used product is brought back to, at least, original performance specification with a warranty to match, through a standardized industrial process, often including steps like disassembly, testing, part replacement, cleaning and reassembly (Ijomah et al. 2007; Nasr & Thurston, 2006; Parker & Butler, 2007).
Method	The most effective way of implementing DfRem is by designing the product and process in an integrated way (Ijomah et al., 2007; Nasr & Thurston, 2006). Design methods supporting this integration can be found in the RemPro-matrix of Sundin & Bras (2005) (Figure 5). According to Ijomah et al. (2007) the most effective design guidelines are the most product-specific ones. The more general guidelines, however, give an idea of product characteristics compatible with remanufacturing, according to Andreu (1995) a product which: - Has a core that can form the basis of a newly build product - Fails functionally, instead of by dissolution or dissipation - Can be disassembled and brought back to original spec. - Has a high potential of recoverable value - Preferably is assembled at the factory - Has spare parts available - Has a stable product and process technology

Product Property \ Remanufacturing Step	Inspection	Cleaning	Disassembly	Storage	Repair	Reassembly	Testing
Ease of Identification	×		×	×			×
Ease of Verification	×						
Ease of Access	×	×	×		×		×
Ease of Handling			×	×	×	×	
Ease of Separation			×		×		
Ease of Securing						×	
Ease of Alignment						×	
Ease of Stacking				×			
Wear Resistance		×	×		×	×	

Figure 5 RemPro-matrix, adapted from Sundin & Bras (2005)

Reported effectiveness	Mature method, widely applied.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

Title	**Service Design**
Author(s)	Various
Aim	To develop a plan for the way of structuring and designing touchpoints (the points in time when interaction between service and user takes place), customer journeys, messages and experiences, supporting value delivery of a company (Halvorsrud et al, 2016; Mager, 2007).
Method	Creating a service is often done by the help of a service blueprint. A service blueprint shapes the delivery process of a service by visualizing the process by means of flowcharts (Halvorsrud et al, 2016). The blueprint is split up in two parts; the front and back stage, of which the latter is not visible for the consumer (Halvorsrud et al, 2016; Rexfelt & Hiort af Ornäs, 2009). Valencia et al. (2015) have presented an overview of characteristics of product-service systems for smart products and can be used as a means to start designing relationships between company and customer. The following characteristics are mentioned: 1. Consumer empowerment, e.g. adding options or possibility to give feedback 2. Individualization of services, e.g. make customer feel unique 3. Community feeling, e.g. enable communication amongst customers 4. Individual/ shared experience, e.g. enable shared experiences 5. Product ownership, e.g. specifying ownership status of offer 6. Service involvement, e.g. encouraging interaction with the service 7. Continuous growth, e.g. keep content topical and attractive
Reported effectiveness	Mature method, widely applied.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

Title

Product journey mapping

(EMF & IDEO, 2018b)

Author(s): Ellen MacArthur Foundation
IDEO

Aim: To assists in designing meaningful beginning, middle and end for a circular offer.

Method: Circular products naturally change hands. To get people feel comfortable and happy with transferring and receiving products from and to others, with or without an intermediary, these transitions should be carefully designed. Five steps to design nifty product journeys:

1. Use the template, start by asking what the original lifecycle of a product is and what are the possibilities to extend this (Figure 6).
2. Ask what circular strategy is the most promising one to help make this happen. Can this be done in multiple cycles?
3. Is there a distinctive journey for the product's parts? Are the part journeys similar to the product journey? What might happen along the way?
4. Formulate the requirements and possible obstacles, to guarantee a circular success
5. In case a product does not easily undergo any circular strategies, might it be promising to redesign the product?

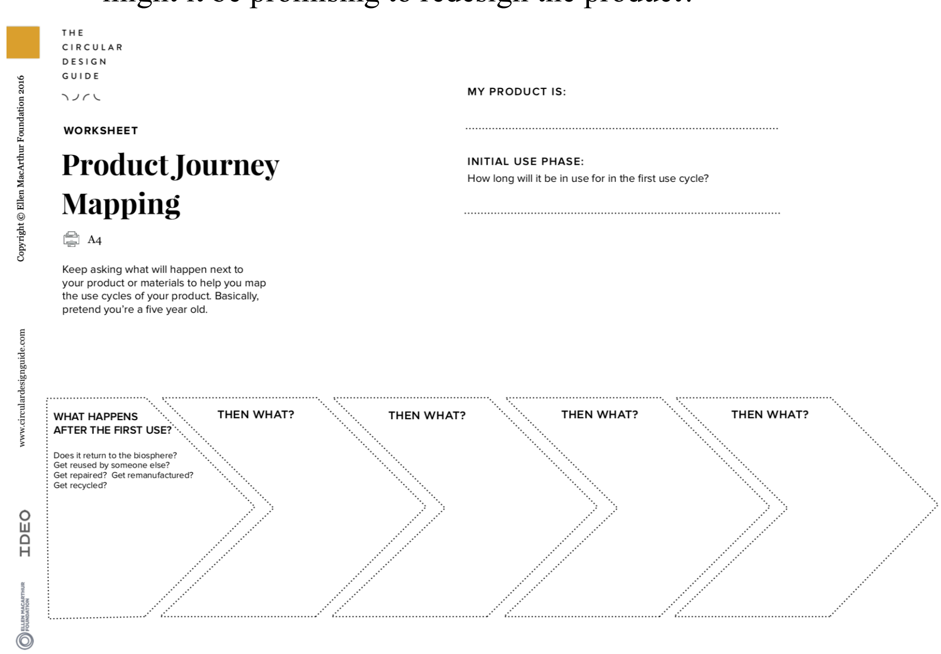


Figure 6 Worksheet Product Journey Map (EMF & IDEO, 2018c)

Reported effectiveness: New method, use unknown

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

4. Demonstrators

This chapter presents an analysis of the current design practices for each of the two demonstrators. The project preceding ReCiPSS, called ResCoM, had the aim to develop the methodologies, tools and networks needed to support the development of closed-loop manufacturing systems (ResCoM project proposal, 2013), whereas ReCiPSS focuses on the large-scale implementation and business integration of access models, circular supply-chain processes and designs for multiple lifecycles. With the help of the methodologies developed during ResCoM, complemented by additional case-study research, in the form of observations and interviews, and literature review. This chapter presents both baselines of the analysis of current design practices for the white goods demonstrator and the automotive spare parts demonstrator.

4.1. White goods demonstrator

4.1.1. Company introductions

4.1.1.1 Gorenje

The OEM joining this project is the company Gorenje, with the main factory located in Velenje, Slovenia, where the larger appliances, like washing machines, are produced. Other appliances are sourced from suppliers, selected by the purchasing unit, based on their resemblance to the vision and mission of the company. Suppliers are typically based in Slovenia or other parts of Europe. Finished products are distributed through regional distribution centers to Gorenje's own selling points in Eastern Europe, as well as retailers throughout the rest of the world. Product innovation is the key factor that makes the difference for Gorenje in the commercial markets and thereby generating revenue for HiSense.

4.1.1.2 HOMIE

The other company joining this project is the company HOMIE, located in Delft, the Netherlands, a spin-off company from the TU Delft. HOMIE delivers a pay-per-use service for household appliances for households throughout two western provinces of the Netherlands, Zuid-Holland and Noord-Holland. For this demonstrator they bring in their knowledge and expertise regarding pay-per-wash services, offering washing machines in per-pay-use systems to households. Their vision is to reduce the environmental impact of domestic appliances. Besides having an active customer base and the experience that comes with it, HOMIE is accustomed to experimenting with their offer and optimizing it by means of customer feedback. The exact tasks for HOMIE within this project are still being determined.

