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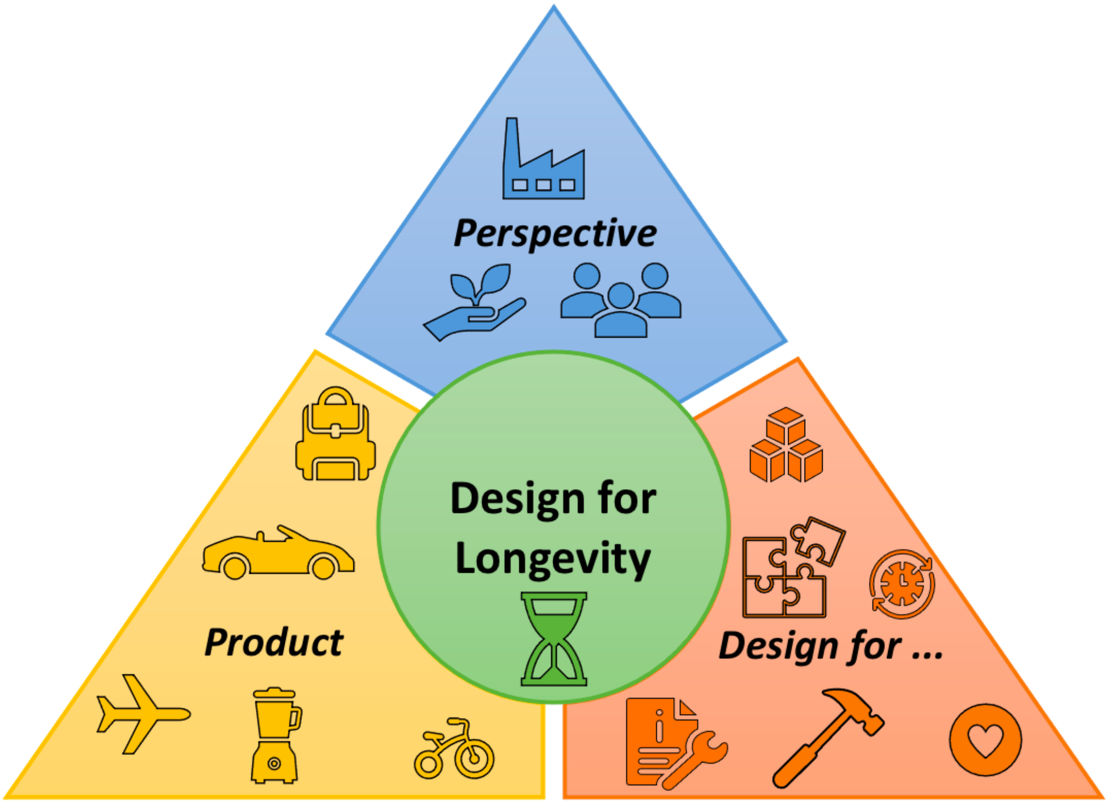

Design for Longevity - *A Framework to Support Product Developers in Identifying Products' Optimal Lifetimes*

Master's Thesis in Product Development

Simon Carlsson & Adam Mallalieu

Department of Industrial and Materials Science
CHALMERS UNIVERSITY OF TECHNOLOGY
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Abstract

This project covers the development of the complete Design for Longevity framework which can be used to aid in the transition towards a circular economy and developing more sustainable products. The project consist of several phases, including a research phase, where a literature review is conducted. In this phase it is concluded of how product longevity should be managed in order to appropriately Design for Longevity, where it more specifically becomes clear that product developers should strive to design for a specific longevity, the optimal. The optimal product lifetime can in theory be obtained by considering the three contextual aspects; the user, the business and the resources efficiency. This way of thinking is used as the basis in the development phase, where a complete theoretical Design for Longevity framework is developed. The developed framework consist of a wholesome definition and mindset, along with a process and visualization tool to support the implementation of it. This framework is later evaluated in the evaluation phase, using semi-structured interviews within the Automotive industry, where several possible improvements are obtained. These improvements are resolved in the creation phase, resulting in an mediating implementation tool, the *Design for Longevity Guide - A developed guide to ease the implementation of Design for Longevity.* The Design for Longevity Guide is then validated in the validation phase, using a combination of a case study and a focus group within the Automotive industry. This entails the possibility to conclude that the Design for Longevity framework works both in theory and in practice. It can either be used and applied on less complex product to obtain feasible actions and smaller improvements, or serve as a facilitation tool to reflect and discuss upon possible improvements on more complex products. The results from the research-, development- and evaluation phase are presented to academia using a scientific article, *Design for Longevity – A Framework to Support the Designing of a Product's Optimal Lifetime.*

Keywords: Product Longevity, Optimal Product Lifetime, Circular Economy, Circular Design, Product Development, Design for X, Sustainability

Acknowledgments

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SIMON CARLSSON & ADAM MALLALIEU
Gothenburg, January 2021

Preface

This master's thesis was carried out during autumn 2020 by two product development master students at Chalmers University of Technology. The project regard 30 credits and was performed at the institution of Industrial and Materials Science at Chalmers University of Technology. As the project was performed an ongoing global pandemic of covid-19 took place, which had some effect on how the project was executed due to regulations at the time (Folkhälsomyndigheten, 2020).

SIMON CARLSSON & ADAM MALLALIEU
Gothenburg, January 2021

Contents

1
Introduction

The introduction presents the background of the project as well as why the topic is of interest both for society and the industry. Then proceed with the aim and research question along with the objectives that are to be achieved after completion. Further, clarify the scope and limitations of the project along with a report outline that describes how the report is structured.

1.1 Background

In today's society, the effects of climate change are gaining more attention. From a wide range of data collected from many years of studying our planet and its climate on a global scale, scientists can determine that the environment and our global situation is changing (Nasa, 2020b). Further, our habits of living along with the consumption of energy and material have had the largest impact on the climate change (Nasa, 2020a). Therefore, the climate question is one of the main challenges that is discussed and debated in today's society, where new directives and objectives are constantly developed in order to determine how to utilize material and energy, for example, the Paris agreement (UnitedNations, 2016). This entails that governments and countries add new regulations and laws in order to meet these directives, which affects both the society and the industry. The climate change is therefore also gaining more attention, not only in the overall society, but more specifically also in today's industry. Many companies have started to reconsider and investigate how their businesses can be more sustainable, in order to stay both competitive on the market and at the same time meet the ever-evolving climate regulations. This results in a growing interest in methods and tools that industries can apply to their products with the purpose to reduce waste, and use material and resources in a more sustainable way. Circular economy is a topic that has gained a growing interest both in academia and in the industry in recent years, and is argued to be a strategy that companies should aim for in order to be more sustainable and meet the coming climate directives (Stahel, 2016).

The linear economy is currently more common than circular economy in, society, and in industry (Stahel, 2016). Hekkert et al. (2017) explain that linear economy can be seen as that products are purchased, used, scrapped and then turned into waste, meaning that the material has an linear flow. Whereas circular economy can instead be seen as that products are purchased, used and then passed on, meaning that the material is reused, and thus have a circular flow or closed loop. This entails that the utilization of material, or resources, are more sustainable in a circular economy. Today, many companies have not realized the business opportunities with a circular economy, which may depend on various number of factors. One could argue that many are comfortable working in the traditional way, where a transition from a linear economy toward a circular economy would most likely demand adjustments in their business models (Stahel, 2016). There is therefore a need for developing strategies and methods that can facilitate the process of increasing the circular mindset for companies. One of the issues today is that circular economy is regarded as an umbrella term, meaning it is rather vague and widely defined (Blomsma & Brennan, 2017; Bakker et al., 2014). However, a commonly used framework is the 9R Framework (Potting et al., 2017). This framework proposes nine strategies that can help companies to increase circularity, illustrated in Figure 1.1.

Circular Economy	Strategies		
Linear economy Rule of thumb: Higher level of circularity = fewer natural resources and less env-ironmental pressure Increasing circularity	Smarter product use and manufacture	R0 Refuse	Make product redundant by abandoning its function or by offering the same function with a radically different product
		R1 Rethink	Make product use more intensive (e.g. through sharing products, or by putting multi-functional products on the market)
		R2 Reduce	Increase efficiency in product manufacture or use by consuming fewer natural resources and materials
	Extend lifespan of product and its parts	R3 Re-use	Re-use by another consumer of discarded product which is still in good condition and fulfils its original function
		R4 Repair	Repair and maintenance of defective product so it can be used with its original function
		R5 Refurbish	Restore an old product and bring it up to date
		R6 Remanufacture	Use parts of discarded product in a new product with the same function
		R7 Repurpose	Use discarded product or its parts in a new product with a different function
	Useful application of materials	R8 Recycle	Process material to obtain the same (high grade) or lower (low grade) quality
		R9 Recover	Incineration of materials with energy recovery

Figure 1.1: The 9R Framework (Potting et al., 2017).

Several strategies are included, where product lifetime extension is illustrated as a solution in the transition towards a circular economy. However, instead of striving towards pure product life extension, this project intends to argue that product developers should strive towards a specific product longevity, such as an optimal product lifetime. Optimal product lifetime or longevity, is something that is and has been troublesome to define but nevertheless of interest for product developers to define or find for a long period time (Van Nes & Cramer, 2005). This is a task that can be argued to be difficult, since an optimal product lifetime depends on many different factors; product, industry, business model, users, only to mention a few. However, the standpoint within this project is the belief that this can be achieved if product developers can actively consider the key aspects and design for this specific longevity.

Design for Longevity (GlobalFashionAgenda, 2020) is a strategy that is currently being used within the clothing industry, where it is said to be the single largest opportunity to reduce the overall environmental impact of clothing. This concept or strategy is far from well-known or nisched within academia or industry. There does not exist any definition of it on a more general note, where it could aim towards any product, or any industry.

The automotive industry is an industry where the introduction of product service system, or functional selling is increasing, where companies such as Volvo Cars are introducing car fleets for common share, where the ownership still lies within the company. For e.g. Sunfleet and Volvo car mobility. This makes Design for Longevity in particular interesting for this industry, since their current product longevity is designed and optimized for their current setting. Introducing a new business model would most likely change that specific longevity. The automotive industry is also one of the single largest industries, meaning it is of interest to guide this industry towards a more circular mindset, thus Design for Longevity. Furthermore, Marcus (2020) argues that up to 80% of the environmental impact of a product can be affected at the design stage, which makes the automotive industry more relevant. There is currently a technology shift, where electrified platforms are being introduced. This can increase the possibility to implement design changes, or a more circular mindset, on platforms that still are in the development phase or at least in the early stage of the product's life.

1.2 Aim and Research Question

As previously touched upon, product longevity, or more specifically designing for a specific longevity can help companies in the transition towards a more circular mindset. In a larger time frame this would benefit both them, and the society. Design for Longevity is currently limited to being used in the textile industry only. The aim of this project is therefore to develop a complete framework [1] that helps companies to Design for Longevity, given any product, and any industry. This in turn entails in the following research question.

- What is Design for Longevity, and how can it in practice be used by product developers to design products with an optimal lifetime?

This research question is rather broad, and could be divided into several sub-questions, which is addressed by formulating several main objectives that are to be achieved.

1.3 Objectives

Four main objectives for this project can be formulated from the aim of the project, and they are presented below.

1. Increase the knowledge of product longevity together with how a Design for Longevity framework can be used to embrace a more circular mindset, and thus design more sustainable products.

[1] Framework - Noun: A system of rules, ideas, or beliefs that is used to plan or decide something (Cambridge, 2020)

2. Increase the usability of Design for Longevity, such that it in theory can be used to design more sustainable products.
3. Increase the usability of Design for Longevity such that it in practice can be used to design more sustainable products.
4. Increase the knowledge of Design for Longevity and its usability within academia.

1.4 Scope and Limitations

The project progress over a defined period of time, and with this in mind, both limitations and delimitations are applied in order to meet the aim of the project. In addition, alongside the project a global pandemic of covid-19 is taking place, which affects both the society and industry (Folkhälsomyndigheten, 2020). It entails that restrictions regarding social distancing is needed to be taken into account during the project. This project is also both restricted by Chalmers University of Technology's own restrictions, as well as the restrictions provided by the Swedish public health authority (Folkhälsomyndigheten, 2020).

One of the main objectives of the project is to increase the knowledge about Design for Longevity in academia, which more specifically is done via a scientific article for the conference: International Conference on Engineering Design 2021 (ICED21). This conference will take place in mid-august 2021 in Gothenburg and Chalmers University of Technology is the organizer for the event this year. The first draft of the scientific article had a deadline of the eleventh of December 2021, for it to be reviewed and graded. Thereafter does the ICED21 committee decide if the article will be included and published at the conference. This report and the scientific article are based on the same material but the article only includes three out of five of the projects phases. The scientific article is restricted to only nine pages and is focused on the results from the project, whereas the report includes all parts and more detailed descriptions of the whole process of the project, along with the results. It means that some of the material and text will be the same in the scientific article and the report.

The topic Design for Longevity correlates to the area of circular economy. This is a widespread expression that has several definitions and different authors use it on different levels. This project limits its research phase to only gain a general understanding of what circular economy stands for in order to develop a framework for Design for Longevity. Therefore, time will not be spent on comparing a wide span of definitions. The main focus in the research phase will be to find information within the area of circular Economy, circular design, product longevity, Design for X, and optimal product lifetime. From this, the data is analyzed and a knowledge gap within the literature is identified. But due to the amount of literature within these topics, the research phase is limited to literature that the project group considers useful and is related to product longevity or Design for Longevity, and circular design.

At the moment the automotive industry is facing new challenges in order to be sustainable and they have an important role to play in order for society to adapt towards a more renewable and eco-efficient way of working. Therefore, this project will focus on the automotive industry and all user studies are limited to only involve participants from this industry. Because of the pandemic, interviews and communication with participants from the industry will be performed online. Physical meetings will only take place if they can be performed without infringing the pandemic restrictions and all involved participants' approval. Additionally, all participants involved in the user study will be anonymous and only approved material will be presented in the report in order to not infringe on confidential material.

1.5 Report Outline

This report is divided into eight chapters in the corresponding order; Methodology and Project Process, Research Phase Results, Development Phase Results, Evaluation Phase Results, Creation Phase Results, Validation Phase Results, Final Discussion, and Conclusions and Recommendations.

The Methodology and Project Process describes the project's process along with the methods that have been used. The project process is divided into five phases: research-, development-, evaluation-, creation- and validation phase. Each phase is described in this chapter using a similar structure, where the purpose of each phase is described along with sub-objectives being formulated. This is followed by all the methods that have been applied as well as how they have been applied.

The Methodology and Project Process chapter is followed by presenting the results from each of the project phases, where each phase is an individual chapter. These chapters are structured differently depending on the content. However, they all end with a short summary, which relates to each of the defined sub-objectives formulated in the Methodology and Project Process chapter. This can be read to get a quick overview of the chapter's result.

The two final chapters are the Final Discussion and the Conclusion and Recommendations. The Final Discussion chapter is a general discussion regarding the overall project process. The Conclusion and Recommendations chapter presents conclusions regarding the project's aim and research question along with the project's main objectives, as well as recommendations for future work.

2

Methodology and Project Process: Methods and Tools Used in the Project Process

Each phase includes specific methods and tools with the purpose of reaching the main objectives of the project, presented in Section 1.3. Several sub-objectives are formulated in each phase as well, which aim to highlight necessary sub-activities for each phase. All methods that are used are well-established methods from product development in general, but the overall methodology does not follow any particular linear flow provided by one specific author. The individual methods are instead hand picked to suit the project process and methodology. The project process is illustrated in Figure 2.1.

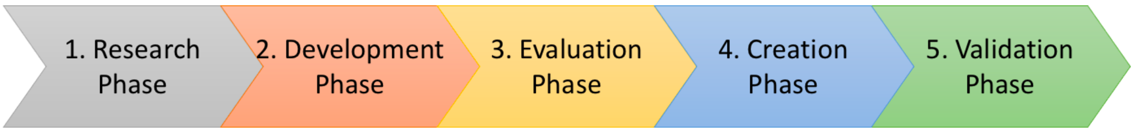


Figure 2.1: The project process.

2.1 Research Phase

The purpose of the research phase was to fulfill Objective 1: "Increase the knowledge of product longevity together with how Design for Longevity can be used to embrace a more circular mindset, and thus design more sustainable products". The first phase did in general include the collection and analysis of literature, divided into two main topics; product longevity, and product development in theory. The first topic was addressed since an understanding about product longevity was required to understand how Design for Longevity relates to a more circular mindset. The second topic was addressed to gain an understanding of what type of elements a Design for Longevity framework could include. The following sub-objectives for this phase were.

- Summarize product development theory.
- Collect a knowledge base about topics related and supporting to product longevity.
- Collect information that opposes and criticizes product longevity.
- Analyze product development in theory and conclude which elements that the Design for Longevity framework should include.
- Analyze literature related to product longevity and highlight aspects to be considered in the elements of the Design for Longevity framework.

The research phase includes four main parts, where each include different methods and tools. The four main parts are; literature review, seminars to analyze and reflect upon literature, documentation of literature, and summary and analysis of product development in theory, as illustrated in Figure 2.2. The first three parts relate to the topic of product longevity, whereas the last relates to the topic of product development in theory.

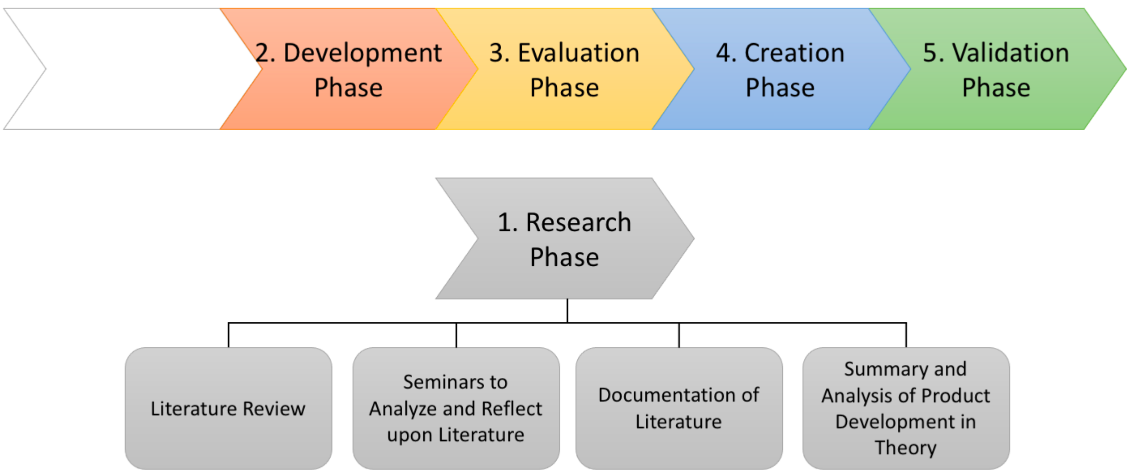


Figure 2.2: Phase 1 - Research Phase.

2.1.1 Literature Review

The literature review mainly consisted of collecting peer-reviewed publications, reports, standards and regulations regarding product longevity and related topics. The literature was collected using databases accessed through the university library. To reach the objectives the literature review started by identifying a number of relevant articles within the topic of circular economy and resource efficiency, as it branches to product longevity (Tillman et al., 2019). The snowballing method (Wohlin, 2014) was applied on these articles to methodically analyze each article to identify relevant authors and topics in order to find more material for the study. Figure 2.3 illustrates the process of how the snowballing method was applied. A snowballing method was deemed as suitable since the study was of an exploratory approach, where several aspects and prior views were to result in the redefined definition of Design for Longevity. Additionally, were internal brainstorming sessions applied to generate a wide range of keywords related to the topic that could be used as search terms to find more literature related to the topic and make sure that a wide perspective was taken into account. Some examples of generated keywords included "circular economy", "circular design", and "author X".

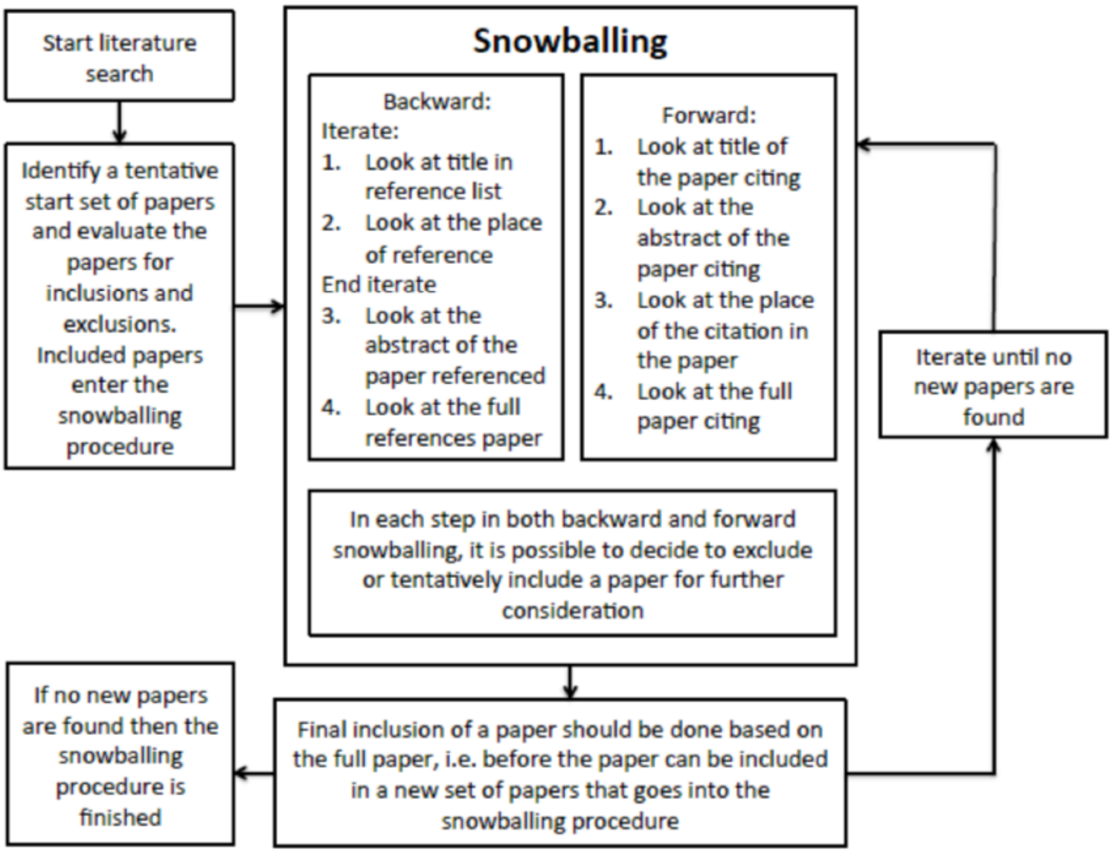


Figure 2.3: The snowballing method (Wohlin, 2014).

The snowballing method and the keywords search were continuously ongoing until the project team considered that enough literature was gathered and that several views from different perspectives had been taken into account. Two main factors determined the amount of literature that was gathered. Firstly, the project had a time limit, which meant that the research phase and this the literature review was restricted. Secondly, along the literature review the team started to consider that no new literature added more knowledge or perspective regarding Design for Longevity. This resulted in the literature review proceed for the first four weeks of the project. However, supplemental literature could be collected throughout the project, when deemed necessary.

2.1.2 Seminars to Analyze and Reflect upon Literature

To make sure that all relevant aspects and key points were taken into account after each article had been read, seminars were used to discuss and analyze the articles. The purpose was to discuss the key points and if there were any questions regarding the literature in order to make sure that the important information was collected. Each article was summarized after each seminar using a summary templace, which can be found in Appendix A. The summaries focused on concluding three things; the main points of the literature, the relevance in regard to product longevity, and the validity of each article. This was ultimately to decide on whether the material should be included or not.

2.1.3 Documentation of Literature

Due to the large amount of literature that was gathered, it was important to have a clear structure on how to save and track all the material. Therefore, a literature data spreadsheet was used in order to save and keep track of all the literature. In the document, the literature was structured into different subtopics which made it possible to visualize the distribution of read literature and if some subtopic needed more focus. Additionally, to enable tracking of the literature the following information was documented in a data spreadsheet; authors, publication title, year, type, source/publisher. In total 29 articles, 2 reports, 12 presentations, and extracts from 4 books were read, discussed, and summarized, the literature and presentation data spreadsheets containing all above stated literature can be found in Appendix B and C.

2.1.4 Summary and Analysis of Product Development in Theory

The product development theory collection was less extensive, where the information was collected and summarized by reading literature and lecture notes previously acquired and provided by the Product Development Master at Chalmers University of Technology. This theory was divided into three categories; product development processes, product development tools, and implementing product design. The analysis consisted of identifying patterns in the literature, and give indications of what type of elements the framework could consist of.

2.1.5 Output from the Research Phase

This phase resulted in an extended amount of data gathered and summarized which gave an increased understanding of product longevity and related topics, as well as a basic understanding of product development theory. Taken all together, this makes it possible to identify relevant elements and develop them into a complete Design for Longevity framework in the following phase. The generated result from this process will be presented in Chapter 3.

2.2 Development Phase

The purpose of development phase was to fulfill objective 2: "Increase the usability of Design for Longevity, such that it in theory can be used to design more sustainable products". This was mainly done by conducting iterations between concept development and evaluation, where the concepts where different elements in the complete framework. The following sub-objectives for this phase were.

- Define which elements to be included in the Design for Longevity framework.
- Define what Design for Longevity in theory means and how it can be used to design product with an optimal product lifetime.
- Develop elements that in theory can be used to Design for Longevity.
- Evaluate and improve the elements until a satisfied result is obtained.

The development phase includes three main parts, where different methods and tools were used, as illustrated in Figure 2.4. The phase consist of the following parts; idea generation of concepts, screening and evaluation of concepts, and interviews with academic experts. The three parts were conducted in iterations, and was ongoing until a satisfying result was obtained.

