Designed to Last

A Study to Support Increased Product Longevity

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BY
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AALBORG UNIVERSITY
DENMARK

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by

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ABOUT THE AUTHOR

Before enrolling as a Ph.D. researcher, Peter Byrial Jensen studied in industrial design engineering at Aalborg University. He received the title of Cand. Polyt-Industrial Design in the summer of 2018. With a passion for merging product design and sustainability, he became fascinated with the concept of minimal living, and a less-but-better lifestyle could support this. Shortly thereafter, he enrolled as a researcher in the Department of Architecture, Design, and Media Technology.

In the research project presented in this dissertation, Peter used his three years as a Ph.D. researcher to investigate how products and good business practices can be combined to make long-lasting products appreciated by consumers. To make the research relevant to industry, Peter solicited the participation of many companies by contributing their relevant knowledge thereto. Peter also shared the knowledge he gained from the research with industry through talks, conferences, newspapers, podcasts, etc.

As part of the research project, Peter was invited to Nottingham Trend University, England, where leading researchers within the field collaborated with him on several papers, one of which can be found in this dissertation.

ENGLISH SUMMARY

This dissertation investigates how to extend product longevity of physical products. It is not only about how long products last but also about the relevance of the product while it lives. It delves into how companies, particularly small and medium-sized ones, can create portfolios based on long-lasting products.

Products with high longevity are not only durable products but also products that end users get emotionally attached to, take care of, repair, and maintain. For products with high longevity to succeed in the market, companies must understand the complexity of developing, producing, and selling them. Investigating the methods that can be used to produce such products can be a small step toward a meaningful transition toward sustainable consumption.

However, the transition toward producing such products can be a challenging transformation process for many companies, especially small and medium-sized ones. Thus, this dissertation contributes to answering the following research question:

How are small and medium-sized companies supported in extending the lifetimes of their products to enable them to contribute to the attainment of the 12th United Nations Sustainable Development Goal of ensuring sustainable consumption and production patterns?

To answer the research question above, the existing academic knowledge on product longevity was first examined. This revealed 14 unique barriers that could make it challenging for companies, developers, and users to create products with high longevity. These 14 barriers and the extensive review of the literature on them form the baseline knowledge from which the research project was built. To further explore the subject, lead designers, managers, and sales leads from 18 European best-practice companies were invited to share their approaches to overcoming the barriers. The result was an overview of 14 approaches that enabled the companies to produce products with high longevity, despite the barriers involved. The academic knowledge on the matter was then combined with the practical knowledge and integrated into a new toolkit that could assist practitioners in producing products with higher longevity.

This dissertation contributes to the academic field a more coherent and comprehensive understanding of the factors that influence product lifetime by synthesizing the existing knowledge on the topic in the literature and looking at it from a fresh and broader perspective. It also delivers insights on the topic from practitioners, both best-practice companies and companies that are interested in improving their product longevity, to explore the most practical approaches, and combines academic theory with practical approaches to test the understandability of the relevant theoretical models. It also presents a new toolkit that makes the relevant knowledge more

accessible for use by industry and easier for academics to research on and add new knowledge to.

Ultimately, the results of the research project reported in this dissertation can help practitioners explore, investigate, and achieve more sustainable production and consumption. The knowledge derived from the best cases, the insights from the participating companies, and the new toolkit all deliver valuable knowledge that can benefit business practitioners who are interested in the subject.

DANSK RESUME

Denne afhandling undersøger, hvordan fysiske produkters levetid kan forlænges. Ikke kun forlænge holdbarheden, men også forlænge produktets relevans for ejeren, mens det lever. Afhandlingen dykker ned i, hvordan virksomheder, især små og mellemstore, kan skabe porteføljer baseret på langtidsholdbare produkter.

Produkter med høj levetid er ikke kun solide og holdbare produkter, men også produkter, som slutbrugere bliver følelsesmæssigt knyttet til, tager sig af, reparerer og vedligeholder. For at produkter med høj levetid skal opnå succes på markedet, skal virksomhederne forstå kompleksiteten i at udvikle, producere og sælge dem. At undersøge de metoder, der kan bruges til at fremstille sådanne produkter, kan være et lille skridt i retning af en meningsfuld overgang mod bæredygtigt forbrug.

Men overgangen til at producere langtidslevende produkter kan være en udfordrende transformationsproces for mange virksomheder, især små og mellemstore. Denne afhandling besvarer således følgende forskningsspørgsmål:

Hvordan støttes små og mellemstore virksomheder i at forlænge deres produkters levetid for at sætte dem i stand til at bidrage til opnåelsen af FN's 12. mål for bæredygtig udvikling om at sikre bæredygtige forbrugs- og produktionsmønstre?

For at besvare det forskningsspørgsmål var første skridt at undersøge den eksisterende viden indenfor feltet. Igennem denne undersøgelse blev 14 unikke barrierer, der kan udfordre virksomheder, udviklere og forbrugere fra at skabe produkter med høj levetid, afsløret. Disse 14 barrierer danner den basisviden, som forskningsprojektet er bygget ud fra. For at udforske emnet yderligere blev ledende designere, ledere og marketingsfolk fra 18 europæiske virksomheder med erfaring inden for at lave langtidslevende produkter inviteret til at dele deres tilgange til at overvinde barrierne. Resultatet var 14 tilgange, der gjorde det muligt for virksomhederne at producere produkter med høj levetid. Den akademiske viden og de praktiske observationer blev kombineret og integreret i et nyt værktøj, der kunne hjælpe virksomheder til at producere produkter med længere levetid.

Denne afhandling bidrager til det akademiske felt med en mere sammenhængende forståelse af de faktorer, der påvirker produktets levetid. Det er opnået igennem en syntese af den eksisterende viden om emnet fra litteraturen med et nyt og bredere perspektiv. Det giver også indsigt om emnet fra praktikere, både virksomheder med praktisk erfaring i emnet og virksomheder, der er interesserede i at forbedre deres produktlevetid, for at udforske de bedste praktiske tilgange og kombinerer akademisk teori med praktiske tilgange for at teste forståeligheden af de relevante teoretiske modeller. Den præsenterer også et nyt værktøj, der gør den relevante viden mere tilgængelig for industrien og lettere for akademikere at tilføje ny viden til.

COLLECTION OF PAPERS

The four papers presented below are the foundations of all the findings of this research project. The papers were published, peer-reviewed, and developed by the author in collaboration with internal and external colleagues.

Paper I Jensen, P. B., Laursen, L. N., & Haase, L. M. (2021). Barriers to product longevity: A review of business, product development and user perspectives. Journal of Cleaner Production, 313(127951), 12. https://doi.org/10.1016/j.jclepro.2021.127951

Paper II Jensen, P. B., Haase, L. M., & Laursen, L. N. (2021). A practical approach to companies' transformation toward product longevity: A best-case study. Sustainability (Switzerland), 13(13312), 16. https://doi.org/https://doi.org/10.3390/su132313312

A preliminary version of the paper was presented at the fourth Product Lifetimes and the Environment Conference (PLATE 2021), Limerick (Online), Ireland, May 26–28, 2021.

Paper III Jensen, P. B., Haase, L. M., Cooper, T., Steward, J., Marsh, P., & Laursen, L. N. (2023). The LaST tool – The longevity and sustainable transition tool. Proceedings of the 18th Global Conference on Sustainable Manufacturing, October 5–7, 2022, Springer, Berlin.

Paper IV Jensen, P. B., Haase, L. M., & Laursen, L. N. (2023). The LaST toolkit – a practical experimentation using a product longevity toolkit in SME development teams. Submitted to International Society for Professional Innovation Management 2023 Conference.

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The list of people to be thanked is long. Without them, this dissertation will not exist.

Many can inspire through their words, but the actions, courage, and calm temper of my main supervisor, Louise Møller Haase, inspired me throughout my research project. Part of being a Ph.D. researcher is falling and getting bruised, but her supervision, support, and motivation made me stand up and try again. For that, I am truly grateful.

I would also like to thank my co-supervisor, Linda Nhu Laursen, for constantly challenging the limits of my abilities and pushing me to perform better in all aspects of my life.

Throughout my research project, I was welcomed by industry with open arms. I thank the leaders and other employees at the participating best-practice companies (Vola, Danfoss, Miele, Bang & Olufsen, Vitsoe, Skagerak Denmark, Hydrema, Takt, Rosti, Porsche Automotive, Marcus Pedersen, Toni, Butchers & Bicycles, Demant, Fredericia Furniture, Monstrum, Morsø Jernstøberi, and Nilfisk) who dedicated their time and effort to contributing to this important agenda, and the individuals from Bent Hansen, ByLindgren, Kreafunk, and Nuura who participated in the workshops. Your practical experience and thoughts are invaluable.

My thanks also go out to my colleagues at Aalborg University, especially Line and Aysegül, and to Martin, Steffen, Sara, and Andreas from my Ph.D. network. Struggles and concerns seemed slightly less important after our meetings.

I also send special thanks to Tim Cooper, Phillipa Marsh, Joseph Steward, and the entire design faculty at Nottingham Trent University for their collaboration in this research project in the fall/winter of 2021. I hope there will be plenty of new opportunities for us to collaborate in the future.

Lastly, I thank my friends, family, and especially my wife-to-be, Anne Sofie. The unconditional love and support they gave me during the three years that I dedicated to this research project are more than anyone could expect. I aim to repay these tenfold.

This dissertation is dedicated with my deepest respect and admiration to Dot Joan Jensen.

Peter Byrial Jensen, 2023

PROLOGUE

Three years have passed, and a new chapter awaits. I cannot help but wonder about the duality of undertaking a research project such as the one I undertook and report in this dissertation. For the entire three years of the project, I focused on creating an impact with research that should be valuable for the world, concentrating on my research output and the citations of my work in journals. What I can now see is that the journey is what matters, not only because it shaped my dissertation but also because it shaped me as a researcher. All the long nights, the buckets of coffee, the tears, and loneliness tested my boundaries and pushed me to perform optimally. This, I hope, is visible not only in the results of this dissertation but also in the person behind all the words.

A retired professor told me at the beginning of my study that, at the start of a Ph.D. project, you want to save the world, but at the end, you just want to save yourself. I no longer agree with this statement. The subject of this dissertation, product longevity and sustainability, has become very dear to me. Becoming a researcher was not an obvious choice for me, but I can now see how independent research can create a huge impact for the individuals that have benefitted in the last three years. I do not think that one can find a better research motivator than the prospect of creating something from scratch that will help change the world. I believe that this idealistic outlook is what the world needs.

It does not matter whether you perceive long-lasting products as a sustainable initiative or a business opportunity. Creating a design that outlives the creator is a huge achievement and is what defines a classic. I may never be able to create my own classic as an industrial designer, but I may be able to create the knowledge and tools that will enable others to do so. If so, I will be satisfied.

Figure 1. Artistic representation of the brain.

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CHAPTER 1. INTRODUCTION

The world is in a climate crisis. The occurrence of extreme weather phenomena is rising globally each year (Beniston et al. 2007; Vajda et al. 2011), and the focus on emissions and green initiatives dominates much of the public debate. Most governments, the public, and industry are currently focused on lowering greenhouse gas emissions, particularly carbon dioxide (CO_2) emissions, to address the dire state of the environment (Lee & Min 2015). While the high level of CO_2 in the atmosphere is certainly one of the major climate issues, the current general state of the climate goes beyond this issue. The United Nations (UN) has highlighted a wide range of climate ecological issues, including different types of pollution, global water shortages, unsustainable material consumption, loss of biodiversity, lack of waste management. These other global ecological issues must be urgently addressed and are mutually influential. Thus, they are addressed through the United Nations Sustainable Development Goals (UN SDGs) consisting of 17 sustainable goals that must be attained globally to stabilize the global environmental situation (independent group of scientists appointed by the Secretary-General, 2019).

Figure 2. Representation of the 17 United Nations Sustainable Development Goals, highlighting the 12th goal: responsible consumption and production.

This dissertation concentrates primarily on the 12th SDG: responsible consumption and production (Figure 2). From 2000 to 2019, the global reliance on natural resources has risen to 69%, while the collection of electronic waste (e-waste) is merely 22.8% globally (Jensen 2022). Globally, we consume more and more, while we still are insufficiently skilled at recycling. Thus, the global reliance on finite natural resources calls for action.

1.1.1. IMPORTANCE OF THE SUBJECT

One of the approaches to achieving responsible consumption is a circular economical approach to materials (Ellen MacArthur Foundation 2019; McDonough & Braungart 2002). The diagram of the circular economic system in Figure 3 illustrates the finite materials used for products globally and how responsible consumption and production promoted through different initiatives can minimize the use of these materials by keeping those that are already in use in the loop. It also describes how to minimize systematic leakage and negative externalities, which is advantageous to "narrowing" the loop, aiming for the smallest circle described by maintaining products or prolonging their use. This loop in the circular economy, if it can be realized, ensures the least amount of loss of materials and energy and is therefore the least environmentally harmful.

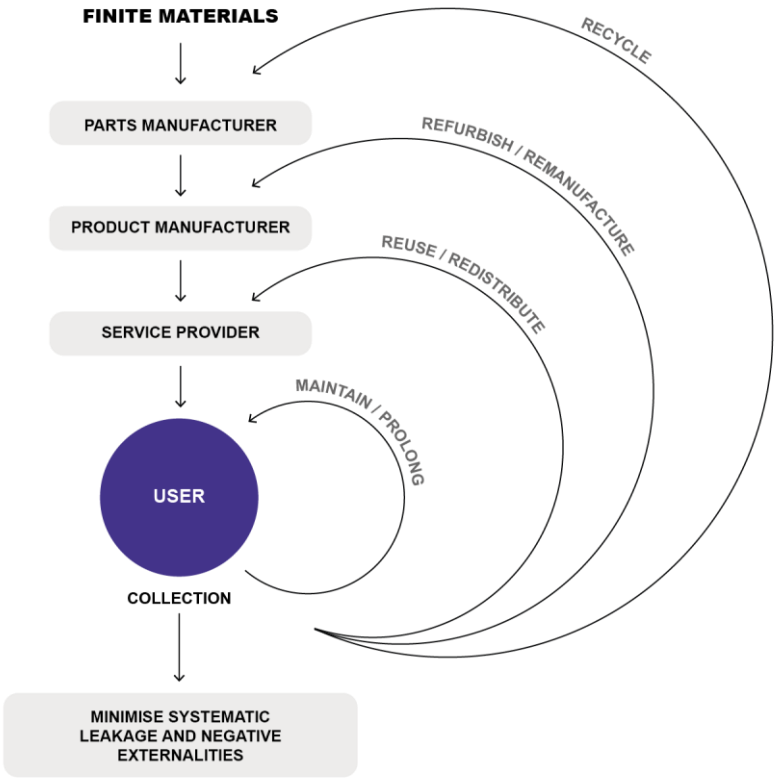

Figure 3. Interpretation of the butterfly model (Ellen MacArthur Foundation 2019; McDonough & Braungart 2002), presenting the material loops in the circular economy.

Therefore, by extending the lifetimes of everyday products, we can slow our consumption of them, which can significantly lower our use of materials (Konietzko et al. 2020; Sinclair et al. 2018).

Further emphasizing the importance of lowering consumption and raising awareness of the need to achieve product longevity, statistics show that the average lifetime of everyday products is in steep decline. For example, the average lifetime of microwave ovens has decreased from 10.9 years to 9.4 years within a 5-year period (Bakker et al. 2013). The average lifetime of mobile phones is currently only approximately 3 years (Suckling & Lee 2015), while the optimal lifetime of a mobile phone based on energy usage, etc., is around 7 years (Frey and Billett 2006; Bakker et al. 2014).

The increased complexity of products and the low prices of new substitute products have promoted the buy-and-throw-away culture and decreased the knowledge of how to repair and maintain products (Duvall et al. 2016). The result is that the average lifetime of almost all household products has decreased, in some cases by 20% within only a 5-year period (Wang et al. 2013; Bakker et al. 2013; Prakash et al. 2016).

As of this writing, the debate on the circular economy dominates the debate on sustainable transition in academia. The notion of a circular economy centers on the belief that materials and energy should be reused carefully and consciously, with as little waste as possible. The Ellen MacArthur Foundation (2019) has created a framework for the circular economy (McDonough & Braungart 2002), defining how materials can be reused in a theoretically infinite loop. However, in the same framework, it is also stated that the "size" of the loop can differ depending on the reuse method employed and the life stage of the products. Therefore, products should not only be treated in a circular way; *how* they are incorporated into such a system is also important.