4.1.2. Objectives

A number of 400 washing machines will be piloted in a pay-per-use model, during the course of ReCiPSS. Gorenje will pilot a pay-per-use system in four countries simultaneously.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

The aim at the end of this pilot is to have a deep understanding of the required business model, product design implications and supply chain implications. The project proposal is drafted in a way that allows easy integration with existing processes at Gorenje. In the following sections the business plan for pay-per-use models is discussed first, followed by an overview of the (expected) implications for the design process. The sections provide an overview of the data collected through interviews and observations at Gorenje during an on-site visit in August 2018, as well and interview with HOMIE in delft October 2018.

4.1.3. Project set-up

The selected washing machine for the pilot will be used for a period of 15 years, and will be offered in three tiers, five years each. During the first tier, running from year 0-5, the goal is to offer the machine in a premium offer to the target group, which is willing to pay most and gets access to a new machine in return. The business goal for Gorenje in this tier is to reach the break-even point (ROI). The second tier, running from year 6-10, is offered in a similar form, with a price reduction for the customer, since the installed machine in this tier will be a previously used one. The business goal for Gorenje in this tier is to make profit. In the last and final tier, running from year 11-15, the objective is to offer a price-competitive offer to the customer, where the attempt is to push low budget competitors out of the market. The offered used machine is still high-end, but is attractively priced.

4.1.3.1 Recovery activities

A take-away from the earlier project, ResCoM, is that the costs of producing appliances turned out to be less relevant than the costs of operating the system (including repair and remanufacturing). In Sweden, for example, the hourly rate of repair technicians approaches €150, while this single hour already covers a big share of the cost price of a new machine. When moving refurbishment or remanufacturing operations to a country where labor force is affordable, reverse logistics becomes an economic bottleneck. Therefore, the decision is made to focus on the pay-per-use service system in this pilot, and not to design a completely new washing machine (which would also take 3 years), In the pilot, a semi-professional ASKO washing machine will be used, with a long lifetime of at least 20,000 cycles. In contrast, a consumer appliance is often only built for 2,500 cycles.

4.1.3.2 Towards a pay-per-wash washing machine

The challenge of the pilot is to design the system around the washing machine. In order to test the repair service, a number of washing machines will be pre-aged prior to installment at the consumer. Besides testing the repair activities, this potentially also allows testing the feasibility of product refurbishment and remanufacturing.
Once the demonstrator ends and the project has proved to be feasible and viable, a dedicated washing machine with long lasting design, upgradable functions and zero maintenance costs will be developed for pay-per-use systems. This product will not be available for purchase, but exclusively available for pay-per-use models, to prevent cannibalization of other markets.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

4.1.4. Service design

The set-up in the pilot is designed as such, that a washing machine will be used over three life cycles. One flexible and customizable value proposition is designed to cover the full lifetime of the machine. The tool for dynamic business models, developed by Marcel den Hollander (2018), can be used to design such a value proposition. This tool is based on the Business Model Canvas (Osterwalder & Pigneur, 2010). The tool constructs a way to approach business scenarios where the business model (orange), and part of which the value proposition (pink), will not be constant over time, see Figure 7. In the following paragraphs, we will discuss a number of building blocks of the BM canvas, for all three tiers.

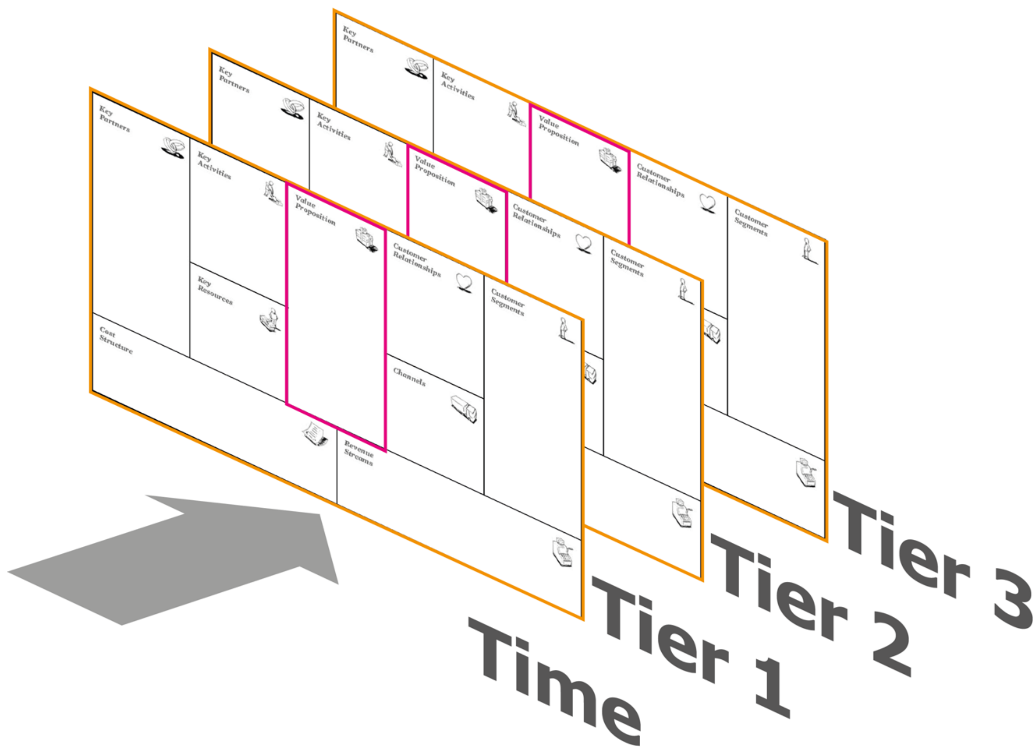


Figure 7 Dynamic business model canvas, adapted from den Hollander (2018), using the Business Model Canvas of Osterwalder & Pigneur (2010)

4.1.4.1 Users of the service

The assumption is that the users of the pay-per-use models will have a different profile from those who buy washing machines. Also, amongst the three tiers, the target group is expected to vary. Gorenje expects that the target group interested in pay-per-use models is younger and more progressive than target groups buying washing machines. Currently the offers are focused on buyers from the 60s 70s, who are more conservative. Besides differences in preferences between current and future target groups, differences can also be identified amongst countries. Where, for example, concerning the aesthetics of the product, a simplistic and geometrical design is appealing to the Dutch, Danish and Swedish consumers, the Slovenian and Austrian consumers much more prefer curves and fluent lines in their products. The co-creation sessions offer an opportunity to go in more depth when it comes to the specific preferences of the target groups.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

4.1.4.2 Customer acceptance of the service

The acceptance of the pay-per-use model depends on how the value proposition is detailed. Motives to buy the professional machine currently include sturdiness, long lifetime and user friendliness. In an access model the sturdiness and user friendliness are expected to still be important and consumers are expected to be willing to make concessions regarding the aesthetics of the product. Especially, because a washing machine is often not located at the most visible location of the house. In pay-per-use models, the offer becomes 100% service based, which means that the expectations of that service are likely to be high. It should be easy for consumers to understand and use the service.