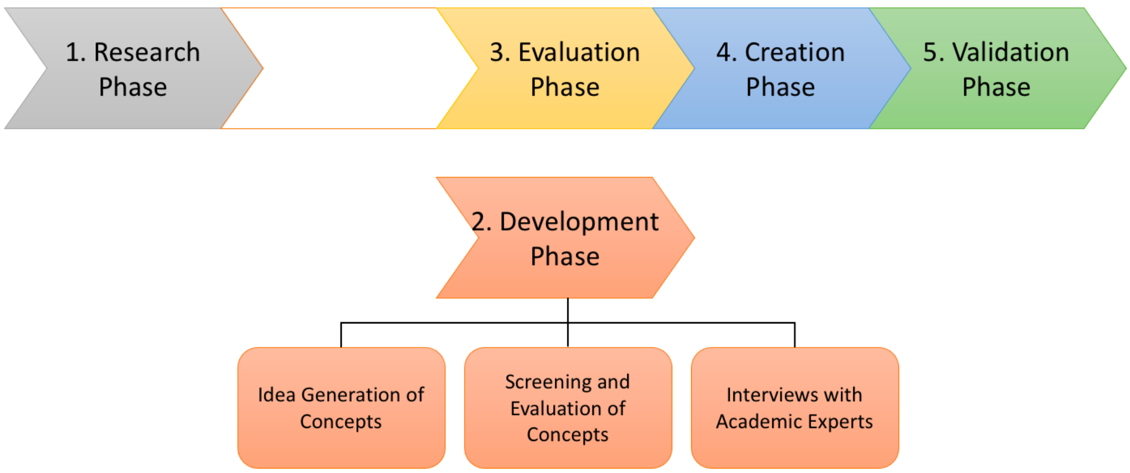


Figure 2.4: Phase 2 - Development Phase.

2.2.1 Idea Generation of Concepts

To generate a wide range of ideas of elements that could potentially be included in the final framework, several brainstorming sessions (Chauncey, 2013) were applied. These sessions were based on the material relating both to product longevity and product development in theory, which is presented in Section 3. Both individual and group brainstorming sessions were performed. The purpose of the individual sessions was to generate many creative ideas separately without being interfered by another person's opinions. The group brainstorming session's purpose was to discuss the material produced during the individual session in order to extend and improve the ideas. This was conducted in several iterations, where each iteration resulted in various concepts that could potentially be included in the complete Design for Longevity framework.

2.2.2 Screening and Evaluation of Concepts

The idea generation resulted in several concepts that could potentially be included in the final framework. The framework to be developed had several criteria to be considered, and they were used to screen concepts. The criteria focused on the framework's usability in industry, and were derived from Almefelt (2005) and Germania et al. (2016):

- How **understandable** the framework is.
- How **applicable** the framework is.
- How **extensive** the framework is to implement.
- How important **experience** is when implementing the framework.
- How the frameworks **visual design** is perceived.
- How **useful** the framework is in determining the optimal product lifetime.
- How well the framework **supports** in identifying potential design changes.

Case scenarios were used to evaluate the developed concepts of the framework within the project team. This by creating example scenarios on real products or potential business cases. Then, the different concepts were applied on these scenarios in order to analyze how well the criteria were achieved, in order to improve the concepts further. Four different scenario examples were used, and brief summaries of the cases are provided below.

- **Case 1:** A car manufacture company wants to change its business strategy, going from selling cars to customers towards instead providing a transportation service to its customers.
- **Case 2:** A company that manufacture and sell coffee brewers wants to analyze the optimal lifetime of their product.
- **Case 3:** A toy manufacture company desires to become more sustainable and therefore wants to identify their optimal product lifetime.
- **Case 4:** A car manufacture company are planning for updating their platform and want to make sure that the product is designed with the correct lifespan.

2.2.3 Interviews with Academic Experts

To gain feedback regarding the ideas and further improvements four semi-structured interviews (McIntosh & Morse, 2015) were performed with people from the academia. They had different backgrounds but were experts within the fields' product development, human factors engineering, and materials science at Chalmers University of Technology. The ideas and concepts of the framework were presented for the participants in order to gain feedback and analyze if the framework was unclear, or if something important was missing. Each interview took approximately 30 minutes.

2.2.4 Output from the Development Phase

This phase resulted in a developed framework, consisting of several elements. The framework was deemed to work in theory, but needs further testing in the industry to work in practice. The results from the development phase are presented in Chapter 4.

2.3 Evaluation Phase

The purpose of the evaluation phase was to fulfill Objective 3: "Increase the usability of Design for Longevity such that it in practice can be used to design more sustainable products". The developed framework works in theory, but that does not necessarily mean that it works in practice. This phase generally consisted of doing further and more extensive evaluations of the framework in industry. The following sub-objectives for this phase were.

- Evaluate each element in the Design for Longevity framework in industry.
- Evaluate how Design for Longevity can be implemented in industry along with its acceptance in industry.
- Analyze the collected data and find potential improvements.
- Conclude future work needed to improve Design for Longevity framework to work in practice.

The evaluation phase only consisted of one part, illustrated in Figure 2.5. Conducting a user study with professionals working in the automotive industry was used to collect data and feedback. This data was later to be analyzed in order to find improvements and evaluate its applicability and acceptance.

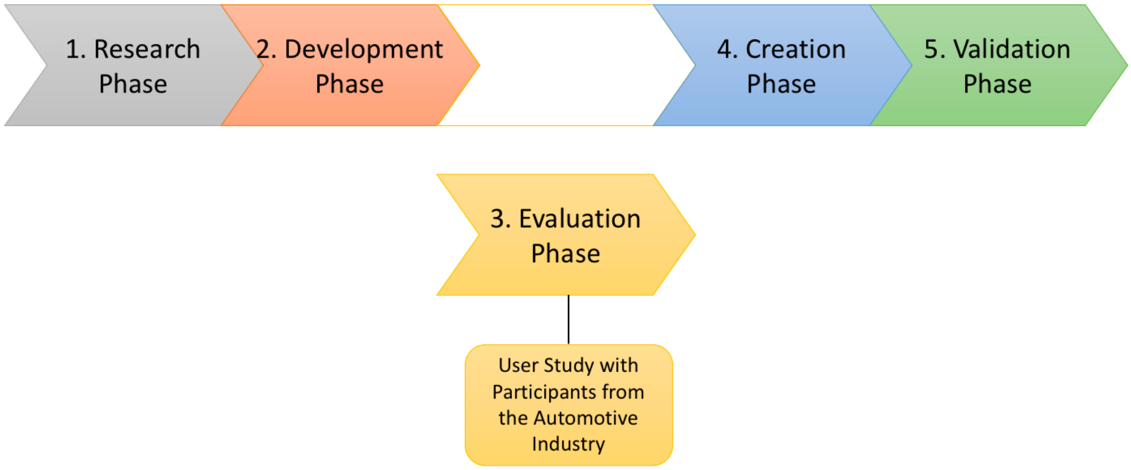


Figure 2.5: Phase 3 - Evaluation Phase.

2.3.1 User Study with Participants from the Automotive Industry

The user study was conducted by eight semi-structured interviews (McIntosh & Morse, 2015) with professionals from the automotive industry. All interviewees had engineering backgrounds but various roles within their companies, but they were all in general working with product development. A formal agenda was prepared in advance to make sure that all interviews had the same structure, and that questions, information and the case were conducted in a particular order. However, a semi-structured interview made it possible for the interviewer to control the process of obtaining information, either by following the formal agenda or follow up with new leads or topics that could arise during the conversation. Each interview was booked for 1-2 hours depending on the availability of the participant and was performed online as a precaution due to the ongoing pandemic of covid-19. This was done through Microsoft Teams, where an interactive PowerPoint presentation was used as a mediating tool to ease the communication with the interviewee. In addition, individual sensitize[1] sessions were used to prepare the interviewees before the interview took place. This involved the interviewee to read a document consisting of a small exercise and information about different design strategies, approximately 24-48 hours before the interview. The aim was to generate interest in the subject and encourage more interaction during the interview.

The interview included three main themes. The first theme included the background of the project and all involved participants introduced themselves in order to create a personal connection. Furthermore, it included questions to the interviewee regarding his or her current knowledge about Design for Longevity. After these questions, the Design for Longevity framework and its elements were explained to the interviewee. The second theme included a case. More specifically, the case was an example where the Design for Longevity framework was applied on a passenger

[1] Sensitize - Noun: To make someone familiar with something such as a problem or bad situation (Cambridge, 2021)

vehicle (Volvo V60). The main data for the case was based on assumptions and was collected before the interview. This data was used as the base material for the interviewee to discuss and reflect upon in this example case, serving as a demo on the Design for Longevity framework. Both the interviewee and the interviewers took part in the demo in order to facilitate a better discussion. The third and last theme included an evaluation, which consisted of 16 questions using a Likert scale to obtain the interviewee's attitude towards the framework (Albaum, 1997), which the interviewee's now had been introduced to. Additionally, one extra question was asked, regarding if they could consider to use this framework in the industry, to more explicitly verify its acceptance. All questions were related and formulated based on the criteria in Section 2.2.2, and the questions can be found in Section 5.1. This ensured to obtain both qualitative and quantitative data, that were later analyzed, making it possible to identify possible improvements and conclude the frameworks usability and acceptance.

2.3.2 Output from the Evaluation Phase

This phase resulted in collected data from participants in the automotive industry, which helped to verify the acceptance of the framework, along with finding possible improvements and how to resolve them. The results from this phase are presented in Chapter 5.

2.4 Creation Phase

The purpose of the creation phase was to fulfill both Objective 3: "Increase the usability of Design for Longevity such that it in practice can be used to design more sustainable products" and Objective 4: "Increase the knowledge about how Design for Longevity and its usability in academia". It became clear in the evaluation phase that the Design for Longevity framework needs to be further improved before fulfilling Objective 3 completely, which was addressed in the creation phase. Objective 4 could be fulfilled by presenting phases 1-3 in the project process to academia. The following sub-objectives for this phase were.

- Resolve the concluded improvements from Chapter 5.
- Create a mediating tool that can help product developers to implement Design for Longevity in practice.
- Present project phases 1-3 to academia using a scientific article.

The creation phase consisted of two parts, visualized in Figure 2.6, the two parts are the creation of the Design for Longevity guide and a scientific article.

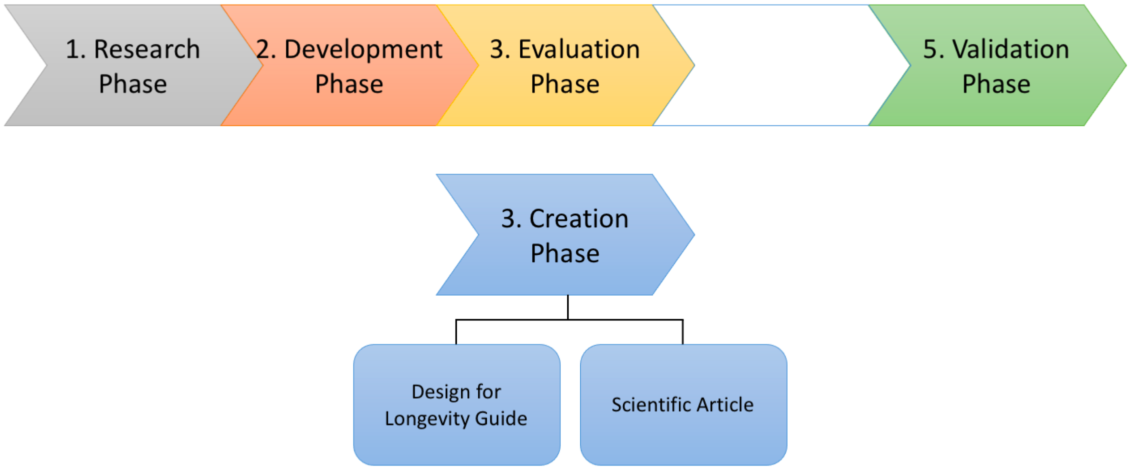


Figure 2.6: Phase 4 - Creation Phase.

2.4.1 Design for Longevity Guide

The evaluation phase identified possible improvements to the Design for Longevity framework that needs to be resolved. In the creation phase, these improvements were applied to the developed framework. The improvements could e.g. be to add more descriptions and explanations, or to clarify the elements even further. A guide was deemed as a suitable mediating implementation tool to address these improvements along with ensuring that the framework can be applied in practice, by any product developer. The developed guide were created using the same criteria as before, seen in Section 2.2.2.

The guide was created in PowerPoint, based on two main reasons. Firstly, PowerPoint it is a commonly used tool in industry, and almost every product developer knows how to use PowerPoint. Secondly, it is important that the guide can be used in a larger group, PowerPoint is sufficient because it can easily be accessed by everyone in a larger group, either on a larger shared screen, or on individual smaller screens.

2.4.2 Scientific Article

One of the main objectives of this project was to contribute with the provided knowledge of Design for Longevity to academia. This was done by presenting a scientific article, more specifically to a conference called International Conference on Engineering Design in 2021. The report and the article are based on the same material and will contain similar results. However, the differences between them are that the article has a limit to a maximum of nine pages, and therefore only contains of some parts of the project. These parts are phases 1-3 of the project process, which also are deemed as sufficient to inform how Design for Longevity can aid in the transition towards a circular economy.

The decision to only include phases 1-3 was based on two reasons. Firstly, the deadline for the first draft of the paper, was of the eleventh of December. Secondly, there was a limit of nine pages for the article. This meant that there were strict limitations regarding the amount of material that could be included. Thus, in order to make sure that the article had an even amount of text in each chapter and had a clear structure, each chapter was allocated with a determined amount of text that could be written.

The article was proofread in several iterations within the team, where the purpose was to find improvements in the text. These improvements could either imply that a sentence could be written with fewer words, or that smaller parts of the text could be re-arranged to streamline the space. The article was also sent into several internal reviews to gain feedback and opinions from other perspectives. Two professors at Chalmers University of Technology did review the first draft article before it was submitted. They both had recommendations and feedback that made it possible to improve the article.

2.4.3 Output from the Creation Phase

This phase resulted in the creation of both a scientific article and a mediating Design for Longevity implementation tool, in the form of a PowerPoint guide. The results from this phase are presented in Chapter 6.

2.5 Validation Phase

The purpose of the validation phase was to ensure that Objectives 1-4 have all been fulfilled. Objective 1: "Increase the knowledge of product longevity together with how Design for Longevity can be used to embrace a more circular mindset, and thus design more sustainable products" and Objective 2: "Increase the usability of Design for Longevity, such that it in theory can be used to design more sustainable products" was validated by discussing the literature review. Objective 3: "Increase the usability of Design for Longevity such that it in practice can be used to design more sustainable products." needed further validation where the resolved improvements was evaluated both internally and externally. Objective 4: "Increase the knowledge about how Design for Longevity and its usability in academia" was validated externally. The following sub-objectives for this phase were.

- Evaluate the credibility of the provided knowledge that contributes to the Design for Longevity framework internally.
- Evaluate the credibility of the proposed the Design for Longevity framework internally.
- Practically test and validate the Design for Longevity framework internally.
- Evaluate the mediating Design for Longevity implementation tool in industry, and conclude its applicability and validity.
- Evaluate the credibility and validity of phase 1-3 in the project process externally.

The validation phase consisted of the four parts; case study, focus group with participants from the automotive industry, ICED21 review, and internal discussions of collected literature. These are visualized in Figure 2.7.

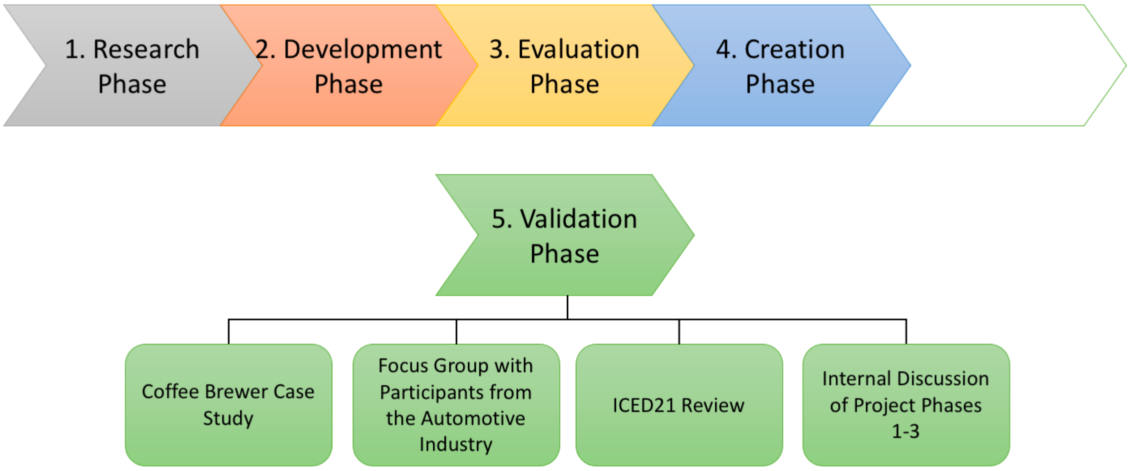


Figure 2.7: Phase 5 - Validation Phase.

2.5.1 Coffee Brewer Case Study

The first part of the validation phase included a real case study on a product where the Design for Longevity implementation tool was applied. This was done to validate the credibility of the results generated from applying Design for Longevity. It was decided that a coffee brewer would be suitable for the case study, mainly based on two reasons. Firstly, the case study was limited to two working days, and it was important that enough information regarding the product could be gathered and analyzed during that period of time. A coffee brewer was therefore considered to be reasonable since the project team had previous experience with coffee brewers' functions and components, as a result of participating in the course Maskinkonstruktion MMF092, at Chalmers University of Technology. Secondly, the participants that would take part in the focus group had expressed a desire that the case study should be performed on a product that did not relate to a passenger vehicle. Nevertheless, they still expected the case study to be on a product with reasonable complexity, where it was possible to recognize and relate to its function. Thus, a coffee brewer being a suitable product, since it contains a reasonable amount of components along with almost every person being in contact with a coffee brewer daily.

The case study was conducted by following the *Design for Longevity Implementation Process* step by step, using the created Design for Longevity Guide. This facilitated the team to reflect and confirm if the improvements from Section 5 had been resolved. After completing the study it was possible for the team to discuss and validate the results from the case internally, and thus start to reflect upon the fulfillment of main Objective 3.

2.5.2 Focus Group with Participants from the Automotive Industry

To evaluate the Design for Longevity implementation tool a focus group (Ulrich & Eppinger, 2012) was conducted with a team of people from a large actor in the Automotive industry. Five people attended the focus group physically, and three attended online through Microsoft Teams. All participants had an engineering backgrounds and worked with product development, they also had some affiliation to either the company's, innovation or sustainability department. Two of the participants had been involved during the interview sessions in the evaluation phase, whereas the rest had not seen the framework before. An PowerPoint was used as a mediating tool to present and ease the communication during the focus group. The focus group was divided and structured into three main stages. The first stage aimed to describe the background of the project and explain the developed Design for Longevity framework and its elements. The second stage consisted of presenting the Moccamaster case study, where the Design for Longevity implementation tools had been used. The third and final stage consisted of the participants to evaluate and discuss their opinions regarding the applicability and validity of both the case study, and the developed Design for Longevity framework. This generated feedback from the industry regarding the results from the case study, along with the applicability and validity of both the framework and the Design for Longevity implementation tool.

2.5.3 ICED21 Review

International Conference of Engineering Design is the world's largest scientific conference within product development. In order to participate in this conference, the article needs to be peer-reviewed through the ICED21 process and then it is up to the ICED21 committee to decide if the article will be published at the conference. Therefore, it is the ICED21 process that evaluates the validity the credibility of the article, and thus phases 1-3 in the project process. The peer-reviewed feedback on the article will be received in February or Mars, thus also the decision if the article will be published at ICED21. This part will therefore not be presented in the results.

2.5.4 Internal Discussion of Collected Literature

The results from the literature review are discussed internally in relation to the methods used, mainly since this part is not validated further within the project but in the external review performed after the project time frame. This is done to facilitate conclusions related to the projects main objective 1 and 2 fulfillment.

2.5.5 Output from the Validation Phase

From this phase, it was possible to gather information regarding the validity and applicability of the developed Design for Longevity framework, including the mediating tool to implement it. Together with the internal discussions it will be possible to conclude to which degree the project main objectives have been fulfilled, and provide potential future improvements and recommendations. The result of this phase is presented in Chapter 7. It should be noted that no conclusion about the fulfillment of main Objective 4 will be possible until after the project have finished, due to the ICED21 time frame.

3
Research Phase Results: Theory that Shapes the Design for Longevity Framework

This chapter presents the results from the research phase, which includes the methods; literature review, seminars to analyze and reflect upon literature, documentation of literature, and summary and analysis of product development in theory, they are further described in Section 2.1. This chapter is divided into the two topics product development in theory and product longevity, where collected literature is presented and then analyzed. The chapter ends with a brief summary where the results are related to the sub-objectives formulated in Section 2.1. Figure 3.1 indicates the phase position in the process.

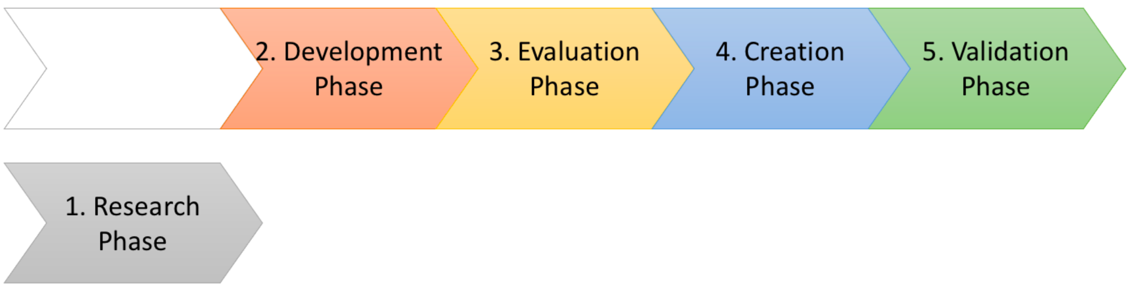


Figure 3.1: The research phase is the first phase in the process.

3.1 Product Development in Theory

The product development theory is divided into three categories; product development processes, product development tools, and implementing product design. The purpose of this theory is to generate ideas of what type of elements the complete Design for Longevity framework should include, and also perhaps where in the product development process the framework is suitable to be used. The theory does not aim to provide an explanation of what it is used for in detail, the presented theory does instead provide an overview of product development in theory.

3.1.1 Product Development Processes

Ulrich and Eppinger (2012) presents three typical product development processes, illustrated in Figure 3.2. The three processes are similar to the extent that they are all linear flows going from left to right, but with various elements in the flow, where one of the processes also suggest iterations between particular steps. This is in line with Wheelwright and Clark (1992) whom divides a product development process into phases of Concept Development-Product Planning-Product/Process Engineering-Pilot Production/Ramp-Up, also as a linear flow.

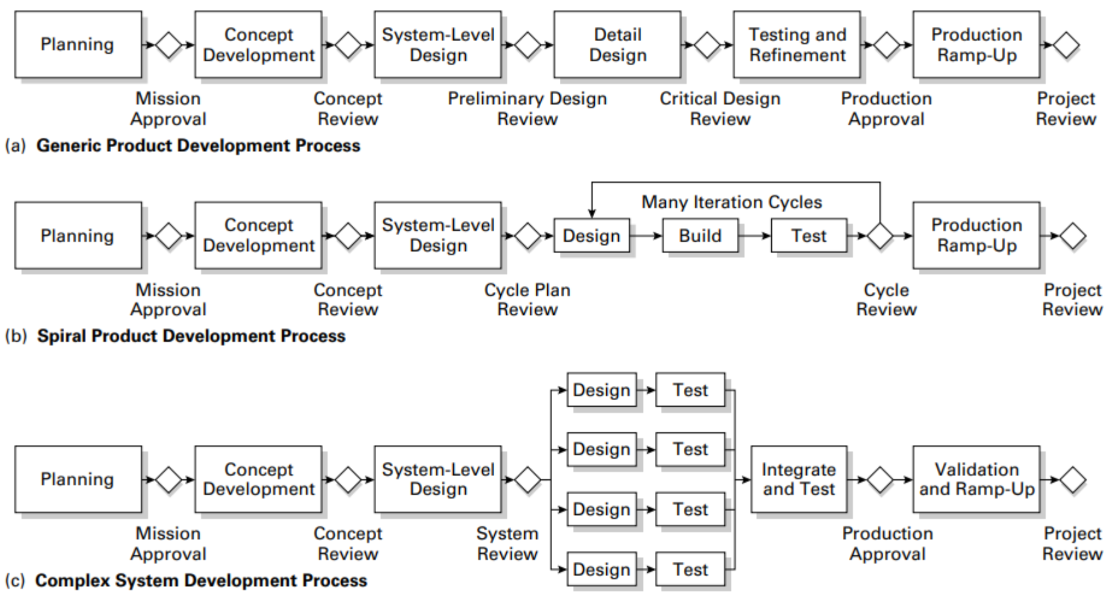


Figure 3.2: Typical product development processes, provided by Ulrich and Eppinger (2012).

Both Wheelwright and Clark (1992) and Ulrich and Eppinger (2012) discusses the concept development as a funnel process starting with several ideas which are screened down to a set of few, as illustrated in figure 3.3. To help screen down the concepts in the funnel can different tools and methods be applied to screen, score and test the concepts between each other.

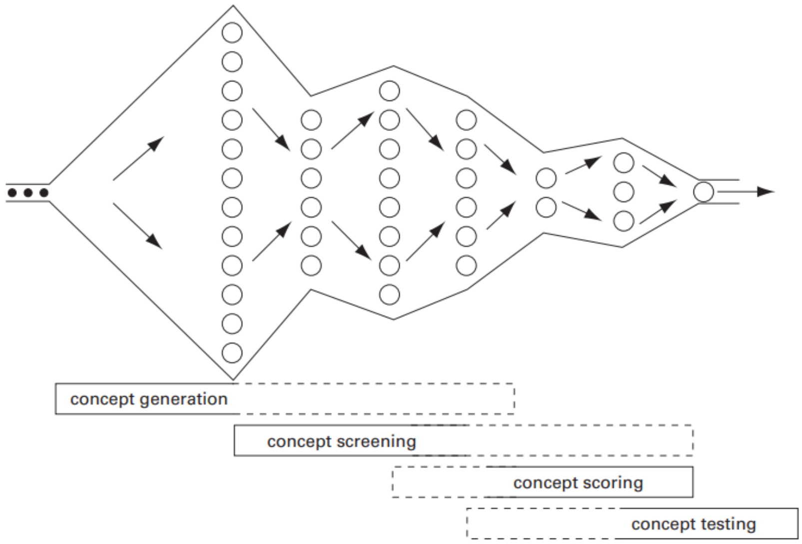


Figure 3.3: Screening of Concepts as a funnel approach, as proposed by Ulrich and Eppinger (2012).