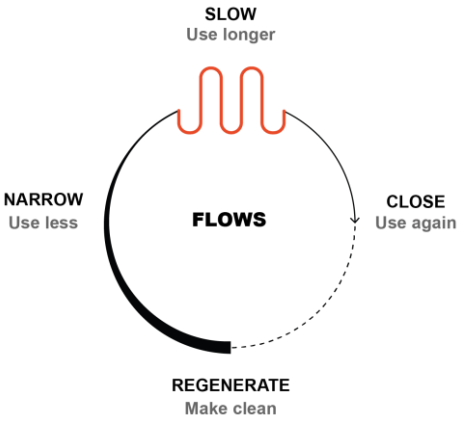

Figure 4. Representation of a circular economy by Konietzko et al. (2020).

As shown in Figure 4, the ecological success of a product's circular life is based on three important factors: closing, narrowing, and slowing the resource loop (Konietzko et al. 2020). Closing the resource loop means reusing all materials and energy multiple times with minimal loss. Narrowing the resource loop means reusing products rather than upcycling them, if possible, and upcycling rather than recycling. Lastly, slowing the resource loop means making and maintaining products that are relevant for individuals, society, or the earth to make them last.

In slowing the resource loop, the easiest life stage for a product to improve is the use scenario. In practice, if product longevity is not achieved, the waste generated in the resource loop rises, resulting in unsustainable consumption patterns.

1.1.2. MOTIVATION FOR THE STUDY

With the increased global awareness of the need for sustainable living and the increased focus on it, a new market is emerging. The number of manufacturing companies that are willing to pursue product longevity is increasing (Lingnau et al. 2022), and more studies on new research models that enable companies to produce long-lasting products are being conducted (Gan et al. 2019; Kang et al. 2012; Lawlor 2014; Montalvo et al. 2016; Baines et al. 2007; Bocken et al. 2016; Hirschl et al. 2003; Tukker 2015). However, companies, especially small and medium-sized enterprises (SMEs), are hesitant to produce products with higher longevity due to their lack of knowledge of how to do so and their inability to create a transparent relevant action plan, which creates great economic uncertainty for companies (Linder & Williander 2017; Ormazabal et al. 2018).

This dissertation thus aims to provide support to SMEs that are considering extending the lifetimes of their products but need support in doing so as the concept of product longevity is challenging for both academics and industry to adopt. In industry, product longevity is often neglected by both management and developers as other factors are often considered more important in the process of developing new products and because the subject of product longevity is complex and intangible, with many considerations counteracting each other. These challenges and their solutions are often rooted in multiple disciplines in companies. This fuels the "throwaway society" (Cooper 2005). The consumption patterns of the throwaway society are enabled by a market dominated by the need for a fast return on investment. However, an emerging market, pushed by both consumers and industry, is aiming for vision-based products and businesses defined by high quality, lifetimes, and personalities (Jensen et al. 2021a). While the public media and general opinions often focus on companies' exploitation of consumers by producing products that are made to break prematurely, academia has recently focused on the factors that allow companies producing long-lasting products to thrive (Verganti 2011).

In this section, the challenges and barriers that the manufacturing industry needs to overcome to be able to produce and maintain products with high longevity are first briefly introduced. This highlights the importance of the subject and points to the need for new and more actionable research to help industry players overcome the challenges. The study's research questions are then presented. Finally, an overview of this dissertation's chapters is provided.

1.2. BARRIERS TO ACHIEVING PRODUCT LONGEVITY

The primary focus of the existing literature on product longevity is the opportunistic perspective, which provides solutions or models to enhance product longevity. This can be through new product designs or the alteration of existing designs to make them more durable (Hagedorn et al. 2018; Lilley et al. 2019), new business models that better support longer product lifetimes (Cooper 2005), or even initiatives that push consumers to keep and maintain their purchased products for a longer time (Ertz et al. 2017). This paved the way for a thorough understanding of solutions and the potential for achieving product longevity. However, before endeavoring to develop products with higher longevity, companies must first understand the barriers and challenges to achieving product longevity across all domains as this can help them qualify the proposed solutions and better comprehend the influence of each solution on specific barriers (Rivera & Lallmahomed 2016). An overview of the barriers and challenges to achieving product longevity already identified in the existing literature must thus first be provided.

BUSINESS BARRIERS	PRODUCT DEVELOPMENT BARRIERS	USAGE BARRIERS
Barrier 1: High cost of changing the business model	Barrier 6: Inability to follow fast-moving trends	Barrier 10: Short life cycles promoted by retailers that affect user behavior
Barrier 2: Customer rejection of change in the business model	Barrier 7: Technological innovation that makes long-lasting products obsolete	Barrier 11: Lack of consumer attachment to products
Barrier 3: High price points of long-lasting products	Barrier 8: Change in societal behavior that makes long-lasting products obsolete	Barrier 12: Customers' marginal awareness of the product quality
Barrier 4: Vulnerability regarding short, fixed leasing periods	Barrier 9: Lack of focus on longevity in innovation	Barrier 13: Evaluation of longevity in a purchase situation
Barrier 5: Time-consuming alteration of customer perceptions of products and brands		Barrier 14: Misperception of modularity in advanced products

Table 1. Summary of the barriers to achieving product longevity divided into three groups of main stakeholders (Jensen et al. 2021b)

As seen in Paper I (Jensen et al. 2021b) in this dissertation, based on a comprehensive literature review, a list of barriers to achieving product longevity was created (Table 1). These barriers were divided into three main stakeholders with a significant influence on product longevity: companies or management, product designers and developers, and consumers or users. Although governments and regulations also influence product lifetime, these were excluded from the study.

The barriers identified through a review of the existing literature include those that hinder the relevant transformation process of companies and the process of maintaining a portfolio dominated by products with high longevity.

The identified barriers suggest that the responsibility for product longevity is shared by companies or management, product designers and developers, and consumers or users, all of whom affect each other and must understand the need for product longevity and how to achieve it. For instance, altering customer perceptions of products and brands is time consuming (barrier 5). This is closely connected to barriers 12 and 13 pertaining to customers' marginal awareness of material quality and reliance on uncertain parameters in the purchase situation, such as brand and prior experiences. It has been made clear that business decisions affect consumers' perceptions of companies and the internal product-related decisions made by product developers. The barriers were categorized into the following three types for a better understanding and a more manageable overview by building on the categorizations of previous studies: business barriers, product development barriers, and usage barriers. Thus, through a comprehensive literature review, the present study prompts a shift from a fragmented-solution focus to a broader perspective involving stakeholders in the product longevity debate.

1.3. CURRENT APPROACHES TO OVERCOMMING THE BARRIERS TO ACHIEVING PRODUCT LONGEVITY

Academia has proposed various solutions to the problem of low product longevity based on different perspectives. Significant attention has been paid to the business perspective, with the proposal of changing business models to address the challenge of low product longevity. From the users' perspective, descriptive studies of user behavior have been proposed and undertaken. From the developers' perspective, academia has proposed the development of tools and toolkits that can be used by product designers and engineers to create long-lasting products.

1.3.1. BUSINESS MODELS FOR PRODUCT LONGEVITY

It has been argued that the business model of a selling company can significantly influence the longevity of its products, such as having a dual sales channel that also offers leasing or renting of the company's products aside from purchasing them (Xiong et al. 2012; Nußholz 2018). Offering their products through only the purchase channel will heighten companies' indifference toward designing and producing products with higher longevity as the companies' profits from their products will rise with each purchase.

Therefore, there has also been great interest from academia in investigating the business models that enable and increase incitement to create products with high longevity. Bocken et al. (2016) highlighted four significant business model strategies that enable higher product longevity (Table 2).

The access and performance models focus on a service rather than a physical product. Companies employing such models aim to provide a service that delivers the same value as if the customer owned the product, such as providing clean clothing instead of buying a washing machine. The ownership of the product is therefore turned over to the providing company, and the customer pays the price only for service use. In theory, the service-providing company is therefore encouraged to produce products with the highest possible longevity as the cost of a unit that provides X number of cycles is the lowest price per cycle if the product longevity is high. Thus, the economic benefit is sustainable innovation. However, users are also economically encouraged to use the service less to save money, therefore also decreasing the wear of the product through the service (Bocken et al. 2016).

Extending product value as a business model centers on recreating value within the product's lifetime. The producing company, or a third-party provider, takes the functioning products back and repairs, remanufactures, or refurbishes them to sell them again. In this case, the cost of the materials for the companies is low as the products are mostly intact and capturing the products at the right moments can lead to a higher total longevity of the original products.

BUSINESS MODEL STRATEGY	DEFINITION	EXAMPLE OF LITERATURE FOCUSED ON THE PERSPECTIVE
Access and performance model	Providing the capability or services to satisfy user needs without needing to own physical products	Whalen (2017) Lewandowski (2016) Lee and Joglekar (2005) Manninen et al. (2018) Pigosso et al. (2018) Suckling and Lee (2015) Rexfelt and Selvefors (2021) Van Loon et al. (2020)
Extending the product value	Exploiting the residual value of products from manufacture to the consumers, and then back to manufacturing, or collection of products between distinct business entities	Antikainen et al. (2017) Gelbmann and Hammerl (2014) Yang et al. (2018) Selvefors et al. (2019)
Classic long-life model	Business models focused on delivering long product life, supported by design for durability and repair, for instance	Sumter et al. (2018) Whalen et al. (2018) Ertz et al. (2019a) Van Nes and Cramer (2005)
Encouraging sufficiency	Solutions that actively seek to reduce end user consumption through principles such as durability, upgradability, service, warrantees, and reparability and a non-consumerist approach to marketing and sales (e.g., no sales commissions)	Haines-Gadd et al. (2018) Sinclair et al. (2018) Ertz et al. (2019b) Whalen (2019) Jaeger-Erben et al. (2020) Cooper (2004) Khan et al. (2018)

Table 2. Overview of business approaches to increasing product longevity, derived from Bocken et al. (2016)

The “classic long-life model” and “encouraging sufficiency” strategies center on providing customers with durable and high-quality products. These products are often delivered by premium brands and thus have relatively high selling prices. Likewise, some companies that provide products with classic long lifetimes also encourage their customers to lower their consumption as part of the strategy (Bocken et al. 2016).

However, many other business factors support product longevity, such as brand value and image, price of products, customer expectations, brand promise, marketing, and sales. An even more subtle factor is the influence of the companies’ employees. Being persistent in marketing, keeping products in the product portfolio, and insisting on quality in all the products across the portfolio can also influence product longevity (Jensen et al. 2021a).

1.3.2. USERS’ ROLE IN THE PURSUIT OF PRODUCT LONGEVITY

Studies on users’ behaviors and attitudes toward product longevity have also presented several perceptions, but most of them have been descriptive studies. A previous study by Ackermann et al. (2018) investigated the decisive motivators, factors, and triggers for the product being cared for. Here, it was found that financial factors play a large role. Expensive products are thus often taken better care of and repaired by users. Likewise, products whose use provides great pleasure because they are aesthetically pleasing, fun, allow satisfying interactions, or bring pride to the user are also often better maintained (Ackermann et al. 2018). Another influencing factor lies in a more latent value with the user. It is argued that users who are generally seeking products with high longevity or rebel against brands that counteract durability are likely to maintain and repair products.

Mugge et al. (2006) identified factors that create stronger user attachment to a product, which increases the user’s chances of maintaining the product well. In line with the studies by Mugge et al. (2006) and Ackermann et al. (2018), Page (2014) cited memories, pleasure of use, appearance, usability, and reliability as some of the most decisive factors that create user attachment to a product, arguing that this attachment can be facilitated through the design of the product. Products that users associate with great memories (e.g., an old traveling backpack or a souvenir magnet from a vacation) are often kept for a longer time, sometimes even though they are no longer in use.

The knowledge on users’ behaviors and attitudes toward product longevity thus centers on the relationship between products and their users. Lilley et al. (2016) emphasized this by describing how customers perceive the aging of different materials. Some materials are more well suited than others for products with higher longevity as customers’ acceptance of use and/or patina is relative to the material. This can be exemplified by an old leatherjacket, whose patina is often considered pleasing, whereas desaturated plastics or paint is often considered to lower product quality. This relates greatly to the term “relative obsolescence” (Cooper 2004), which

refers to the replacement of a product even though it is still functional. The discussion of the user's role in this matter is especially interesting as many durable goods are discarded prematurely relative to their durability.

1.3.3. DESIGNERS' AND SEVELOPERS' ROLES IN THE PURSUIT OF PRODUCT LONGEVITY

The literature on product designers' and developers' roles regarding product longevity highlights strategies to assist practitioners in this regard, with different foci. Some of the foci have been identified by Haines-Gadd et al. (2018), who argued that product designers and developers could address product longevity through different approaches (Table 3).

Product designers can therefore design a product with a focus, for example, on narrative, integrity, or seeking relationships by actively considering how the product is used or whether it captures a moment, promotes reflection on its use, or is part of a ritual or habit (Haines-Gadd et al. 2018).

STRATEGIES	RESEARCHERS
Design for attachment and trust	Bakker et al. (2014), Mugge et al. (2005), Van Nes and Camer (2005)
Design for adaptability and upgradability	Bakker et al. (2014), Mugge et al. (2005), Van Nes and Cramer (2005)
Design for ease of maintenance and repair	Bakker et al. (2014), Mugge et al. (2005), Van Nes and Cramer (2005)
Design for durability and longevity	Bakker et al. (2014), Ellen MacArthur Foundation (2019), Ljungberg (2007), Mugge et al. (2005), Van Nes and Cramer (2005)
Design for memories and longevity (nostalgia)	Mugge (2007), Schifferstein and Zwartkruis-Pelgrim (2008), Maclachlan (2011), Page (2014)
Design for pleasure	Mugge (2007), Schifferstein and Zwartkruis-Pelgrim (2008), Maclachlan (2011), Page (2014)
Design for enjoyment	Schifferstein and Zwartkruis-Pelgrim (2008)
Design for self-expression or self-support identity	Mugge (2007), Schifferstein and Zwartkruis-Pelgrim (2008), Maclachlan (2011)
Design for usability	Page (2014)
Design for sensory design	Maclachlan (2011), Ludden (2008)
Design for superior appearance	Mugge et al. (2010)
Design for utility and reliability	Schifferstein and Zwartkruis-Pelgrim (2008)
Design for product personality	Mugge (2007), Maclachlan (2011)
Design for group affiliation	Mugge (2007)

Table 3. Haines-Gadd et al.'s (2018) design strategies to promote product longevity

1.4. POSITIONING

The roles of the three stakeholders mentioned in the previous section in achieving product longevity have already been debated and investigated in academia (Barth 2013; Scipioni et al. 2021; Lies 2020; Antikainen et al. 2017). However, there are still gaps in the current knowledge on producing products with high longevity (Giacomo et al. 2020).

At the time of the start of this research project, there was no comprehensive overview of the barriers to achieving product longevity. Thus, there was no common understanding of the problem (Cooper 2016; Cooper 2018). As mentioned previously, the focus and perspective of the research differed significantly, mainly in terms of four influencing factors: the responsibilities of product designers (E.g., Lilley et al. 2019; Ackermann et al. 2019; Grosse-Herring et al. 2013), users (E.g., Page 2014; Jaeger-Erben et al. 2020; Hou et al. 2020), companies (E.g., Montalvo et al. 2016; Rivera-torres 2019; Zhou and Gupta 2019), and governments (E.g. Kronsell et al. 2019; Okereke et al. 2019). All of these have impacts on the lifetimes of products, but there was no consensus at that time regarding the extent of the responsibility of each actor. The responsibilities in the transition thus vary; however, this dissertation argues that it is important to perceive the problem more broadly. That is, there should be an agreement among producers (companies), product designers, and users to pursue sustainable innovation, and this should be supported by a relevant regulatory and legal framework.

Likewise, the business literature on product longevity is largely focused on an ideal business model to be implemented on a large scale in companies. The aim of the business model is often cited as a radical transformation from traditional asset sales into a more share-based business model, such as leasing or renting (Verganti 2011; Lassen 2020; Boons et al. 2013). This business model increases the chances of a second ownership of a product and incites companies to create products with higher longevity to maximize their profit (Bakker et al. 2014). However, radical business transformation often cannot be immediately implemented and involves great risks for companies. Customers can reject new business models if these are implemented immediately (Poppelaars et al. 2018); their implementation is often costly and requires organizational restructuring (Grösser et al. 2017). In addition, companies hesitate to move toward a market where they have no prior experience. The present study thus investigated how incremental changes in the behaviors of companies, product designers and developers, and users could create lasting impacts on the longevity of a product portfolio.