The main medium of communication with the end-users will be an application for the smart phone. The basic lay-out for this app can be copied from other connected devices Gorenje developed for their daughter brands. The ambition of the company is to take the position of a laundry expert, offering its customers information about the best way to wash. One way in which this can be supported, is by tracking the usage of the machines. Another possibility is to offer upgrades for the washing programs, to also meet the changing needs of the user, for example in the case of family expansion. A decision should be made whether these functions are to be bought, earned or made freely available.

For the second and third tiers there is an extra challenge when it comes to user acceptance, since the machine already has a use-history. A summary of topics influencing the consumer acceptance of product-service systems are listed in Table 8, divided into the categories: price, product/service, consumer and relationship with the company (den Hollander 2018, adapted from Antikainen et al. 2015). These factors need to be carefully evaluated and if needed, taken actions on in the design of the product-service system. Take for example, managing the state of returned machines. A standardized check-up could be relevant here, between machine collection and delivery at another customer. Or certain incentives, like rewards, to the existing user to encourage them to take good care of the machine. Another way to convince the customers it by pointing out the benefits, by for example sharing an evaluation of the environmental, social and economic impact of the service.

Factors influencing customer acceptance of PSS-based business models	
Category	**Factor**
PRICE	Perceived fixed and variable costs; insight in total lifecycle costs
	Price of products; costly offers tend to be most successful
PRODUCT/SERVICE	Perceived relative advantages compared to alternatives
	Availability wherever and whenever needed; convenience
	Transaction costs (time and money)
	Quality of the PSS, reliability

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

CONSUMER	Habits as an obstacle to acceptance
	Issue of ownership
	Environmental attitudes, may have relatively little importance
RELATIONSHIP WITH COMPANY	Reputation, image
	Uncertainties, risks, costs and responsibility
	Communication between supplier and consumer

Table 8 Instance level factors influencing customer acceptance of PSS-based business models (den Hollander 2018, adapted from Antikainen et al., 2015, whom adapted from Rexfelt & Hiort af Ornäs, 2009)

Tiers 1-3 take as a starting point the use of a washing machine for a period of five years, but users are free to use the washing machine for a longer, or a much shorter, period of time. Considerations from the customer's point of view, and the required actions from Gorenje's point of view, can be made visible using a customer journey map, like in the example of HOMIE shown in Figure 8 (*Gonzalez Sanchez, 2017)*. Shortening or lengthening the access period of a washing machine should be experienced as a hassle-free moment for the consumer, without any unnecessary interference of the company. At the end of the third tier, or at the end of 15 years, the washing machine is expected to reach its end-of-life. At this point a decision can be made whether or not to sell the washing machine to the last user, continue the operations as-is, or to ship the machine back to the manufacturing plant for parts harvesting and recycling end-of-life has been reached.

One of the challenges HOMIE sees an a priority in their business, is how to keep consumer satisfaction high, while keeping changes to the physical product at a minimum. Developing a product with timeless design, durable technical specifications and cutting-edge innovations increases the potential for the product to last. However, consumers are also sensitive to irrational considerations, like wanting something new or different after a certain period of time. Therefore, the success of the service, depends on the flexibility of the service to keep the users emotionally engaged and attached.

4.1.4.3 Service network design

For the service to run smoothly, Gorenje should consider which partnerships are important to develop. The ability to react within certain time boundaries, when for example a machine requires maintenance, is expected to be key. Carefully managed aftermarket services have an effect on the loyalty of customers as well as the perceived brand value. Therefore, at this moment, the technicians who execute these services operate under a licensing agreement with Gorenje. In Slovenia time required for servicing is on an average 1.5 days. All servicing data is collected and shared with the quality assurance department. Activities within the warranty period are in place in the form of repairs or replacement of faulty parts. Depending on the region the company offers a warranty ranging from two to five years.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

HOMIE points out the changed company role when offering access models. To guarantee a good service experience to the user, the service needs to be flexible and should be executed as quick as possible. To fulfill this brand promise, HOMIE organizes the forward logistics in a fragmented way, by the following steps:

- Product are purchased from the distributor
- A service provider takes care of installing the tracker in the machine
- The machine will be installed at the customer by a logistics partner, using the HOMIE brand
- Reverse logistics are organized in different ways, depending on the cause for picking up a machine as well as the moment in time.

Fragmenting forward logistics allows HOMIE to offer high quality to the client and to make efficient use of the partners their skills.

4.1.4.4 Pricing strategy of the service

A feasible price range for the tier 1-3 offers depends on combination of several factors: willingness to pay, efforts from competitors, the total cost of ownership, and the ability for the company to make a profit. Even though this section is investigated into more depth in WP 2, this is a valid input for the consecutive task in WP 3, task 3.2, and is therefore mentioned in this report.

In case of scenarios when customers fail to pay, HOMIE highlights the importance of marking the machines so that it becomes clear the company owns the machine, not the home owner.

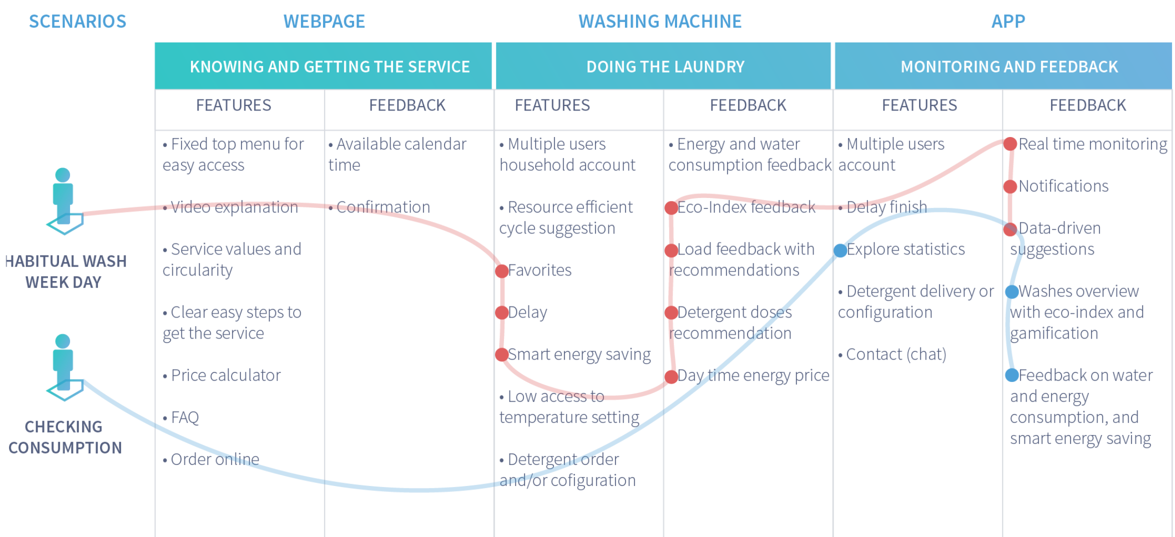


Figure 8 Customer journey map: HOMIE (Gonzalez Sanchez, 2017)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

4.1.5. Product design

Based on interviews with Gorenje, the following product design activities are currently in place that have relevance for the development of the pay-per-use offer: product roadmap, design and branding, product architecture, standardization, product returns and design capabilities.

4.1.5.1 Development of new washing machines

A new generation of washing machines is introduced every six or seven years. At the start of the development of a new product, the product development team at Gorenje is provided with a roadmap. The roadmap is a combination of all aspects which need to be considered for the development of a new product, with input from the R&D and brands departments. The roadmap indicates deadlines for the development of new products as well as the timing for introducing new generations. The selected set of product functions in the roadmap can for instance be a combination of competitor's solutions for non-technical features which are interesting to mirror, as well as the R&D input, with new functions developed in-house. Product development for pay-per-use models are likely to require their own roadmap, given that these products need to be designed for three consecutive target groups.