Almefelt (2020b) highlight an issue related to the typical linear product development process, which is uncertainty. As illustrated in Figure 3.4 more information tends to be known in the later stages of a product development process, where there is less design freedom.

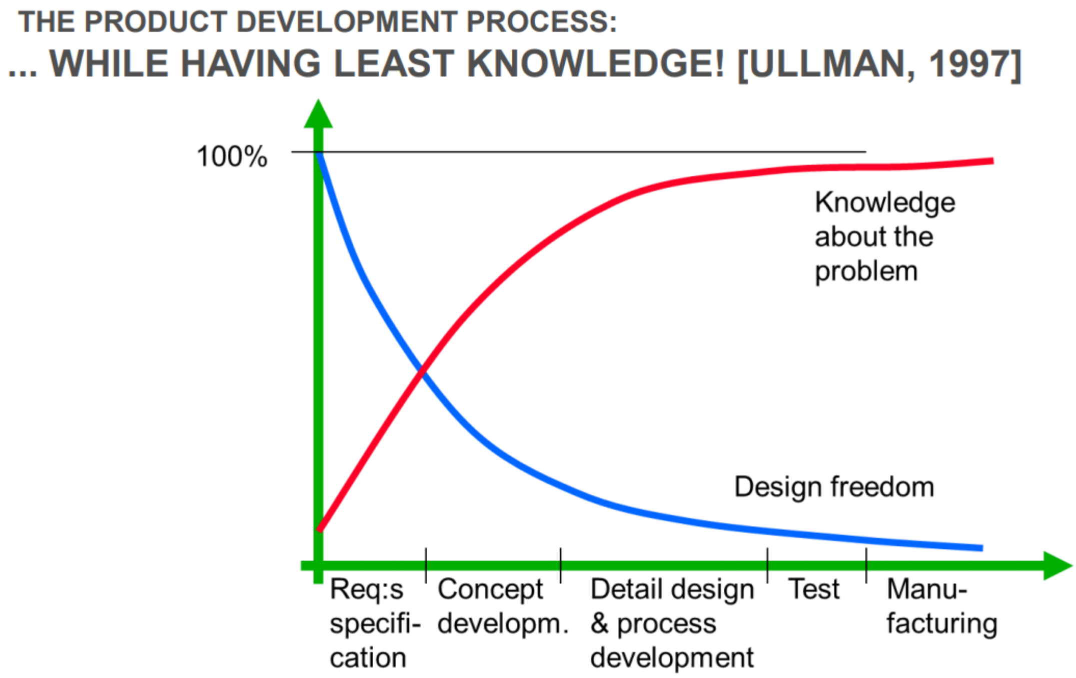
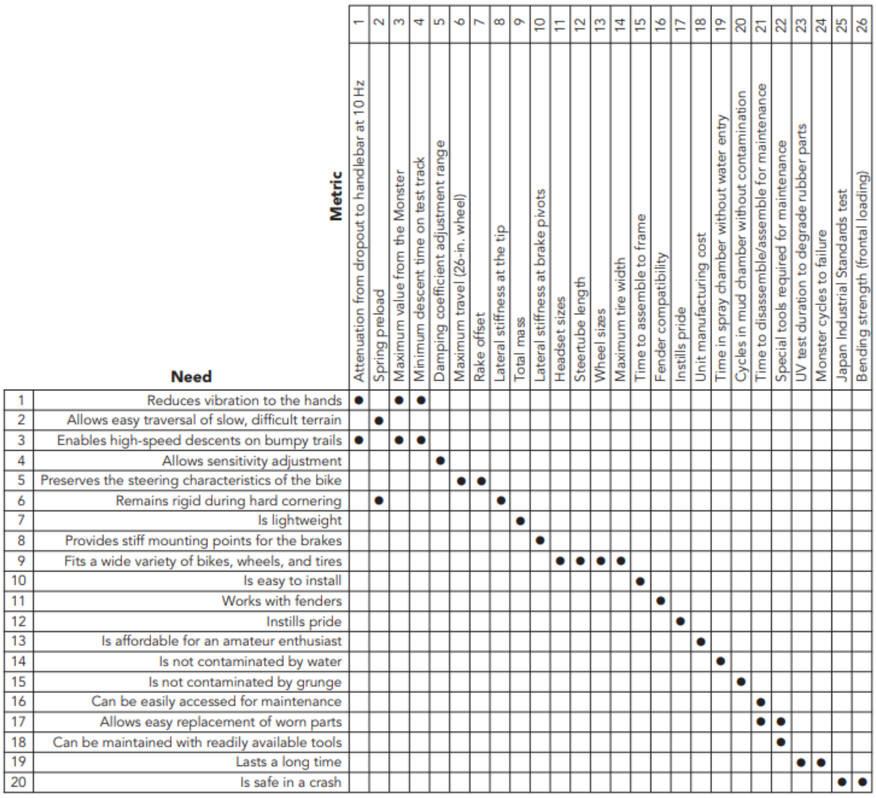


Figure 3.4: Common dilemma in product development processes (Almefelt, 2020b).

3.1.2 Product Development Tools

Ulrich and Eppinger (2012) suggest a visualization tool to manage customer needs, called customer needs-metrics matrix, illustrated in Figure 3.5. This tool supports the product developer by translating the customer needs and requirements into measurable technical requirements, which makes it possible to analyze if the requirements are fulfilled.



	Need / Metric	1 Attenuation from dropout to handlebar at 10 Hz	2 Spring preload	3 Maximum value from the Monster	4 Minimum descent time on test track	5 Damping coefficient adjustment range	6 Maximum travel (26-in. wheel)	7 Rake offset	8 Lateral stiffness at the tip	9 Total mass	10 Lateral stiffness at brake pivots	11 Headset sizes	12 Steertube length	13 Wheel sizes	14 Maximum tire width	15 Time to assemble to frame	16 Fender compatibility	17 Instills pride	18 Unit manufacturing cost	19 Time in spray chamber without water entry	20 Cycles in mud chamber without contamination	21 Time to disassemble/assemble for maintenance	22 Special tools required for maintenance	23 UV test duration to degrade rubber parts	24 Monster cycles to failure	25 Japan Industrial Standards test	26 Bending strength (frontal loading)
1	Reduces vibration to the hands	●		●	●																						
2	Allows easy traversal of slow, difficult terrain		●																								
3	Enables high-speed descents on bumpy trails	●		●	●																						
4	Allows sensitivity adjustment					●																					
5	Preserves the steering characteristics of the bike						●	●																			
6	Remains rigid during hard cornering		●						●																		
7	Is lightweight									●																	
8	Provides stiff mounting points for the brakes										●																
9	Fits a wide variety of bikes, wheels, and tires											●	●	●	●												
10	Is easy to install															●											
11	Works with fenders																●										
12	Instills pride																	●									
13	Is affordable for an amateur enthusiast																		●								
14	Is not contaminated by water																			●							
15	Is not contaminated by grunge																				●						
16	Can be easily accessed for maintenance																					●					
17	Allows easy replacement of worn parts																					●	●				
18	Can be maintained with readily available tools																						●				
19	Lasts a long time																							●	●		
20	Is safe in a crash																									●	●

Figure 3.5: Customer needs-metrics matrix - Visalization tool provided by Ulrich and Eppinger (2012).

Ulrich and Eppinger (2012) also present a visualization that breaks down a concept into systems, illustrated in Figure 3.6. Each system represents different means to provide a function, whereas in this case different "energy carriers" are visualized. This can help product developers to generate new and creative ideas.

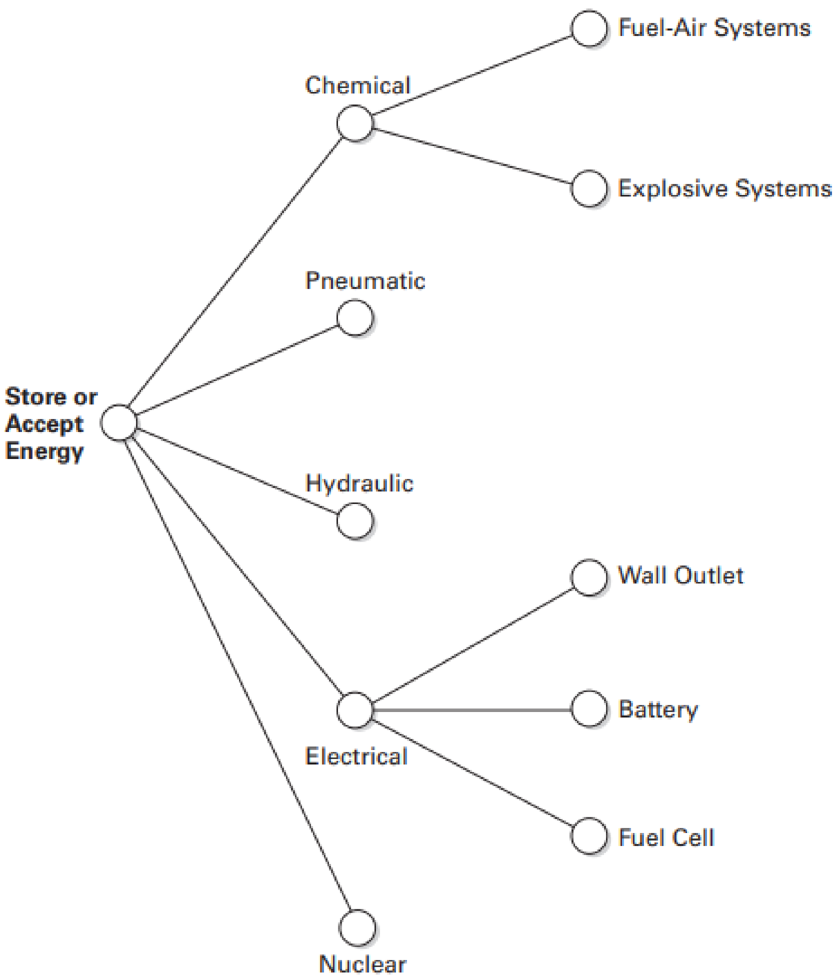


Figure 3.6: Concept Classification Tree - Visalization tool that simplify concepts, provided by Ulrich and Eppinger (2012).

3.1.3 Implementing Product Design

Product design can be implemented using Design for X, or DfX, where X represent the cause. Ulrich and Eppinger (2012) presents two design for X approaches. Design for Environment (DfE) is a method used to minimize the environmental impact of a product. DfE is a method based on the following key principles, as formulated by Ulrich and Eppinger (2012) and also illustrated in Figure 3.7.

1. Eliminate use of nonrenewable natural resources (including nonrenewable sources of energy).
2. Eliminate disposal of synthetic and inorganic materials that do not decay quickly.
3. Eliminate creation of toxic wastes that are not part of natural life cycles

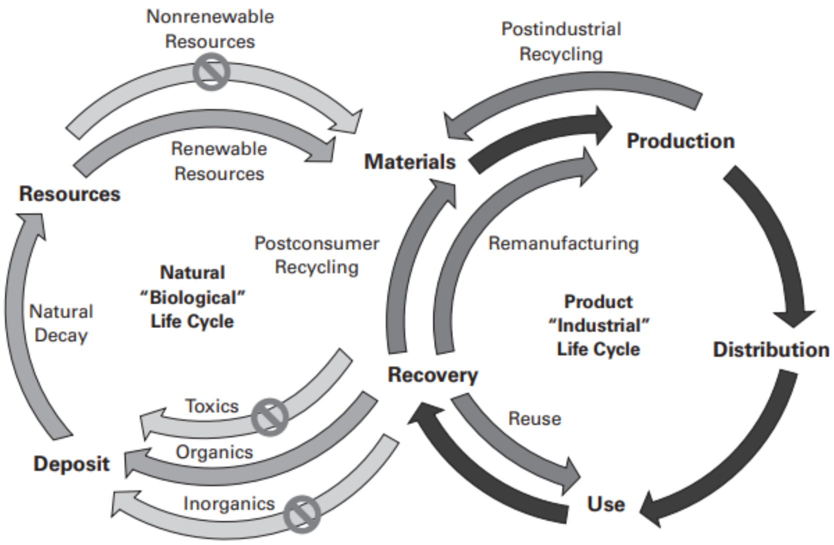


Figure 3.7: Design for Environment illustration - The natural life cycle and the product life cycle, provided by Ulrich and Eppinger (2012).

A 7-step process is also presented as tool to appropriately implement DfE, visualized in Figure 3.8. The 7-step process includes various steps going from uncertain to more certain territory, similar to the processes presented in Figure 3.2, but this illustration is more precise and adapted to suit DfE.

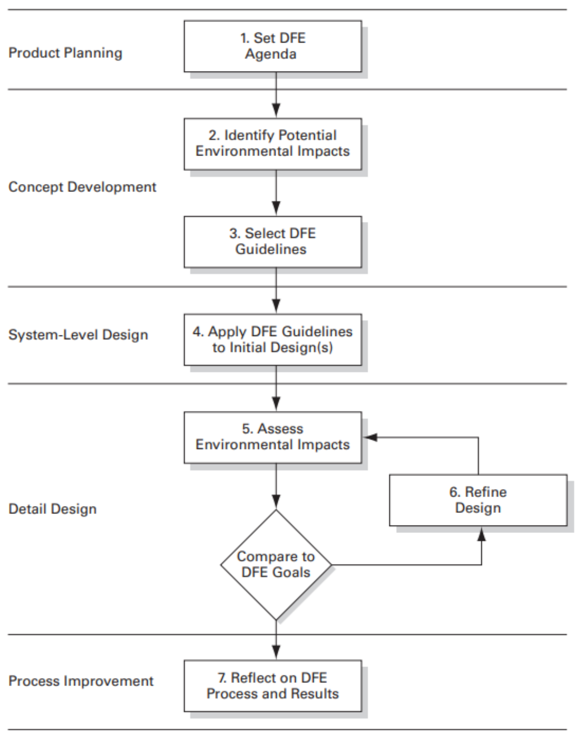


Figure 3.8: The DfE process involves activities throughout the product development process (Ulrich & Eppinger, 2012).

Ulrich and Eppinger (2012) propose Design for Manufacturing (DfM) as a suitable design method to reach certain goals, illustrated in Figure 3.9. The process consist of several steps which aims at improving the manufacturing aspects of a product. This approach uses iterations to ensure that the goals have been met.

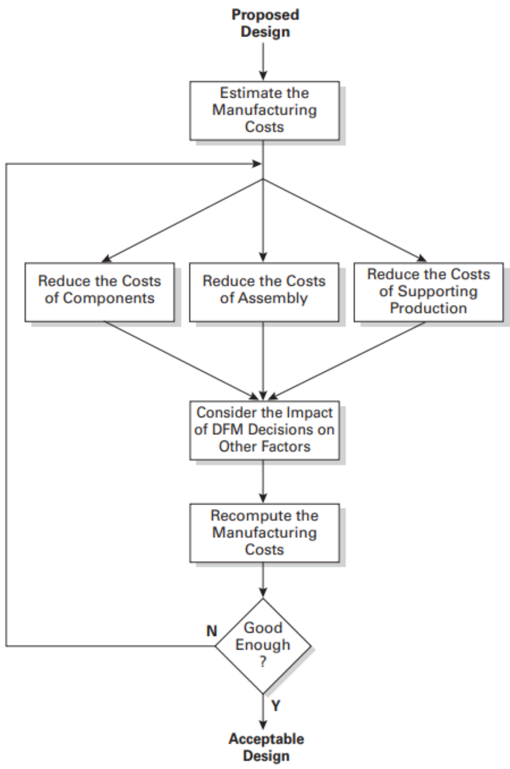


Figure 3.9: The Design for Manufacturing method and its step, provided by Ulrich and Eppinger (2012).

3.2 Product Longevity

This section presents literature related to product longevity, and is divided into the categories; product lifetime in two dimensions, desired product lifetime from different perspectives, and design approaches. The purpose of this literature is to provide knowledge that can be used to develop Design for Longevity framework and its elements.

3.2.1 Product Lifetime in Two Dimensions

Almefelt (2020a) discusses product longevity as a concept of two dimensions, desired service life, and actual service life, without specifying the perspective. Products can be designed in such a way that these two dimensions either match or not, illustrated by the examples in Figure 3.10. Based on an user perspective - appliances do not match their expectations on service life, whereas for a fishing net, now seemingly as a ghost net, the lifetime exceeds the desired service life - from an environmental perspective.

Figure 3.10: Product Longevity - Desired vs actual service life (Almefelt, 2020a).

An empirical study by Cooper (2004) endorse this type of two dimensional thinking regarding longevity, and more concretely prove that there can be a mismatch between these dimensions. In the empirical study, 51-52% of the respondents stated that appliances do not match their expected lifetime. Marcus (2020) highlight the dimensional thinking of desired service life, and actual service life, but further introducing another dimension to it, perspective. It is stated that users prefer a longer lifetime than five years on mobile phones and tablets, whereas they currently replace them after two years due to the degradation of the battery. A design enabling battery change could prolong the lifetime of the products, which is desired by users. However, such a design is in contrast of what the manufacturers might prefer, merely based on their economic incentives, thus resulting in a mismatch between these desired lifetimes.

3.2.2 Desired Product Lifetime from Different Perspectives

Marcus (2020) highlights that desired product lifetimes could be seen from different perspectives, and that it could generate different desired product lifetimes. More literature was gathered regarding different perspective, and divided into three contextual aspects.

The User Perspective

Haug (2016) highlights the importance of including the user aspect when designing products towards a certain lifetime. This can be viewed in two ways. Firstly, the users are the ones that use the product and affect the overall wear of the product, hence influence the real product longevity. Secondly, the users are the absolute deciders of when they deem the product obsolete and thereby replace it. Cooper (2004) suggest that products can become obsolete and replaced for many reasons; technological-, psychological-, and economical obsolesce to mention a few. Selvefors et al. (2019) suggest that products must be designed with the user in mind and that viewing a product's lifecycle from a user's perspective can aid in this. Instead of a typical cycle of distribution-use-end of life, products can be seen and understood from as a lifecycle of obtainment-use-riddance, as illustrated in Figure 3.11.

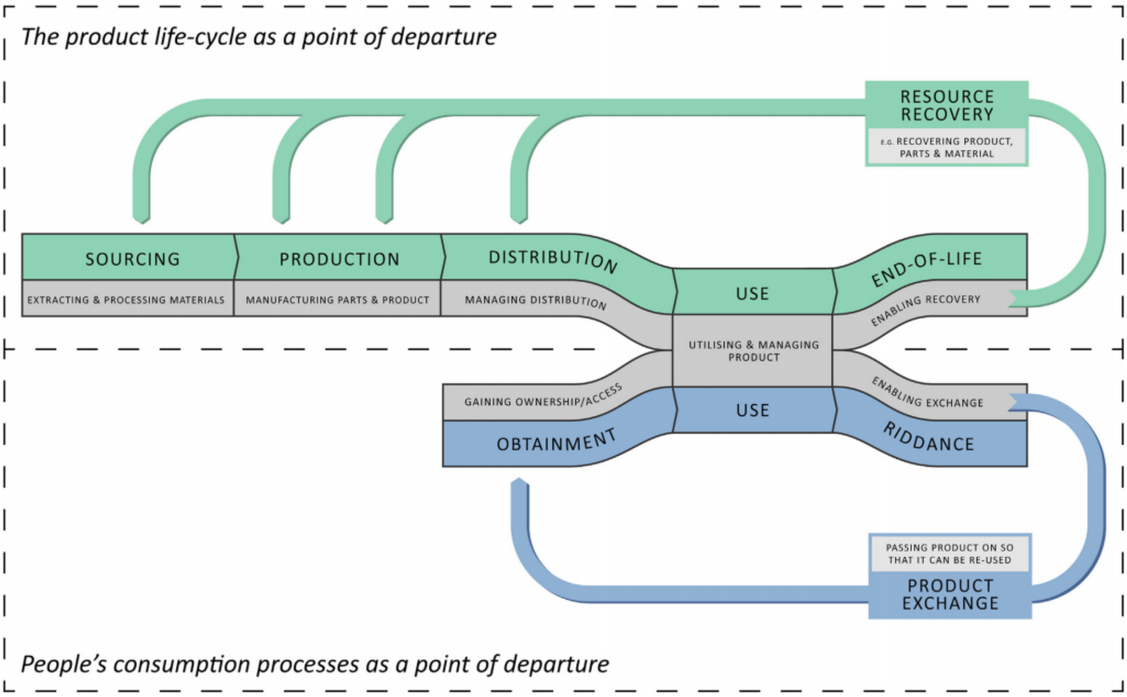


Figure 3.11: Alternative view of a product's lifecycle (Selvefors et al., 2019).

The Business Perspective

More interest regarding companies' roles in the transition towards a circular economy has emerged, and different business models have been suggested, along with discussions of how and why companies need to adapt to a circular economy. Stahel (1997) started to discuss this early. Specifically, one idea regards strategies where companies sell the use of goods, or services, rather than of the objects as such. The main points in this literature were that companies need to start to apply a more cyclic or circular thinking in their business and reassess how they currently work.

De los Rios and Charnley (2017) highlights the importance of how companies more holistically must reassess how they do business and adapt appropriately in order to follow the recently started transformation towards a more circular economy. Allenby (1997) stated: *"The fundamental purpose of a for-profit corporation in a free market economy is to make money for its owners, that is, the shareholders"*. This is still relevant today since it highlights the fact that companies must adapt their business in line with the transition in such a way that they still are profitable.

The Resource Efficiency Perspective

Marcus (2020) argues that product developers sometimes inappropriately tend to design around the belief that product lifetime extension always is desirable. However, one must consider both product- and sector-specific aspects across the whole life cycle of a product. Marcus (2020) suggested that products such as washing machines or other energy draining products (in the usage phase), might not benefit from life extension, if more energy efficient solutions are developed over time. Based on theory, Van Nes and Cramer (2006) suggest a method in line with this reasoning called *ecological pay back period*. This method's goal is to optimize a product lifetime from an environmental or resource perspective, and calculates a point which indicates when it is beneficial to replace a given product, illustrated in Figure 3.12.

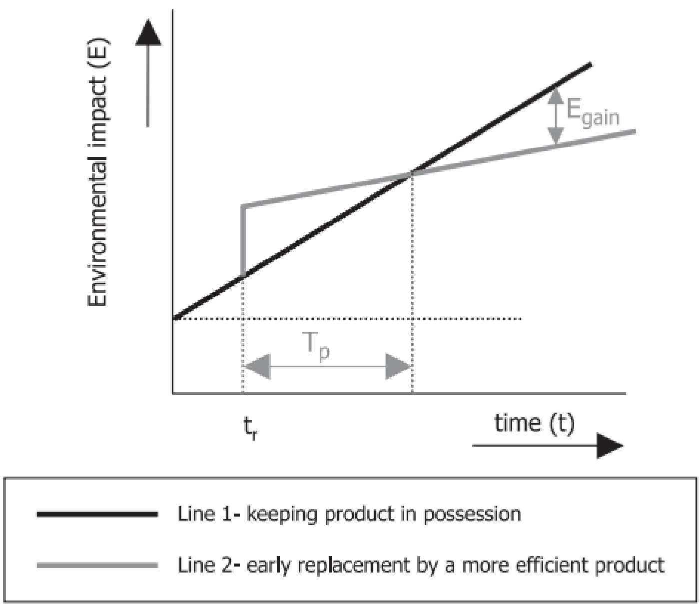


Figure 3.12: Ecological payback period illustration - Indicating potential environmental gain if product is replaced early (Van Nes & Cramer, 2006).

Two empirical studies that have been conducted around this resource or environmental focus are Bakker et al. (2014) and Kagawa et al. (2008). Bakker et al. (2014) investigated the optimal lifetime of refrigerators and laptops. Their study consists of a method different from the *ecological pay back period*, but use similar factors and mindset. It was concluded that it was beneficial to prolong the life of both laptops and refrigerators. The study by Kagawa et al. (2008) was conducted in

Japan between 1990-2004 where the goal was to investigate whether it was beneficial to prolong the lifetime of vehicles compared to purchasing new vehicles. It was concluded that the environment would benefit from a prolonged lifetime of vehicles, during this period of time and context.

3.2.3 Design Approaches

There are several approaches that can help product developers to prolong the life of products and the resources they contain. Potting et al. (2017) present five general approaches that can aid in extending lifespan of products and its parts; *Repurpose*, *Remanufacture*, *Refurbish*, *Repair* and *Re-use*, explained in Figure 3.13 which is an extract from Figure 1.1.

Strategies		
Extend lifespan of product and its parts	R3 Re-use	Re-use by another consumer of discarded product which is still in good condition and fulfils its original function
	R4 Repair	Repair and maintenance of defective product so it can be used with its original function
	R5 Refurbish	Restore an old product and bring it up to date
	R6 Remanufacture	Use parts of discarded product in a new product with the same function
	R7 Repurpose	Use discarded product or its parts in a new product with a different function

Figure 3.13: Approaches to extend lifespan of products and its parts (Potting et al., 2017).

Bakker et al. (2019) provide several specific design strategies that can redesign a product, and are argued to promote a circular design and a longer lasting product design. These design approaches are grouped into six strategies, and formulated accordingly by Bakker et al. (2019):

- **Design for Attachment and Trust** is a holy grail for many designers. They explore the way in which users develop a certain bond with the objects they use. The complexity of attachment and trust is a fantastic challenge.
- **Design for Durability** is based on defining optimum product reliability. It is a well defined technical field. Ideally a product's durability should match its economic and stylistic lifespan.
- **Design for Standardization and Compatibility** is constantly evolving. Digital technology, for instance, has come a long way. There is an inter-

esting field of tension between setting standards and the reality of personal customization.

- **Design for Ease of Maintenance and Repair** is a tough one. Maintenance and repair are currently divided among the original manufacturer, the gap exploiting service provider and users. Users are treated in a rather patronizing way. Repairs is not allowed, under penalty of loss of warranty.
- **Design for Adaptability and Upgradability** implies to incorporate possibilities to change a product. Adaptation to different functions by part exchange is common, upgrading less so. Particularly digital technology develops with so much speed that upgradability is limited. Value propositions would have to be different.
- **Design for Dis- and Reassembly** is partly new. Easy disassembly is a classic requirement for sustainability. The possibility to reassemble is similar to the previous three strategies, but may include assembly with components of other product to become something different.

3.3 Analysis of Theory

This section analyzes the result obtained from the research phase, which is divided into two mentioned topics; product development in theory and product longevity.