In relation to business models, much of the current research on product longevity focuses on large companies. In SMEs, the role of each employee is often more fluid, and employees are often more involved in larger parts of the process (Scipioni et al. 2021). Perceiving companies based on their individual employees instead of as whole

organizations can help elucidate how SMEs can more easily approach transformation toward product longevity. This dissertation thus aims to enable SME transformation as a crucial step in addressing the global need for more sustainable business and consumption.

To help small, medium-sized, and large companies achieve product longevity, several relevant academic tools and toolkits have been established. These tools include those that map companies' current positions, ideals, and goals and those that suggest ways by which companies can achieve the relevant transformation. However, within the vast range of tools and toolkits, there is still a knowledge gap. On one hand, some of the tools address the need for companies to identify their current relevant positions and ideals (E.g., Garza-Reyes et al. 2019; Sinclair et al. 2018; Pigosso et al. 2018). This static identification can be extremely useful for companies that have yet to be introduced to the importance of product longevity and the possibility of achieving it. However, these tools often lack specific suggestions for improvement and often remain at a tactical level of organizational management. On the other hand, other tools address the specific approaches that companies can adopt to achieve transformation toward higher product longevity (E.g., Chapman 2009; Boavida et al. 2020; Choi et al. 2018). These tools are useful for companies that are already aware of the relevant challenges they are facing in their pursuit of product longevity; however, they are often specific to niche situations and difficult to use in practice when they are needed. Thus, the tools become irrelevant or unapproachable for industry in many scenarios and are consequently neglected and ignored in practice. This dissertation therefore also aims to create a more comprehensive understanding of the transformation process toward producing products with high longevity, creating a guide for industry to make existing tools and toolkits more accessible.

To sum up, this dissertation proposes a practically grounded approach to achieving product longevity that perceives the problem holistically, considering all the stakeholders, and builds on the existing academic literature to come up with a more approachable perspective on product longevity. This was realized through expert interviews, identification of existing knowledge, and development of a framework to make existing tools and toolkits more accessible to companies seeking to achieve product longevity. This led to the following research question:

How are small and medium-sized companies supported in extending the lifetimes of their products to enable them to contribute to the attainment of the 12th United Nations Sustainable Development Goal of ensuring sustainable consumption and production patterns?

1.5. RESEARCH QUESTIONS

As previously mentioned, the overarching research question in the present study was as follows:

How are small and medium-sized companies supported in extending the lifetimes of their products to enable them to contribute to the attainment of the 12th United Nations Sustainable Development Goal of ensuring sustainable consumption and production patterns?

The aforementioned research question was divided into the following four research sub-questions:

- ***RQ1:*** *What are the barriers to developing and creating viable businesses based on long-lasting products and to ensuring their long-term use?*
- ***RQ2:*** *What are the tactical approaches and decisions within best-practice companies that enable a transition toward producing long-lasting products?*
- ***RQ3:*** *How can a new tool bridge existing mapping tools and action tools for product longevity to be more practically usable by industry practitioners?*
- ***RQ4:*** *To which extend does the LaST toolkit enable companies to change attitude and behaviour towards product longevity and to recognize incremental change opportunities, that can improve the product longevity?*

Answering RQ1–4 could provide valuable insights not only to academia but also to practitioners who are currently searching for a sustainable balance in their businesses.

1.6. THESIS OUTLINE

Chapter 1: Introduction

This chapter functions as a guide to the subject of product longevity and positions this dissertation in the discussion of sustainability and the circular economy. In addition, by identifying the current gaps in the literature, this chapter presents the overarching research question of the present study. This research question is broken down into four research sub-questions that are different in both approach and perspective regarding the subject but whose answers can all build a common understanding of the importance of products with high longevity.

Chapter 2: Theoretical Framework

This chapter presents the theoretical framework that was used for the research in the present study. The theoretical framework presents the key knowledge in the existing research on the general topic of the present study and on the topic of each research sub-question.

Chapter 3: Methodological Approach

The methods used to answer the research questions in the research project reported in this dissertation are presented in this chapter. These included a comprehensive literature review, a best-practice study, and workshop-based activities, which collectively provided the study data. The methods used to analyze and interpret the obtained data are also presented in this chapter.

Chapter 4: Paper Outlines

This chapter presents the four papers that form the cornerstone of this dissertation. Individually, they answer one of the research questions, which are all related to product longevity.

Chapter 5: Conclusion and Discussion

This concluding chapter provides a summary of the study results and findings, particularly on approaches to achieving product longevity, and discusses these and avenues of further research.

CHAPTER 2. THEORETICAL FRAMEWORK

In this chapter, we investigate the theoretical framework used throughout this dissertation. The theoretical framework is part of the theoretical foundation of the study and is used to form our understanding of the subject. In line with the introduction, this dissertation positions the conversation about product longevity as part of the discussion about the circular economy and sustainable transition. While the Introduction section mainly focuses on the positioning of this dissertation in relation to the existing literature, this chapter focuses on the perspectives used to understand the topic of product longevity in relation to sustainability, business opportunities, and attitudes (Figure 5).

Figure 5. Timeline of the Theoretical Framework chapter.

First, in this chapter, it is important to understand the relationship between product longevity and the current sustainability debate. Sustainability is currently a widely used term covering financial, social, and environmental sustainability. This dissertation mainly focuses on environmental sustainability from a perspective that integrates product longevity as a key element in circular-economy thinking. This perspective provides academic lenses that do not necessarily consider the affordability of specific initiatives in context but merely perceive the possibility of environmentally sustainable innovation within companies. This understanding influenced the methodological approaches used in the study, leading to findings of some good intentions rather than merely costs and benefits for companies pursuing higher product longevity.

Second, this chapter dives into the theoretical framework that was used to understand how to assist companies in developing products that slow consumption. This is done in this chapter through four lenses, each of which describes the perspective used in the academic approach to understanding product longevity (Figure 6).

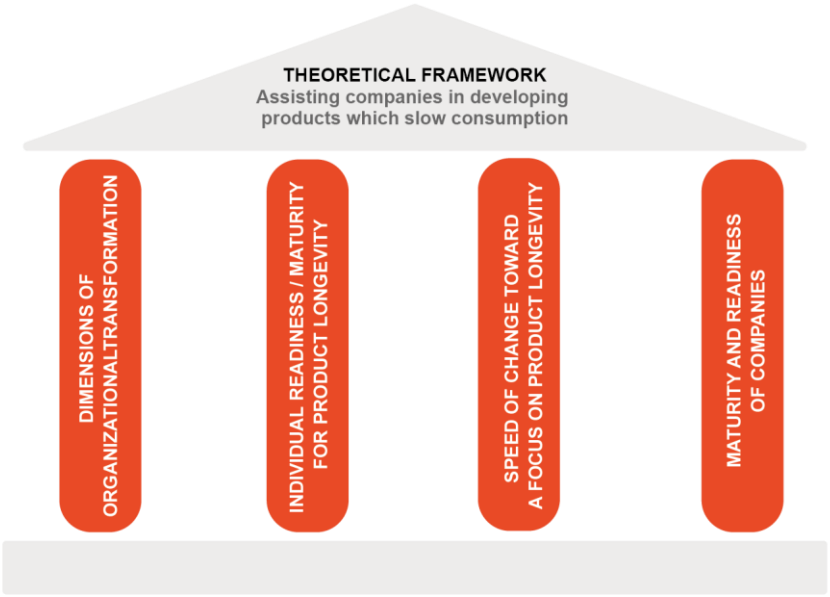

Figure 6. Representation of the four pillars constituting the theoretical framework of this dissertation.

The four lenses are as follows: (1) how the research needs to perceive several stakeholders in relation to each other in the effort to produce longer-lasting products; (2) how the process of business transformation toward product longevity is affected by the stakeholders; (3) how incremental change is needed to make a lasting impact; and (4) how different sustainable dimensions influence the decisions within companies and how companies and their employees need to mature and be ready to become producers of products with high longevity if they desire this. How the integration of products with high longevity in a company needs to be an incremental approach deeply rooted in the company's identity and in the customers' perceptions of the company and product is also discussed.

After the foregoing, the theoretical foundation of the dimensions within companies is presented. These dimensions explain how sustainable transformation is a negotiation between companies' maturity for product longevity and the corporate activities that companies engage in to pursue the goal of achieving product longevity.

Lastly, the theoretical foundation for understanding the individuals within companies is presented. To understand how decisions within companies are made, individuals within companies need to be investigated. The theoretical framework for decision-making toward producing long-lasting products based on attitudes, knowledge, and actual behaviors is thus presented and discussed.

2.1.1. LIMITATIONS

To elaborate, the theoretical framework of the research project reported in this dissertation established the importance of perceiving the company transformation toward producing longer-lasting products as a knowledge exchange between the stakeholders. Based on the broad perceptions of product longevity and sustainability, the typical stakeholders are the management, product designers and developers, consumers or users, and the government and regulators. However, the stakeholders considered in the theoretical framework of the research project were companies (perceived here through the eyes of management), product designers and developers, and customers or users of the final products. Even though another important stakeholder in the debate is the government or the intergovernmental law and regulation framework, which encourages or pushes for sustainable innovation, this stakeholder is not the focus of this dissertation.

For a full understanding of how product longevity relates to sustainability, the next chapter discusses how the circular economy integrates product longevity into the environmental sustainability debate.

2.2. THE CIRCULAR ECONOMY AND PRODUCT LONGEVITY

The traditional perspective on product and material consumption consists of a linear timeline, starting with the extraction of raw materials to production, distribution, use, and disposal. Through consumption in line with this pattern, consumers fuel the buy-and-throw-away society by disposing of the products they purchased as soon as they are done using these (Cooper 2004). This method of consuming raw materials without reusing finite materials is not very sustainable (Mura et al. 2020). The linear consumption pattern is therefore not ideal, and, fortunately, neither is it the only way of consumption. Even though some raw materials still live purely in linear life, such as medical equipment, foods, and clothing (Ertz et al. 2019), many products are either produced with recycled materials or can provide materials that can be recycled when their life ends. Likewise, many products can be repaired, reused, or reproduced (Jaeger-Erben et al. 2020).

The foregoing is highlighted in the circular economy. The circular economy, first described by McDonough and Braungart (2002) in the "cradle to cradle" theory and later by the Ellen MacArthur Foundation (2019), is opposed to the traditional linear product lifetime as it is a circular understanding of material and energy flows (Figure 7).

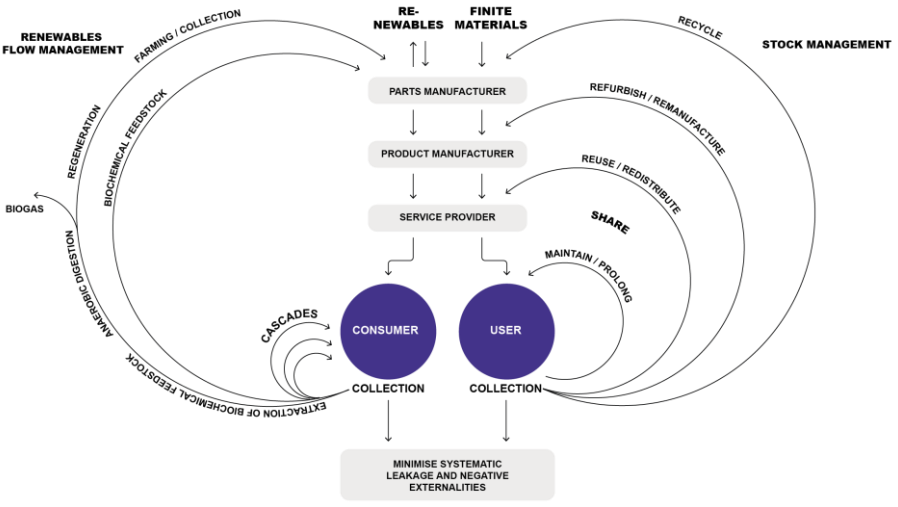

Figure 7. Full representation of the butterfly model (Ellen MacArthur Foundation 2019; McDonough & Braungart 2002), presenting the material and energy loops in the circular economy.

Both raw materials and energy can be seen in the butterfly model's circular loops. As the system is circular, it is theoretically possible that all the materials and energy that are put into the loop will never need to leave the loop again. This is because they can

be reused in the different loops described. For example, if a product is well maintained, it can last a long time; if a product is no longer relevant to the user, then it may be used by someone else or may be made into something else. Therefore, theoretically, if materials and energy are preserved within the system, then their environmental impacts will be minimized.

Likewise, the Ellen MacArthur Foundation (2019) argued that the smaller the loop, the lower the environmental impact; therefore, it is preferable to aim to produce products that can be maintained, reused, or redistributed rather than recycled. This is because the actual loss of energy, materials, and material properties is higher in bigger loops. For example, if a product needs to be recycled and used for something else, there is an energy loss, a material loss, and sometimes a loss of material properties when the product is broken down into its raw materials and when a new product is produced from it.

Product longevity is not included in the original representation of the circular economic model as the model focuses on how to maintain finite materials and energy in use in theory. However, the speed of consumption also plays a large role in the preservation of energy and materials. Many materials lose properties by being reused too many times, polluted, mixed with other materials, or simply worn out. This, combined with the fact that few product materials are suited for the circular economy, indicates that the preservation of materials through high product lifetimes in the use phase should be seriously considered to limit the waste generated, even in an ideal circular loop situation. The use phase, highlighted as “user” in the model, is therefore an ideal phase for slowing consumption, maintaining existing products within the loop, and slowing our general consumption of products, materials, and energy.

Products with low lifetimes, such as single-use products (e.g., plastic straws, cardboard cups, single-use cameras) or products with much packaging, may have relatively low carbon footprints compared to products produced for multiple uses. However, products that can be used multiple times may have lower overall carbon impacts if calculated by carbon footprint for each use. Even if low-lifetime products are easily recyclable, their recycling often causes a loss of energy and materials in all phases of the circular economy, such as through a wrong way of recycling, loss of material properties, mixing of different materials, wear, and energy use of tools for manufacturing purposes. Higher product longevity can postpone many of these losses as the products remain in the user’s ownership for a longer time.

Producing products with higher longevity can therefore be seen as a way of slowing consumption and thus the speed at which the products move in the circular economic model (Konietzko et al. 2020).

2.2.1. PRODUCT OBSOLESCENSE

There are many ways to slow consumption, as described in the circular economic model. At the same time, there are many ways in which consumption is accelerated, the most obvious being when products are worn out or broken. However, previous studies have implied that products are discarded or disposed of not only due to low durability and product breakdown but also due to many other factors (Van Nes & Cramer 2005). The reasons for product disposal are often labeled "obsolescence" and have been divided into four categories: product failure or breakdown, technological/functional obsolescence, physiological obsolescence, and systemic obsolescence.

Product failure or breakdown

The most obvious reason for product disposal is product failure or breakdown. That is, many products break down prematurely due to wear and tear or poor maintenance. Some of these products are deliberately designed to last only for a predetermined time or after a number of uses (Wieser 2016; Rivera & Lallmahomed 2016). The most famous examples are light bulbs, which are designed to break after X hours of use (Dannoritzer 2010). The European Union is currently working hard to introduce regulations that limit this behavior (European Commission 2019) on the part of companies, and similar laws have already been enforced in France (Boring 2017).

Technological/functional obsolescence

Another reason for product disposal is technological or functional failure. Technical obsolescence is a term used to refer to the state at which a product has become obsolete due to the release of new and better products (Levinthal & Purohit 1989; Rai & Terpenny 2008). In this case, the product's condition is still good, but its performance is subpar to that of new alternatives, thus lowering the product's value as perceived by the owner. This can lead to the product's replacement simply because the customer demands "something new" (Jenab et al. 2014; Cooper 2004). This kind of customer behavior can be seen in relation to mobile phones, video games, personal computers, and many other electronic products.

Psychological obsolescence

Another kind of product obsolescence is psychological obsolescence. Sometimes referred to as aesthetic obsolescence, it is likewise associated with the desire for something new. Not all products age gracefully, and those that do not age gracefully become increasingly unpleasant to look at, which can lead to their substitution (Hagedorn et al. 2018; Lilley et al. 2016; Amolo & Beharry-Ramraj 2016). Likewise, some product categories are more prone to trends and can thus go out of style, leading to users' desire to replace them.