HOMIE sees the role of the physical product changing, when applied in access models. In these models, companies are not bound to the contemporary way of designing products for sales. Product can be viewed much more as platforms for parts, both used and new, instead of producing new products only. Access model allow bringing back used parts into the manufacturing processes of newly assembled products, since a company never sells the ownership of these products. Besides, when designing product platforms, upgrading parts to obtain a sense of newness for the user, is easier to manage.

4.1.5.2 Product specification

The product used for the pilot, the ASKO semi-professional washing machine, is a coin-operated product developed for the professional market. For the pilot, the coin operator will be removed and replaced by a standard consumer interface and the machine will be connected to wi-fi using a wi-fi module. The user can access the functionality of the machine through a smart phone. The appearance of the machine is inspired by Scandinavian minimalistic design. The product was awarded 'best in class' at the RedDot awards 2017. Additional specifications of the machine:

- The machine is a semi-professional machine. This means that the durability is as high as a fully professional machine, with the exception that a professional machine usually has a capacity of 30 kilos.
- The machine can weigh the load, but not before closing the lid. The load will be communicated in the app.
- The new model will have a wi-fi connector built in.
- The new machine will be equipped with the functionality to share the usage of the machine with other users, outside of one household.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

4.1.5.3 Embodiment design

The different Gorenje brands each have a unique brand positioning, different aesthetics and materials are used. Even the pattern on the inside of the drum is part of the branding, and this means that drums are not interchangeable across brands. The design for the pay-per-use washing machines require their own form language as well. This form language needs to be designed in such a way that it is still attractive after 10 years of use. A design challenge here, is whether the form language should convey a specific message or experience, other than washing machines which are sold to consumers. What HOMIE sees as an opportunity, is carefully selecting the materials used for the user interfaces, so that use traces are prevented. This improves the customer acceptance, and therewith has the potential to lengthen the total lifetime of a machine.

Gorenje collects information regarding the lifetime of different parts. This data is used when designing new products, specifically for designing the product architecture. In the product brief, the duration the washing machine will be available on the market is determined. According to the required lifetime of the washing machine, the parts making up the machine are selected. The selected parts and components have a lifetime similar to the washing machine. For products designed for pay-per-use models, it is in the benefit of the company to design all parts for a long lifetime, at least 15 years. Moving parts and parts prone to wear, can be designed for an even longer lifetime.
The product is built up in such a way that it is easy to repair, because of the relatively long warranty. Since it is relatively costly to repair, the time needed to perform this task needs to be reduced to a minimum. Especially the time to disassemble the product is crucial. Designing the product in such a way that it is easy to repair, is even more important when offering products in a pay-per-wash model. The cost for repair in this case is not paid by the customers, but by the company itself.

4.1.5.4 Design for product recovery

Design changes are required to make a product's design more circular. Often the costs of design changes are the main barrier for implementation. Gorenje provided the example of designing modular products, which is one of the pointers in the ResCoM tools. If you develop a circular design specification and apply this in 10 million appliances, but only 1% makes use of this specific function, the investment for design changes is relatively big. Therefore, Gorenje mentions, that when applying modularity in the hardware of a large-scale environment, the investment becomes too high. On the contrary designing upgradability in the digital offer does offer an interesting opportunity, since it does not come with similar production costs. Regarding the hardware, re-use of the components is a more interesting topic and less costly to execute. This is already being done to a certain extent. However, interchangeability of parts through standardization is only used for the parts invisible to the customers, to maintain the distinctiveness amongst different machine types. If this is not done carefully, consumers might mix up the different channels, positions and expectations of the different machines. For example, the fit and finish is expected to be different for a mid-platform than for a superior platform.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

4.1.5.5 Design capabilities

Most of the design capabilities are already in-house. Gorenje has design teams in Sweden and in Slovenia. For the pilot product, some adjustments are needed. During the project it will become more clear what types of design changes should be made for the future pay-per-use generation machines.
Design for recycling and design for reparability are already incorporated in the product development process. Relevant design input is collected during team meetings with repair technicians, supplemented with feedback from the market. These design changes become effective for the next product platform.
The development of mechanical tools for the production process, is exclusively done for the most complex systems at first, and later on, adjusted with tool inserts for the less complex products.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

4.2. Automotive spare parts demonstrator

The following section provides an overview of the data collected through interviews and observations, for the combined case of Bosch and C-ECO, at the remanufacturing facility of Bosch in Göttingen, Germany, during an on-site visit in October 2018.
The core activity of Bosch is to produce car parts for car manufacturers. Besides producing new parts, the company also produces remanufactured parts for the automotive aftermarkets at the point production of new parts stops. Several key facilities are located in Göttingen, Germany. That is, the remanufacturing plant for rotating electrical parts, but also the central sorting location for Germany and a main core warehouse of the CoremanNet service network.
There is also another major remanufacturing plant in Jihlava, Czech Republic for the diesel parts. The headquarter of the Bosch Automotive Aftermarket division is located in Karlsruhe.
C-ECO offers an international reverse-logistic-service for used parts under the brand 'CoremanNet', with a simple and reliable return process including compensation of financial incentives, to the automotive spare parts market. The services of C-ECO are not bound to one industry, however, C-ECO has many years of experience and deep knowledge of the automotive industry, so for the course of this project, the automotive industry will be the target industry.

4.2.1. Objectives

The objective for this case is twofold, coming from both participating companies Bosch and C-ECO. From the point of view of C-ECO, currently, the existing models and platforms are servicing the remanufacturers and the relationship between them and the first trade level stakeholders. Then, first level traders they have a different model between them and the second trade level and so on. Additionally, every remanufacturer has a different way to handle cores with different contracts with the first level trader, which is increasing the complexity. Therefore, the core focus is setting up a cloud-based portal. The goal is to structure reverse logistics in a cost and time effective way, with less complexity for all the involved parts. This way the stakeholders are enabled to transfer the right to return with the sale of the exchange reman part. This also enables outsourcing core handling activities.
Supportive to this portal, is the second part of the objective, proposed by Bosch, which concerns data collection of cores. This data can contribute to the quality and effectiveness of the proposed platform.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

4.2.2. Requirements of cores collection at Bosch

The decision whether or not to remanufacture certain cores is dependent of several core-related factors and is not decided at the start of production. Even when cores of a certain car part are being collected and stored in the warehouses, the decision to remanufacture is not necessarily been made. The reason for this, is that developing a remanufacturing platform, the plan describing how to execute remanufacturing for a specific part, is time-consuming and will only be done in case there is sufficient demand for remanufactured products and sufficient volume collected cores. The minimum volume of required cores to let the process be feasible depends strongly on the product group. Occasionally, pilot production lines are set up, requiring an additional 100 cores, to determine the best way to execute remanufacturing. Generally, sufficient demand can be reached best with an original equipment servicer (OES) customer. However, again depending on the product, sufficient demand can also be reached with other customers. Thorough data collection is expected to increase the number of usable for remanufacturing cores and therefore can intensify remanufacturing production.

Depending of the type of product, the decision will be made to starting up remanufacturing production before end of series (=end of new part production) or after. The actual remanufacturing production starts after end of series (=end of production), 7-8 years after the start of series (=start of production) (Figure 9), because this is the point where the costs price of spare parts starts rising. Cores are only eligible for remanufacturing in case the core was taken out of the car within five years relative to its production date. It is important to keep track of the time a part has been in a car, since it determines whether the part may be remanufactured.