3.3.1 Product Development in Theory

Product development is a multi-disciplinary profession or research field that most certainly can be considered complex, where both large set of parameters are managed while also being in an ever changing environment. One could argue that the contingency theory being most relevant for product development. The contingency theory basically states that there is no best way to organize, but some ways are more effective (Schoonhoven, 1981). Being applicable on product development processes, meaning that there is no best process, but the choice of process matter.

As seen in the provided theory, a linear step wise approach seems the most obvious way to develop products, going from a uncertain territory to a more certain territory. This causes complications, since less is known but also fixed in the beginning, and more is known but also fixed going further in the process. Product development is therefore also provided with several tools with the intention to aid in this dilemma and solve complex problems, where tools are created to both visualize and simplify them. Product development processes and theory has been further concretized by trying to narrow down a whole process into a more narrow but extensive goal, called design for X. Design for X is usually a mindset or set of guidelines to be followed, which are to be implemented using a step-wise approach with developed tools.

3.3.2 Product Longevity

Several authors have provided several views on product longevity, introducing various aspects to consider along with how to view product longevity. As it appears there can be a mismatch between real and desired lifetime, and it is not always desirable to prolong the lifetime of products in their current state. Desired product lifetime heavily depends on which perspective it is viewed from. E.g. the lifetime could be desired to be three years - from a user perspective, if they are sensitive to trends and emerging technologies, but still wants to save money. The lifetime could also be desired to be longer than three years - from a resource efficiency perspective, if the product consumes little to none energy during use. The product could also be desired to be shorter than three years - from a business perspective, such that the company increases its sales. Resulting in a mismatch between the desired lifetimes.

During the exploratory literature review it became clear that there are many aspects and views to consider, generating different dimensions. However, there was seemingly no literature where all of these dimensions are managed and discussed in relation to each other, nor combined into a wholesome definition or mindset. Moreover, products can become obsolete for various reasons, where psychological- , economical- and technological obsolescence are considered to be some of the reasons why customers decide to replace products. In addition to this, one can also discuss how the product's lifetime itself can be redefined. The product life cycle is typically viewed as production-usage-end of life. This can be considered to be true from an manufacturer point of view. However, from a user point of view the life cycle of a product can be argued to be viewed as obtain-use-riddance. Therefore, it is possible to argue for that both views should be considered since it can help to understand what longevity really means, as well as help to design for it. From a simple point of view products consist of parts and components. However, from a more complex point of view it can also consist of both material and immaterial resources, and one could argue that it is in our interest to maximize the utilization of these.

3.4 Summary of Research Phase Results

The results from the research phase aimed to fulfill several sub-objectives, formulated in Section 2.1, and they are presented and discussed below.

- Summarize product development theory.
- Collect a knowledge base about topics related and supporting to product longevity.
- Collect information that opposes and criticizes product longevity.
- Analyze product development in theory and conclude which elements that the Design for Longevity framework should include.
- Analyze literature related to product longevity and highlight aspects to be considered in the elements of the Design for Longevity framework.

All of the above stated sub-objectives are deemed to be fulfilled. A summary of product development in theory was presented in Section 3.1. A knowledge base of topics both supporting and opposing product longevity was presented in Section 3.2. Both of the two topics were later analyzed in Section 3.3, and the analysis will be the basis in the next phase of the project, which is the development phase.

4

Development Phase Results: Proposed Design for Longevity Framework

This chapter presents the results from the development phase. Several methods have been applied in an iterative approach, and they are all further described in Section 2.2. The results are a final Design for Longevity framework which intends to work in theory, it more specifically contains the following elements; a redefined definition, a visualized mindset which is broken down into smaller blocks, and two supporting tools. Figure 4.1 indicates the phase position in the process.

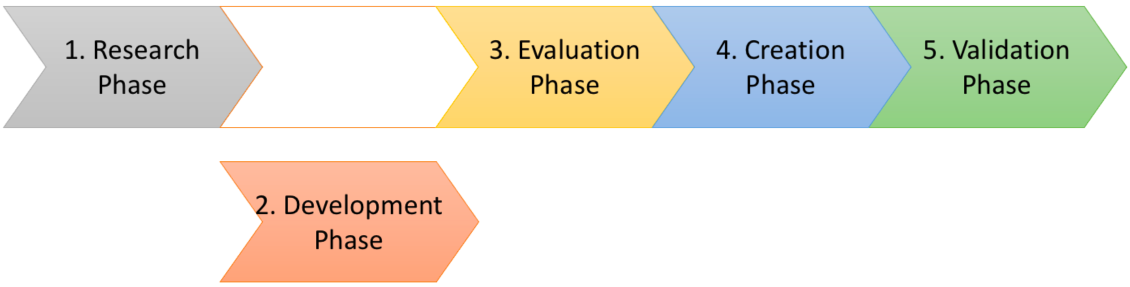


Figure 4.1: The development phase is the second phase in the process.

4.1 Design for Longevity Definition

Based on the analyzed literature of product development in theory, it became evidently clear that mindsets or guidelines are commonly used to facilitate the implementation of a certain Design for X. Meaning it would be suitable to develop a definition or mindset for Design for Longevity. A redefined definition of Design for Longevity has therefore been developed, based on the collected and analyzed literature of the topic product longevity. The purpose of this definition is to widen the view of Design for Longevity such that it can be applicable on any product, and any industry. This ultimately entails the following redefined definition of Design for Longevity.

> *Design for Longevity includes the careful consideration of how a product's life cycle is defined. Longevity is defined as for how long a product can perform any desired function over a certain period of time, either as a set of resources or as an object that serves as a means to provide a function. Design for Longevity aims at designing products with an optimal lifetime, where optimal means taking the user, the business and the resource efficiency into account when designing the life of a product.*

In theory, this aims to result in products that are designed in a way that uses the optimal amount of resources to provide a desired function, over a desired period of time.

4.2 Design for Longevity Mindset

Per the redefined definition of Design for Longevity, or more seemingly a wholesome mindset of how to design products, the following flowchart is generated, seen in Figure 4.2. Implementing this mindset is not considered trivial, and it is therefore broken down into smaller blocks, also illustrated in Figure 4.2. Furthermore, the flowchart illustrates how the mindset is to be anticipated in general.

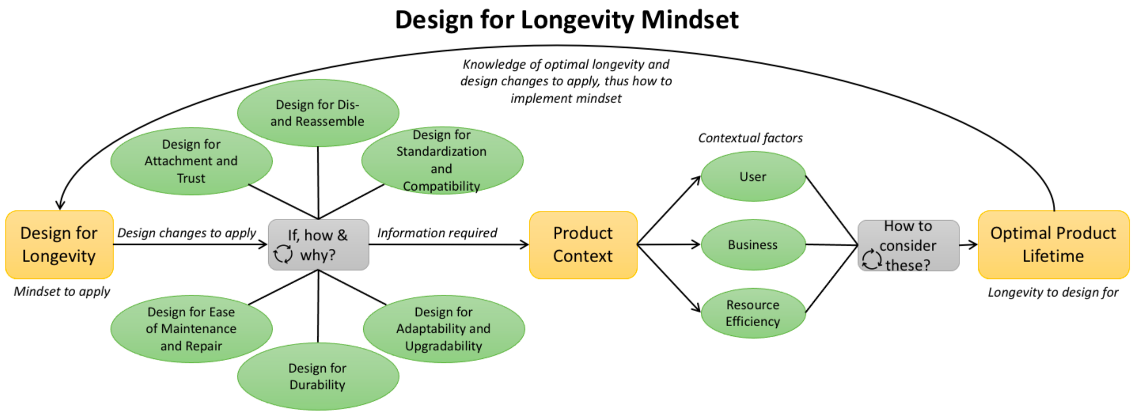


Figure 4.2: The Design for Longevity flowchart illustrates the mindset of Design for Longevity.

Design for Longevity relates to the redefined definition of Design for Longevity, and should serve as the starting point. The six strategies originally provided by Bakker et al. (2019) are proposed in the framework as possible design strategies to translate and realize the mindset into product design, with the notion that they all have various effects on how they influence the product's lifetime depending on various contextual factors. This entails the product context, where it is possible to argue that companies must analyse their own contextual factors, in order to understand if, how, and why a certain design strategy should be implemented. This can be done by analyzing their product from three main contextual aspects; the user, the business and the resource efficiency, and considering them appropriately, further described in Section 4.2.2, will in turn entail a pronounced optimal product lifetime. After completing this cycle, should be able to implement Design for Longevity.

4.2.1 Adapted Design Strategies and Product Context

The six design strategies presented by Bakker et al. (2019) have an impact on a product's life, and can be used to prolong and redesign a products life, and therefore included in Design for Longevity framework. However, as previously mentioned not every individual strategy is suitable for all products for two main reasons. Firstly, it is not possible to implement all strategies on all products, since different products aim to provide different functions. Secondly, Design for Longevity aims at designing products for a certain period of time, meaning that it is not always desired to prolong the product's lifetime. This highlights that these strategies should be implemented reasonably, and that companies need to analyze and understand their product context. The six strategies are presented below with adapted descriptions. Adapted in the sense that the descriptions in a concise manner can provide an understanding of the strategy along with potential benefits and drawbacks.

Design for Attachment and Trust

The strategy is to design the product to evoke attachment and trust between the customer and the product. If the customer associates the product with an own significant value or feeling, it can increase the consciousness of responsibility and obligation to take care of the product. The product's lifetime likely increases because of emotional bonding between the customer and the product. However, there is a risk that a product that is obsolete remains in the customer's possession for a prolonged period of time, when in fact a replacement of the product would be beneficial from a resource efficiency point of view.

Design for Durability

The strategy is to design durable products with the ability to perform their function over a prolonged period of time. Designing more durable products that can perform their function over a longer period of time, can increase the products lifetime since the customer can use the product longer. Different products are exposed to various amounts of stress and wear during their lifetime, and this complicates the design process of increasing the products' durability. Moreover, designing products that can perform their function over a period of time that exceeds the lifetime desired by the user, can result in a waste of resources.

Design for Standardization and Compatibility

The strategy is to focus on implementing standards in the design in order to increase compatibility. The product's level of compatibility affects the performance of adaptability to interact with other products and easiness of exchanging aged components. Standards are continuously evolving and established depending on technology and industry, and it is therefore important to distinguish the level of implementation and their use before adapting the product's design. Products designed with outdated compatible standards could obtain a reduced customer value because of a decreased usefulness, affecting the product's lifetime.

Design for Ease of Maintenance and Repair

The strategy intends to simplify maintenance or reduce the need for maintenance on the product. This facilitates the process of maintaining the performance and functionality of the product in order to meet the customer's expectations on the product. It can result in an increased product lifetime by reducing the risk of the customer considering the product obsolete. The product's architecture needs to be designed to enable maintenance of essential components. This affects the product's architecture and likely increases its own complexity.

Design for Adaptability and Upgradability

The strategy is to design the product to make it adaptable for future updates with newer technologies or customizable to follow trends. If the product's performance and style continuously can be upgraded, it reduces the probability that customers consider the product obsolete. Instead it enables the customer to upgrade the product according to their desires and maintain a performance standard. The future is uncertain however, and it can therefore be difficult to design for new technologies and trends.

Design for Dis- and Reassembly

The strategy is to design the product in order to facilitate the process of disassembly and reassembly of components and material from the product. This can be done through increased accessibility of components and material which makes it easier to recover resources. Product architectures developed for dis- and reassembly influences the placement and connection of components, and material selection, likely to an expense of complexity. It can also be difficult to optimize the components' design and the product's architecture if the process of dis- and reassembly is considered to be implemented in all aspects.

4.2.2 Product Context and Optimal Product Lifetime

Product Context is, a non-specified, set of information, and will differ depending on product and industry. However, it aims to emphasize and remind product developers that it is important to consider the product out of three pre-defined aspects while designing products. The user can be defined as the person that actively consumes or use the product. The business can be defined as the actor that gains value in return of providing this product. Finally, the product contain resources as a means to fulfill its function, and these can be measured in terms of resource efficiency. It is important to understand that the desired product lifetime can differ between these, since they all have their own objectives to strive for. It is also important to consider that a product lifetime consist of two dimensions, real and desired. Designing products with desired lifetimes without fulfilling them entails a mismatch, and is non-ideal. Product developers should therefore strive to design products where the real and desired lifetime are the same. This entails the following definition of an optimal product lifetime.

> *A product's optimal lifetime is the point where the user's, the business's and resource efficiency's desired and real product lifetimes coincide.*

4.3 Design for Longevity Support Tools

To support the implementation of Design for Longevity, two tools were developed. As it appeared in product development in theory, linear step-wise processes are commonly used to implement different design for X, and was therefore also developed as a tool to implement Design for Longevity. A visualization tool, more specifically a diagram, was developed to simplify the most complex and demanding steps of the process.

4.3.1 Design for Longevity Implementation Process

The definitions and elements in the framework are intended to be used to asses an optimal product lifetime and facilitate the implementation of Design for Longevity. The *Design for Longevity Implementation Process* is illustrated in Figure 4.3 aims to facilitate an appropriate implementation of Design for Longevity, and realize the mindset into product design.

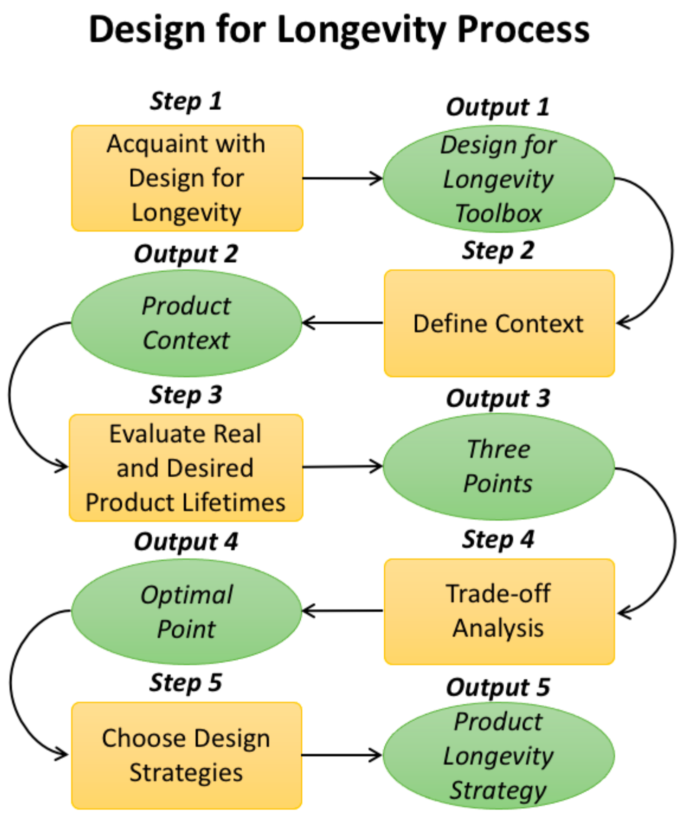


Figure 4.3: Step-wise Design for Longevity implementation process.

Each step in the process results in an output which in turn is required to proceed to the following step in the process. This process will ultimately give the product developer indications on what design strategies to proceed with and how their current business could be adapted accordingly.

4.3.2 Optimal Product Lifetime Diagram

The optimal product lifetime is most likely demanding and difficult to identify and design for. The developed visualization tool *Product Lifetime Diagram* aims to help product developers assess this. Illustrated to the left in Figure 4.4, is a template of the diagram.

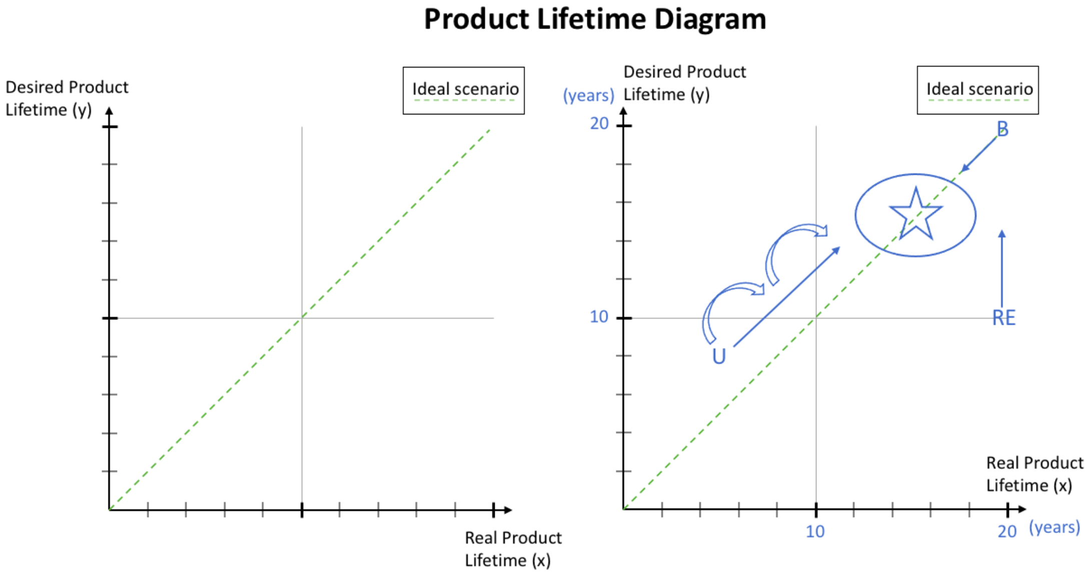


Figure 4.4: A empty template of the *Product Lifetime Diagram* is located to the left. The *Product Lifetime Diagram* after a completed reflection is located to the right, where the blue illustrations in the *Product Lifetime Diagram* are specific results from a simplified case analyzing a passenger vehicle. The axes represents time in years. The user (U), the business (B) and the resource efficiency (RE) represent the three corresponding aspects with their current lifetimes. The arrows indicate how potential actions, more specifically implementing the design strategies to different extents, could result in new positions. The circle and star represent the area that the three points are converging towards, which corresponds to the optimal product lifetime for this case.

The x-axis represent the real product lifetime and the y-axis represents the desired product lifetime. Those parameters can e.g. be represented as either time or use cycles. This model is more precise and should be used in quantitative measures to map out the product lifetimes, in comparison to Figure 3.10. There is also an ideal scenario illustrated with a dotted green line, this line represents the one-to-one relation a product lifetime should strive to have. This occurs when the desired product lifetime is equal to the real product lifetime. The three contextual aspects; the user (U), the business (B) and the resource efficiency (RE), should be indicated as points on the diagram, in their current state. Each point consist of two dimensions, the desired and the real product lifetime. These should be assessed individually without respect to each other, as objective as possible. Following developed definitions for the three pair of coordinates are stated as:

- **U** [**x**]: *For as long as the user actually uses the set of resources to provide a certain function.*
- **U** [**y**]: *For as long as the user desires the set of resources to be used to provide a certain function.*
- **B** [**x**]: *For as long as the resources are planned to be used to provide the certain function.*

- **B** [**y**]: *For as long as the company desires the set of resources to be used to provide the certain function.*
- **RE** [**x**]: *For as long as the set of resources can be used to provide the certain function.*
- **RE** [**y**]: *For as long as the set of resources should be used to provide the certain function.*

The purpose of the *Product Lifetime Diagram* is mainly to serve as a mediating tool and stimulate a discussion regarding the product's different lifetimes. The optimal product lifetime can be elicited from the converging of the three points into a optimal point, as a result of implementing the design strategies to different extents. The blue illustrations, seen in Figure 4.4 to the right, show how the tool can be used to analyze a product where there is a clear mismatch between the three aspects along with a poor ratio between the two dimensions, where the one-to-one is not fulfilled.

Four notions are important to consider before using this tool in order to use the diagram appropriately. It is important to take these notions into account to make sure of the relevance of the result and its credibility to determine the result's usability and its limitations. The following four notions are listed as:

1. The optimal point will most likely be the result of a subjective analysis, thus resulting in several possible outcomes. Mainly since the starting coordinates are dependent on to which degree the definitions have been fulfilled properly, where they might require assumptions. In addition to this, the three points or named aspects importance will most likely be weighted against each other differently for different products and industries.
2. The goal is to make the three points coincide, where the most straight forward approach is to make three points converge towards a specific point or area. This can be done in two ways, either by moving the points simultaneously towards each other, or move one point at the time independently towards a certain area on the diagram.
3. It is also important to converge the points towards the ideal one to one ratio, meaning the two dimensions coincide as well. There are two ways to address the two dimensions, one can either apply actions that move the real product lifetime towards the desired, which is deemed to be a more conventional method. However it is also possible to apply actions that moves the desired product lifetime towards the real. This is mainly based on the belief that the desired product lifetimes are dependent of the current product context, which can be altered using various design strategies.
4. The possible actions and outcomes should be discussed in relation to the design strategies and possible changes in the business. Mainly since the implementation of the design strategies can alter the position of any point, in any of the two dimensions. The business should be discussed since a design strategy might require changes appropriately to be implemented. The design strategies can be discussed in relation to the three points two different approaches. They can either be individually assessed or in combination with each other

on one of the three points at a time. However, it should be noted that the synergy between two or several design strategies can be beneficial, even though implementing one is not. For example, prolonging the life of a product that exceeds the currently desired lifetimes through Design for Durability might not be beneficial, but combining it with Design for Dis- and Reassemble could be beneficial. Assuming that the company ensures the components are extracted and used in another product. Thus, utilize the prolonged life in the products components i.e. resources which otherwise would go to waste.

4.4 Summary of Development Phase Results

The results from the development phase aimed to fulfill several sub-objectives, formulated in Section 2.2, and they are presented and discussed below.

- Define which elements to be included in the Design for Longevity framework.
- Define what Design for Longevity in theory means and how it can be used to design product with an optimal product lifetime.
- Develop elements that in theory can be used to Design for Longevity.
- Evaluate and improve the elements until a satisfied result is obtained.

All of the above stated sub-objectives are deemed to be fulfilled. There are several elements presented in this chapter, where both their purpose is described as well as they are explained. Section 4.1 provides redefined definition of Design for Longevity which explains how Design for Longevity can be used to develop products with an optimal lifetime. All of the developed elements in the Design for Longevity framework have been developed using an iterative approach, this was ongoing until a satisfied result was obtained and they were all deemed to work in theory. The results from this chapter will be used in the next phase of the project, which is an evaluation of the Design for Longevity framework performed in industry.

5

Evaluation Phase Results: User Data and Verification of Acceptance

This chapter presents the results from the evaluation phase, where a user study was conducted based on the developed Design for Longevity framework developed in the previous phase. The methods used in the user study are further described in Section 2.3. The data obtained from the user study is later analyzed in order to facilitate a discussion of the Design for Longevity framework and its included elements. At last several possible improvements are proposed for the Design for Longevity framework. Figure 5.1 indicates the phase position in the process.

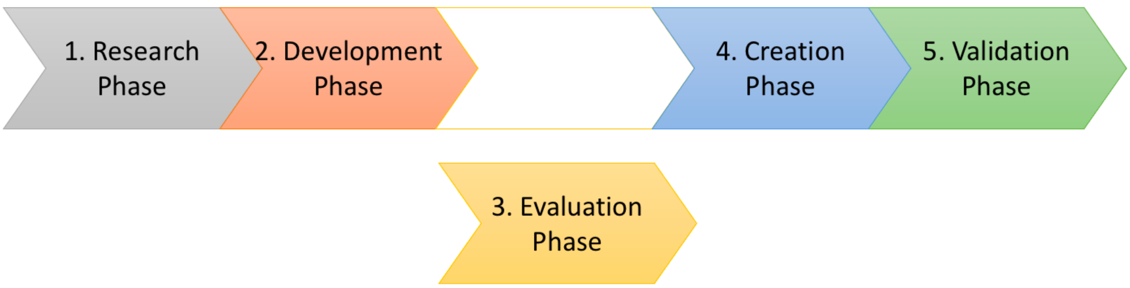


Figure 5.1: The evaluation phase is the third phase in the process.

5.1 Summarized User Data

Both qualitative and quantitative data were obtained from the user study, the interviewees opinions regarding the framework are summarized and discussed in this section. The summarized user data consist of opinions collected using a Likert scale. The opinions were based on the material presented in the interviews, which more specifically contained the Design for Longevity framework along with the example case of passenger vehicle, further described in Section 2.3.

Table 5.1: Questions and answers from the Likert scale user study evaluation. A scale from 1-5 is used, where 1 is low and 5 is high.

Likert Scale Evaluation			
No.	**Question**	**Average**	**Median**
1	How relevant was the definition of Design for Longevity in this exercise?	4.57	5
2	How understandable was the definition of Design for Longevity?	4.21	4
3	Did your perspective on Design for Longevity change after this exercise?	2.79	2.5
4	How well do you consider the three perspectives to cover an eventual optimal lifetime?	4.08	4
5	How understandable were the design strategies?	4.71	5
6	How helpful were the descriptions of the design strategies in this exercise?	4.29	4
7	How relevant were the design strategies in this exercise?	4.5	5
8	How ease was it to use the optimal lifetime diagram?	4.14	4
9	How stimulating was the optimal lifetime diagram to reflect over an "optimal" lifetime?	4	3.5
10	How helpful was the optimal lifetime diagram to evaluate an "optimal" lifetime?	3.31	3.5
11	How understandable was the process to evaluate an optimal lifetime?	4	4
12	How helpful was the process to evaluate an optimal lifetime?	3.88	4
13	How applicable was the process on this case?	3.88	4
14	How useful was the process in order to find an optimal lifetime?	3.86	4
15	How extensive does this type of process need to be in order to be helpful to evaluate an optimal lifetime?	3.67	3.5
16	How important is the "right" experience when performing this type of exercise?	5	5
17	Could you consider using this process and its tools in order to evaluate an optimal lifetime?	7/8 YES	

5.1.1 Likert Scale Data

The results from the Likert scale evaluation collected during the interviews with the participants from the automotive industry is presented in Table 5.1, where the results are presented in the form of average- and median values. The evaluation contained 16+1 questions, and where answered using a scale from 1 to 5, where 1 is low and 5 is high. The results will be further discussed in relation to each topic evaluated and the corresponding comments made by the interviewees in the upcoming sections.

5.1.2 The Design for Longevity Mindset

The Design for Longevity mindset was considered to be enlightening and highlighted relevant aspects. Many of the interviewees had seen some of the elements before, such as the contextual aspects, but not in a combined view. One interviewee explicitly said that the redefined definition contains several components which had been seen before, but never in such a cohesive manner. However, even though the mindset was deemed to be appropriate, more general explanations that clarify the contextual aspects were desired. This was considered to be needed since it was argued that the components within each aspect will differ for different products. Many of the interviewees explicitly said that a passenger vehicle needs to consider both safety regulations and emission standards within the business aspect, whereas this might not be true for another product.