Systemic obsolescence

The last reason for product disposal is systemic obsolescence (De Oliveira 2013; Miao 2010). Systemic obsolescence is closely related to innovation. Product standards change, and consumers move from one system to another in their consumption (Feldman & Sandborn 2007). An example of this is the change from DVD and Blu-ray players to streaming. With the change in society, many DVD and Blu-ray players became obsolete because their relevance disappeared along with the system.

2.2.2. DELIMITATIONS AND SUMMARY

In summary, there are many reasons why users and owners of products dispose of these, therefore limiting their lifetimes, increasing consumption, and not slowing the product loops. Some studies have indicated that there are companies that deliberately design and manufacture products that need to be substituted prematurely. This is labeled planned obsolescence, but it is not focused on in this dissertation. On the other hand, companies that promote higher product lifetimes can sometimes experience that the users/customers do not support this initiative, making it not feasible to pursue. This is an interesting avenue for further research on how to make product longevity feasible for companies, as a sustainable sales point and as an indication of the production of products of high quality.

After this short introduction of product longevity in relation to the circular economy, the four pillars of the perspectives presented in Figure 7 are addressed next, as follows:

1. an understanding of why companies need to become mature and ready to adopt product longevity initiatives;
2. an understating of how fast companies, developers, and consumers can change toward producing products that last longer;
3. an interpretation of the dimensions within companies that enable them to transform; and
4. an interpretation of the maturity of individuals within companies and their ability to conduct business based on products with high longevity.

2.3. MATURITY AND READINESS OF COMPANIES

First, it is important to understand the different stakeholders' roles in the pursuit of product longevity and those who influence decisions toward product longevity and how they influence this. Many stakeholders influence product lifetime: management, product designers and developers, and users.

- Management consists of the decision-makers on the managerial level. These stakeholders make important business decisions, such as what business model to use and the sales channels, suppliers, sub-suppliers, and advertisements. Management's influence on product longevity may or may not also influence product durability, but it certainly influences consumers' impressions and expectations of products that are first introduced to them.
- Product designers and developers are the main stakeholders from idea generation to development, detailing, and launch. Their choices of the materials to use have major impacts on product durability, but through their choices regarding interaction, aesthetics, functions, etc., they also largely influence the users' product experiences.
- Users are the consumers who buy and own products. Consumers' purchase choices largely influence the focus of the management and the market in general. If users seek products with high longevity, these products will probably be presented to them in time. Users likewise influence the lifetimes of products in the ownership stage, depending on how well they maintain and repair the products.

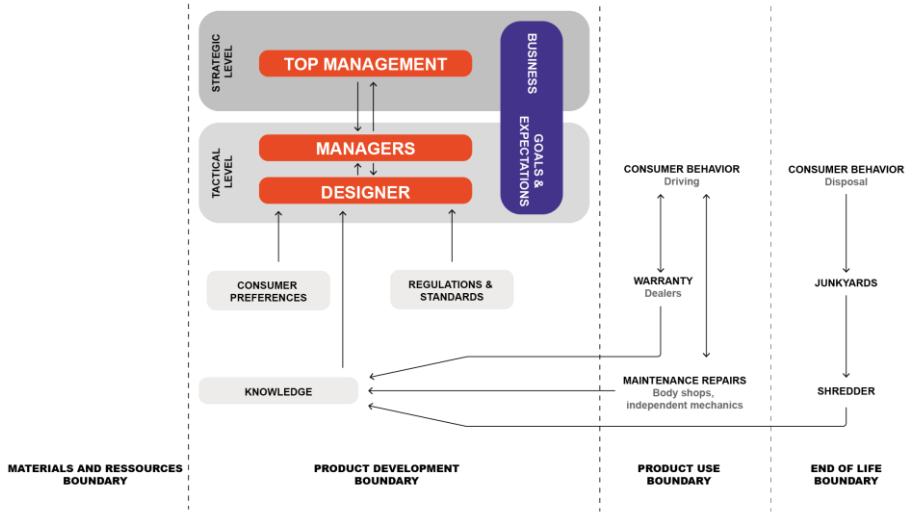

Figure 8. Full representation of Rivera and Lallmahomed's (2016) model of interactions.

Rivera and Lallmahomed (2016) developed strategies to counteract product obsolescence and enhance knowledge sharing among all the actors involved in the pursuit of product longevity (Figure 8).

Rivera and Lallmahomed's (2016) model of interactions in the value chain between stakeholders in a company describes how knowledge is transferred from the top management (who focuses on the company strategy) to the designers (who focus on the products). These stakeholders are likewise influenced by the customers (who have product preferences) and by the rules and regulations they must follow.

The model further demonstrates how the company, by observing the customers with the products, can better understand customer behavior and how the product is maintained, repaired, and disposed of. This knowledge is ideally incorporated at the designer level and passed on to the middle and top management.

2.3.1. KNOWLEDGE SHARING AND COMPREHENSIVE PERSPECTIVE ON PRODUCT LONGEVITY

Rivera and Lallmahomed (2016) argued that knowledge is shared among management (strategic decisions), designers (tactical decisions), and consumers (through products). Therefore, it is important to understand that all actors working to increase the longevity of new products are important stakeholders. The role of management is to make business decisions. It can influence the business model used to support high longevity and how to market, support, and advertise the company's products, among others. On the other hand, the designers control the products and the related tactical decisions, such as choosing durable materials, mechanical solutions, and future-proof technologies, as well as the aesthetics, interactions, and innovation, which also affect the longevity of products. Lastly, consumers control the actual lifetimes of the products, which are influenced by the decisions of the two other stakeholders.

This dissertation positions itself in the spectrum of three agents: business, product designers, and users. By perceiving the subject of product longevity as a complex problem across stakeholders and that must be considered from the perspectives of all three agents to succeed in practice, this dissertation aims to provide a broader interpretation of the difficulties and ways of achieving the longevity of physical products.

2.4. SPEED OF CHANGE TOWARD A FOCUS ON PRODUCT LONGEVITY

Another important perspective to consider with respect to achieving product longevity is the speed at which companies can change their focus. This is worth considering when asking the overall research question "How are small and medium-sized companies supported in extending the lifetimes of their products to enable them to contribute to the attainment of the 12th United Nations Sustainable Development Goal of ensuring sustainable consumption and production patterns?" as the speed of transformation is vital to practical approachability for companies.

On the one hand, the transformation process for management, product designers and developers, and consumers has proven to be difficult in practice. Pigosso et al. (2018) argue that companies that experiment with sustainable initiatives on a small scale often fail, thus deeming the pursuit of such initiatives unaffordable for companies.

Much of the existing literature on product longevity centers on radical innovation and transformation. An example of this is a sudden change of the business model, such as from the traditional asset sales model to a leasing or renting business–based model (Agrawal et al. 2011). Business models based on service rather than ownership encourage innovation of products to improve their longevity as this minimizes the cost of the service-providing company. A rapid change in the business model can therefore create a change in company behavior that counteracts the decreasing longevity of many products. However, as illustrated by Bocken et al. (2018), the innovative process of changing one's business model to a more circular one is often chaotic and risk-filled; thus, it must be approached with care (Figure 9).

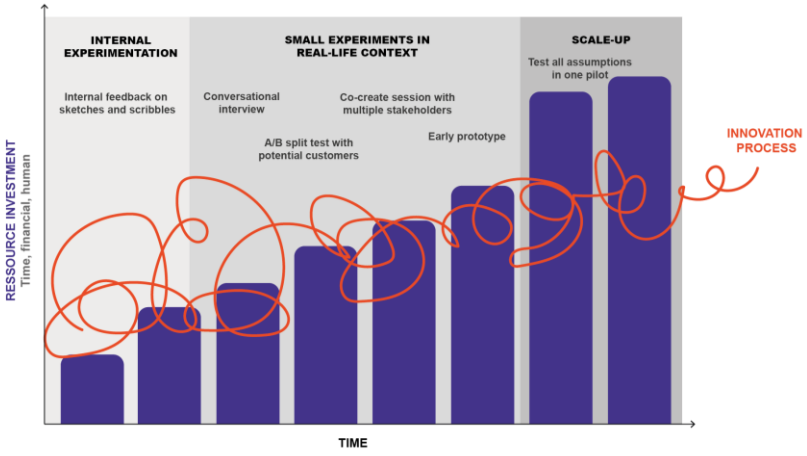

Figure 9. Bocken et al.'s (2018) representation of the messy progression in the innovative process.

A sudden change of the business model can also prove difficult for companies in practice as extreme uncertainty from customers and lack of knowledge on the part of both the management and developers can hinder successful transformation. These barriers are often exogenous and cannot be immediately controlled by the company. An example of this is customer behavior (Gnanapragasam et al. 2018; He et al. 2016; Cox et al. 2013; Amolo & Beharry-Ramraj 2016; Kuppelwieser et al. 2019). If customers do not accept renting rather than owning, then the business will fail. This is just one example of the barriers that hinder companies from adopting radical transformative business models; many researchers thus argue for a more incremental approach to transformation (Kopecka et al. 2011; Debref 2017; Kiefer et al. 2021; Campos et al. 2016). One example of these researchers is Bakker (2017), who presented general frameworks for transformation toward higher product longevity. However, even though this provides a solid foundation of knowledge, there is still a lack of knowledge of relevant practical approaches that companies can directly adopt, which may differ significantly depending on the companies' situations, markets, products, etc.

Incremental changes toward higher product longevity in companies are not necessarily strategic management decisions (Lopes et al. 2019); a push from product designers and developers can influence management to approach the problem in this way. This perspective, presented by Rivera and Lallmahomed (2016), is likewise used in this dissertation: incremental change can happen on a strategic level (through middle and top management) or a tactical level (through product designers and developers).

This dissertation builds on a broad foundation rooted in product design and development understanding. Inspired by the iterative process and minimally viable products, the dissertation argues that incremental steps enable companies, product designers and developers, and consumers to minimize the risk of transformation toward higher product longevity. Through this slow transformation, companies, product designers and developers, and consumers can explore the most rational approaches tailored to their respective situations, thus heightening the sustainable innovation internally.

2.5. DIMENSIONS OF ORGANIZATIONAL TRANSFORMATION

Organizational maturity is an important factor to consider when determining a company's ability to transform toward producing products with higher longevity.

If we adopt the notion that companies need to implement incremental changes to minimize the risk involved and increase the chances of success in achieving product longevity, then companies must also follow a hierarchy of maturity. This maturity pertains to that of the company as a whole and the company's ability to execute initiatives that improve product longevity. Less mature companies need to engage with initiatives that are less invasive to their businesses, such as developing a new product that can prove the success of higher longevity. Meanwhile, more mature companies that already have experience with products with high longevity are able to approach more invasive solutions, such as adopting a new business model or changing the company's behavior.

In an incremental transformation, several more in-depth but easily adoptable approaches to transforming the business to improve product longevity must be employed. To analyze this, a framework building on Müller and Pfleger's (2014) "Sustainable Maturity Cube" was established.

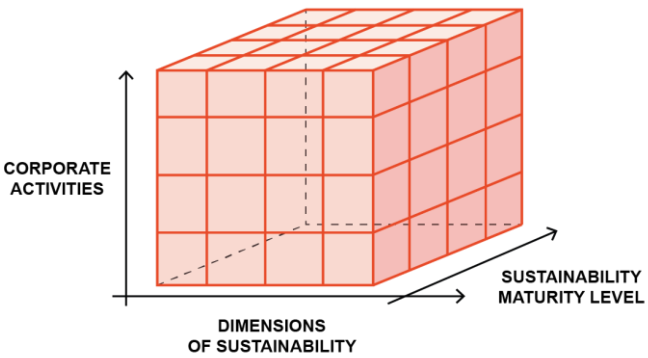

Figure 10. Müller and Pfleger's (2014) Sustainable Maturity Cube.

Müller and Pfleger (2014) first looked at all types of sustainability: ecological, social, and economic (Figure 10). They argued that all these three dimensions contain certain aspects of sustainability, which differ depending on the perspective employed. In the case of ecological sustainability, it can be broken down into waste, pollution, CO_2 and other greenhouse gases, light, finite materials, etc., but in terms of avenues of research, it can also be broken down into recycling, longevity, manufacturing, disposal, etc.

The other axis in the Sustainable Maturity Cube represents corporate activities and sustainable maturity levels. Corporate activities are the activities that are available to companies at their current maturation level. As previously mentioned, companies that are just beginning to engage with product longevity are not necessarily ready to change their respective business models; however, they may be able to work with corporate activities on a design level to promote the higher durability of their products. More mature companies are then able to build further on these corporate activities and implement new and more defining activities as they have already experienced success with their previous activities.

The focus of the present research project was limited to ecological sustainability and its longevity perspectives (Figure 11). This enabled the analysis not only of the kinds of corporate activities that companies use to overcome the barriers to achieving product longevity but also of the maturity and paradigm that companies need to adopt to attain success in their initiatives (see Paper II).

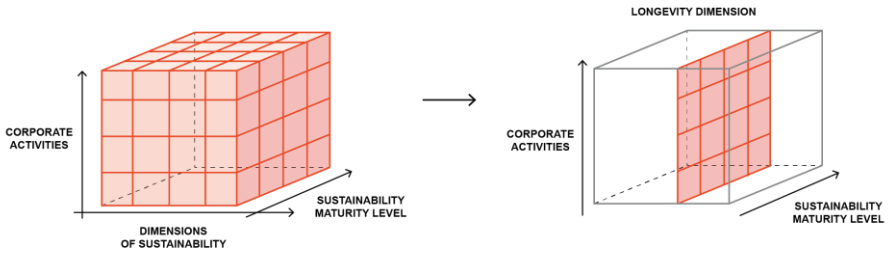

Figure 11. Interpretation of Müller and Pfleger's (2014) Sustainable Maturity Cube, as presented by Jensen et al. (2021a).

The foregoing was investigated through a best-practice study of companies that pride themselves in being producers of high-quality products with high longevity and that are commonly acknowledged by the public as producers of quality goods. These companies use different approaches that collectively make them producers of long-lasting products. Investigating the solutions that they propose to position themselves in this unique place leads to answers to the question of how to overcome the usual barriers to companies' transformation toward producing long-lasting products. However, looking at the actions that best-practice companies use for producing different types of products can help identify the kind of maturity that must be developed to succeed in producing products with high longevity. It is thus important to look not only at the actual approaches used by companies but also at companies' maturity levels.

2.6. INDIVIDUAL READINESS/MATURITY FOR PRODUCT LONGEVITY

When determining how companies can more easily transform toward producing products with higher longevity, it is relevant to investigate how companies can mature for this process. Here, it is worth distinguishing between the maturity of the company as a whole and the maturity of the teams and individuals within the company.

The most obvious approach to analyzing companies' sustainable maturity is through their behaviors. However, to truly understand and improve sustainable maturity, companies need to improve not only their behaviors but also their knowledge about longevity and their attitudes toward the subject.

As argued by Kollmuss and Agyeman (2002), environmental behavior is the consequence of many factors, foremost of which is the employees' knowledge on the subject. Are they aware of the opportunities and challenges involved in the pursuit of product longevity? Lack of knowledge is often considered the largest barrier to change, and many express an unwillingness to engage as "they simply do not know enough about the matter yet." Second, employees' attitudes toward the subject of longevity are important. If the employees strongly identify with the value of product longevity and feel pride in engaging with it, then the company's efforts to achieve it are likely to succeed. Conversely, if the employees do not consider product longevity as important as other values, it may be neglected and decrease, or the company's efforts to achieve it may not succeed.

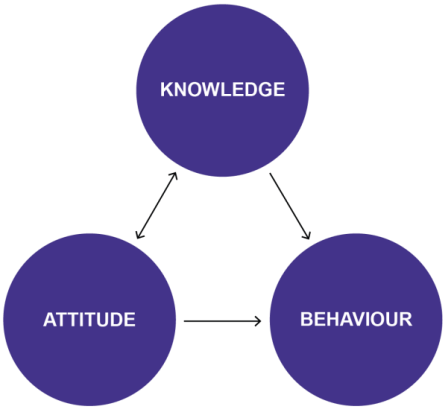

Figure 12. Visual representation of the three decisive factors for change, as presented by Jensen et al. (2023a).

Finally, employees' behaviors are also influencing the longevity. This addresses whether the employees have the right tools to achieve the product longevity goals they have set. Behavior does not necessarily imply sustainable maturity as the reason behind it (attitude), and the knowledge foundation of the actions may not have been established (Figure 12). An example of sustainable behavior that is not necessarily motivated by sustainable maturity can be seen in greenwashing cases, in which companies promote environmental behavior only as a marketing positioning strategy.