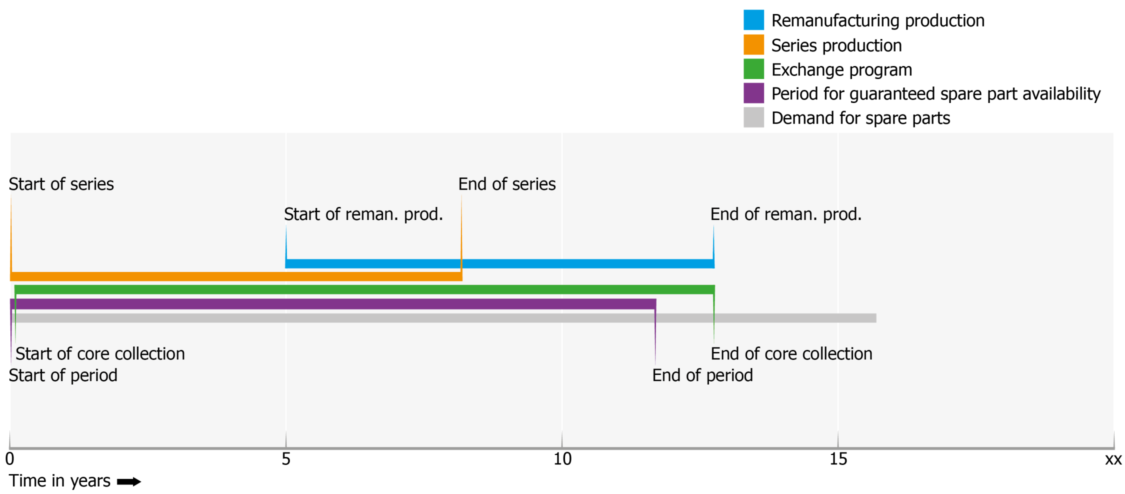


Figure 9 Manufacturing and remanufacturing production timeline

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

4.2.3. The problem statement regarding the reverse logistics of cores

Currently, reverse logistics for the automotive aftermarket usually take place via the exact same route as the forward supply chain. The forward supply chain exists out of an OEM on one side of the chain, and a car technician, serving a car owner, on the other side of the chain. In between these two ends, numerous buying groups, wholesalers, distributers and jobbers take in their place, from more centralized parties to decentralized parties, located closely by the workshops.
Reverse logistics can be divided into three different types of flow: logistics of physical cores, informational flows and financial flows, of which the latter two can take place via a digital medium. Logistics of physical cores, simply put, is the transportation of a core from point A to point B. The informational stream contains data related to the technical specifications of the core (type, model, series, production date, etc.), quality of the core, and after the project the following destination of the core (hub, warehouse, plant, etc.) or to the next trade level. The financial stream contains information about agreements regarding the exchange of parts and their accompanying deposits, in accordance with the contracts that remanufacturers sign with their customers. Buyers of remanufactured parts get charged with an extra fee, a deposit, additional to the sales price, giving them the right to return a core under certain criteria by the remanufacturer that the core must comply. These criteria are the minimum technical requirement which ensure remanufacturability of the core. Only when the core corresponds to the return criteria, the remanufacturer accepts it and the deposit is paid to the customer.
Decoupling the informational and financial streams from the physical reverse logistics, gives the entire value network access to information of all available cores and allows transactions with trade levels which are normally out of reach. The other effect is that the cores can be transported straight from the seller to its final destination, without having to pass all the trade levels positioned in between, reducing the reverse logistic costs and saving significant time and effort for all the intermediates. Summarizing, an online platform allows more freedom to all buyers and sellers of cores, to shift focus to sales of new and reman products and at the same time avoiding core handling, which is sometimes a hassle and/or inconvenient. By today, the only way to return a core against the financial incentives is to return it to the one who sold the remanufacturing unit. Within the project, the aim is to enable all the users of the ReCiPSS platform to exchange cores and obligations for financial crediting, without limitation to the initial sales transaction.

4.2.3.1 Set-up of the ICT service

The earlier mentioned online platform resembles the financial stock market with put and call options, and therewith acts like a clearing-house between two parties, see Figure 10. Through the implementation of such a system, various obstacles are resolved. Firstly, it takes away excessive core diagnostics and evaluation, which currently take place at every single trade level, after every single transaction. With that the risk of core rejection by the next trade level, while the intermediate accepted it from the previous trade level, decreases significantly.
Secondly, the complexity of information regarding core management is reduced. The high numbers of core transactions are challenging for the intermediate, as they have to keep track of to whom they have to return the core in order to receive the deposit. The