5.1.3 The Design Strategies

The design strategies were considered to be relevant in regards to Design for Longevity. The adapted descriptions contained enough information to provide an understanding of each design strategy, and what benefits and risks they possess. The participants found it relevant to acquaint themselves with the design strategies before addressing the product lifetimes since it helped them to generate an understanding of how different design strategies can affect a product's lifetime. This was also explicitly expressed to be needed. Mainly since there is usually a various degree of knowledge among the people involved in product development projects at companies.

5.1.4 The Product Lifetime Diagram

The *Product Lifetime Diagram* was considered to be a suiting tool helping to visualize and stimulate a reflection over a product's optimal lifetime and how the product's lifetimes vary for the same product. It was explicitly said that the tool was easy to use, the contrast between desired lifetime versus real lifetime was deemed to entail an interesting reflection on the product. However, the reflection was occasionally considered difficult, it can be difficult to distinguish between desired and real lifetime. One additional issue was that it was considered difficult to determine the precision of the results gained from using the diagram.

5.1.5 The Design for Longevity Implementation Process

The *Design for Longevity Implementation Process* was deemed applicable on the provided example case by most of the interviewees, but some considered a passenger vehicle to be too complex and suggested that it instead could be used on separate components in a passenger vehicle. The interviewees could see several possible improvements. The process contains several steps, where each step requires a set of questions to be answered. These questions need to be adapted for different products. Some products need more data to obtain the appropriate precision while not becoming too time-consuming or complex. The amount of data and as well as the involved competence in the process have a large impact on the final result. Therefore, the product developer performing the study needs to have the appropriate experience and knowledge in order to achieve a desired result. More specifically, being able to conclude when, what and where assumptions can be made. The accuracy and precision of the process may decrease if the data is built on inappropriate assumptions. However, it was considered to serve its overall goal, since seven out of eight interviewees said that they could consider themselves to use this process and its tools to assess an optimal product lifetime.

5.2 Analysis and Discussion of User Study Results

The summarized user data is discussed below, where both benefits and drawbacks are highlighted followed by the framework's acceptance within the industry.

5.2.1 Benefits and Drawbacks

The developed framework can bring several benefits, where the most distinguishable benefits are the possibilities it brings in terms of being able to actually visualize and reflect upon complex matters, such as a possible optimal product lifetime. In addition to this, several design strategies that can affect the product lifetime are presented along with their possible drawbacks. The framework also highlights key aspects and definitions that can ease the task of determining an optimal product lifetime itself, without necessarily using the proposed process and tools. These key aspects and definitions also have the possibility to be further investigated and elaborated upon.

The framework also entails possible drawbacks that need to be discussed. The overall framework will have a variation in how extensive it is to implement, depending on the product. More complex products will most likely be more demanding and require more data. The data which is collected and the information it contains will also have an impact on the result. This means that both the amount of data along with its information will affect the precision and accuracy of the results, and it is therefore a pronounced uncertainty regarding the overall extensiveness implementation of the framework. The product developer must therefore be able to conclude how extensive the process needs to be in order to implement the mindset appropriately and obtain proper results.

5.2.2 Verification of User Acceptance

The user study aimed to test professionals acceptance and is used to verify the framework and increase its credibility. The user study's results, obtained using a Likert scale evaluation, indicated a positive attitude towards the framework and its elements. Thus concluding that professionals accept our framework. The framework is therefore deemed to support companies to identify a products optimal lifetime, and thus Design for Longevity. However, it is still unclear to which degree it can support them, meaning that the second part of the research question "how can it in practice be used by product developers to design products with an optimal lifetime?" can not yet be answered. Relating this further to product development in theory, more specifically Figure 3.2, where Ulrich and Eppinger (2012) separates a product development processes into different phases, going from uncertain to certain. It is still unclear where Design for Longevity can be used in practice, either in the earlier phases, such as planning, or in the later phases, such as detailed design.

It is also important to distinguish between acceptance and reality. Professionals accepting the framework does not necessarily mean that the mindset actually determines the real optimal product lifetime, and designs for it. This makes it troublesome to make a conclusion about the mindset's validity, other than that it works in theory. The framework needs further validation through testing since it has been tested on example cases only, before it can be concluded if the Design for Longevity framework works in practice.

5.3 Conclusion and Possible Improvements Design for Longevity Framework

By analyzing the data from the case study it is possible to draw some conclusions regarding the criteria from Section 2.2.2. The framework was concluded to be **understandable**, all interviewees understood all elements and their purpose, but desired more detailed descriptions. It was concluded to be **applicable** on a passenger vehicle, whereas a few considered a complete passenger vehicle to be too complex, and instead saw it as applicable on specific components. The **extensiveness** is difficult to conclude, since it was argued that its implementation will differ for various products. **Experience** was argued to be important, and descriptions of the design strategies supported those with less experience. The **visual design** was considered logical, and the *Product Lifetime Diagram* was explicitly praised. The **usefulness** of the framework to determine an optimal product lifetime is difficult to conclude, it was deemed as supportive, but the precision of the result and uncertainties was a considerable issue. The framework was also considered to **support** in identifying design changes during the user study. The following future work is proposed in order to improve the framework further and thus work in practice.

- Create an mediating implementation tool with more detailed descriptions and explanations of each element in the Design for Longevity framework.
- The Design for Longevity framework needs to be tested on several real cases to validate its results and conclude where in the product development process it can be useful.
- The Design for Longevity framework needs to be tested on several real cases to improve its applicability on different products.
- The framework needs to be tested in larger focus groups to evaluate its usability and find further improvements.

5.4 Summary of Evaluation Phase Results

The results from the development phase aimed to fulfill several sub-objectives, formulated in Section 2.3, and they are presented and discussed below.

- Evaluate each element in the Design for Longevity framework in industry.
- Evaluate how Design for Longevity can be implemented in industry along with its acceptance in industry.
- Analyze the collected data and find potential improvements.
- Conclude future work needed to improve Design for Longevity framework to work in practice.

All of the above stated sub-objectives are deemed to be fulfilled. The Design for Longevity framework and its elements have all been evaluated and analyzed based on external data collected from user studies performed in the Automotive industry in Section 5.1. This data was later analyzed in Section 5.2, where more concrete improvements were proposed along with how to resolve them in Section 5.3. These improvements will be resolved in the next phase that is the creation phase.

6

Creation Phase Results: Design for Longevity Guide and Scientific Article

This chapter presents the results from the creation phase, where more specifically a Design for Longevity Guide was created, and a scientific article for the International Conference on Engineering Design. The creation of these is further presented in Section 2.4. The Design for Longevity Guide was created based on the Design for Longevity framework presented in Chapter 4, and the input collected from Chapter 5. The scientific article is created based on project phases 1-3. Figure 6.1 indicates the phase position in the process.

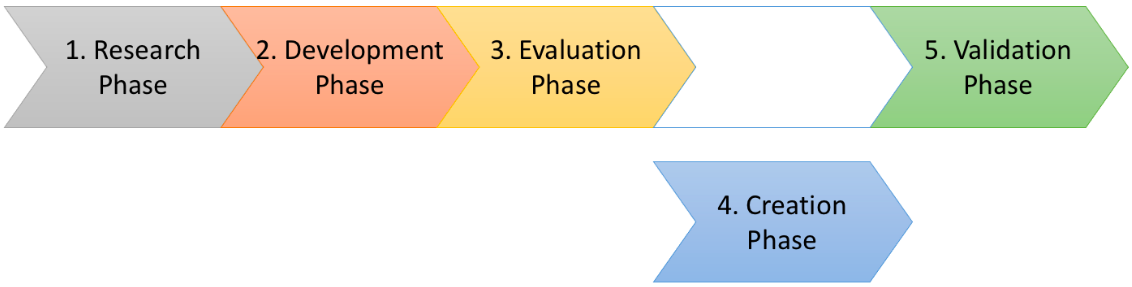


Figure 6.1: The creation phase is the fourth phase in the process.

6.1 Design for Longevity Guide

A guide called *Design for Longevity Guide - A developed guide to ease the implementation of Design for Longevity* (Carlsson & Mallalieu, 2021) was created based on the Design for Longevity framework and its elements developed in Chapter 4. Several improvements were identified in Chapter 5. The guide more specifically provides more detailed explanations of each step in order to apply the Design for Longevity framework. The guide also provides explanations or clarifications of each element and what they contain on a more general note. This aims to make it possible to apply the framework on any product and any industry. The guide also includes a more detailed part where the overall extent of the implementation process is concluded, which mainly depends on the product and the purpose of implementing Design for Longevity. The guide is formulated as an explaining guide and integrates the product developer by referring to him or her as "you" and is therefore explained using a "we" formulation.

Parts of the guide will be presented based on the material from Carlsson and Mallalieu (2021). The overall structure and design, along with all steps in the implementation process from Section 4.3.1 will be presented with extracts of information. The guide consists of a total of 47 PowerPoint slides, and the cover page illustrated in Figure 6.2.

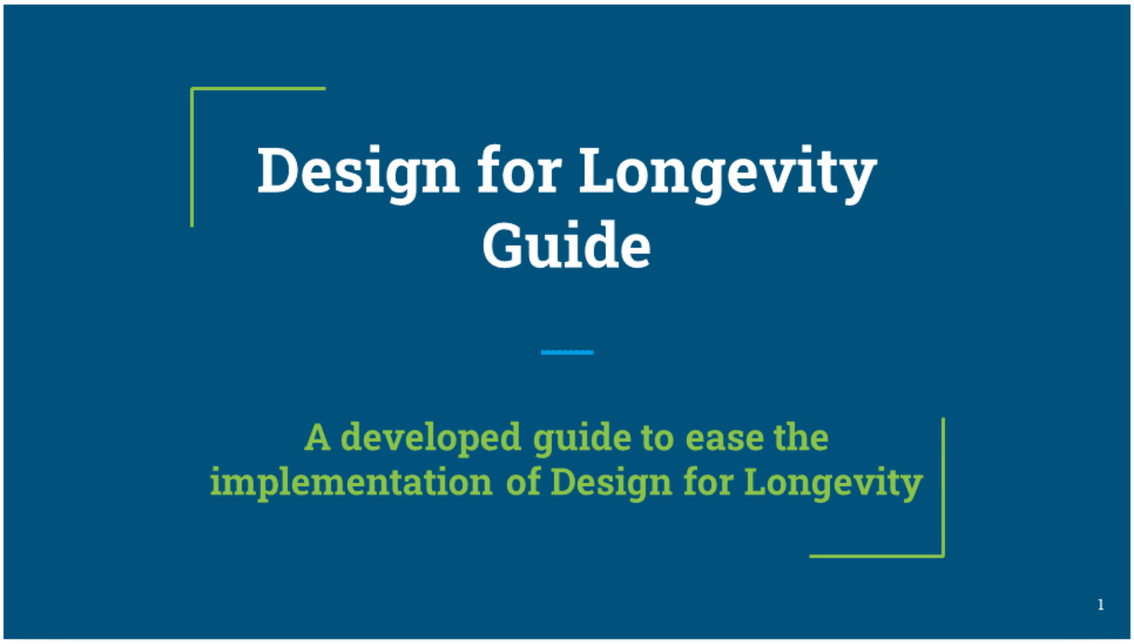


Figure 6.2: Cover page Design for Longevity Guide.

6.1.1 Content and Layout

Figure 6.3 top left illustrates the Design for Longevity definition and is placed in the beginning of the guide since this is the overall mindset to implement. Figure 6.3 top right illustrates the content that the guide consists of. The guide does in general provide a walk-trough of the *Design for Longevity Implementation Process* presented in Section 4.3.1, but is more detailed, the implementation process is illustrated in Figure 6.3, bottom left. The guide also contains all needed templates as appendices placed at the end of the guide.

The created guide follows a similar structure throughout, different steps require a different type of work, they can be seen in the bottom right of Figure 6.3. This symbol is placed in the top right corner of each slide. All slides are given numbering in the bottom corner, and a specific color-coding in the top right corner. This aims to ease the orientation in the guide. Two questions are reoccurring and aim to explain and clarify each element in the framework, and they are;

- What is this?
- Why do we do this?

Many of the steps require a set of questions to be answered to collect the appropriate information. The guide provides several suggested questions. However, it is also highlighted in the guide that the product developer might need to formulate supplemental questions depending on product and industry. This is further solved by the explanations and clarification of each element, where the intent is to describe them in a general manner such that companies understand them and can formulate their own questions. One example of such an explanation is illustrated in Figure 6.4, bottom left, where one of the contextual aspects are explained more generally.

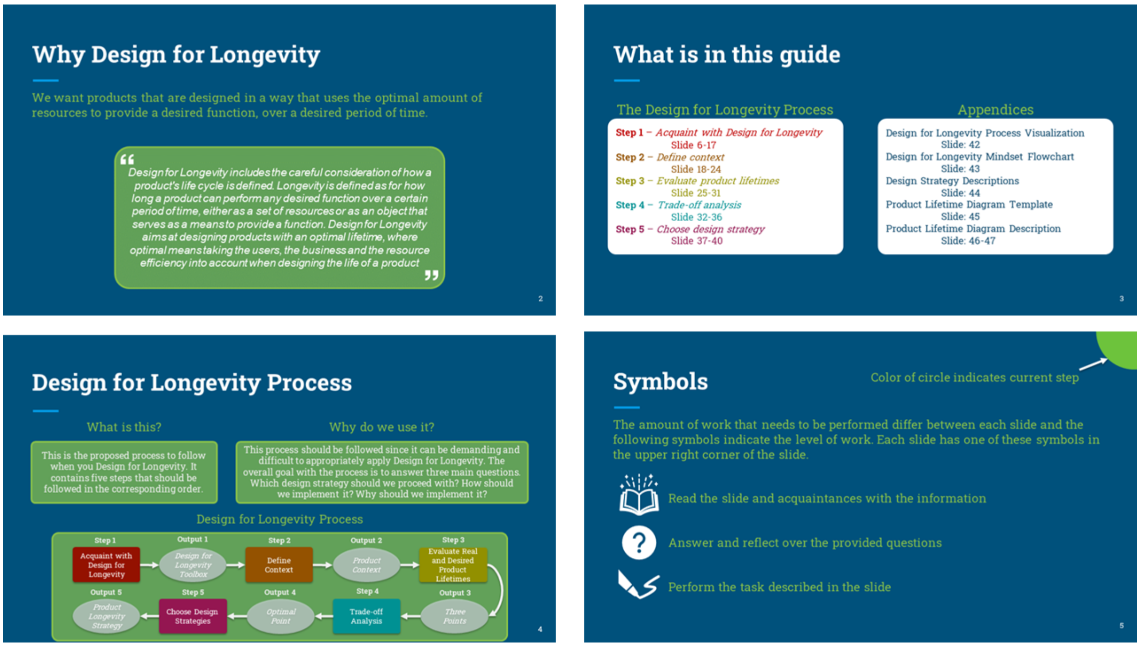


Figure 6.3: Top left: Design for Longevity definition. Top right: Guide content. Bottom left: The *Design for Longevity Implementation Process*. Bottom right: Different types of work and their symbols.

6.1.2 Step-wise Implementation Process

Each step in the implementation process will be presented along with extracted elements to illustrate what type of information a slide can contain. The division and order of the steps indicate the sequence that that the product developer should use when implementing Design for Longevity.

Step 1 - Acquaint with Design for Longevity

Step 1 in the implementation process consists of acquainting with the framework and its elements. The step starts with illustrating where we are in the process, seen top left in Figure 6.4, followed by an explanation of the step. This is followed by slides containing information about all the elements, similar to what is shown to the bottom left in Figure 6.4. It can also be noted that the slides have the "reading" symbol in the top right corner. When the step is completed it is illustrated with a slide visualizing the completed step and its output in the process, seen bottom right in Figure 6.4.

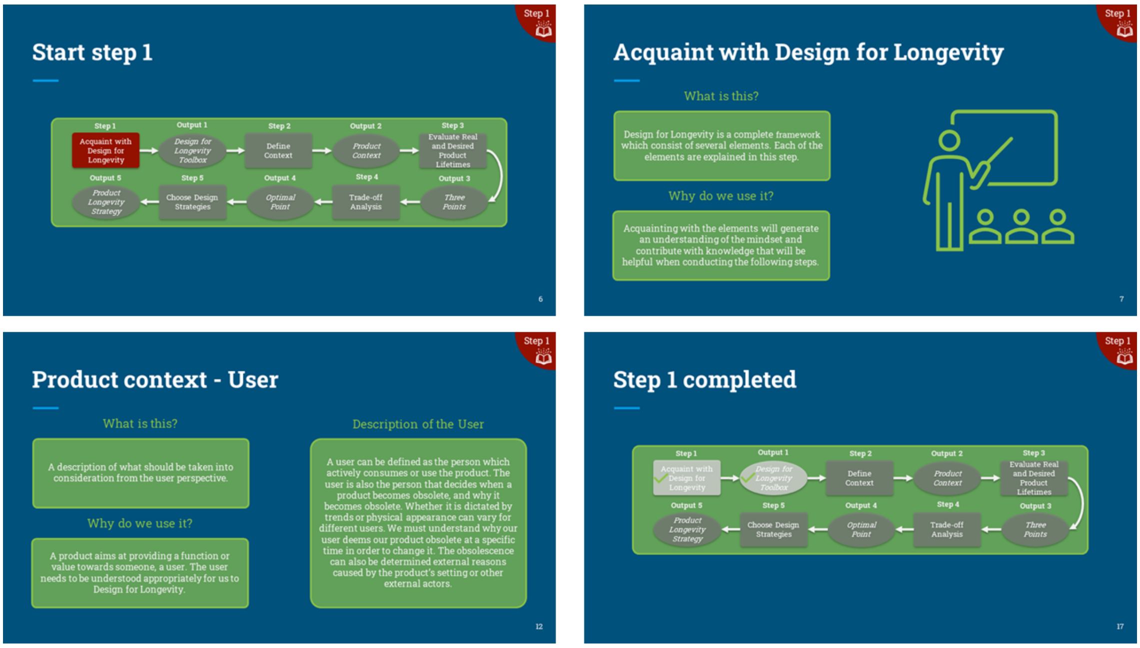


Figure 6.4: Top left: Illustrating that we are beginning step 1. Top right: Explanation of step 1. Bottom left: Information about the contextual aspect "user". Bottom right: Illustration that step 1 is completed.

Step 2 - Define Context

Step 2 consist of defining the context, more specifically the product setting and the product context, where the first aims to conclude the overall extent of the implementation process. The step starts with illustrating where we are in the process, seen top left in Figure 6.5, followed by an explanation of the step. Several supporting questions are provided to ease this, and it can be noted that the "answering" symbol is used on this slide, illustrated in Figure 6.5, bottom left. When the step is completed it is illustrated with a slide visualizing the completed steps and the output in the process, seen bottom right in Figure 6.5.

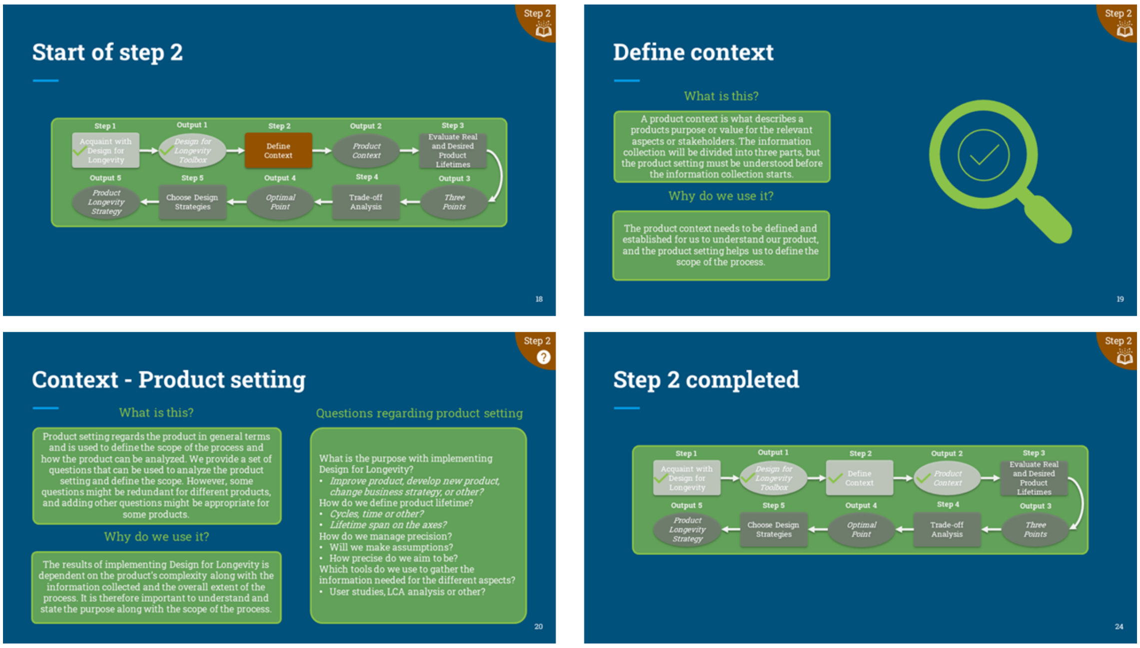


Figure 6.5: Top left: Illustrating that we are beginning step 2. Top right: Explanation of step 2. Bottom left: Explanation and questions to be answered about the product setting. Bottom right: Illustration that step 2 is completed.

Step 3 - Evaluate Product Lifetimes

Step 3 requires us to evaluate the product lifetimes for each contextual factor. The step starts with illustrating where we are in the process, seen top left in Figure 6.6, followed by an explanation of the step. It can also be seen that this step also requires us to perform a task, as this symbol can be seen in Figure 6.6, bottom left. When the step is completed it is illustrated with a slide visualizing the completed steps and the output in the process, seen bottom right in Figure 6.6.

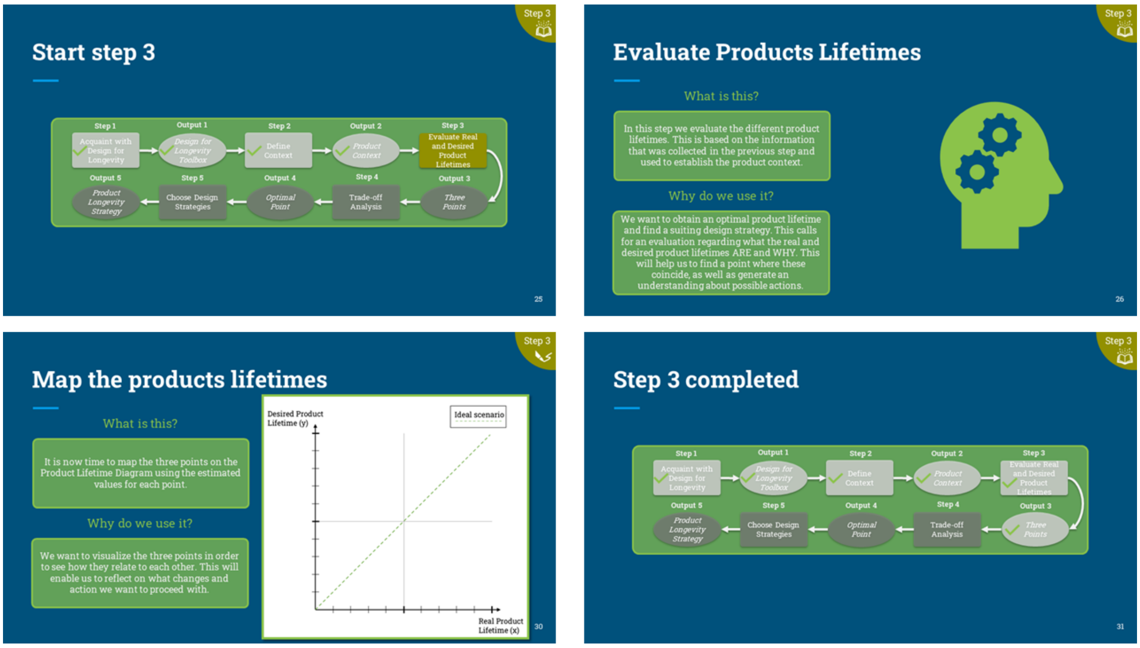


Figure 6.6: Top left: Illustrating that we are beginning in step 3. Top right: Explanation of step 3. Bottom left: Task of mapping product lifetimes on *Product Lifetime Diagram*. Bottom right: Illustration that step 3 is completed.

Step 4 - Trade-off Analysis

Step 4 consist of a trade-off between the product's different lifetimes. The step starts with illustrating where we are in the process, seen top left in Figure 6.7, followed by an explanation of the step. The *Product Lifetime Diagram* was not considered to be in need of further improvement in Chapter 5, but several approaches are provided to ease this step even further. These approaches are illustrated in Figure 6.7, bottom left. When the step is completed it is illustrated with a slide visualizing the completed steps and the output in the process, seen bottom right in Figure 6.7.

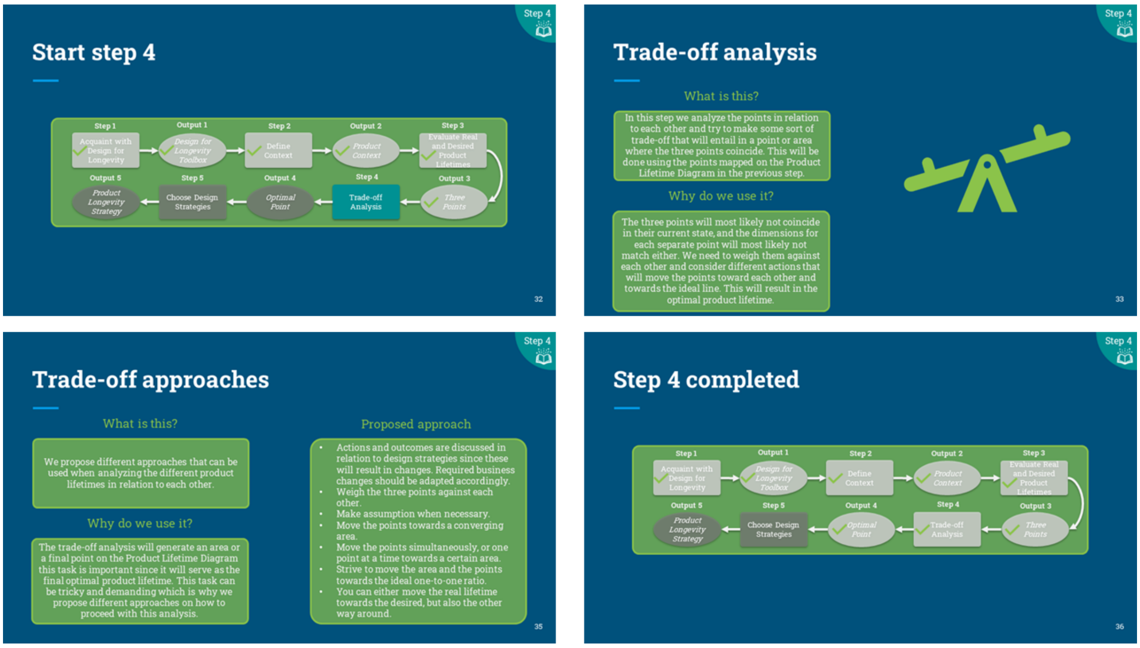


Figure 6.7: Top left: Illustrating that we are beginning step 4. Top right: Explanation of step 4. Bottom left: Potential trade-off approaches are described. Bottom right: Illustration that step 4 is completed.