Likewise, early literature has suggested a linear perception of behavior, stating that if a person (or company) has enough knowledge about a subject, this will lead to a change in attitude and subsequently to a change in behavior (Burgess et al. 1998, p. 1447). However, this has recently been proven inaccurate as many other factors (e.g., normative beliefs, subjective norms, evaluative beliefs) highly influence the decision to embrace actual behavioral change.

Without knowledge, it will be difficult for a company to decide which actions to take, even if it has the intention to act (attitude). Likewise, even though a company has sufficient knowledge to make the "right" decision, it must have an attitude toward the subject that will drive it to create change. However, even with sufficient knowledge and a proper attitude, there is often still a gap in the actual action seen in practice (Morwitz et al. 2007).

Therefore, to facilitate the sustainable maturation of companies, they need to gain new knowledge in the field of product longevity, work toward implementing a vision and goal toward product longevity, and act on the goal.

2.7. SUMMARY

To summarize, the theoretical setup for this dissertation builds on the following understandings:

- Product longevity is a key element in the success of a circular economy as its pursuit is an ideal way of slowing the consumption of materials, thereby minimizing the waste and energy loss involved in moving in a circular lifetime pattern.
- For product longevity to be realizable in practice, it must be investigated as the subject of negotiations among business managers, developers, and users, supported by rules and regulations.
- Companies aiming to adopt initiatives that strengthen product longevity must do so incrementally to minimize the economic risk posed by such initiatives and to embed the initiatives deeply in the business.
- Likewise, for companies that aim to adopt new product longevity–improving initiatives, there exists a hierarchy of adaptation, which is a negotiation between the corporate activity and the sustainable maturity of the company.
- Companies' sustainable maturity is not limited to the actions that they take (behaviors) but includes their attitudes toward and knowledge on the area. They need to improve on all three factors (knowledge, attitude, and behavior) to raise the level of their sustainable maturity.

The aforementioned assumptions are used as a viewpoint for the dissertation and form the foundation of the knowledge of the papers included in this dissertation.

CHAPTER 3. METHODOLOGICAL APPROACH

This chapter aims to highlight the methodological approaches used throughout the present research project, specifically in the studies reported in the four papers, from which the core knowledge acquired in the research project was derived. Thus, this chapter presents an overview of the scientific methods that form the baseline of methodological approaches used, and of how these were applied in the research. Based on this, the chapter is structured as follows:

- how pragmatism was used as a cornerstone in the scientific approach adopted in the present research project;
- a thorough walkthrough of the methodological approaches used in each of the studies reported in the four papers included in this dissertation; and
- an overview of all the research methods used in the present research project.

Table 4 shows the methods that were used in the studies reported in the papers included in this dissertation.

However, to understand why the methodological approach and research question adopted by each of the studies reported in the papers were selected, we first examine the scientific paradigm and overall research method that were used based on the design research methodology (DRM) (Blessing & Chakrabarti 2014).

PAPER NO.	PAPER I	PAPER II	PAPER III	PAPER IV
Research question	RQ1: What are the barriers to developing and creating viable businesses based on long-lasting products and ensuring the long-term use of such products?	RQ2: What are the tactical approaches and decisions within best-practice companies that enable a transition toward producing long-lasting products?	RQ3: How can a new tool bridge existing mapping and action tools for product longevity to be more practically usable by industry practitioners?	RQ4: To what extent does the LaST toolkit enable companies to change their attitude and behaviour towards product longevity and recognize incremental change opportunities that can improve product longevity?
Purpose	To create an overview of existing knowledge on product longevity	To conduct a best-case study of companies' approaches to achieving product longevity	To create a new toolkit that bridges the mapping of companies' situations and potentials for achieving product longevity and the planning of their actions for attaining this goal	To test the practical applicability of the LaST toolkit in collaboration with four Danish SMEs
Methodological approach	Research clarification	Descriptive study I	Prescriptive study	Descriptive study II
Research	Literature review, grounded theory and coding	Best-case data structure model	Literature review, tool development	Constructive discursive analysis, tool testing
Outcomes	A map of 14 barriers to achieving product longevity	Approaches to achieving product longevity from best-case companies	The LaST toolkit, created by combining the knowledge from the existing literature on product longevity and relevant toolkits with practically usable tools and approaches	Testing of the practical applicability of the LaST toolkit in SMEs

Table 4. Methodological overview of the studies reported in the papers included in this dissertation

3.1. SCIENTIFIC PARADIGM: PRAGMATISM

Many studies on design, engineering, innovation, and development are based on a pragmatic research paradigm. This paradigm was also selected for the present research project. In pragmatism, such as in the social and natural sciences, reality is objective (John Dewey, 1859–1952; Jane Addams, 1860–1935). However, pragmatic research results, such as in the social sciences, are based on a social and cultural understanding and are accepted only if they make sense in practice (Brinkmann 2006) or deliver value in real-life settings, and only if the research aims to deliver this value to practitioners.

This dissertation aims to deliver new perspectives to practitioners of product longevity. Through the knowledge acquired by experts in the field and by building on the existing relevant academic literature, it synthetizes a new perspective and suggests a practical new process for engaging with the subject. This new knowledge is relevant only in the context of companies that can benefit from it. Thus, the knowledge is subjective but makes sense in practice, which reflects a pragmatic paradigm.

In turn, the research needs to be continuously supported as it remains relevant only if it is updated to reflect the realities of companies (Rylander 2012; Feilzer 2009). However, the knowledge that companies' realities change creates great uncertainty during the research as the search for knowledge is uncertain and the results are unknown.

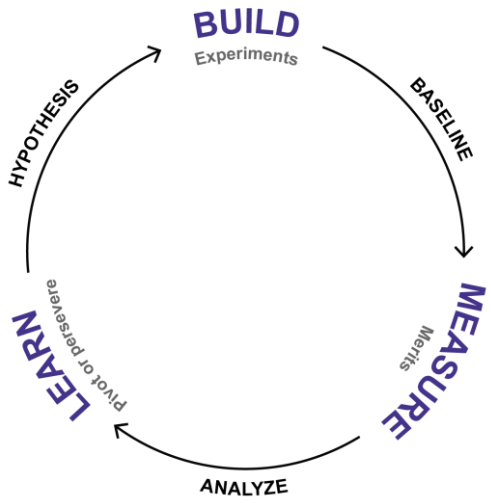

Figure 13. Representation of the iterative process of working with pragmatic science (based on Horváth, 2001).

To qualify the use of pragmatism in the present research project, we adopted the notion that it builds on the goal of delivering value to reality and that a pragmatic approach to research can be applied through a three-step model that ensures the relevance of reality through all its steps (Figure 13).

First, through a baseline, the current reality must be observed, measured, and analyzed. This creates an updated understanding of the real situation companies are in. The environment in which the businesses are conducted, and the actors involved are identified, which creates a foundation for understanding the context of the research.

Second, based on the foregoing, a hypothesis on how to improve the situation is built. This hypothesis forms a direction for the research, pointing out the gaps in the current knowledge and the relevance of the research for practitioners. The hypothesis builds on the reality and context of the research (Frankford-Nachmias and Nachmias 1996).

Third, the hypothesis must be tested to determine whether it has an impact on the relevant situation. To this end, it must be tested in the context of reality. This not only ensures that the research is objectively correct but also creates meaning for companies that will likely benefit from and utilize the knowledge obtained in the research.

This aforementioned process can then be repeated in an updated understanding of reality, building on the knowledge acquired. This iterative process is also the aim of this dissertation. The knowledge acquired throughout the research presented here builds on a similar perspective, DRM, which also utilizes the iterative process of updating the existing knowledge to reflect the most current reality.

3.2. OVERALL METHODOLOGICAL APPROACH

The overall research methodology applied in the research project presented in this dissertation is based on DRM (Blessing & Chakrabarti 2014). DRM aims to provide a framework for design and engineering research, as well as define a structure that can help qualify the research approach. This, in turn, will create a more rigorous approach to design research and strengthen the argumentation provided by researchers. Likewise, the structure of DRM enables the adoption of a transparent approach to research where the selection of appropriate methods of investigation is made approachable.

The theory is based on an overall structure that begins with a research clarification, followed by descriptive and prescriptive studies, and finally, a second descriptive study. This setup enables a research project to acquire a thorough understanding of the existing knowledge within the field, create new knowledge, and test the hypotheses (Figure 14).

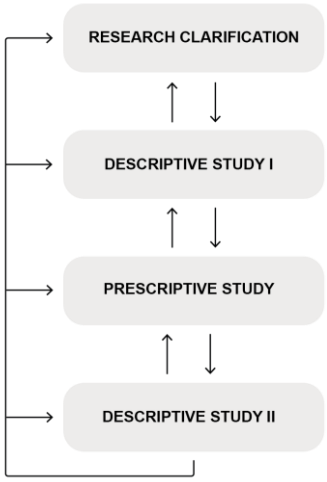

Figure 14. Complete representation of the design research methodology framework, as presented by Blessing and Chakrabarti (2014).

To explain further, a research clarification is first formed as a literature analysis. This is also the stage in which the overall research question is formed, and evidence that the research question is worth pursuing is presented. This is often displayed as a comprehensive review of the existing literature. Through this literature review, knowledge gaps and potential avenues of future research can be identified.

Second, a descriptive study builds on the identified existing knowledge on the research topic. Research sub-questions are formed, and the direction of the study is presented. Descriptive studies help define the reality and practical implications that challenge the research question. Practitioners are often used as cases in descriptive studies as knowledge acquisition from them can provide an updated view of reality.

The third stage of DRM is a prescriptive study. At this stage, the accumulated knowledge is used to form a new understanding of the topic. A prescriptive study aims to create changes in the approach or thought patterns previously used, change the current situation, or provide practitioners with guidance and assistance in changing it, and provide practitioners with the tools that they need to overcome the challenge defined in the research question through practical usable research.

Finally, a second descriptive study is conducted to investigate the impact of the prescriptive study on the desired effect. Here, whether the tools that the prescriptive study provided have the desired impact and/or create further implications or avenues of research is investigated. This is also why the model is circular; that is, the second descriptive study unveils likely improvements and new research agendas that can further elucidate the topic.

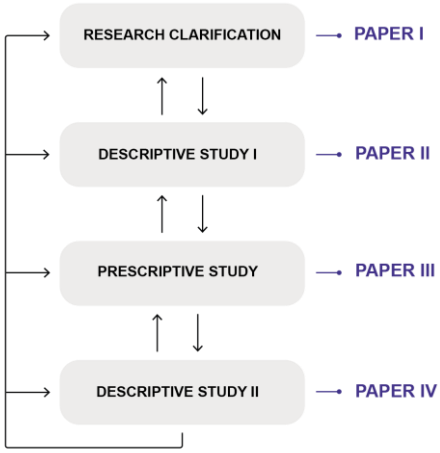

Figure 15. Design research methodology framework, as presented by Blessing and Chakrabarti (2014), modified to display its relatability to this dissertation.

The present study followed the DRM framework through the studies reported in the papers included in this dissertation, beginning with a research clarification and followed by descriptive study I, a prescriptive study, and descriptive study II (Figure 15).

Paper I functions as a research clarification. The review-based study reported in this paper focused on the existing literature on the research topic, particularly the perspectives presented in the literature. This approach positions the entire dissertation and forms the direction for the other papers included in it. By presenting the results of a comprehensive review of the existing knowledge on product longevity, the paper highlights some of the barriers to companies' practical transformation toward product longevity. This list of barriers functions as a baseline throughout the dissertation as a link between academia and practice.

In Paper II, the empirical data collected through interviews with individuals from best-case companies are presented. This paper reports the results of the first descriptive study that was conducted, which involved industry actors. A relatively large number of interviews (20, with 18 different companies) were conducted to search for practical ways to produce products with high longevity. The companies described the methods they use to overcome the barriers to achieving product longevity and the business opportunities that they see in the market. This describes the current reality from the practitioners' perspective.

The results of the prescriptive study that was conducted are presented in Paper III. This study was conducted through a presentation of the newly developed Longevity and Sustainable Transition (LaST) toolkit (Jensen et al. 2023b), which bridges the gap between academic knowledge and companies' ability to apply this in practice. Through this newly developed tool, the study aimed to deliver a new method of engaging with product longevity that combines academic knowledge and practical methods to develop a more approachable method of producing products with higher longevity.

Finally, the study that was conducted and reported in Paper IV tested the practical applicability of the LaST toolkit. Through 12 workshops with four companies, the toolkit was applied in a real-life context to qualify the approach and confirm the reliability of the tool. Here, the participants' knowledge about and attitudes toward product longevity were challenged, thus potentially creating lasting changes in their perceptions of producing products with longevity.

Based on Blessing and Chakrabarti's (2014) recommendations, the present study adopted a methodological approach in each part of the DRM framework. As such, the dissertation has the structure shown in Table 5.

RESEARCH CLARIFICATION	DESCRIPTIVE STUDY I	PRESCRIPTIVE STUDY	DESCRIPTIVE STUDY II
Paper I	Paper II	Paper III	Paper IV
Review-based	Comprehensive	Comprehensive	Initial

Table 5. Overview of the types of papers included in this dissertation

A comprehensive study (Papers II and III) also aims to present a partial literature review, as well as the research results obtained by the researcher. The case study reported in Paper II and the LaST toolkit reported in Paper III represent the research results.

In the initial study reported in Paper IV, the pragmatic contribution obtained through the prescriptive study was tested. Therefore, the initial study aimed to show the consequences of using the model in practice. However, it is likely only the first step in displaying and investigating the model's impact (hence, "initial" study) and can be further elaborated upon in additional studies.

3.3. RESEARCH CLARIFICATION

3.3.1. PAPER I: BARRIERS TO PRODUCT LONGEVITY: A REVIEW OF THE BUSINESS, PRODUCT DEVELOPMENT, AND USER PERSPECTIVES

In line with the DRM framework, the study reported in the first paper presented in this dissertation was a research clarification. The goal of a research clarification is to determine the goals of the entire research project. To determine how to support SMEs in improving their product longevity, it is important to first determine the research results that have already been obtained in the field. This is done through a walkthrough of the existing knowledge in the field in the form of a literature review, which leads to a positioning expressed in the overall research question. The study reported in the first paper in this dissertation did this through a comprehensive literature review of publications concerning the topic of product longevity.

Simultaneously, to contribute a new perspective to the field, the study reported in Paper I identified the potential barriers to achieving product longevity highlighted in the existing literature. This created a foundation of knowledge about the relevant problems and the reasons why product longevity is currently not self-evident. This, in turn, evolved into the following research question:

What are the barriers to developing and creating viable businesses based on long-lasting products and ensuring the long-term use of such products?

Identification of the literature

As mentioned earlier, to answer the aforementioned research sub-question, a comprehensive literature review was conducted. The methods used in the selection and review process of existing literature were based on a three-step approach: snowball search, systematic search, and post-identification of additional information.

Snowball Search

First, a snowball search was conducted to obtain an overview of the fields of sustainability and longevity and of the terms used within these fields. The result was that the terms span several different literature streams, highlighting that the subject of longevity can be perceived from many different angles. Even though a snowball search is not sufficiently thorough, it created a foundation of knowledge about the subject, allowed the identification of key literature, and increased the understanding of the problem, which was later searched thoroughly and systematically.

The articles that were identified in the Google Scholar database using the search term “product lifetime” were the first to be included. After this, the most relevant and popular peer-reviewed articles from the first batch of articles selected were

highlighted after rough sorting. These articles numbered 45 and were included in the literature review.

The aforementioned process also revealed that the topic of product longevity spans three different major terms: “product durability,” “product lifetime,” and “product obsolescence.” These terms varied depending on the perspective on product longevity and were therefore actively used later in the systematic search.

Systematic Search

After the snowball search, a systematic search was conducted to gain depth in the identified literature and to expand the nuances regarding the subject. The systematic search was conducted on the Scopus and EBSCOhost databases as these spanned multiple disciplines and complemented each other. The search terms that were used on the two databases were the keywords identified from the snowball search: “product durability,” “product lifetime,” and “product obsolescence” (Table 6).