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

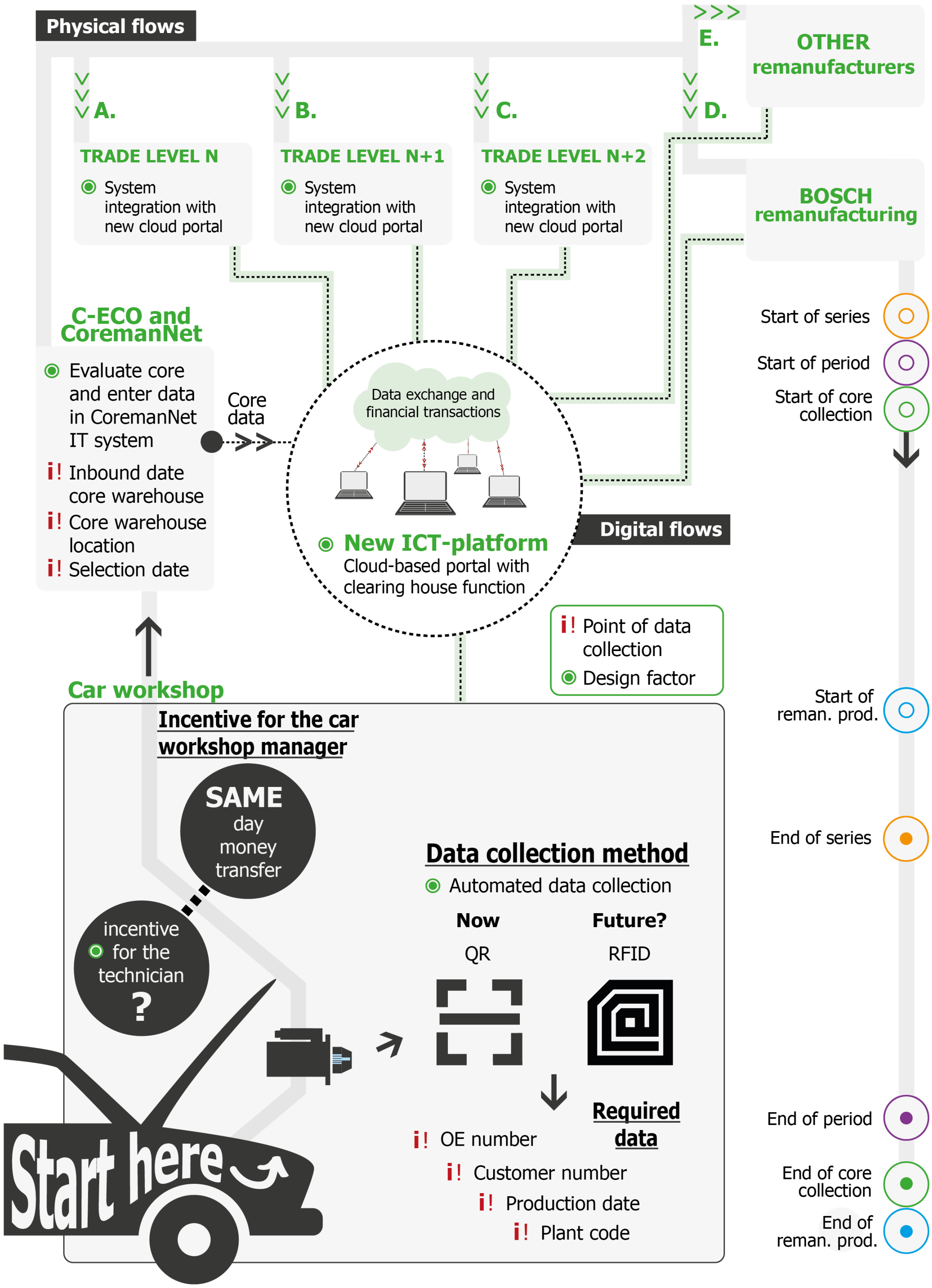


Figure 10 Automotive demonstrator infographic

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

platform will provide information about the open and used return options to different traders, and will also allow transfer and creation of return options. Additional issues, like irregularities of diagnostics, stains from handling cores with use traces and fractioned reverse logistics, are also addressed and resolved.
Besides, with the use of improved data collection of cores, more accurate estimations can be made on their potential for remanufacturing, preventing unnecessary waste of cores and allowing remanufacturing projects to be calculated on a more secure basis. An additional benefit is gaining insights in the core's history, allowing more accurate decision making for remanufacturing. The challenges this demonstrator faces, are presented in Table 9.

Design factors	
Service characteristic	**Design considerations**
The novelty of the service - The cloud-based portal, including its function needs to be designed from scratch.	All facets of the service need to be developed and designed, including all layers of informational complexity, onboarding of customers, teaching users how to use the service as well as the user interaction.
The target customers - Even though the target segment is defined, it remains unclear which companies exactly make up the trade levels, and therefore the specific needs are unknown.	The functions of the service and the user experience are largely based on the needs and wished of the future users and stakeholders, which are in the process of being identified.
Market introduction - The service product which will be created needs explanation to the customers and it will difficult to introduce it to the market. The market is not that open to changes. Competitor of the new product will be the local/ in-house solutions which are developed by the stakeholders so far.	A strategy for market introduction and onboarding needs to be carefully designed, in order to reach the intended impact of the service.
IT system - Besides developing an IT system, robust enough to handle considerable informational and financial transactions, a solid integration of IT systems throughout the value chain is needed as well.	Part of the service as such is the integration of the service with the customer's IT systems. The possibilities for integration need to be explored, as well as the way to inform and convince the customer to execute the procedure
Data collection technology - The requirements and conditions to the data collection technology for cores require careful consideration. Data which will follow the core at its whole life are difficult to be collected.	The interaction of the product with its context needs to be determined, integration of the data in the IT system, the presentation of the data and type of data relevant to each stakeholder.

Table 9 Automotive demonstrator - Design factors and considerations

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

4.2.4. Development of the service

4.2.4.1 Service design of the ICT platform

Keeping in mind the points mentioned in the previous section, the table below provides a description of the tasks to design the platform service (Table 10).

Design opportunities for service design	
Process attribute	**Design contribution**
Service design	Identification of the touchpoints for the service design, by creating a customer journey map. A customer journey map depicts how a user would use a service, determining its interactions with the service, and therewith supporting decision making during service design.
	Service design, including UX and UI, cloud-based portal, based on the value proposition developed for the target group and its sub-groups.
	Service design, including user interaction (UI) and user experience (UX), of the IT system for car workshop, based on the value proposition developed for this target group, to enable: - Incentives for workshop technicians to insert data in ICT platform - Incentives for workshop management to share data with ICT platform
	The service needs to be designed carefully to minimize perceived complexity and to communicate the user-specific benefits. Co-creation workshops, as a form of user-centered design, are proposed to give direction for the design process.

Table 10 Design opportunities for service design

4.2.5. Design of the physical operation of core handling

Except of the service design of the ICT platform, the physical operation of the core handling has to be changed and optimized. Nowadays, the model doesn't run with a clear circular way, but with a 'reverse-linear', as the cores are using the same route to return to the remanufacturer. For the optimization of the physical logistics the journey from the final trade level to remanufacturer has to be defined with enabling more circularity on the model and decoupling financial flows from the process and the stakeholders.

Special challenge for the physical operations is the dynamic interlink in the logistics flows and the clearing-house function, resulting from the individual allocation of return option on every particular core return. This requires an optimization considering not only core's specific data but also customer's contract parameters and commercial rules. Another challenge is that the automated decision making incorporated from the

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

clearing-house every time in the inspection centres has to be more or less on-line or pre-calculated by an algorithm.

4.2.5.1 Data collection plan

Collecting core data should take place as early as possible in the process, preferably at the car workshop. To enable capturing data from the cores, a data collection plan is needed, describing the type of data and technology required for collection. Important here is the identification of the type of data wanted and the moment of data collection, which should be as early in the process as possible. The type of data required, is data which are factual, data which cannot be altered by any of the parties involved. A condition here, therefore, is that the collection is performed either mechanically or electronically.

The data points which, according to Bosch, have the potential to add value, are the following:

- Production date
- Plant code
- OE-Number
- Customer number
- Selection date
- Inbound date core warehouse
- Core warehouse location

4.2.5.2 Technology for data collection and future opportunities

Today a one-dimensional barcode is used for the packaging of the cores. This code contains one piece of information. This could be replaced by a two-dimensional barcode, for example, a QR code or a similar data matrix code, which has the capacity to capture more data points. Critical for storing this data, is that the data should be able to move along with the parts. In other words, it should be transferable when the part is moved to a different party. In the case the data is not transferred, the party receiving the cores still needs to reassess the data. This causes extra workload and therefore can get very costly. Introducing a two-dimensional barcode is said to be feasible, when looking at the IT system. However, to label all the cores and parts, might be costly.

The Electronic Control Unit (ECU) of a car collects data about how a car is used and therefore can contain useful information for remanufacturers. In theory it could be possible to connect an RFID chip to the parts of the car with the ECU, so that the revolutions per minute for each car part can be collected. However, OEMs do not share this data with remanufacturers, since it might contain competitive sensitive data. Arguments to convince the OEMs to start sharing this data would be providing them with a business case, allowing more effective use of their products, improving the access to cores and legislation.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

5. Discussion and conclusions

5.1. Discussion

This report discusses the most topical design methodologies and their potential value in specific use contexts. These will form the starting point for the development of a more coherent design strategy for circular manufacturing systems. This section touches upon topics which are expected to influence the success of a design methodology for multiple product life cycles. What factors make a design methodology of value for a company, apart from presenting new information?

The decision to design for long use, extended use or recovery takes place in the early phases of new product development. Therefore, besides determining how these methodologies work technically, it is important to determine under which conditions a company is willing to implement these methodologies, by addressing, for example, possible tensions with current business operations that may occur as a result of applying the methods.
Another issue is the compatibility with the existing design process. Important here is to find out how to enable smooth integrating of the new information in companies' current processes.
A third point considers the training of designers and is about getting acquainted with the presented methodology, to enable time-efficient and accurate use. Design for multiple use-cycles constitutes of relatively new methodologies. It is essential to gain insight in:

1) How can designers recognize enablers and barriers for the suitability of products and/ or parts for multiple use-cycles?