Step 5 - Choose Design Strategy

Step 5 is the final step in the implementation process, and it more of a conclusion or summary of what the company wants to proceed with. The step starts with illustrating where we are in the process, seen top left in Figure 6.8, followed by an explanation of the step. This step aims to summarize all of the information that have been collected by completing all previous steps, several key questions can be answered and will help the company to implement Design for Longevity. These are illustrated in Figure 6.8, bottom left. When the step is completed it is illustrated with a slide visualizing the completed steps and the output in the process, seen bottom right in Figure 6.8.

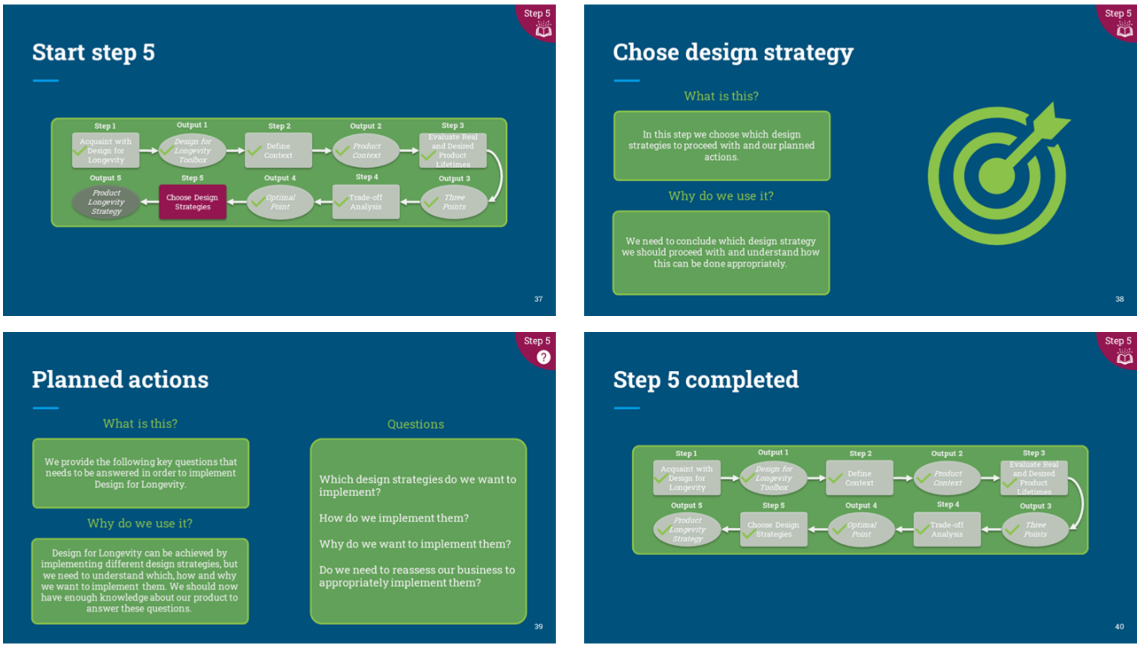


Figure 6.8: Top left: Illustrating that we are beginning step 5. Top right: Explanation of step 5. Bottom left: Key questions to be answered to appropriately implement Design for Longevity. Bottom right: Illustration that step 5 is completed.

6.2 ICED21 Scientific Article

A scientific article called *Design for Longevity – A Framework to Support the Designing of a Product's Optimal Lifetime* (Carlsson, Mallalieu, Almefelt, & Malmqvist, 2021) was created based on the material from project phases 1-3. The article points out the result that has been generated in those phases and aims to present the Design for Longevity framework for academia. The article is a first draft that is sent to ICED21 committee in order to be peer-reviewed and examined if it will be published at the conference. By writing a scientific article and by publish the article at the world's largest scientific conference of product development enables a wider spread of the article within academia. The article was created in collaboration with two professors at Chalmers University of Technology, who contributed with feedback and input that improved the quality of the article.

6.3 Summary of Creation Phase Results

The results from the research phase aimed to fulfill several sub-objectives, formulated in Section 2.4, and they are presented and discussed below.

- Resolve the concluded improvements from Chapter 5.
- Create a mediating tool that can help product developers to implement Design for Longevity in practice.
- Present project phases 1-3 to academia using a scientific article.

All of the above stated sub-objectives are deemed to be fulfilled. A Design for Longevity Guide was presented in Section 6.1, where it resolves the proposed improvements in Chapter 5. The guide is created as a mediating Design for Longevity implementation tool, but needs to be tested and validated before it can be verified to work in practice. A scientific article, presented in Section 6.2 was created to present project phases 1-3 to academia. The developed guide will be further tested and validated in the next phase, that is the validation phase.

7

Validation Phase Results: Case Study and Focus Group including Developed Framework

This chapter presents the results from the validation phase. It consist of a case study of a Moccamaster, a focus group performed in the automotive industry, a scientific article review and internal discussions of the collected literature. Further explanation of these parts can be found in Section 2.5. Figure 7.1 indicates the phase position in the process.

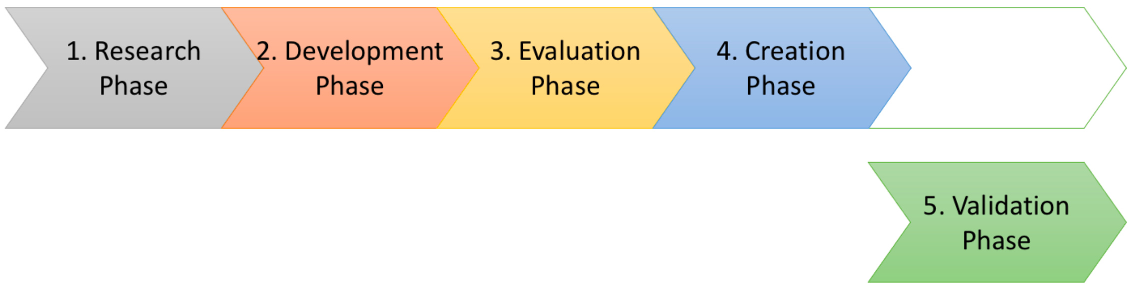


Figure 7.1: The validation phase is the fifth and the final phase in the process.

7.1 Coffee Brewer Case Study

A case study of a Moccamater was conducted. As mentioned in Chapter 5, one issue was that no real case had been applied on the framework. The Design for Longevity Guide was used when analyzing this case, the implementation process from the guide can be seen to the right in Figure 7.2. The guide is used as if product developers would use it on any product, in this case a Moccamaster. The term "we" will be used throughout the case study since this is how the guide is formulated. The case was performed on a Moccamaster KB952AO, illustrated to the left in Figure 7.2.

Figure 7.2: Moccamaster KB952AO (Moccamaster, 2020) is illustrated to the left. The *Design for Longevity Implementation Process* is illustrated to the right.

The case study will be presented step-wise following the Design for Longevity process chronologically, where the methods used, the collected information, and the corresponding result will be presented for each step. The case is formulated as if an user has filed a complaint about a Moccamaster, as formulated in Section 7.1.2.1. The case is formulated like this to make it more realistic, and it should be clarified and emphasized that the scenario and the collected information is real, this user was a recent victim of a Moccamaster breakdown.

Section 7.1 ends with a reflection of the the performed case study. The case study reflection's purpose is to reflect upon the results from this case study, and is considered necessary since this is the first real case that have been tested on the Design for Longevity Guide. The reflection is included as a part of this project, and it is important to note that it is not included as a part in the Design for Longevity Guide.

7.1.1 Step 1 - Acquaint with Design for Longevity

This step only requires us to read through this step in the guide and assure that all elements are understood and how to use them. No further comment is made on this step.

7.1.2 Step 2 - Define Context

In this step, we need to define the context, both the product setting and the product context. The product setting begins with analyzing our current scenario, where a user filed a complaint about his Moccamaster.

7.1.2.1 Moccamaster Product Setting

A Moccamaster has a warranty of either five or ten years, and this will be the time span the product is analyzed from. The setting is focused on the one user that has provided this scenario. Assumptions will be made regarding business and resource efficiency, since this study is restricted by time, two working days, and information available. The product will also be disassembled to analyze and make assumptions about the resources it contains as well as the companies design strategy. Figure 7.3 illustrates the product and its main parts.

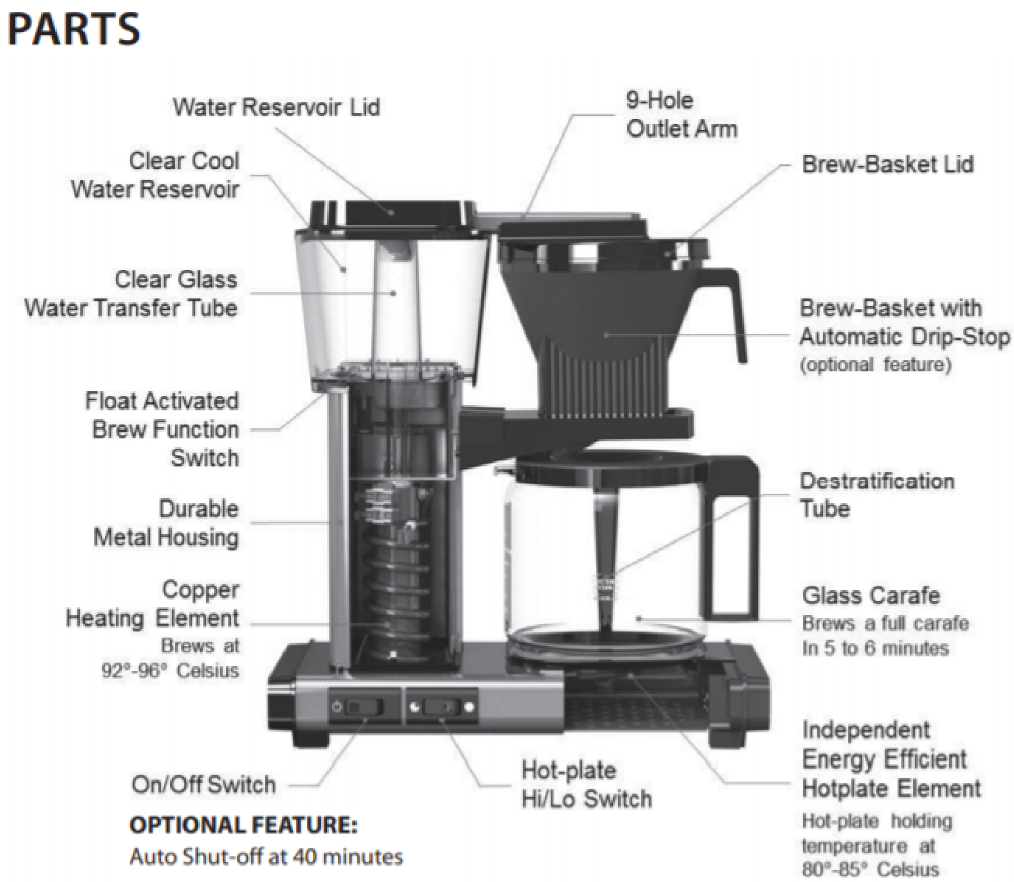


Figure 7.3: Moccamaster and its main parts - Retrieved from Moccamaster (2020).

Purpose of this Case Study

A user has reviewed a Moccamaster due to the fact that it broke down and was beyond repair. The Moccamaster had been in the user's possession for almost ten years. The Moccamaster had been maintained regularly by the user, and this included cleaning its removable parts. The pot had been replaced once due to cracks in the previous. The button had also been repaired a couple of times, more specifically the contactor. The button was beyond repair this time. The attachments on the module were broken and were not able to be attached to the whole structure. This led to the act of trying to glue the contactor to the surface of the whole structure. This did not result in a fix, the button was instead not able to be pushed down. This resulted in the user to scrap the product and leave it at a recycling center. Design for Longevity is therefore applied in order to find potential changes in the product's life that could have prevented this scenario.

Tools to Be Used and Information Collection

Several tools and methods was used to collect information.

- 45 minute online interview with user - Questions and answers, in Swedish, can be found in Appendix D
- Patent search
- Disassembly of Moccamaster
- Online research
- Hypothetical cost calculation

7.1.2.2 Moccamaster Product Context

The information collected from each tool or method will be presented in this section.

User study

The reason to replace the product was a result of the Moccamaster unable to perform its original function, brew coffee. More specifically the button broke down, and the user was not able to repair it. There is a possibility to submit it to retailers for service, but the user considered these options too expensive. The Moccamaster had been in the user's possession for almost ten years, and ten years was expressed as the expected lifetime since this is expressed by the retailers. The user did also consider another option. The user works as a restaurant equipment seller and has access to a workshop. The product could possibly have been repaired with the tools available there. However, the user was too eager to fix it and did therefore instead try to repair it at home.

The user would have preferred if it was easier to fix this button. The user has some experience of fixing coffee brewers and knows that this cause of failure (the button/contactor) is common. The user explicitly said that "Manufacturers sometimes make things complicated intentionally". Both to indicate that it should not be fixed by the user as well as designing it such that users cannot fix it themselves. The user also stated that he got an electric shock while trying to repair it, along with this, subtly indicating that this might be for the best. However, the user would have wished that the contactor or button would have been in metal instead of plastic, such that it could have been repaired easier.

The Moccamaster had been in the user's possession for almost ten years, as mentioned. However, the user would have preferred it to last longer, beyond the expected lifetime. The expected lifetime of ten years was as a result of the expressed warranty. The user is also aware that the brewer had paid its dues, considering the user has a large family where a lot of coffee is brewed. The user stated that wear and tear are expected, but this was not considered an issue since the brewer worked as desired. The wear and tear mainly meant that the Moccamaster appeared as well-used, and the second button, not commonly used, had also broken down. This was neither considered an issue but highlights that the contactor/button is a common and reoccurring issue.

The user did replace the product with a new Moccamaster of the same model as the previous one. This was considered as a natural choice, as they were very pleased with the product and its performance. The user would however have preferred to keep the current Moccamaster if it could have been repaired, and the design is considered, as explicitly expressed "stylish". The user does not feel anything could have been done to prevent this failure, as parts are cleaned regularly.

The Moccamaster was rather unique when purchased ten years ago, whereas several similar models are available now. However, no model is deemed being as near as "stylish" as the Moccamaster. The main reason why a Moccamaster was chosen ten years ago was a result of being recommended by a friend. Where it was suggested that Moccamasters performed well and last long. This led to the purchase argument of "it is better to buy a brewer for 2000 SEK that lasts ten years instead of one for 500 SEK that lasts for around two years". The Moccamaster's appearance along with its performance was the main reason for the purchase. The user stated that in comparison to other brewers and kitchen equipment, which are "in the way", and that a Moccamaster "does not need to be hidden in the kitchen". It is considered as something to show purposely. The user value temperature and speed of brewing but are not aware of the ECBC marking a Moccamaster has.

Patent Search

A patent search investigating emerging trends and technologies was conducted using espacenets advanced search, with IPC A23F: "COFFEE; TEA; THEIR SUBSTITUTES; MANUFACTURE, PREPARATION, OR INFUSION THEREOF". The number of patents filed for the last 15 years is illustrated in Figure 7.4.

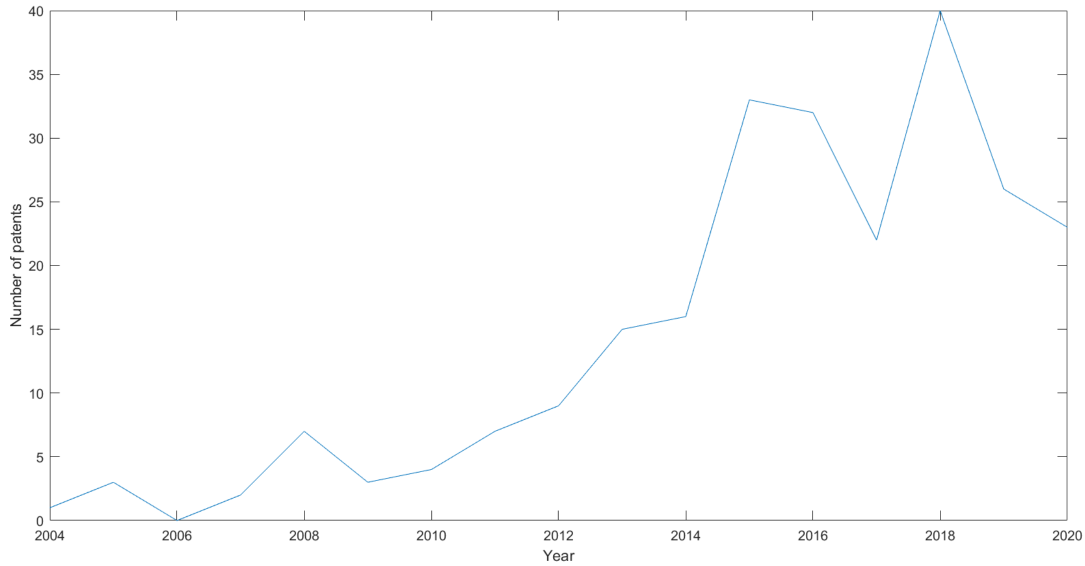


Figure 7.4: Patents filed categorized within IPC A234: "COFFEE; TEA; THEIR SUBSTITUTES; MANUFACTURE, PREPARATION, OR INFUSION THEREOF" during the last 15 years, based on data taken from espacenet.

There appears to be some increase of filed patents in the later years. However, there is no clear trend that it is going upwards. The patents from the last two years were instead eyeballed to investigate if there are any potential patents that could drastically improve coffee brewers in the coming years.

The patents did in general regard methods of dispensing coffee in professional brewers, coffee extraction and processing methods, alternative coffee such as ice coffee, water treatment. The majority of the patents regarded professional brewers and not brewers for private use, thus not affecting this Moccamaster. There appear to be no inventions that drastically improve energy efficiency. The second patent could potentially increase energy efficiency, but nothing regarding this is mentioned in the information provided. However, few vague patents could enable more connected brewers and new solutions, and potential business cases, including digitalized coffee brewers. Four specific patents could be of interest:

1. A device that distributes coffee homogeneously and applies controlled and measurable pressure - Aims to dispense coffee, controlling beans and water, automatically (Espacenet, 2020d).
2. A device or system for creating a vapor filled bubble - Aims to improve the water injection (Espacenet, 2020c).
3. Beverage dispensing systems and methods - Aims to dispense the coffee (Espacenet, 2020b).
4. Application of calcium hydrogen-rich water additive in tea leaves, milk powder, coffee, or malted milk - Aims to improve quality of water (Espacenet, 2020a).

The water could be improved by the fourth patent, which could potentially increase the quality of the coffee. Patent two can improve water injection. These could be argued to improve the performance and quality of the coffee, as well as potentially improve energy efficiency. The patents regarding automatic dispensing are not in the interest of this particular user, since he valued design, performance, and quality. Some patents could potentially result in new and improved coffee brewers, and they could make the current design obsolete if the performance is essentially increased.

Disassembly

A two to three year old, well used, Moccamaster was disassembled, and the disassembly had several goals, stated as following:

- Analyze how the issue described in the scenario could be solved.
- Analyze how modular the product currently is.
- Analyze the ease of disassembly.
- Analyze the product's materials.
- Analyze to which degree the components can be reused or recycled.

The disassembly was conducted in four steps to analyze and clarify how easy it was to disassemble different parts and components, and if tools were required.

Figure 7.5 illustrates before and after the first step was applied. This step corresponded to "Disassemble parts that are meant to be disassembled by user without using tools". Only a selection of parts could be removed during this step.

Figure 7.5: Moccamaster disassembly - Comparison before and after first step.

Figure 7.6 illustrates the components that the user can disassemble to either replace (purchase at retailers) or clean (maintain).

Figure 7.6: Parts that the user both should be able to remove and can be removed without using tools.

Figure 7.7 illustrates the parts and components after conducting the second step, which corresponded to "Disassemble parts that are not meant to be disassembled by user without using tools".

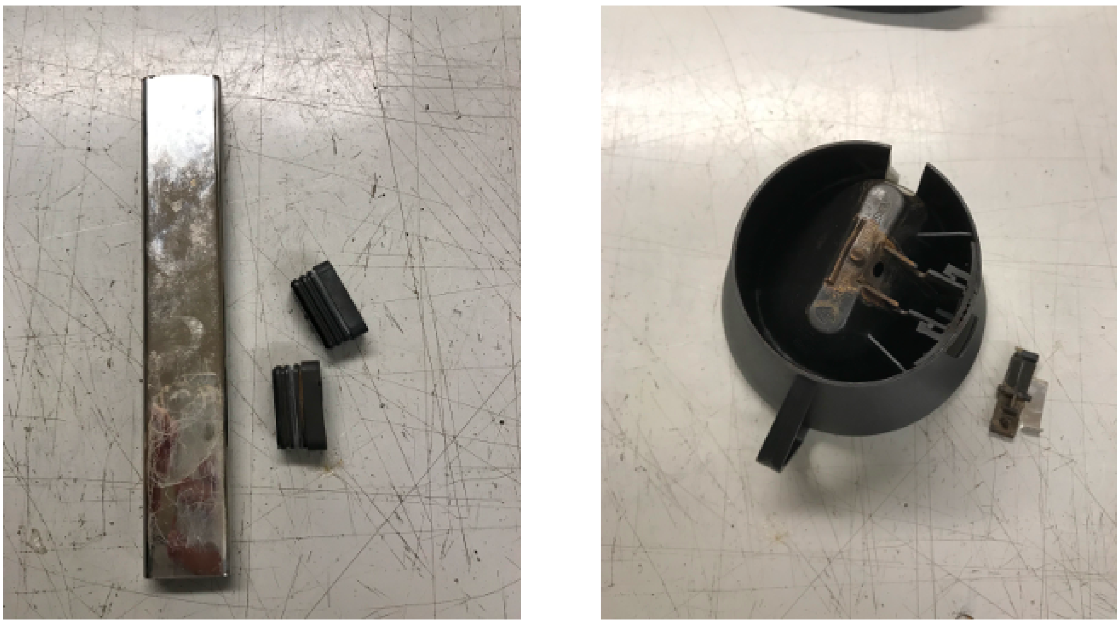


Figure 7.7: Parts and components that should not be removed but can be removed without using tools.

The third step corresponded to "Disassemble parts that are meant to be disassembled by user with the use tools". However, this step was redundant since no part that is intended to be disassembled by the user could be disassembled without using tools.

Figure 7.8 illustrates components divided into modules, this is after performing the fourth step. The fourth step corresponded to "Disassemble parts that are not meant to be disassembled by user with the use of tools". Almost every of the remaining components could be disassembled without breaking, where the only exception was the hotplate element, seen in Figure 7.8, top right.

Figure 7.8: Components and parts removed using tools divided into modules.

Figure 7.9 illustrates all components divided into groups, categorized as; electronics, metal, rubber, glass, plastic and other. All materials could be separated without difficulties.

Figure 7.9: Top left: Electronics. Top middle: Metal. Top right: Rubber. Bottom left: Glass. Bottom middle: Plastic. Bottom right: Other (Hot plate and heat exchanger).

Figure 7.10 illustrates the button or contactor that broke down in the user scenario. The component is attached using plastic snaps, and the bottom plate needs to be removed, which is attached by screws, in order for it to be repaired. The component also require several wires to be unattached before it can be removed completely.

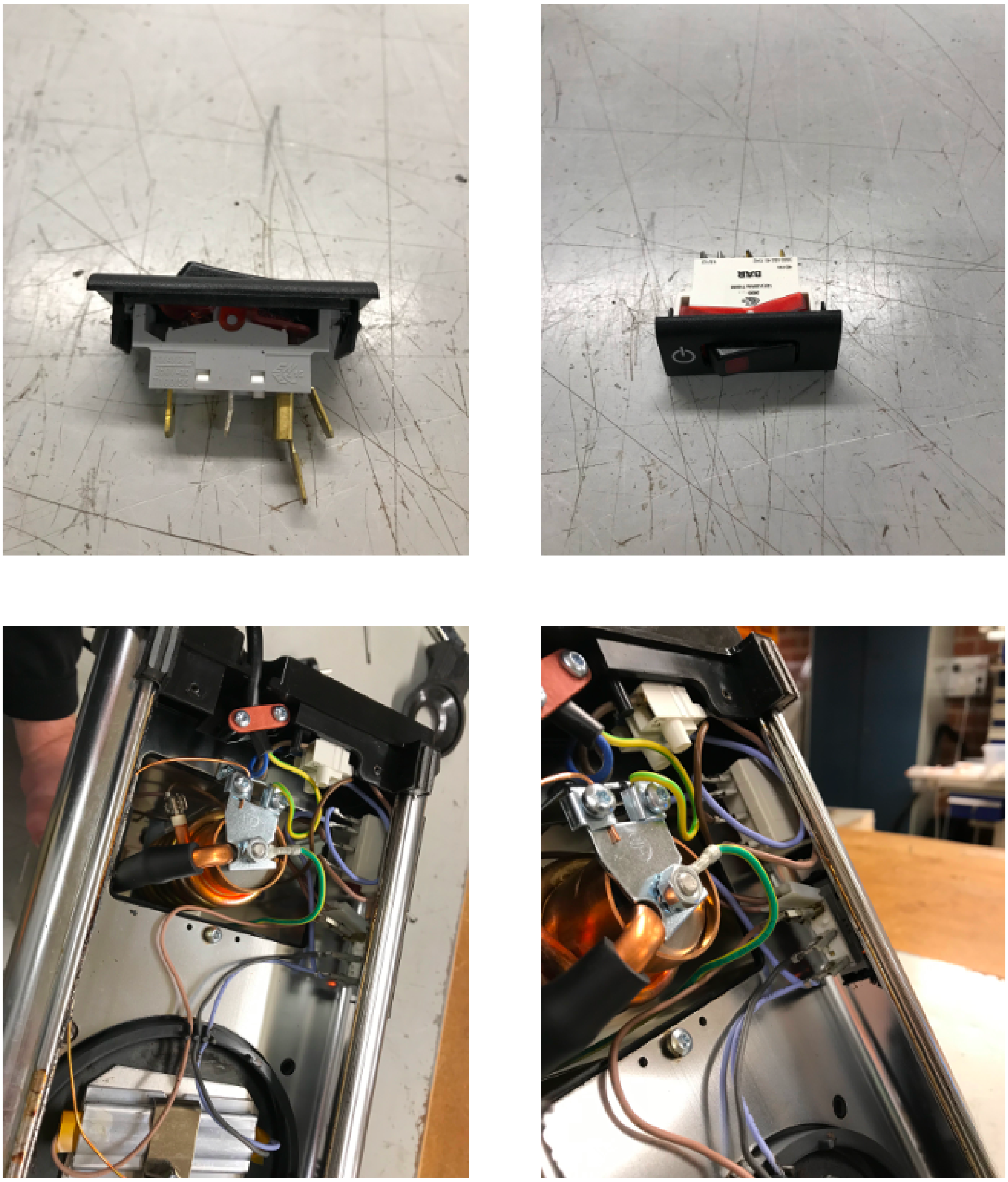


Figure 7.10: Top right and left: Button/contactor module. Bottom right and left: Button/contactor placement and surrounding components.