KEYWORDS	DATABASE	NUMBER OF ARTICLES (2001–2020)
Product lifetime	Scopus EBSCOhost	611 243
Product AND obsolescence OR obsolete*	Scopus EBSCOhost	1,391 1,691
Product durability	Scopus EBSCOhost	247 558
Subtotal (including duplicates)		4,741
Total unique articles		4,204

Table 6. Overview of the numbers of articles found through the database searches conducted in the study reported in Paper I (Jensen et al. 2021b)

A rough selection process was conducted, excluding fields irrelevant to the subject and articles published before 2001, and including only full articles. This resulted in 4,204 articles, which were then reviewed based on their titles, keywords, and abstracts, resulting in 143 articles that were identified as relevant to the subject. In the review process, the articles were checked to see whether their titles were relevant to the research topic, whether the abstracts showed clear indications of relevance to the research topic, or whether the keywords included any one of the terms “product obsolescence,” “product durability,” “product lifetime,” “lifecycle,” or “circular economy”.

Post-Identification

Finally, a post-identification process similar to the snowball search was conducted. This revealed another 17 publications that were added to the identified literature.

Thus, combined with the articles identified in the snowball search 205 articles were used in the literature review.

Processing of collected data

To utilize the gathered data, a grounded theory approach inspired by open coding (Strauss & Corbin 1998) was applied. Open coding is part of the grounded theory approach, which works as a qualitative data analysis. In open coding, data (in the case of the present study, articles) are analyzed and sorted out under short terms that describe them. In the present study, this led to the identification of 14 barriers to achieving product longevity. These barriers ranged from customers' marginal awareness of product quality in a purchase situation to the high cost of changing a business model to produce long-lasting products. The full list of barriers can be seen in Table 7.

Barrier 1: High cost of changing the business model	Barrier 6: Inability to follow fast-moving trends	Barrier 10: Short life cycles promoted by retailers that affect user behavior
Barrier 2: Customer rejection of change in the business model	Barrier 7: Technological innovation that makes long-lasting products obsolete	Barrier 11: Lack of consumer attachment to products
Barrier 3: High price points of long-lasting products	Barrier 8: Change in societal behavior that makes long-lasting products obsolete	Barrier 12: Customers' marginal awareness of the product quality
Barrier 4: Vulnerability regarding short, fixed leasing periods	Barrier 9: Lack of focus on longevity in innovation	Barrier 13: Evaluation of longevity in a purchase situation
Barrier 5: Time-consuming alteration of customer perceptions of products and brands		Barrier 14: Misperception of modularity in advanced products

Table 7. Overview of the identified barriers to achieving product longevity, as presented by Jensen et al. (2021b)

Outcome

The identification of the 14 barriers to achieving product longevity also enabled an analysis of the data to compare the similarities and differences between the barriers. This led to the categorization of the barriers into three types: business barriers, product development barriers, or usage/consumer barriers (Table 8).

Type of barriers	Business barriers	Product development barriers	Usage/consumer barriers
Focus point	Business models, the economy and marketing, business strategy, value creation	Product design; production and optimization; technological, functional, and aesthetic attributes	User attitude and behavior, choice, maintenance, and repair

Table 8. Overview of the types of barriers to achieving product longevity, as identified by Jensen et al. (2021b)

3.3.2. PAPER II: A PRACTICAL APPROACH TO COMPANIES' TRANSFORMATION TOWARD PRODUCT LONGEVITY: A BEST-CASE STUDY

The second paper presented in this dissertation reports the first descriptive study, particularly describing the situation that companies, product designers, and consumers currently face when dealing with product longevity. The study investigated the approaches that companies and designers use and the decisions they make to produce longer-lasting products. As mentioned earlier, this investigation was done through qualitative data collection in the form of 20 interviews with top management and decision-makers from 18 European best-case companies, who explained their approaches to producing products with high longevity. The following research question was focused on in this investigation:

What are the tactical approaches and decisions within best-practice companies that enable a transition toward producing long-lasting products?

Selection of cases

The participating best-case companies were selected based on several parameters. First, it was important to include diverse companies in terms of size, age, pricing structure, markets, and product category. Second, the companies that were selected were those commonly considered producers of products with high quality and longevity. The participants within the companies who were selected to participate in the interviews were key decision-makers (chief executive officers [CEOs], chief finance officers, design heads or leads, founders, directors, or managers).

The companies that participated in the interviews were major producers of physical products across many categories situated in Denmark, Germany, or the United Kingdom: Porsche Automotive, Fredericia Furniture, Danfoss, Miele, Toni, Vola, Bang & Olufsen, Vitsoe, Skagerak Denmark, Hydrema, Takt, Rosti, Marcus Pedersen, Butchers & Bicycles, Demant, Monstrum, Morsø Jernstøberi, and Nilfisk.

Data collection

The interviews were semi-structured and centered on four topics: business decisions for product longevity, design and development decisions toward longevity, consumer interaction to support longevity, and future ambitions regarding longevity. The following are some examples of the questions:

- What do you experience as the greatest challenge or barrier to making long-lasting products?
- Even if your product is long lasting, do you experience certain factors in the market or in the retailer business models that promote frequent replacements (e.g., sales or leasing)?
- Do you encounter the issue of long-lasting products that are often unable to follow fast-moving trends? If so, how do you address this issue?

Each interview had one to three participants, lasted for 1–2 hours, and was audio-recorded (Table 9).

INTERVIEW NUMBER	COMPANY	NUMBER OF PARTICIPANTS	EMPLOYMENT POSITION	DURATION
1	A	1	Owner and CEO	1:44:13
2	B	2	CEO Lead industrial designer	1:22:35
3	C	2	CEO and founder Design director	1:03:45
4	D	1	CEO and co-founder	1:15:39
5	E	1	CEO	1:56:46
6	F	2	Owner and CEO Senior designer	1:56:55
7	G	3	CEO Sales and marketing director Head of design/MA	2:04:31
8	H	2	VP R&D Director of portfolio management	2:07:15
9	I	1	Global product manager	1:27:20
10	J	1	R&D manager	1:31:09
11	K	2	CEO Creative director	1:18:17
12	L	1	Head of hardware development	1:14:02
13	M	2	Brand manager Purchasing manager	2:00:51
14	N	1	Director, product quality management	1:45:46
15	O	1	Director	0:57:55
16	O	1	Manager advanced design	0:43:59
17	P	1	Vice president and head of innovation	1:37:20
18	Q	2	Owner Head of design and product management	1:48:04
19	R	1	Vice president of design	1:03:19
20	R	1	Executive director	1:12:03

Table 9. Overview of the interviews in the study reported in Paper II, as presented by Jensen et al. (2021a)

Data analysis

The data collected in the form of audio recordings from the interviews were analyzed using the program: Atlas.ti. An example of the coding in the program can be seen below (Figure 16).

Code Groups	
Innovation	(5)
Modularity	(3)
Personal beliefs	(8)
Profitability	(5)
Salespoints	(5)

Name	Grounded	Density	Groups
Informing about quality through design	2	6	
Opportunity: We wan't to make things slow	1	6	
Opportunity: We have a set of quality laws	1	6	
Opportunity: Modularity is not an obstruction in design	1	5	
Design driven business	6	5	[Profitability]
Brand nurturing through design	7	4	[Innovation] [Salespoints]
Transparency to inform consumers	8	4	
Develop idetrations	4	3	
Assosiate to other durables	6	3	
Selling experiences rather than products	6	3	[Salespoints]
Overdimensioning to exceed customer expectations	6	3	[Innovation]
Create product-user relation	8	3	
Opportunity: We don't want to follow fashion	1	3	
Assosiation to Furniture	5	3	[Personal beliefs]
Problem based development	3	3	
Involvement of entire firm in process	5	3	
Modularity for fashion	1	2	
Personal sustainability agenda	2	2	[Personal beliefs]
Cashcows as a side business	5	2	[Profitability]
Fast moving fashion used to reach new markeds	2	2	
Personal pride	6	2	[Personal beliefs]
Keeping limited portfolio	2	2	
Limit consumer choice	1	1	
Close relation to consumers	2	1	
Assosiate to textile	1	1	
Rethink business for durability	3	1	
private label products	1	1	[Profitability]
Vanity towards result	9	1	[Personal beliefs]
Long development time	8	1	[Profitability]
Modularity for maintainance	7	1	[Modularity]
Modularity for new needs	4	1	[Modularity]
User centered design	8	1	[Personal beliefs]
Close relation to supliers and subsupliers	2	1	[Personal beliefs]

Figure 16. Screenshot of coding in Atlas.ti.

The data analysis was based on the basic open coding technique (Strauss & Corbin 1998). In practice, this meant breaking down the data into discrete parts, then comparing the fractions and looking for similarities and differences, which led to categorization.

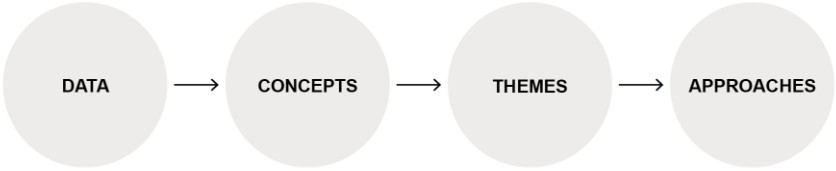

Figure 17. Visual representation of Gioia et al.'s (2012) data structure model.

Inspired by Gioia et al.'s (2012) data structure model (Figure 17), the fractions were then used as codes for analysis to enable a more coherent interpretation. The grouping process revealed patterns (referred to as themes in Gioia et al.'s [2012] methodology) and further groupings. The themes were thus further clustered into concepts that were actively used in the analysis.

DATA	CONCEPTS	THEMES	APPROACHES
"Our customers just want to be comfortable, so there's no reason for a wide range of customization options. If we talk about low maintenance, then you also have to select components that are durable in the use situation." (Company D, 0:21:07)	High performance expectations and demand	Setting extraordinary performance criteria	Performance-driven approaches
"We are very careful not to interfere with these groups as they provide us with the raw truth about our products. We use this a lot to tweak the product to become even better." (Company F, 1:17:00)	Observing lead users	Following performance lead users	

Table 10. Examples of coded data (Jensen et al. 2021a)

An example of the coding process is that the interview data were analyzed for quotes, which formed the data. These data were then clustered into concepts that described the meaning of the data and were analyzed further and grouped into themes. From this, it was seen that there were groups of approaches within which several of the themes fitted, as can be seen in the examples in table 10.

3.3.3. PAPER III: THE LAST-TOOLKIT – PRACTICAL EXPERIMENTATION WITH PRODUCT LONGEVITY TOOLKIT IN SME DEVELOPMENT TEAMS

The study reported in the third paper included in this dissertation represents a prescriptive study. The aim of a prescriptive study is to enable change within society. In the case of this study, this was facilitated through the development of a new toolkit for practitioners (companies) that enables the mapping of their current positions, attitudes, and goals toward product longevity and finally assists them in achieving their goals. To enable the development of this toolkit, a review of the literature on the existing relevant models was conducted. This literature review revealed that two types of tools and toolkits exist: mapping tools, which are used to map companies' current positions and ambitions, and action tools, which enable achieving the desired transformation (Figure 18).

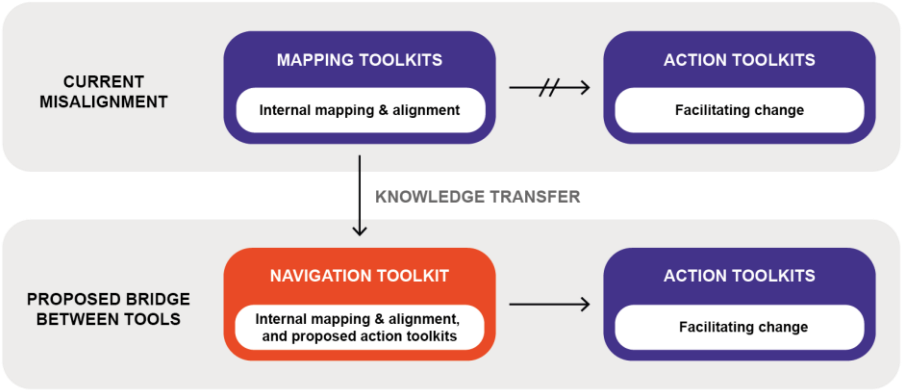

Figure 18. Visual representation of the misalignment in the current tool/toolkit literature (Jensen et al. 2023b)

The aforementioned types of tools and toolkits, however, are not linked to each other, which creates much confusion for companies when they want to use them in practice. This problem led to the following research question:

How can a new tool bridge existing mapping and action tools for product longevity to be more practically usable by industry practitioners?

To answer the aforementioned research question, a literature review was first conducted.

Identification of relevant literature

The literature used in Paper III was identified through a three-step process. First, a previous literature review by Bocken et al. (2019) formed the basis of 13 papers describing tools and toolkits for improving product longevity. Second, five additional papers on tools and toolkits were added, inspired by a forthcoming review by Özçelik et al. (2023) and another two tools.

Finally, a literature search on the Scopus, SciTech Premium Collection, DOAJ, Abi/Inform Collection, and Springer Online Journals Complete databases was conducted. This was done using the search terms "product longevity" AND "tool," with the search limited to peer-reviewed articles, open-access journal papers, books, and book chapters. This search showed 124 results, which, after screening by abstract and later full-text filtering, were narrowed to 17 additional relevant articles. This totaled 37 papers on tools for improving product longevity.

Clustering of data

The process of analyzing the identified literature was based on the setup of a study reported in a conceptual paper whose aim was to highlight the relationship between already known data and propose a new logical and complete argumentation that supports the proposition (Jaakkola 2020). In this paper, the 37 articles on tools and toolkits form the data mass. Within the discussion of conceptual papers, there is a category that aims to create a theoretical framework that predicts the relations between concepts. This is called a model. The model in Paper III in this dissertation can be seen in Figure 18, which shows that there exist two types of tools: mapping and action tools.

Mapping tools aim to identify a position, whether current or future. This means that the tools and toolkits build the argumentation about a company's current attitude, abilities, or maturity toward product longevity and/or ambition of improving its products' longevity. However, most of these tools and toolkits lack a specific direction or the ability to assist companies in transforming toward product longevity, therefore limiting companies to merely learning about their positions (knowledge acquisition).

The other type of tool is the action tool. Action tools propose methods of improving product longevity within companies, being oriented toward creating change. The tools often propose solutions to specific problems, such as changing or improving business models and selecting more study materials. However, for these tools to be relevant for companies, the individuals making up the companies must first know where they are and what their goals are. Action tools propose how to transform but often lack knowledge of what to transform from or toward.

Therefore, it is obvious that the relevant tools lack connections, making them irrelevant in practice. The study data were analyzed to identify connections between the two types of tools, but none were found.

Therefore, Paper III synthesizes the existing mapping and action tools into a new type of tool: a navigational tool. The new navigational tool proposed in this paper is the Longevity and Sustainable Transition (LaST) toolkit, which utilizes knowledge from both mapping and action tools. A more detailed explanation of the LaST toolkit can be found in section 4 (Paper III) and in the visual representation of the toolkit in Figure 19.

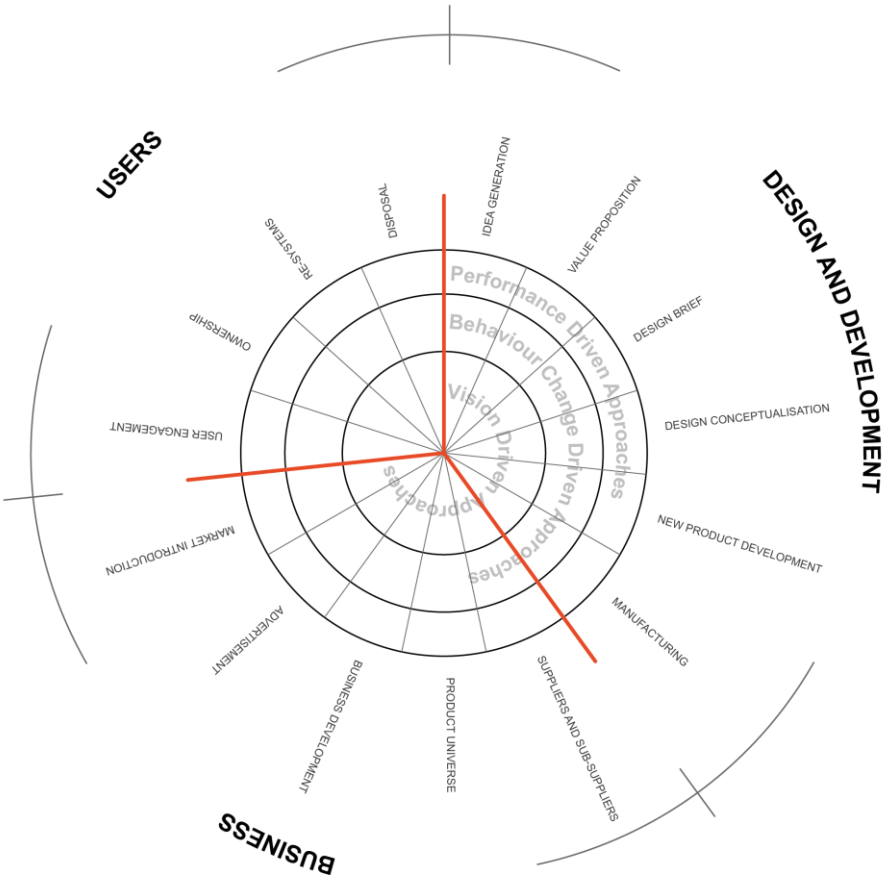

Figure 19. The centerpiece of the LaST toolkit, as presented by Jensen et al. (2023b).