2) How should designers be trained to use the proposed methodologies?

3) How should these methodologies be integrated into the existing operational design methodology?

Finally, a world of fast developing technologies can be an advantage for design for multiple product life cycles as well as an obstacle. One of the points to consider in the ReCiPSS project is the need to create a set of methods that allow for company-specific adaptations. Also, the methods should have enough flexibility to adapt to changing circumstances over time.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

5.2. Conclusion

The novelty of the services that will be developed in this project, requires the participating companies to develop a range of new capabilities. Design methodologies for multiple product life cycles can assist them in this. Where both OEMS are very experienced in the development of physically durable products, opportunities lie in the development of products for emotional durability, value creation through extended lifetimes and product recovery activities, with a strong focus on the strategic and user-centered aspects. This requires additional capabilities, where the user is put center stage. Services are more flexible in the selection of channels through which value is offered to the customer as well as their ability to change over time.

The range of methodologies presented in this report reflect the state of the art. It consists of a balanced mix of technical and more strategic oriented methodologies. Most methods are based on existing methodologies, adjusted to fit circular objectives. The main task for this project is to modernize, adapt and expand these methodologies, with the end goal is to find the right mix of methodologies for the demonstrators, and to create a toolbox that is dynamically adaptable to different corporate needs and circumstances and carefully considering the possibilities offered by the digital revolution (IoT, blockchain). This way we can turn the methods toolbox into a true enabler.

Both demonstrators are setting up new services and therefore can benefit from applying user-centered design methods like service design and customer journey mapping, to ensure consumer acceptance. A challenge for the white goods demonstrator is to design for customer acceptance of previously used machines. The automotive spare part demonstrator faces the challenge of consumer acceptance of the decoupled physical infrastructure of cores from the informational and financial infrastructure.
Moreover, efforts to improve ease-of-maintenance and repair can result in profitability on the long term for the white goods demonstrator. Whereas improved skills regarding design for attachment and trust are important for the automotive spare parts demonstrator, in their facilitation of valuable transactions by introducing an ICT platform.

The learnings and insights derived from tasks 2.1 (WP2), 3.2 (WP3) and 4.1 (WP4), related to product design, were taken into careful consideration while completing this report for task 3.1 (WP3). Successful circular economy strategies are often said to emerge from extensive interdisciplinary collaboration. Especially the cost structures are highly interlinked. In the case of design for remanufacturing, for example, the accuracy with which core returns can be managed, determines what design investments are sensible. In return, the amount of standardized parts throughout a product family or generation, might affect the costs of supply chain management. The same is true for business model. The type of business model, e.g. access or ownership, affects the maximum cost price of a product. An iterative design process is required to safeguard aligned decision making.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

6. References

[1] Achterberg, E., Hinfelaar, J., & Bocken, N. M. (2016). Master Circular Business with the Value Hill. *White paper. Financing Circular Business. Accessed from http://www. circle-economy. com/financing-circular-business*. Accessed Januari 2019

[2] Achterberg, E., van Tilburg, R., (2016). *Six guidelines to empower financial decision-making in the circular economy.* Circle Economy, Amsterdam. Retrieved from https://www.circle-economy.com/6-guidelines-to-empower-financial-decision-making-in-the-circular-economy/.

[3] Andreu, J. J. (1995). The remanufacturing process. *Internal paper from Manchester Metropolitan University, UK.*

[4] Antikainen, M., Lammi, M., Paloheimo, H., Rüppel, T., & Valkokari, K. (2015, December). Towards circular economy business models: Consumer acceptance of novel services. In *ISPIM Innovation Symposium* (p. 1). The International Society for Professional Innovation Management (ISPIM).

[5] Aziz, N. A., Wahab, D. A., Ramli, R., & Azhari, C. H. (2016). Modelling and optimisation of upgradability in the design of multiple life cycle products: A critical review. *Journal of cleaner production*, *112*, 282-290.

[6] Bakker, C., den Hollander, M. C., Van Hinte, E., & Zijlstra, Y. (2014). Products that last. *Product Design for Circular Business Models*.

[7] Balkenende, A. R., Bakker, C.A. (2018). Designing for a circular economy: Make, Use and Recover Products. In K. Niinimäki (Ed.), *Sustainable Fashion in a Circular Economy* (pp. 76-95). Espoo, Finland: Aalto ARTS Books.

[8] Brennan, L., Gupta, S. M., & Taleb, K. N. (1994). Operations planning issues in an assembly/disassembly environment. *International Journal of Operations & Production Management*, *14*(9), 57-67.

[9] Buijs, J. A. (2012). *The Delft Innovation Method; a design thinker's guide to innovation.* The Hague, the Netherlands: Eleven international Publishing.

[10] Castro, M. B. G., Remmerswaal, J. A. M., Reuter, M. A., & Boin, U. J. M. (2004). A thermodynamic approach to the compatibility of materials combinations for recycling. *Resources, Conservation and Recycling*, *43*(1), 1-19.

[11] Chapman, J. (2015). *Emotionally durable design: objects, experiences and empathy*. Routledge.

[12] Charter, M., & Gray, C. (2008). Remanufacturing and product design. *International Journal of Product Development*, *6*(3-4), 375-392.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

[13] de Aguiar, J., de Oliveira, L., da Silva, J. O., Bond, D., Scalice, R. K., & Becker, D. (2017). A design tool to diagnose product recyclability during product design phase. *Journal of cleaner production*, *141*, 219-229.

[14] Demirbilek, O., & Sener, B. (2003). Product design, semantics and emotional response. *Ergonomics*, *46*(13-14), 1346-1360.

[15] den Hollander, M. C. (2018). Design for Managing Obsolescence: A Design Methodology for Preserving Product Integrity in a Circular Economy.

[16] den Hollander, M. C., Bakker, C. A., & Hultink, E. J. (2017). Product design in a circular economy: Development of a typology of key concepts and terms. *Journal of Industrial Ecology*, *21*(3), 517-525.

[17] Desmet, P. (2002). *Designing emotions*. Delft University of Technology, Department of Industrial Design.

[18] Desmet, P. M., & Hekkert, P. (2007). Framework of product experience. *International journal of design*, *1*(1), 57-66.

[19] Ellen MacArthur Foundation (EMF) (2018a, January 1). Infographic Circular Economy System Diagram. Retrieved from https://www.ellenmacarthurfoundation.org/circular-economy/infographic

[20] Ellen MacArthur Foundation (EMF), IDEO, (2018b, December 13). Product journey mapping. Retrieved from https://www.circulardesignguide.com/post/product-lifecycle-mapping

[21] Ellen MacArthur Foundation (EMF), IDEO, (2018c, June 13). Worksheet Product journey mapping. Retrieved from https://www.ellenmacarthurfoundation.org/assets/design/Product_Journey_Mapping_Final.pdf

[22] Ericsson A, Erixon G (1999) Controlling design variants-modular product platform. ASME Press, New York

[23] Fegade, V., Shrivatsava, R. L., & Kale, A. V. (2015). Design for Remanufacturing: Methods and their Approaches. *Materials Today: Proceedings*, *2*(4-5), 1849-1858.