All parts that can be removed without any tool are parts that can be replaced by purchasing separate spare parts at retailers and is possibly something the company makes a profit from. All parts except the heat plate could be disassembled without breaking any part, and the parts could be divided into different modules. This indicates that the business uses a clear modular design. This also means that if a specific part breakdown there is a possibility to reuse several parts. The parts appeared to be in a valuable condition after this disassembly, however, this product was only two to three years. It is not necessarily the same for a product that is older than that. The parts could also be divided into several material categories, where the separation was deemed easy. It was also easy to separate the components into different categories which would ease the complete recycling of the product.

The contactor or button could be redesigned into a module which the user could replace by themselves. This would require the module to be accessible without removing the bottom plate, which could be done by either attaching it from the outside or creating a space on the bottom plate. It also requires the wires to be pre-attached on the inside of the bottom module, enabling the user to "click" the button module onto the intended place. Another, perhaps more simple option, would be to make the "snaps" on the button more durable and longer lasting.

Online Research

Moccamaster was founded by Gerard-Clement Smit in 1964 and he had a clear vision of developing a coffee brewer that provides the customer with the best homemade brew coffee in the world. This is still the vision within the company, and they focus on developing reliable brewers that provide high-quality coffee and maintain the same performance over time. In addition, they also aim for developing sustainable products that are energy efficient and last for a longer time. This entails a focus on material selection and they aim for only using material that is recyclable and degradable (Moccamaster, 2020).

It is a global brand and sells products worldwide. Their products it sold both in stores and online. They have their own webpage where it is possible to find information about the brand and purchase both their products, spare parts, and accessories. Additionally, they have several retailers that sell their products in stores and can offer Moccamaster's own spare parts and accessories to the customer. They have one main factory located in the Netherlands where Technivorm manufacture all their products (Technivorm, 2020). All products are handmade assembled and tested before leaving the factory, to control the performance of each product in order to ensure the product's quality. They have an established knowledge base on how to assemble and disassemble their products and how to maintain production.

Moccamaster's products have well-known quality certifications that prove and assure the high quality of the products. All products that are included in Moccamasters assortment are certified with Specialty Coffee Associations of America and Europe (SCAA and SCAE) (SCACertifiedHomeBrewerProgram, 2020) and European Coffee Brewing Centers (ECBC) (ECBC, 2020). In addition, they also offer 5 years of warranty to all customers and customers can even gain an extended warranty up to 10 years if they register the purchase of the product on Moccamaster's webpage (Moccamaster, 2020). This entails an increased safety for all their customers and Moccamaster ensures that the customers will receive the quality they promise.

The product itself has a modular design, which makes it easy to change parts and components. The customer himself can easily change and remove the main parts without using any tools. This facilitates the process of maintenance of the parts and makes it possible for the customer to repair the product if a part break. Moccamaster offers a wide range of spare parts on their webpage (Moccamaster, 2020), but only for the parts that the customers can remove and replace without using any tools, for example; pot, filter holder, and top cover. The modular design makes it easy to remove and change components in order to repair and sort out and disassembly the product when it is considered obsolete. This facilitates the process of recycling and re-use the product's components.

The coffee brewer both have an environmental impact during the manufacturing phase and the use phase. The impact during the manufacturing phase is too extensive to investigate due to the time limit in this case. However, an LCA would be reasonable to perform in order to conclude the environmental impact during the manufacturing phase. During the use phase the brewer consumes energy and data regarding the energy consumption on a Moccamaster and other relevant products are listed in Table 7.1 (Energimyndigheten, 2017).

Table 7.1: Energy consumption on different products during the use phase. Data taken from Energimyndigheten (2017).

Energy Consumption Data		
Product	**Value**	**Comment**
Moccamaster	65 kWh/year	The value is based on that one pot of coffee is brewed each day for one year.
Kettle	57,7 kWh/year	The value is based on that the kettle is used one time each day.
Washing machine	170 kWh/year	The value is based on a washing machine capable of 7 kg and with energy class A+++ with a combination of 60- and 40-degrees programs performed 220 times for over one year.

Additionally, Moccamaster is certified with CE, which indicates that the product achieves EU's regulations regarding energy consumption and the use of resources. The CE is framed after the eco-design perspective and demand certain energy efficiency and the utilization of the resources (Energimyndigheten, 2018).

Hypothetical Cost Calculation

The price of this Moccamaster depends on the retailer, but the price is between 1500 to 3000 SEK. It is unknown in which volumes this Moccamaster is sold. A cost calculation with three hypothetical cases was provided. Moccamaster Scandinavian AS (MSAS) is one sub-company that includes Sweden, Denmark, and Norway and their markets. According to LargestCompanies (2020) does MSAS have a profit margin of 15.2 percent and a turnover of 564520000 SEK, resulting in a profit of 85.8 million SEK, since 564520000*0.152 = 85.8 million SEK. These numbers are used to hypothetically provide different sales volumes.

Their overall profit margin of 15.2 leads to the assumption in this case that MSAS has a 15.2 percent margin of profit for their Moccamaster as well. We then assume a price of 2250 SEK, which is in the middle of 1500 and 3000 SEK. This leads to the following profit for a sold Moccamaster.
Profit per Moccamaster: $2250 - (2250 * (1 - 0.152)) \approx 340$ SEK.
This entails that in order for the company to reach the current sales profit: 85.8/340 ≈ 252 350 Moccamasters need to be sold annually.
The total market, which is the amount of combined households, with the assumption that 70% of them have coffee brewers: 4 700 000 (Sweden) (SCB, 2020) + 2 430 000 (Denmark) (Statista, 2020) + 2 475 000 (Norway) (SSB, 2020) * 0.7 = 6.7235 million households, and potential sales volume. This is then later translated into how often a coffee brewer must be sold to a household, for three hypothetical cases, where the market share varies.

- Case one - assuming 5% market share: Possible volume = 336 175 sold ⟶ moccamaster turnover per household = 336175/252350= 1.33 years.
- Case two - assuming 10% market share: Possible volume = 672 350 ⟶ moccamaster turnover per household = 672350/252350= 2.66 years.
- Case three - assuming 15% market share: Possible volume = 1 008 525 ⟶ moccamaster turnover per household = 1008525/252350 = 4 years.

It should also be noted that this cost calculation is made on rough estimations and vague assumptions. There is no real knowledge of how large market share is, or the overall market. There is also no real knowledge about the profit per sold Moccamaster. It can also be said that the business have many other products than this specific Moccamaster, which which contributes to revenue of the company.

7.1.3 Step 3 - Evaluate Product Lifetimes

The product lifetimes can be evaluated using the information obtained from step 2. Each contextual aspect should be evaluated individually. Several potential points were mapped on the *Product Lifetime Diagram* based on the different information collected in the previous step. The lifetime that was deemed as the most suitable, in relation to the coordinate definitions in Section 4.4 was concluded to be the final point. This was done for each of the contextual aspects; user, business and resource efficiency. Each definition is also provided for the different product lifetimes below.

Real User Product Lifetime

Definition: *For as long as the user actually uses the set of resources to provide a certain function.* The different real user product lifetimes that were proposed are presented below:

- 7 years - Button broke, could be solved by own actions since user had experience.
- 8-9 years - Pot cracked, could be solved by purchasing spare part.

- 10 years - Button broke again, unable to repair.

Final real product lifetime for the user is concluded to be 10 years, since this is when the product ultimately broke down, and the user stopped using it to provide its function.

Desired User Product Lifetime

Definition: *For as long as the user desires the set of resources to be used to provide a certain function.* The different desired user product lifetimes that were proposed are presented below:

- 10 years - Expected lifetime by user due to warranty.
- >10 years - Desired it to last as long possible, thinks that the design is lasting and does not bother wear and tear.
- <10 years - Emerging technologies can improve performance, the user values performance. However, not clear indication that performance will increase.

Final desired product lifetime for the user is 15 years. The user desired it as long as possible, minimum 10 years expected. Could be any value above 10 since no specific value was mentioned, 15 is chosen due to the overall time span analyzed.

Real Business Product Lifetime

Definition: *For as long as the resources are planned to be used to provide the certain function.* The different real business product lifetimes that were proposed are presented below:

- 5 years - Standard warranty.
- 10 years - Improved warranty by registering on website.

Final real product lifetime for the business is 10 years. It can be assumed to be planned to last 10 years since the improved warranty is 10 years.

Desired Business Product Lifetime

Definition: *For as long as the company desires the set of resources to be used to provide the certain function.* The different desired business product lifetimes that were proposed are presented below:

- 4 years - Best case scenario cost calculation.
- 10 years - Branded as long lasting product, also part of corporate value to produce lasting products. Strategy focus on providing spare parts and service, along with robust and durable design.
- <10 years - Emerging technologies can make their product obsolete, want costumers to purchase potential new model.

Final desired product lifetime for business is 10 years, since it align with their current strategy, it is not possible to know exactly what they desire.

Real Resource Efficiency Product Lifetime

Definition: *For as long as the set of resources can be used to provide the certain function.* The different real resource efficiency product lifetimes that were proposed are presented below:

- 7 years - Button broke, could not perform function, but was however repaired by user.
- 10 years - Product breakdown due to broken button.
- 10+ years - (>90% components) Could perform function except for the button, according to the user.

Final real product lifetime for the resource efficiency is 10 years. Same reason as for the user, the product ultimately broke down.

Desired Resource Efficiency Product Lifetime

Definition: *For as long as the set of resources should be used to provide the certain function.* The different desired resource efficiency product lifetimes that were proposed are presented below:

- <10 years - Emerging solutions can improve energy efficiency marginally, also digital solutions can improve user consumption.
- 10+ - >90% resources could perform function.

Final desired product lifetime for the resource efficiency is 15 years. The product consumes little energy and resources should be used as long as possible, where it is unclear if future solutions will improve it. 15 is chosen due to the overall time span that is analyzed.

Current Product Lifetimes

By having analyzed all the contextual aspects and their resulting product lifetimes, it possible to map out each respective lifetime on the *Product Lifetime Diagram*, illustrated in Figure 7.11. The final product lifetimes of the Moccamaster are also listed in Table 7.2.

Table 7.2: Real and desired product lifetimes of product in its current state.

Moccamaster's Lifetimes			
	User	Business	Resource Efficiency
Real Product Lifetime	10 years	10 years	10 years
Desired Product Lifetime	15 years	10 years	15 years

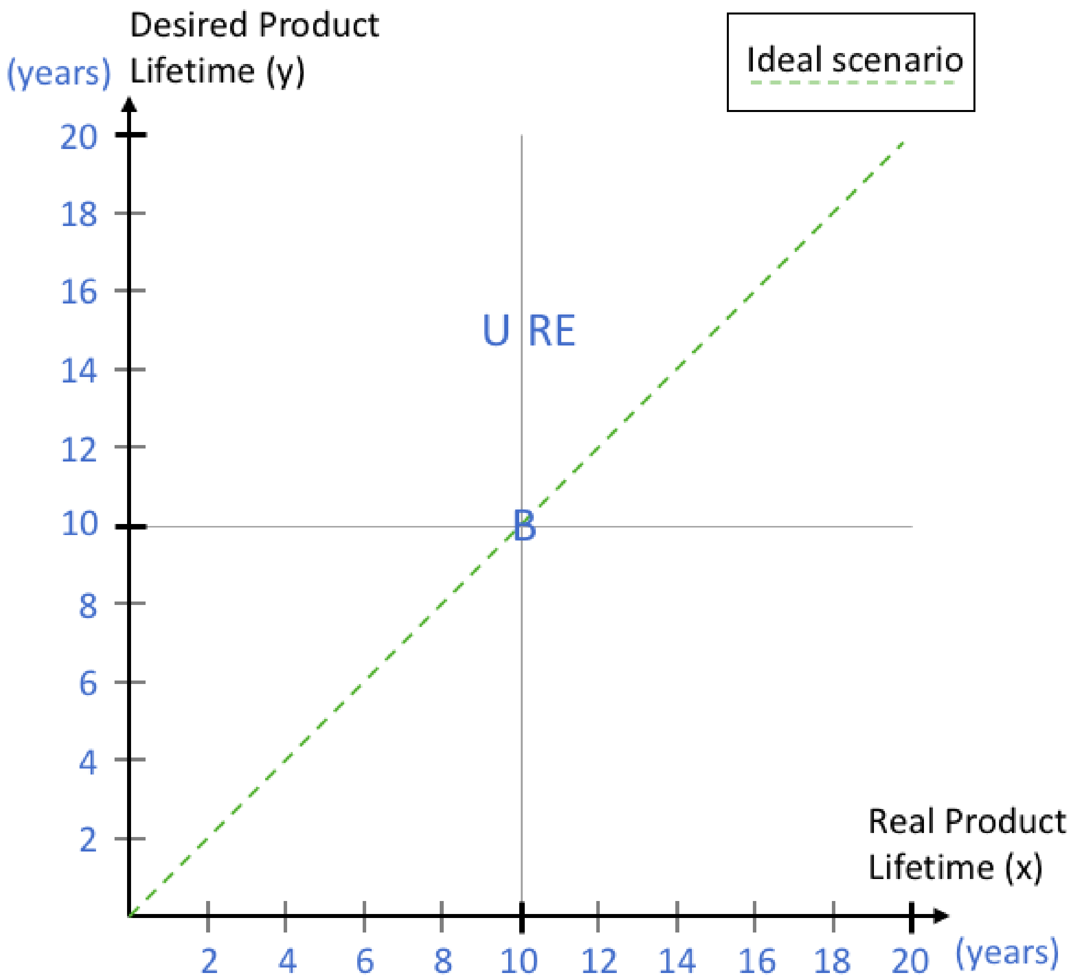


Figure 7.11: Product lifetimes mapped on *Product Lifetime Diagram*, the axes represent time in years. The user (U), the business (B) and the resource efficiency (RE) are all mapped out based on the values presented in Table 7.2.

7.1.4 Step 4 - Trade-off Analysis

Step 4 can be conducted since the different product lifetimes have been evaluated and obtained. This step has been divided into two different cases, where different approaches are used. Case 1 is more hands-on, where feasible actions and outcomes are presented. Case 2 is merely based on reflections in order to find more innovative actions.

Case 1

The first case uses the approach to weigh the point against each other. This case is based on the user scenario, with the goal to solve this issue, hence this is the point to strive for. This means that the goal is to move all initial point towards the user, for all dimensions. Possible actions and outcomes for case 1 will be discussed below, for each design strategy from Section 4.2.1.

- **Design for Attachment and Trust** (D1) - Does not affect any lifetime.
- **Design for Dis- and Reassembly** (D2) - Increase real and desired product lifetime for business. Their product strategy is to disassemble product easy along with repair, whereas only one component broke. Business needs to collect product, was currently scraped by user. Real increases for resource efficiency since all components can be reused. User benefits from D2 if along with D4, meaning the user can repair button themselves.
- **Design for Standard and Compatability** (D3) - Screws used different standards, which required various tools. Would benefit user and business along D2 and D4. Product appear to be standardized through the years, and benefits RE since components can be reused.
- **Design for Maintenance and Repair** (D4) - Can increase real user if they can repair by themselves. Provide examples in manual how to replace parts. Increase RE since components can be used longer. Business needs to find cost incentives to proceed with this. Can provide premium warranty by cost annually, and thus provide with parts. Retailers currently provide service. Alternative provide loyalty premium, 10 years warranty and return old Moccamaster to obtain discount on new Moccamaster.
- **Design for Durability** (D5) - Can increase real user and resource efficiency if button is more durable. Does not benefit company in any way if cost is not increased.
- **Design for Adaptability and Upgradability** (D6) - Is not beneficial for any part, user did not express desires of upgrades or new technologies.

All of the discussed actions and outcomes for case 1 are illustrated in *Product Lifetime Diagram*, seen in Figure 7.12.

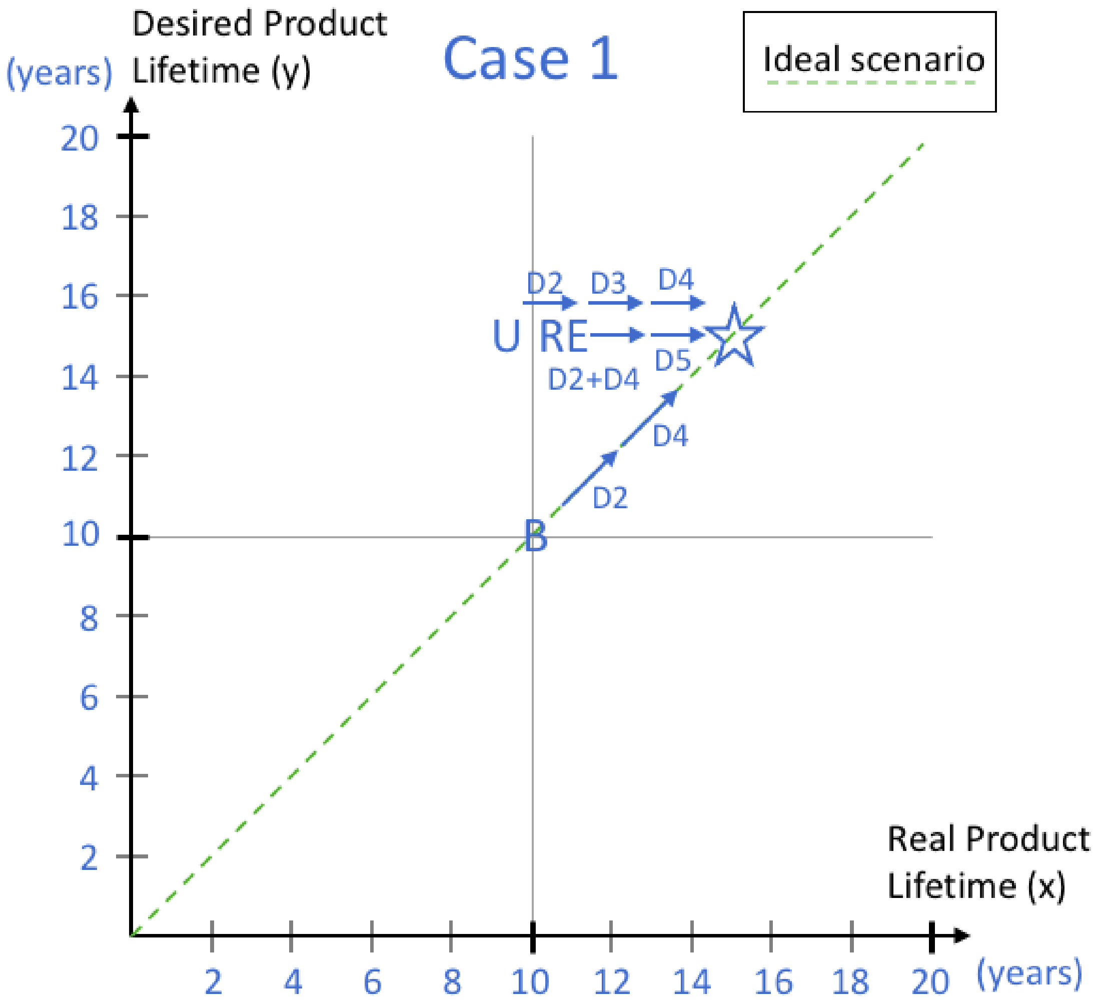


Figure 7.12: Possible actions and resulting outcomes for each design strategy Case 1, represented in years. Where, Design for Attachment and Trust (D1), Design for Dis- and Reassembly (D2), Design for Standard and Compatability (D3), Design for Maintenance and Repair (D4), Design for Durability (D5), Design for Adaptability and Upgradability (D6).

Case 2

The second case is more based on reflection. This case is based on the notion that both user and research efficiency desired a high as possible product lifetime, it can be difficult for business to encompass for their own goals while achieving this, as they currently work. It is therefore tested if a product service system business model could facilitate this. Emerging technologies could also be a potential threat to the current product, where more digital solutions and apps are emerging. This makes it interesting to reflect on how the company could adapt to this. It is important to note that this results in the user's lifetimes to be considered "infinite-infinite" since they pay a fee to be provided with a coffee brewer. Possible actions and outcomes for case 2 will be discussed below, for each design strategy from Section 4.2.1.

- **Design for Attachment and Trust** (D1) - Important to improve branding and provide strong value since customers can end premiership any time.
- **Design for Dis- and Reassembly** (D2) - Can increase business by improving reuse of components, and close the system. Also increase user and resource efficiency since components can be user longer. User can either repair themselves or provided service. Provide service can result in high premiership cost, since it is non cost efficient to perform service. Thus either replace product or instruct user to perform self service.
- **Design for Standard and Compatability** (D3) - Strive to have same standard within the machines, can replace components. Basic degree is vital. Does not affect user or resource efficiency, business will be charged for cost of changing standard.
- **Design for Maintenance and Repair** (D4) - User expects service to be possible, business will be charged if not possible. Resource efficiency benefits as well since components last longer.
- **Design for Durability** (D5) - Can be used to repair less. Difficult to decide between more repair or more durable. Perhaps easy solve to fix button issue, appeared to be common problem and critical component.
- **Design for Adaptability and Upgradability** (D6) - Emerging technologies and trends could make product obsolete and non energy efficient. Need to enable upgrades of new technologies. Replacing all products will be costly.

All of the discussed actions and outcomes for case 2 are illustrated in *Product Lifetime Diagram*, seen in Figure 7.13.

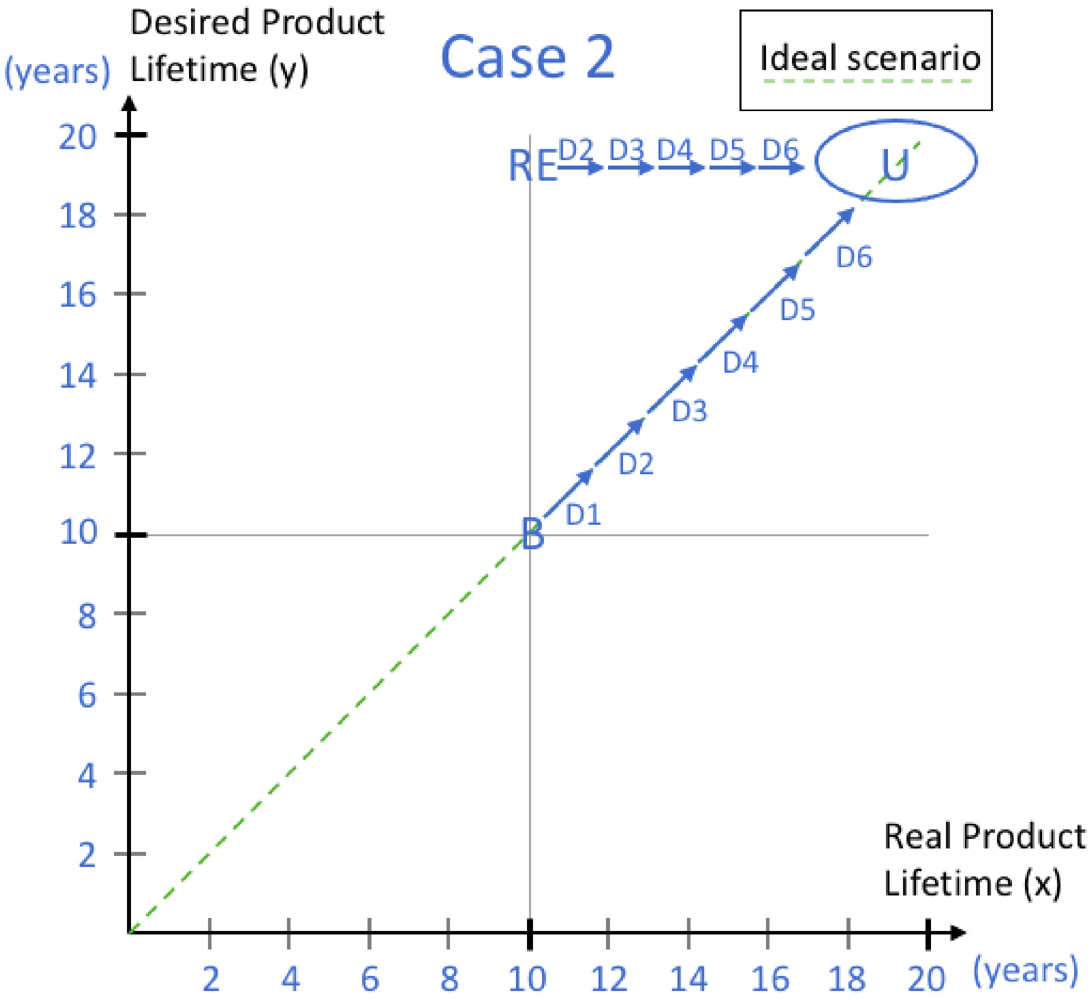


Figure 7.13: Possible actions and resulting outcomes for each design strategy Case 2, represented in years. Where, Design for Attachment and Trust (D1), Design for Dis- and Reassembly (D2), Design for Standard and Compatability (D3), Design for Maintenance and Repair (D4), Design for Durability (D5), Design for Adaptability and Upgradability (D6).