3.3.4. PAPER IV: THE LAST TOOLKIT – A PRACTICAL EXPERIMENTATION USING A PRODUCT LONGEVITY TOOLKIT IN SME DEVELOPMENT TEAMS

The study reported in the fourth paper in this dissertation (Paper IV) represents the second descriptive study, as referred to in the DRM framework previously described. This study aimed to investigate the impact of the study reported in Paper III, the prescriptive study. Therefore, the impact of the newly developed toolkit (the LaST toolkit) developed in Paper III was investigated.

In line with the pragmatic approach adopted in the present research project, the second descriptive study was facilitated through workshops with four companies. The workshops represented a controlled process of using the developed toolkit and testing its applicability in practice. This hopefully led to a change in the participants' understanding of and engagement in the production of longer-lasting products.

To support the aforementioned investigation, the following research question was formulated:

In what way does the LaST toolkit support SMEs in prolonging product lifetimes?

Materials

To answer the aforementioned research question, 12 workshops were conducted with four different SMEs (three with each company). SMEs were specifically chosen as cases because the limited number of employees therein often results in a diversity of tasks for each employee, therefore heightening the chances of all important key decision-makers participating in the workshops.

The participating companies were from different industries, and the participating individuals varied in age. One company produces speakers and consumer electronics and sells them at relatively low price-points. Three other companies produce high-end furniture with relatively high price points and in-house production, high-quality outdoor wear for children and adults, and indoor and outdoor lighting, respectively.

Each workshop was conducted using the LaST toolkit, lasted from 1 hour and 30 minutes to 2 hours (Table 12), and was audio and video recorded.

COMPANY	WORKSHOP	DURATION
A	1	1:53:19
B	1	1:52:10
C	1	2:01:12
D	1	2:19:45
A	2	1:52:20
B	2	2:11:00
C	2	2:00:14
D	2	2:34:30
A	3	2:03:52
B	3	1:44:37
C	3	1:39:44
D	3	1:59:29

Table 11. Overview of the workshops conducted for Paper IV (Jensen et al. 2023a)

The workshops were conducted as described in the sections below.

Workshop 1: Mapping existing positions and attitudes

The focus of the first workshop was to map the current positions and attitudes of the participating companies toward product longevity using the LaST toolkit. The participants drew and wrote on an A1 printout of the model, which led to a discussion that facilitated alignment among the participants. The toolkit enabled a more nuanced conversation of when product longevity should be actively considered in the product development, business strategy, and ownership stage of the product lifetime. The results were maps of the product lifetimes and of the mental models of the companies' current attitudes toward product longevity throughout the lifetimes of their products.

Workshop 2: Mapping potentials and ambitions

In the second workshop, the participants from each company were tasked with identifying the areas where the focus on product longevity could be improved using the LaST toolkit. Based on the maps created in Workshop 1, the participants were easily able to identify the most approachable areas of action, which they discussed. The areas of action identified were then highlighted, and the participants were asked to work on possible end goals for each area, such as where they saw themselves in an area in 5, 10, or 15 years. A brainstorming session, followed by an open discussion about the suggestions, again led to an alignment of goals in the participating companies, which was then mapped onto the LaST toolkit model.

Workshop 3: Actions to achieve transformation

Based on the results of the first and second workshops, the companies were now aware of their current positions and attitudes toward longevity, as well as their aspirations and goals for a transformation toward the production of longer-lasting products. However, they lacked the tools, knowledge, and plans to achieve such goals. By utilizing existing tools and toolkits from other academics, the participants were able to create subgoals in their plans to achieve the relevant transformation.

Data analysis

While the output for the participants centered on enhancing their internal alignment and understanding of product longevity, the data analysis consisted of an analysis of the conversations between the participants in the workshops. The aim of the analysis was to identify whether the discourse between the participants changed from one workshop to another. To determine this, a framework for conversation analysis was established (Figure 20), building on the work of Kollmuss and Agyeman (2002). This framework is based on the notion that to create behavioral change within a company, the participants need sufficient knowledge and a change in attitude to acknowledge the need for transformation (Morwitz et al. 2007).

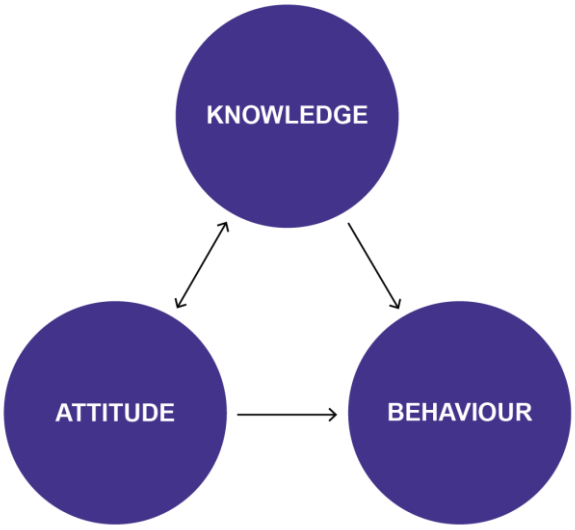

Figure 20. Visual representation of factors for achieving individual change in organizations (Jensen et al. 2023a).

The conversations in the workshops were subsequently analyzed for changes in the knowledge of the subject displayed by the participants therein (e.g., did their later conversations include new limitations and observations based on the knowledge fed to them in the previous workshops?). Likewise, the changes in attitude toward the

subject were analyzed based on the participants' ways of talking about the subject, such as a change from "How do we engage with longevity?" to "Why are we working with our products in this way?" The change from "how" to "why" displays a change in the participants' attitudes as they begin to take on the responsibility of transformation and see it in their own contexts.

As the workshops were conducted within a 4-week timeframe, it was not clear whether an actual behavioral change in the companies could be measured; however, changes in attitude and knowledge create a foundation for future change of behavior (Kollmuss and Agyeman 2002).

CHAPTER 4. PAPER OUTLINES

This dissertation presents four research papers on product longevity. Collectively, they reflect the research process and results of the three-year research project "Designed to Last."

The meaning and importance of product longevity are made clear through the papers, as well as the evolution of the terminology from "long-lasting products" to "products with increased longevity." As the research evolved, so did the understanding of the nuances of the topic. Product longevity covers a broad understanding of both the physical and emotional durability of a product as well as the factors influencing it, such as business, culture, and governance. This increased understanding of product longevity is made clear through the chronological papers and highlights the importance of a nuanced view on the topic.

This chapter presents the highlights and main findings of the individual papers. Each paper can be found in its full form in the appendices.

4.1. PAPER I

Barriers to product longevity: A review of business, product development and user perspectives

Jensen, P. B., Laursen, L. N., & Haase, L. M. (2021)

Journal of Cleaner Production, 313(127951)

Paper I (Appendix A) discusses the first study conducted as part of the research project reported in this dissertation. It centers on the challenges to achieving product longevity, highlighting the barriers to the production and use of products with high longevity that practitioners (e.g., designers, engineers, business developers, consumers) can encounter. Before this study, the barriers had been described individually, but no comprehensive overview of the existing barriers had been provided.

A comprehensive review of the existing literature on product longevity was conducted in this study. A systematic search of 4,204 papers was first conducted, and after screening, 143 papers were used in the review. The knowledge obtained from the review functioned as a knowledge foundation for the entire dissertation and revealed 14 barriers to achieving product longevity that practitioners and academics could investigate.

A summary of the methodology, theoretical foundation, and main findings of the study reported in Paper I is shown in Table 12 as an overview of the paper.

Methodology	Literature review Snowball search Systematic literature search Open coding
Databases	Google Scholar Scopus EBSCOhost
Theoretical Framework	Maturity and readiness (framework building on Rivera & Lallmahomed, 2016 – model of interactions)
Main Findings	Solid theoretical knowledge foundation and identification of 14 barriers to product longevity divided onto three main stakeholders: Business barriers, Product development barriers, and Usage barriers

Table 12. Overview of the methodology, databases, theoretical framework, and main findings from Paper I

4.1.1. MAPPING THE BARRIERS TO ACHIEVING PRODUCT LONGEVITY FOR COMPANIES, DEVELOPERS, AND USERS

The study reported in Paper I aimed to answer the following research question:

What are the barriers to developing and creating viable businesses based on long-lasting products and ensuring the long-term use of such products?

As mentioned earlier, Paper I presents the barriers to achieving product longevity identified through a comprehensive literature review on product longevity. Through a screening of 4,204 initial papers, 205 articles on product longevity were identified as providing insight into the research topic and actively engaging with barriers to producers' and consumers' pursuit of products with higher longevity. The result was a list of 14 barriers to achieving product longevity divided into three main categories: business, product development, and usage barriers. As previously mentioned in Chapter 2 (Theoretical Framework), it is important to consider all three stakeholders (developers, business management, and consumers/users) when engaging with product longevity as they all have significant impacts on products' lifetimes.

The identified barriers to achieving product longevity are shown in Table 13.

BUSINESS BARRIERS	PRODUCT DEVELOPMENT BARRIERS	USAGE BARRIERS
Barrier 1: High cost of changing the business model	Barrier 6: Inability to follow fast-moving trends	Barrier 10: Short life cycles promoted by retailers that affect user behavior
Barrier 2: Customer rejection of change in the business model	Barrier 7: Technological innovation that makes long-lasting products obsolete	Barrier 11: Lack of consumer attachment to products
Barrier 3: High price points of long-lasting products	Barrier 8: Change in societal behavior that makes long-lasting products obsolete	Barrier 12: Customers' marginal awareness of the product quality
Barrier 4: Vulnerability regarding short, fixed leasing periods	Barrier 9: Lack of focus on longevity in innovation	Barrier 13: Evaluation of longevity in a purchase situation
Barrier 5: Time-consuming alteration of customer perceptions of products and brands		Barrier 14: Misperception of modularity in advanced products

Table 13. List of barriers to achieving product longevity, as presented by Jensen et al. (2021b), Appendix 1

An example of a business barrier is the considerable time it would take for a company that wants to produce products with higher longevity to alter consumers' perceptions of the brand (Simpson & Radford 2012). It is important for consumers' perception of the longevity of a brand's products to match the actual longevity of the brand's products because consumers buying physical products such as chairs, washing machines, and cars often consider brand one of the indicators of quality (Slack and Johnston 2009; Sinclair et al. 2018). Owning a car from a specific brand that does not need frequent repair alters the customer's perception of the brand as a producer of products of high longevity. However, for brands that previously did not produce long-lasting products, customers should first recognize the change in their products' longevity through experience. This is naturally a time-consuming alteration. The problem lies in the potential extra cost of producing long-lasting products. Therefore, in some cases, companies will experience that making the necessary changes to produce products with high longevity does not necessarily directly pay off.

The aforementioned example further highlights the fact that the decisions made regarding any of the identified barriers to achieving product longevity often affect the other barriers, and that many of the barriers influence each other and are thus inseparable. This further highlights the need for a collective overview of the challenges involved.

An example of product development barriers is that a company that wishes to produce products with high longevity cannot follow fast-moving trends that are ever-shifting aesthetically. Products that follow trends are thus often disposed of prematurely, even though they are still functional (Hagedorn et al. 2018; Cupchik 2017). This can be seen especially in the textile and home decoration industries. If companies insist on following fast-moving trends, they may not benefit from producing products with high longevity as the likely extra costs of producing such products may not be appreciated by the customers.

The study thus found that there are many barriers to achieving product longevity in general. The barriers are complex, intertwined, and unlikely to apply in all product categories, markets, or settings. It is also likely that there are more barriers existing in more niche markets that apply to a broader context.

4.1.2. IMPLICATIONS OF FINDINGS

The findings of the study reported in Paper I are important for understanding the barriers to achieving product longevity. Through a literature search, the nuances of the complexity of product longevity were highlighted, and it was revealed that to produce products with longevity, it is not enough to produce durable products because many functional products are discarded prematurely. It is therefore important to acknowledge that the challenges involved must be perceived from the perspectives of all the stakeholders (companies, developers, and users), and that collective solutions that stretch across internal departments in companies must be sought.

Paper I forms a solid foundation for investigating possible practical approaches to overcoming the barriers to achieving product longevity, which was conducted in the study reported in Paper II.

4.2. PAPER II

A practical approach to companies' transformation toward product longevity: A best-case study

Jensen, P. B., Haase, L. M., & Laursen, L. N. (2021)

Sustainability (Switzerland), *13*(13312) – Published in an earlier version as a conference proceeding at *The Product Lifetimes and Environment Conference (PLATE 2021)* in Limerick and online, May 2021

Paper II (Appendix B) builds on a curiosity regarding the practical approaches to overcoming the barriers to achieving product longevity. How do practitioners manage these barriers, and what approaches do they use to overcome them? Twenty individual interviews were conducted with 29 key decision-makers from best-practice companies in Europe to map the approaches that the companies utilize to ensure longevity in their product portfolios and overcome the barriers thereto.

The result of this paper is a collection of 14 practical approaches that enable key decision-makers to overcome the identified barriers to achieving product longevity and develop and maintain a product portfolio that includes products with high longevity. These approaches were categorized into three types of approaches based on their focus: performance-driven approaches, behavior change–driven approaches, and vision-driven approaches.

A short summary of the methodology, theoretical foundation, and main findings of the study reported in Paper II can be found in Table 13.

Methodology	Best-case studies (semi-structured interviews)
Case companies	Miele Vola Danfoss Bang & Olufsen Vitsoe Skagerak Denmark Hydrema Takt Rosti Porsche Automotive Marcus Pedersen Toni Butchers & Bicycles Demant Fredericia Furniture Monstrum Morsø Jernstøberi Nilfisk
Theoretical Framework	The sustainable maturity cube (Müller and Pfleger, 2014)
Main Findings	The main findings from Paper II centres on the mapping og the 14 practical appraoches to product longevity as expressed by the key decision makers from the best-practice companies. Furthermore, the categorisation of the approaches indicate that there is a hiarchy between the approaches.

Table 14. Overview of the methodology, theoretical framework, and main findings of the study reported in Paper II

4.2.1. CONTRIBUTION TO MAKING THE PRODUCTION OF LONG-LASTING PRODUCTS MORE ACCESSIBLE

Building on the barriers to achieving product longevity identified in Paper I, Paper II confronts the issue of how to develop, produce, sell, and maintain products with high longevity. This was done through semi-structured interviews. The main finding is a collection of 14 approaches to overcoming the barriers.

The participants were key decision-makers (e.g., CEOs, design, and marketing leads) in 18 European best-case companies, who can directly influence product longevity through their decisions. These key decision-makers expressed a variety of approaches to overcoming the barriers to achieving product longevity. One of the approaches mentioned was for a company to set extraordinary performance criteria for its newly developed products. The desire to be the best in the market creates a common goal for the company across departments. This goal is exemplified in the following quote:

> *I set up two criteria when we develop [a product]. The first is that it's not allowed to look like anything else in the market.... Second, it must perform extremely well. Naturally, there are also some underlying criteria for price points, etc. (Quote from participating company from Jensen et al. 2021a)*

The notion of being unique and performing "extremely well" made products stand out in the market but also distinguished their brands as producers of quality goods with high longevity.

Another example of a goal relating to product longevity is a company's being locally present for consumers. Direct sales to customers and physical presence to deliver a unique service to them can provide them with an experience that they can embed in products and that can make them cherish these more, leading to better maintenance, repair, and care of these.