[24] Fischer, A., Achterberg, E., (2016). *Create a financeable circular business in 10 steps.* Circle Economy, Amsterdam. Accessed from https://www.circle-economy.com/wp-content/uploads/2016/12/finance-whitepaper-20161207-EN.pdf. Accessed Januari 2019

[25] Flipsen, B., Bakker, C., & van Bohemen, G. (2016, September). Developing a reparability indicator for electronic products. In *Electronics Goes Green 2016+(EGG), 2016* (pp. 1-9). IEEE.

[26] Flores-Colen, I., & de Brito, J. (2010). A systematic approach for maintenance budgeting of buildings façades based on predictive and preventive strategies. *Construction and Building Materials*, *24*(9), 1718-1729.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

[27] Ghanbari, A., Laya, A., Alonso-Zarate, J., & Markendahl, J. (2017). Business development in the Internet of Things: A matter of vertical cooperation. *IEEE Communications Magazine*, *55*(2), 135-141.

[28] Gonzalez Sanchez, D.L. (2017). Internet of Things for Circular Economy, design of a Pay-per-Use smart PSS eco-system (Unpublished master's thesis). Delft University of Technology, Delft, The Netherlands.

[29] Halvorsrud, R., Kvale, K., & Følstad, A. (2016). Improving service quality through customer journey analysis. *Journal of service theory and practice*, *26*(6), 840-867.

[30] Hatcher, G. D., Ijomah, W. L., & Windmill, J. F. C. (2011). Design for remanufacture: a literature review and future research needs. *Journal of Cleaner Production*, *19*(17-18), 2004-2014.

[31] Healthyprinting (2019, January 1). Cradle to Cradle. Retrieved from http://www.healthyprinting.eu/cradle-to-cradler/

[32] Hekkert, P. (2006). Design aesthetics: principles of pleasure in design. *Psychology science*, *48*(2), 157.

[33] Hollander, M. C. Den, C. A. Bakker, and H. J. Hultink. 2017. *Product design in a circular economy: Development of a typology of key concepts and terms.* Journal of Industrial Ecology 21(3): 517–525

[34] Höller, J., Boyle, D., Karnouskos, S., Avesand, S., Mulligan, C., & Tsiatsis, V. (2014). *From machine-to-machine to the internet of things* (pp. 36-37). Cambridge: Academic Press.

[35] IDEAL&CO Explore, Bakker, C., van Dam, S., Asif, F., (2017). Deliverable 3.4 Report ResCoM Design Methodology for Multiple Lifecycle Products. Retrieved from https://www.rescoms.eu/project/deliverables

[36] Ijomah, W. L., Childe, S., & McMahon, C. (2004). Remanufacturing: a key strategy for sustainable development. In Proceedings of the 3rd International Conference on Design and Manufacture for Sustainable Development.

[37] Ijomah, W. L., McMahon, C. A., Hammond, G. P., & Newman, S. T. (2007). Development of robust design-for-remanufacturing guidelines to further the aims of sustainable development. *International Journal of Production Research*, *45*(18-19), 4513-4536.

[38] Keoleian, G. A., & Menerey, D. (1993). Life cycle design guidance manual: Environmental requirements and the product system. Document reference: EPA600/R-92/226. Ann Arbor, MI, USA: National Pollution Prevention Center, University of Michigan

[39] Khan, M. A., Mittal, S., West, S., & Wuest, T. (2018). Review on upgradability–A product lifetime extension strategy in the context of product service systems. *Journal of Cleaner Production*, *204*, 1154-1168.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

[40] Linton*, J. D., & Jayaraman, V. (2005). A framework for identifying differences and similarities in the managerial competencies associated with different modes of product life extension. *International Journal of Production Research*, *43*(9), 1807-1829.

[41] Ma, J., & Kremer, G. E. O. (2016). A systematic literature review of modular product design (MPD) from the perspective of sustainability. *The International Journal of Advanced Manufacturing Technology*, *86*(5-8), 1509-1539.

[42] Mager, B. (2008). Service design. In *Design dictionary* (pp. 354-357). Birkhäuser Basel.

[43] Matsuda, A., Shimomura, Y., Kondoh, S., & Umeda, Y. (2003). Upgrade planning for upgradable product design. In *Proceedings of the Third International Symposium on Environmentally Conscious Design and Inverse Manufacturing, EcoDesign2003* (pp. 8-11).

[44] McDonough, W., & Braungart, M. (2002). *Cradle to Cradle: Remaking the Way We Make Things.* New York, NY, USA: North Point Press.

[45] Mobley, R. K. (2011). *Maintenance fundamentals*. Elsevier.

[46] Moss, M. A. (1985). *Designing for minimal maintenance expense: the practical application of reliability and maintainability* (Vol. 1). CRC Press.

[47] Murakami, S., Oguchi, M., Tasaki, T., Daigo, I., & Hashimoto, S. (2010). Lifespan of commodities, part I: The creation of a database and its review. *Journal of Industrial Ecology*, *14*(4), 598-612.

[48] Nasr, N., & Thurston, M. (2006). Remanufacturing: A key enabler to sustainable product systems. *Rochester Institute of Technology*, 15-18.

[49] Osterwalder, A., & Pigneur, Y. (2010). *Business Model Generation*. Hoboken, NJ, USA: John Wiley & Sons.

[50] Pahl, G., & Beitz, W. (2013). *Engineering design: a systematic approach*. Springer Science & Business Media.

[51] Parker, D., Butler, P. (2007)., An Introduction to Remanufacturing. Retrieved from http://www. remanufacturing.org.uk/pdf/ story/1p76.pdf

[52] Rexfelt, O., & Hiort af Ornäs, V. (2009). Consumer acceptance of product-service systems: designing for relative advantages and uncertainty reductions. *Journal of Manufacturing Technology Management*, *20*(5), 674-699.

[53] Sumter, D., Bakker, C., & Balkenende, R. (2018). The Role of Product Design in Creating Circular Business Models: A Case Study on the Lease and Refurbishment of Baby Strollers. *Sustainability*, *10*(7), 2415.

[54] Sundin, E., & Bras, B. (2005). Making functional sales environmentally and economically beneficial through product remanufacturing. *Journal of cleaner production*, *13*(9), 913-925.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

[55] Valencia Cardona, A. M., Mugge, R., Schoormans, J. P., & Schifferstein, H. N. (2015). The design of smart product-service systems (PSSs): An exploration of design characteristics. *International Journal of Design, 9 (1), 2015*.

[56] Van Boeijen, A. G. C, Daalhuizen, J. J., Zijlstra, J. J., & Van der Schoor, R. S. A. (eds.) (2013). *Delft Design Guide.* Amsterdam, The Netherlands: BIS Publishers.

[57] Vezzoli, C., & Manzini, E. (2008). *Design for environmental sustainability* (p. 4). London: Springer.

[58] Website: Ellen MacArthur Foundation (2018, January 1). Milstones. Retrieved from https://www.ellenmacarthurfoundation.org/our-story/milestones.

[59] Xing, K., & Belusko, M. (2008). Design for upgradability algorithm: configuring durable products for competitive reutilization. *Journal of Mechanical Design*, *130*(11), 111102.

[60] Xing, K., Wang, H. F., & Qian, W. (2013). A sustainability-oriented multi-dimensional value assessment model for product-service development. *International Journal of Production Research*, *51*(19), 5908-5933.

[61] Zafarmand, S. J., Sugiyama, K., & Watanabe, M. (2003). Aesthetic and sustainability: the aesthetic attributes promoting product sustainability. *The Journal of Sustainable Product Design*, *3*(3-4), 173-186.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2