7.1.5 Step 5 - Choose Design Strategy

Three more concrete action plans can be generated based on the trade-off analysis. The first case provided two action plans with different approaches. Case 2 generated a more radical approach which perhaps is less feasible.

Action Plan 1a - Self Repair

The following actions are proposed.

- Design for Attachment and Trust - Do not implement.
- Design for Dis- and Reassembly - Implement. Re-design button into a replaceable part.
- Design for Standard and Compatability - Do not implement.
- Design for Maintenance and Repair - Implement. User can repair button, offer spare part at retailers. Provide self repair guide in product sheet.
- Design for Durability - Do not implement.
- Design for Adaptability and Upgradability - Do not implement.

Action Plan 1b - Loyalty Bonus

The following actions are proposed.

- Design for Attachment and Trust - Do not implement.
- Design for Dis- and Reassembly - Implement. Re-design such that all parts can be removed without breaking, specifically heat plate. Change along with D3 such that there is less variety of screws.
- Design for Standard and Compatability - Implement. Standardize into one type of screw.
- Design for Maintenance and Repair - Do not implement. Business instead offer loyalty bonus such that user return obsolete product. Business reuse parts.
- Design for Durability - Do not implement.
- Design for Adaptability and Upgradability - Do not implement.

Action Plan 2 - Product as a Service

The following actions are proposed.

- Design for Attachment and Trust - Implement. Provide user with several add-on's that can increase their customization of the product. Equip new product with digital solutions. User can e.g. analyze their habits and improve their consumption. When do I prefer to drink coffee? When did I deviate from my habits? How much coffee goes to waste? Ensure user is reliant of product.
- Design for Dis- and Reassembly - Implement. The company now owns a fleet of coffee brewers. The components should be able to be replaced and reused when necessary to save costs. Involve the user to perform simple repairs where self repairs will consist of parts that are able to be removed without using tools.
- Design for Standard and Compatability - Implementation is vital. Same product will be used and upgraded for new technologies. Ensure company standards are followed. Company responsible for change of product if component cannot be replaced due to new standard.
- Design for Maintenance and Repair - Implement. Ensure user can repair components that commonly break down.
- Design for Durability - Implement. Company benefits of less service. Identify critical components and increase durability.

- Design for Adaptability and Upgradability - Implement. Company provides coffee brewers with highest performance.

7.1.6 Case Study Reflection

Performing the case study while using the Design for Longevity Guide was considered straightforward. The flow of tasks is considered to be good in terms of being logical, and there was no issue where for example knowledge was lacking while going into the next step in the process. The explanations of each task were considered enough to be able to grasp what was needed from us. This can perhaps be difficult to argue for since we are the creators of the guide and will most likely have a greater understanding of the elements we have created, ourselves. However, we tried to strictly limit ourselves by performing each task in the process with the information provided in the guide. For example, answering the questions that are provided in certain steps, as well as using the different definitions when solving the tasks. The visualization tool *Product Lifetime Diagram* made it considerably easy to visualize the results, as well as performing the reflection or analysis of how to solve the current issues.

This product was also considered to be a suitable product, in terms of complexity and available information to collect. In addition to this, if a companies were to be a part of a process such as this, more information would most likely be accessible. For example, there was not enough time or available information to perform an LCA, but the product was simple enough to make appropriate assumptions. Having more time would perhaps have made it possible to make a more thorough analysis, where more effort could have been put on the disassembly and material analysis. The results are still deemed valid, where possible solutions to implement which actually improve the product are obtained.

The case was rather easy or simplified regarded the analysis from the user's point of view, since only one user was considered. In order to benefit a company even further, several users would preferably be used to create some sort of average user. This would in turn make this analysis more demanding, unclear to which extent. Another issue regarding the analysis and outcomes was the fact that this particular product already performs rather well, where the lifetimes from all three contextual aspects are close to each other. Performing this process on a "poor" product would most likely result in bigger differences between the aspects and lifetimes, and in turn generate more possible actions.

To summarize, we as performers of this case consider the guide to be logical and containing sufficient descriptions. It is suitable to apply on a product of this complexity, in relation to the available amount of time, that was two working days. The *Product Lifetime Diagram* is a tool useful in both performing an analysis of a product as well as presenting results. Time is an important factor that will affect the results, and the product itself will affect the result, where both complexity and its current state will affect the outcomes. The process generated interesting results that most likely would not have been identified without performing the process. The results and outcomes are also deemed useful and feasible according to us, but the company that produces and sells them is not necessarily of the same opinion. No conclusion of how the company would use these results can be made.

7.2 Focus Group with Participants from the Automotive Industry

The participants in the focus group showed an interest in the topic and the presented elements. All contributed to the focus group and were committed to discussing ideas and input regarding the topic. The focus group had three main questions that the participants in the group were to discuss in 5-10 minutes each, at the end. The first question was.

- How relevant and important is Design for Longevity within the Automotive industry today?

They specifically stated that the topic of Design for Longevity is of high interest for the automotive industry, especially due to the current transformation towards electrification and also because of other potential factors that can affect the industry in the future. One person specifically expressed, that the automotive industry is facing interesting challenges and that several factors such as the environment, new technology, and society will have a large impact on how the industry will look in the future. Ideas such as having a car fleet and providing a service instead of a product, self-driving cars, or utilize the resources in the best way, are thoughts that companies need to consider in their business model in order to stay competitive. Furthermore, a tool like the Design for Longevity framework could help companies to reflect and find suggestions on how the products' design could be changed or adapted in order to benefit this type of transformation, and help in the discussion around the product related to the business model. With that said, they thought that the framework could be helpful to reflect and facilitating ideas for a new business model. Additionally, also help to perform idea generations to find potential improvements on current products.

The second question that the group discussed was.

- How well do you think the results and conclusions from the case study comply with reality?

Regarding the case study of the Moccamaster, they thought that the collected data was relevant and trustworthy, and this made it possible to draw conclusions from the case. Therefore, they considered the result to be relevant, but they thought it was hard to determine the credibility of the result even if they considered it to be reasonable. To make it possible to analyze the credibility, they recommended considering more scenarios and also other coffee brewers. However, they understood that the case was limited due to the time limit of two days, and when taken that into account they considered the results useful in order to make conclusions and generate ideas to improve the product. To summarize, they thought this case was a good example to visualize how the Design for Longevity Guide work and its overall use, but more cases and scenarios need to be performed in order to prove the credibility and usefulness of the framework other than just providing feasible actions to implement.

The final question that the group discussed was.

- How applicable do you think Design for Longevity and its process is within the Automotive industry?

They believed that a car is a too complex product for implementing the Design for Longevity framework. However, they still considered it to be useful to apply on a car, but instead of applying it on the whole product, apply it on system- or module level. Therefore, they expressed an interest in implementing the process on specific components in order to analyze the result and the outcome, to evaluate the usefulness of the framework in the automotive industry. This would be a good start, because it is important to understand components varying lifespan in order to determine the car's longevity. They also expressed that this framework currently is of large interest due to the transformation towards electrification, which implies that many components' lifetimes will be changed due to the transformation.

7.3 Internal Discussion of Collected Literature

The Design for Longevity framework is intended to serve as a tool or method to be used to embrace a more circular mindset and generate more sustainable products. The framework itself is tested in multiple ways along the project, including user studies and internal evaluation, to validate and ensure its credibility. However, this framework is created based on knowledge obtained from a literature review. While this set of knowledge is not validated using any specific methods, other than what a sufficient literature review merely is itself, its validity or credibility needs to be discussed, at least. Literature reviews consist of collecting knowledge previously created by different authors. This knowledge is of course heavily dependent on both how knowledge was created and its quality along with the amount of knowledge collected. This have mainly been managed by reviewing the authors validity within the said subject as well as the time it was published. Older literature is not necessarily wrong or of less quality, but was of course relevant to consider. All the articles sources have also been in consideration. The aspect of collecting enough literature is more difficult to conclude upon since there is always possible to collect more literature and knowledge. This literature review was more of an exploratory research, and there is considered to be a big variation regarding the literature collected, where many different views on product longevity were merged into a complete framework, which is deemed to increase the credibility of the results. This collected knowledge was then used to generate or develop the Design for Longevity framework, which has been evaluated both internally and externally on several occasions throughout the project, for example using cases and interviews.

7.4 Summary of Validation Phase Results

The results from the research phase aimed to fulfill several sub-objectives, formulated in Section 2.5, and they are presented and discussed below.

- Evaluate the credibility of the provided knowledge that contributes to the Design for Longevity framework internally.
- Evaluate the credibility of the proposed the Design for Longevity framework internally.
- Practically test and validate the Design for Longevity framework internally.
- Evaluate the mediating Design for Longevity implementation tool in industry, and conclude its applicability and validity.
- Evaluate the credibility and validity of phase 1-3 in the project process externally.

All of the above stated sub-objectives are deemed to be fulfilled. A case study was conducted using the mediating Design for Longevity implementation tool in Section 7.1, which tested the Design for Longevity framework internally, while also reflecting upon its results. The knowledge that generated this framework was discussed internally in Section 7.3. The results from the case study along with the mediating Design for Longevity tool was evaluated using a focus group, and the results from this are presented in Section 7.2. The credibility and validity of phase 1-3 in the project process will be evaluated after the project time frame. Using the results from this phase it will be possible to conclude to which degree the project's main objectives have been fulfilled.

8
Final Discussion

A final overall discussion about the project is provided in this chapter. The project process in relation to the project's nature in terms of complexity and ambiguity is discussed. Design for Longevity as a topic is also discussed along with its nature along with the issue of identifying a knowledge gap. At last, the research question is addressed in relation to the findings of this project.

8.1 Project Complexity and Ambiguity

This project has been rather unique for us, considering it is very theoretical and analytical where a tool is generated from collected knowledge. In comparison to other projects previously performed, where we are given a specific problem and a given process to solve it. In this project, the problem has been very complex as well as changing over time. This has made the overall project rather demanding but instead resulted in new and useful experience. In order to tackle this ambiguity, we used our own proposed project process, where we handpicked methods and tools. This was not done in a planning phase, mainly due to the fact that the problem to be solved was changing over time, making it more suitable to adapt and use methods as the problem arose.

8.2 Product Longevity as a Topic

The overall project has been to identify a knowledge gap within the topic product longevity or Design for Longevity which is mainly a phrase where product longevity is managed. This was indeed troublesome since it is a widely debated subject and has been of interest for a long time. This resulted in the knowledge gap as well to be changing over time, since more collected knowledge solved the previous knowledge gap. However, the knowledge gap was finally concluded to be the lack of a wholesome view or theoretical point of view, where several aspects are merged together. This might also be the fact why many of the interviewees felt familiar with the subject. This is perhaps also a strength with this topic, we consider it to be very graspable by all product developers, and even users. Product longevity is perhaps one of the least complex topics, in terms of understanding what it means. However, very complex to manage, in terms of designing for it. We believe that this framework has contributed much to the overall product longevity discussion, where almost everyone who has been presented to the framework is provided with ideas they never had before.

8.3 Project Finding and Research Question

What has been a major obstacle for this project is the ongoing pandemic of covid-19, where we have been unable to conduct workshops in larger extents. We believe that this tool is very useful in a workshop setting, where a combination of minds can either debate or discuss upon optimal product lifetimes. This also highlights our research question, where the later part of it "how can it in practice be used by product developers to design products with an optimal lifetime" has been briefly mentioned. Additionally, relating it once again to the typical product development process, going from uncertain to certain, we ask ourselves where our framework is suited. We believe it can be used both early in the process to generate input in the planning of a product, where its lifetime of course is a rather important aspect, along with actions to realize it. In addition to this, we believe it can be used in more certain parts as well. However, this would require the process to be perhaps longer than a workshop or a two workdays study. Generating simulations and calculations using the rules within optimization theory could most likely generate a theoretical optimal product lifetime, where the three contextual aspects are considered. This would however most likely also be too time and resource-consuming, but still interesting to reflect upon. It has however been shown in this project that Design for Longevity indeed serves a purpose in less certain parts of the product development process.

9
Conclusion and Recommendations

This chapter consists of the project's overall conclusions, which are presented in relation to the project's main objectives, research question and overall aim. This is followed by three recommendations for future work.

9.1 Conclusion Related to Project Objectives

The conclusion of this project will be related to the degree of which the project's main objectives have been fulfilled.

Objective 1:

- Increase the knowledge of product longevity together with how a Design for Longevity framework can be used to embrace a more circular mindset, and thus design more sustainable products.

This objective is concluded to have been fulfilled. Mainly based on two things. Firstly, literature was collected in an appropriate manner as discussed in Section 7.3, that all together generated a knowledge base about the topic product longevity and where it can take place in the transition towards a circular economy.

Objective 2:

- Increase the usability of Design for Longevity, such that it in theory can be used to design more sustainable products.

This objective implies that Design for Longevity can be used to design sustainable products, even if it is limited to work in theory only. This objective was fulfilled in Chapter 4, where a Design for Longevity Framework working in theory was developed.

Objective 3:

- Increase the usability of Design for Longevity such that it in practice can be used to design more sustainable products.

This objective is concluded to be fulfilled. The developed Design for Longevity framework was concluded to be useful in Chapter 5.1, but in need of improvements. The improvements were later addressed in Chapter 6, and then validated in Chapter 7 increasing the Design for Longevity Framework's use further.

Objective 4:

- Increase the knowledge of Design for Longevity and its usability within academia.

This objective can not be concluded to be fulfilled since it is without this project's time frame, as previously mentioned.

9.2 Project Aim and Research Question

Relating the overall project outcomes to the project aim and its research question, the aim:

- The aim of this project therefore to develop a complete framework that helps companies to Design for Longevity, given any product, and any industry

The aim is concluded to be partly fulfilled, simply by fulfilling Objective 3. However, this project has been limited to only apply the Design for Longevity framework on two different products, a coffee brewer and a passenger vehicle. The project scope did relate to the automotive industry and thus justify the obtained results to only being two different products.

In order to address the research question:

- "What is Design for Longevity, and how can it in practice be used by product developers to design products with an optimal lifetime?"

The research question needs to be separated into two parts, the first being "what is Design for Longevity", whereas the definition in Section 4.1 answers that part. Whereas the second part "and how can it in practice be used by product developers to design products with an optimal lifetime?" it can now be concluded that it can be used by product developers to both facilitate a discussion and reflection upon an optimal product lifetime. As well as be used to find possible and feasible actions to realize for medium-complex products, such as a coffee brewer where the extent of the implementation is of at least two workdays.

9.3 Future Work and Recommendations

The following recommendations are proposed for future work.

- Conduct more case studies on other product to investigate Design for Longevity's complete applicability on different products.
- Conduct larger workshops to investigate Design for Longevity's use in those settings.
- Conduct more extensive case studies lasting longer than two workdays to investigate Design for Longevity's use in more certain parts of a product development phase.

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Appendix A - Reading template

Reading template

Read the "literature" thoroughly, while reading the article several questions are asked and should be answered afterwards.

- **What is the literature about?**
    - **Does it raise any questions regarding the topic?**
    - **Does it prove the topic?**
- **What are the main points in the literature?**
- **Why is the literature relevant for the project?**
- **Is the validity of the literature sufficient?**
- **What is your personal reflection/opinion after reading the literature?**

Summarize the article in minimum 2-3 sentences answering the questions above:

Appendix B - Literature data spreadsheet

Author 1	Author 2	Author 3	Publication title	Year	Type	Source/publisher
Circular economy						
Geissdoerfer, M & Hultink, EJ	Savaget, P	Bocken, MP N	The Circular Economy - A new sustainability paradigm?	2016	Journal	Cleaner production
Stahel, WR			The Circular economy	2016	Journal	Nature news
Benton, D	Hazel, J	Hill, J	The guide to the circular economy. Capturing value and managing material risk,	2014	Book	Oxford: DoSustainbility
Blomsma, F	Brennan, G		The emergence of circular economy: A new framing around prolonging resource productivity. Journal of Industrial Ecology	2017	Journal	Journal of Industrial Ecology
Kirchherr, J	Reike, D.	Hekkert, M	Conceptualizing the circular economy: An analysis of 114 definitions. Resources, Conservation and Recycling	2017	Journal	Resources, conservation & recycling
European Environment Agency			European Environment Agency (2020) Resource efficiency and the circular economy in Europe 2019	2019	Report	European Environment Agency
Stahel, WR			The performace economy	2010	Book	Springer
Kalmykova, Y	Sadagopan, M	Rosado, L	Circular economy – From review of theories and practices to development of implementation tools	2018	Journal	Resources, conservation & recycling
Korhonen, J	Honkasalo, A	Seppälä, J	Circular Economy: The concept and its limitations	2018	Journal	Ecological Economics
Figge, F & Thorpe, AS	Givry, P & Canning, L	Franklin-Johnson, E	Longevity and Circularity as Indicators of Eco-Efficient Resource Use in the Circular Economy.	2018	Journal	Journal Ecological Economiccs
Circular design						
Bakker, C	Hollander, MD	Hinte, EV & Zijlstra	Products that last - circular design	2019	Book	Laurence King Publishing
Hollander, MC	Bakker, C	Hultink, E	Product Design in a Circular Economy - Development of a Typology of Key Concepts and Terms	2017	Journal	Journal of industrial ecology
Bocken, N & Pauw, I	Bakker, C	Grinten, B	Product design and business model strategies for a circular economy	2016	Journal	Journal of industrial and production engineering
Haug, A			Design of resilient consumer products	2016	Conference	Proceedings of DRS 2016 international conference
Nes, N	Cramer, J		Influencing product lifetime through product design	2005	Journal	Business strategy and the environment
Selvefors, A & Rexfelt, O	Renström, S	Strömberg, H	Use to use - A user perspective on product circularity	2019	Journal	Journal of cleaner production
Policy Department for Economic			Promoting product longevity	2020	Report	European Parlament
Bakker, C & Hollander, MD	Wang, F	Huisman, J	Products that go round: exploring product life extension through design	2014	Journal	Journal of clenear production
Kagawa, S & Kudoh, Y	Nansai, K	Tasaki, T	The Economic and Environmental Consequences of Automobile Lifetime Extension and Fuel Economy Improvement Japan s Case	2008	Journal	Economic systems research
Nes,N.V	Cramer, J		Product lifetime optimization: a challenging strategy towards more sustainable cosnumption patterns	2006	Journal	Cleaner Production
Berg, M.R	Bakker, C.A		A product design framework for a circular economy	2015	Conference	PLATE conference
Bovea, M	Perez-Belis, V		Identifying design guidelines to meet the circular economy principles: A case study on electric and electronic equipment	2018	Journal	Journal of Environmental Management
Toxopeus, M.E	Hout, N.B	Diepen, B.G.D	Supporting prodcut development with apractical tool for applying the strategy of resource circulation	2018	Conference	CIRP Life cycle Engineering (LCE)
Known concepts						
Schöggl, J	Baumgartner, R	Hofer, D	Improving sustainability performance in early phases of productdesign: A checklist for sustainable product development tested in the automotive industry	2017	Journal	Journal of cleaner production
Hermenau, U	Hansen, S	Abele, E	Integration of Life Cycle Design in Industrial practice: Problems and solutions	2005	Conference	IEEE
Bhande, G	Hauschild, M	McAloone, T	Implementing Life Cycle Assessment in Product Development	2003	Journal	Environmental Progress
Mayyas, A & Qattawi, A	Omar, M	Shan, D	Design for sustainability in automotive industry: A comprehensive review	2012	Journal	Renewable and sustainable energy
Gits, C.W			Design for maintenance concepts	1992	Journal	Production Economics
Vanegas, P & Peeters, JF	Cattrysse, D & Tecchio, P &	Mathieux, F & Dewulf, W	Ease of disassembly of products to support circular economy strategies	2018	Journal	Resources, Conservation & recycling
Kuo, T	Huang, S	Zhang, H	Design for manufacture and design for 'X': concepts, applications, and perspectives	2001	Journal	Computers & industrial engineering
Sassanelli, C & Urbinati, A	Rosa, P & Chiaroni, D	Terzi, S	Adressing ciecular economy through design for X approaches: A systematic literature review	2020	Journal	Computers in Industry
Companies and CE						
Xiang, W	Ming, C		Implementing extended producer responsibility: vehicle remanufacturing in China	2012	Journal	Journal of cleaner production
Allenby, R.B			Environmental Constraints and the evolution of the private firm	1997	Book	The Industrial Green Game
Stahel, W			The functional economy: Cultural and organizational change	1997	Book	The Industrial Green Game
De los Rios, I.C	Charnley, F		Skils and capabilities for a sustainable and circular economy: The changing role of design	2017	Journal	Journal of cleaner production
Devaraj, S	Matta, K	Conlon, E	Product and service quality: the antecedents of customer loyalty in the automotive industry	2001	Journal	Production ns operations management

Appendix C - Presentation data spreadsheet

Author 1	Author 2	Author 3	Publication title	Year	Type	Source/publisher
Presentations						
Ljunggren, M			Waste management intro and overview	2020	PowerPoint	Chalmers Univesity of Technology
Rexfelt, O			User perspective	2020	PowerPoint	Chalmers Univesity of Technology
Ljunggren, M			Circular measures	2020	PowerPoint	Chalmers Univesity of Technology
Ljunggren, M			Natural resources	2020	PowerPoint	Chalmers Univesity of Technology
Ljunggren, M			RE and environmental impacts	2020	PowerPoint	Chalmers Univesity of Technology
Ljunggren, M			IE (1/2)	2020	PowerPoint	Chalmers Univesity of Technology
Ljunggren, M			WM Recycling	2020	PowerPoint	Chalmers Univesity of Technology
Ljunggren, M			IE (2/2)	2020	PowerPoint	Chalmers Univesity of Technology
Wijkman, A			Industrial Ecology	2020	PowerPoint	Chalmers Univesity of Technology
Almefelt, L			From Principles to Synthesis of Resource-efficient Solutions	2020	PowerPoint	Chalmers Univesity of Technology
Isaksson, O			Development of PSS	2020	PowerPoint	Chalmers Univesity of Technology
Isaksson, O			Servitization in industry	2020	PowerPoint	Chalmers Univesity of Technology

Appendix D - User study questions and answers

Fråga 1 - Berätta lite om vad som hände?
Det har hänt tidigare, men finns en kontaktor som sitter fast i en plasthylsa, den gick av. Han skruvade av locket för att komma åt. Första gången detta hände kunde han trycka dit den. Men denna gång hade plasten runt omkring gått sönder. Det var då svårare att laga den. Superlim användes för att fästa den igen, men då fastnade knappen också. Det var lätt att komma åt, men skruvarna var små. Detta var något han hade erfarenhet av då han gjort det tidigare på andra kaffemaskiner. Det är plastdetaljer som går sönder. Man ska kunna byta en kontaktor. Första gången hade ena delen gått av, denna gång hade båda gått av. Han hade tillgång till verkstad via jobb. Han hade aldrig lämnat in den till återförsäljare, men hade gärna lämnat in till egen verkstad. Men han var för otålig och lämnade inte in den.

Fråga 2 - Anledning till utbyte av bryggare?
Knappen gick sönder. Hade han inte limmat så hade den kanske gått att laga på ett annat sätt.

Fråga 3 - Vad var felet med bryggaren?

Fråga 4 - Hur hade du hellre sett att det gick till i din situation?
Tillverkarna gör ibland sakerna mer komplicerade för att man inte ska fixa själv. Han fick själv en stöt då han glömde ta ur kontakten. Tidigare kaffebryggare (industri) är modifierade sådant att knapparna är enklare att byta, men inte för kund, utan tekniker. Hade gärna sett att hylsan var i annat material än plast, fanns inget att sätta fast den i. Hade det varit metall som man kunde skruva på hade det funkat. Det är för dyrt med service på återförsäljare, hade den varit två år gammal hade det kanske varit värt att byta. Men att byta en knapp är inte värd att byta för ca 700kr.

Fråga 5 - Hur länge hade ni haft kaffebryggaren?
Kaffebryggaren hade hållit i nästan 10 år. Stor familj. Hade hoppats på att den skulle hålla i 10 år. Hade hellre att den hade hållit längre. Dyrt med 2000kr för en bryggare. Brygger mycket kaffe, så det är normalt slitage.

Fråga 6 - Vad var den i för skick?
Den knappen till höger hade lossnat. Men den användes inte så den fixades aldrig. Så verkar vara ett återkommande problem med produkten (knapparna). Det syntes att den var använd, men fungerade helt felfritt. Har tidigare bytt ut kanna.

Fråga 7 - Hade ni bytt den ändå eller hellre haft kvar den?
Att den blir sliten gör inget. Hade den funkat så hade han haft kvar den ändå. Den håller sig stilren eller “stylish” ändå.

Fråga 8 - Hade ni kunnat gjort något annorlunda för att bevara den bättre?
Avkalkning har aldrig gjorts, men är enkel att göra ren. Mycket löstagbara detaljer som går att ta dän och diska i maskin och för hand. Finns inget som hade kunnats göra annorlunda för att bevara den bättre.

Fråga 9 - Var det självklart att det var just en moccamaster som ni skulle köpa igen?
Det var självklart, har varit jättenöjda. Bästa bryggaren de haft.

Fråga 10 - Hur kommer det sig att ni köpte en moccamaster och inte en annan bryggare från början?
Den var ganska unik när den köptes för 10 år sedan, finns många liknande. Tidigare köpt billigare, en moccamaster är mycket snyggare, var stor anledning till varför den köptes. Design motiverar pris. "Behöver inte ställa in en moccamaster i ett skåp". Andra maskiner är annars i vägen, men inte en moccamaster. Det var inte designen som var anledning till inköp. Det var via rekommendation från kompis. Det var självklart att köpa. Den var ganska dyr i jämförelse med tidigare bryggare. Men hade hört så gott, och att den ska hålla så länge. Bättre med 2000kr för 10 år vs 500 för 2-3 år.

Fråga 11 - Vad är viktigt för dig när det kommer till en kaffebryggare?
Att den håller temperaturen, bygghastighet. Prestanda, och utseende. Kända märken med liknande designer, så var ändå moccamaster mer värt pga design. Inte reflekterat över att den är ECBC godkänd.