There were also examples of companies working with extraordinary confidence in their portfolios. Their products that did not sell well in certain periods were not removed from the market or discontinued. The companies explained that they did this to show that they fully vouched for their products and believed that their sales would pick up later. To quote one of the key decision-makers interviewed:

> *If we had discontinued our production of the [product], it would not have become iconic, because it needs to be nurtured. You have to be brave enough to stick to one idea. (Quote from participating company from Jensen et al. 2021a)*

As shown in the examples above, the approaches expressed by the interviewees varied in type. Some of them were business decisions, some were product decisions, and some were mental decisions. These differences in approaches enabled the following categorization of the approaches:

Performance-driven approaches mainly focus on the physical product, improving its performance and aiming to create the best-performing product in the market. These approaches can help create very durable products and products that are aesthetically pleasing and long-lasting interaction-wise. That is, they can facilitate a product–user relationship that nurtures more care toward the product and a higher chance of the product being repaired, maintained, and considered valuable instead of being substituted by other alternatives.

Service and behavior change–driven approaches aim to create a desire to make a behavior change, whether in the company, market, or end users. An example of this is a company's introduction of a new business model, such as leasing products instead of traditional asset sales (an internal behavior change) and efforts to make consumers accept the fact that the ownership of the product has moved from the user to the company in that process (external behavior change).

Vision-driven approaches are abstract approaches that relate much more closely to the mental states or personal paradigms of certain individuals in best-practice companies. They can pertain to a mental model of how to do business that is passionately shared in the company by the owner. "Champions" manifest their visions throughout the company, making such visions a core part of the company's DNA.

It is also observed that the three categories of approaches are linked to each other as they build on each other. The participating best-practice companies that were engaged with service behavior change– and vision-driven approaches to achieving product longevity often also manifested elements of performance-driven approaches. Likewise, many of the companies where vision-driven approaches to achieving product longevity were observed also manifested elements of both performance- and service and behavior change–driven approaches. This led to the development of the staircase model, which presents the approaches as a sequence rather than separated from each other.

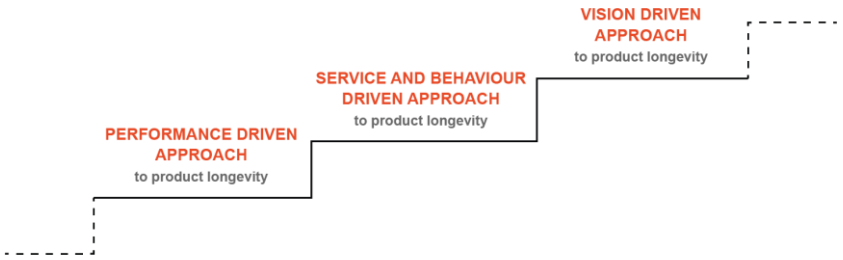

Figure 21. Sequence of the approaches to product longevity, as presented by Jensen et al. (2021a), App. 2.

4.2.2. IMPLICATIONS OF FINDINGS

It was found from the study reported in Paper II that there exist key decision-makers in best-practice companies who actively pursue products with high longevity. The decision to pursue these products is both a business opportunity for the companies and a personal pursuit for the concerned decision-maker. However, the participating companies' approaches to product longevity varied significantly. Some companies focused mainly on the physical product, particularly on creating products with high performance and durability that provide great interactions and experience. Other companies focused on customer experience, service delivery, and changing consumer behavior toward cherishing, maintaining, repairing, trading, and nurturing their products. Finally, some companies were fully devoted to producing products with high longevity through a personal vision shared throughout the company. All the companies that were focused on producing products with higher longevity used performance-driven approaches, and all the companies that were driven by a vision toward longevity were also focused on changing their businesses and products toward higher longevity.

The aforementioned approaches and insights provide a broad view across product categories for academics who want to investigate product longevity and for practitioners who want to improve it. To help practitioners who are currently in the transformation process toward producing longer-lasting products, the findings from the study reported in this paper were also incorporated into the LaST toolkit presented in Paper III.

4.3. PAPER III

The LaST tool – The Longevity and Sustainable Transition tool

Jensen, P. B., Haase, L. M., Cooper, T., Steward, J., Marsh, P., & Laursen, L. N. (2022)

Manufacturing Driving Circular Economy – Proceedings of the 18th Global Conference on Sustainable Manufacturing, October 5–7, 2022, Springer, Berlin

Paper III (Appendix C) introduces the newly developed Longevity and Sustainable Transition (LaST) toolkit. This toolkit represents a new type of tool that links existing academic toolkits to practical applicable approaches and ties together the results of the research project reported in this dissertation. The toolkit aims to create a common understanding among the research project participants and deliver the academic knowledge or research results acquired on product longevity to practitioners in a three-step model that helps practitioners identify their current positions, goals, and approaches regarding transformation toward producing products with high longevity.

A short summary of the methodology, theoretical foundation, and main findings of the study reported in Paper III can be found in Table 15.

Methodology	Metatheoretical analysis Literature review
Cases	Existing tools and toolkits
Theoretical Framework	Bocken et al. (2018) Messy progression in the innovative process
Main Findings	Incremental change towards product longevity can be facilitated as a controlled process assisted by tools and toolkits, which follow the companies from ideas of improvement to implementation.

Table 15. Overview of the methodology, theoretical framework, and main findings of the study reported in Paper III

4.3.1. CONTRIBUTION TO MAKING THE PRODUCTION OF LONG-LASTING PRODUCTS MORE ACCESSIBLE

Many companies have struggled to identify and design a roadmap for practically engaging with product longevity. Identifying an organizational position on the topic, setting goals, and planning how to attain such goals are time-consuming and infused with uncertainty, both economically and process-wise. Existing relevant academic tools and toolkits can help companies in this transformation and mapping process. However, the tools and toolkits are often inaccessible and specific to a given situation and thus limited in their use. The study reported in this paper therefore aimed to provide a new toolkit that follows users throughout the iterative and messy incremental process of transformation toward producing products with higher longevity.

A metatheoretical analysis of the existing academic literature on tools for product longevity revealed that there mainly exist two types of tools: those for mapping companies' current positions and ambitions and those that facilitate relevant change in companies. These two categories of tools are called mapping and action tools in this dissertation. However, the two types of tools are not connected to each other and often leave companies stranded in the middle of the transformation process.

An example of a mapping toolkit is the circularity measurement toolkit (Garza-Reyes et al. 2019). This toolkit aims to identify an SME's maturity for circular initiatives. Through a questionnaire, the company is evaluated, and its current positions are mapped. However, at this point, the toolkit leaves it to companies to suggest and initiate circular and longevity initiatives.

An example of an action tool is the Cards for Circularity tool (Dokter et al. 2020). This tool provides the participants with cards on which different concepts related to product longevity and sustainability are reflected. Through a collaborative discussion, the participants then discuss the different concepts in relation to their situation and how these can be used to improve their business. However, this tool requires prior knowledge about circularity, longevity, and sustainability and awareness of the relevant positions of the participants' companies.

The new toolkit integrates the findings from both existing types of tools and toolkits and combines these with the practical approaches collected in the study reported in Paper II.

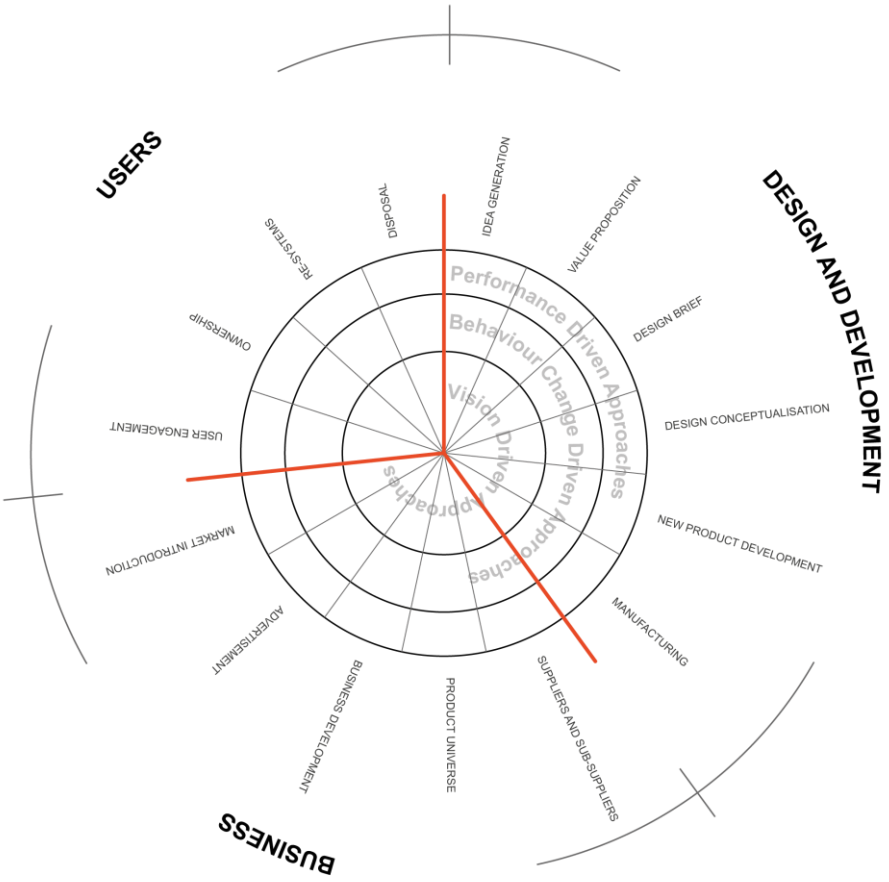

Figure 22. Visual representation of the LaST toolkit (Jensen et al. 2023b).

The result of the study reported in Paper III is the LaST toolkit (Figure 22), which first displays the entire product lifetime and presents it as a circular model to acknowledge the importance of a circular business. The circle is then broken down into discrete parts based on the foci of the existing action tools. Each of the 15 life stages has an impact on product longevity and has specific action tools that suggest actions for improvement in different areas. Finally, based on the findings of the study reported in Paper II, evaluation parameters were added to the toolkit. That is, the toolkit asks the following: Is the company engaged with product longevity on a performance-, behavior change–, or vision-driven level?

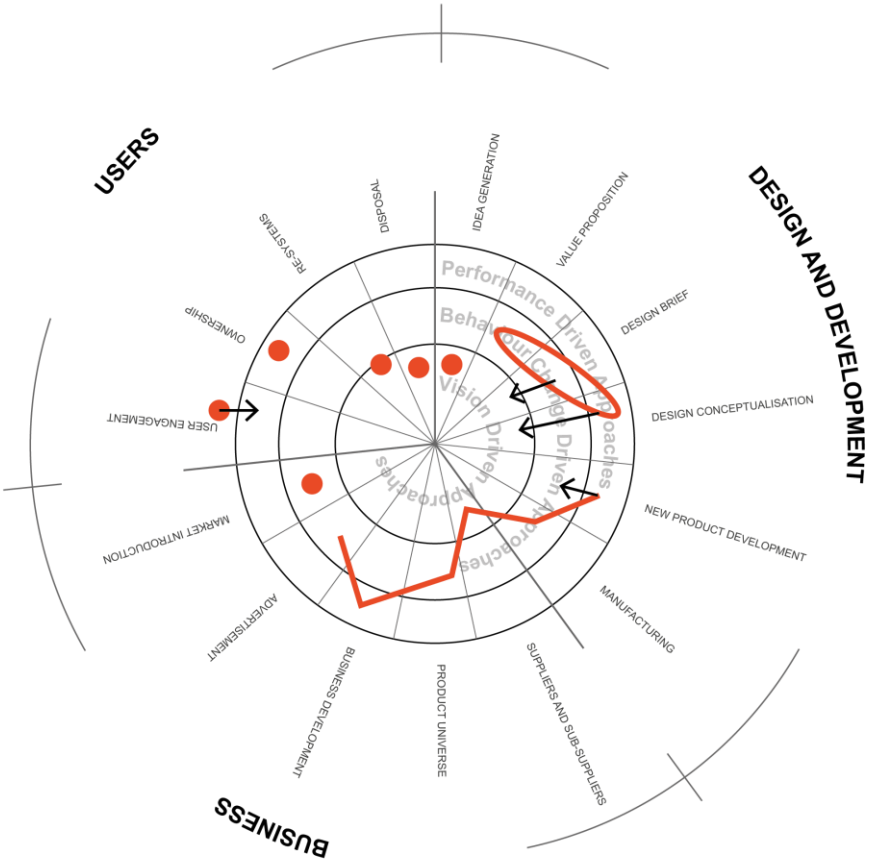

Figure 23. Example of the LaST toolkit filled out by the study participants (Jensen et al. 2023a).

Mapping a company's attitudes, current positions, ambitions, and products facilitates a conversation that can enable the participants from the company to align with each other (Figure 23). This is illustrated by a company that is already producing durable products. In the design and conceptualization phase, designers and engineers may already be knowledgeable about how to work actively with durability. However, communicating the value of durability to customers through a suitable business model or advertisement and through user engagement may be difficult if the knowledge from the development phase is not shared with the other departments. The LaST toolkit can help align the knowledge and understanding of the product and company values and highlight which knowledge needs to be shared, and from whom. With a new overview of its current position, the company can then decide in which area it finds it most suitable to improve its approach.

Because the mapping afforded by the LaST toolkit is based on the focus areas of existing mapping tools, it is relatively easy to pinpoint the action tools that can help facilitate the change that the company desires and has decided to aim toward.

The LaST toolkit likewise aims to be used iteratively, reevaluated frequently, and updated to reflect new goals. Through this process, incremental change is expected to be facilitated.

4.3.2. IMPLICATIONS OF FINDINGS

The findings of the study reported in Paper III were integrated into the LaST toolkit, which ties together the existing knowledge in the field of product longevity. The toolkit aims to provide the insights needed to facilitate incremental change within a company; however, prior to the study reported in Paper IV, its practical applicability had not been tested and was therefore only theoretical. To test the toolkit's applicability in practice, a workshop-based setting could be used as a framework for introducing the necessary information. Thus, the practical applicability of the toolkit was tested in the study reported in Paper IV through a three-step workshop conducted in collaboration with SMEs from Denmark.

4.4. PAPER IV

The LaST toolkit – a practical experimentation using a product longevity toolkit in SME development teams.

Jensen, P. B., Haase, L. M., & Laursen, L. N. (2022)

Submitted to the International Society for Professional Innovation Management 2023 Conference

The last paper presented in this dissertation is Paper IV (Appendix E), which reports the conduct and results of an experimental study that tested the applicability of the LaST toolkit in practice. In collaboration with four Danish SMEs, the toolkit was used as a driver of conversation on opportunities to produce products with higher longevity. It was used in three workshops for each company, assisting first in mapping the company's current attitude and abilities toward product longevity, then in identifying the company's relevant goals and ambitions, and finally in facilitating the actions necessary to attain such goals. The study investigated the participants' conversations about product longevity to determine whether the LaST toolkit could create room for conversation that could make longevity a cornerstone of future business.

A short summary of the methodology, theoretical foundation, and main findings of the study reported in Paper IV can be found in Table 16.

Methodology	Conversation analysis
Cases	ByLindgren Kreafunk Nuura Bent Hansen
Theoretical Framework	Organisational behaviour (Kollmuss & Agyeman, 2002)
Main Findings	The main findings from Paper IV displays that throughout the workshops using the LaST toolkit, there is observed a change in conversation between the participants. This change indicates a change in attitude towards the subject and is the first step towards behavioural change.

Table 16. Overview of the methodology, theoretical framework, and main findings of the study reported in Paper IV

4.4.1. CONTRIBUTION TO MAKING THE PRODUCTION OF LONG-LASTING PRODUCTS MORE ACCESSIBLE

The study reported in Paper IV investigated the usefulness of the LaST toolkit in relation to the process of business transformation toward product longevity based on the following research question:

To what extent does the LaST toolkit enable companies to change their attitude and behaviour towards product longevity and recognize incremental change opportunities that can improve product longevity?

The study reported in Paper IV aimed to test the practical applicability of the LaST toolkit presented in Paper III. The study investigated whether there were changes in the discourse regarding product longevity. It was found that throughout the workshops, the participants' questions changed from "How should we approach product longevity?" indicating a lack of knowledge on the subject to "Why are we conducting business as we are?" indicating a more reflective understanding of their situation in the realm of product longevity.

Individuals from four different SMEs participated in a series of workshops that investigated their engagement with product longevity using the LaST toolkit. There were three workshops for each SME (Figure 24).

Figure 24. Timeline of workshop execution facilitated through the LaST toolkit (Jensen et al. 2023a).

The aim of the first workshop centered on a mapping process that tried to align and map the current positions and possibilities of the company and the individual participants from it regarding product longevity. First, the participants were walked using the toolkit, as explained in the outline of Paper III. They were then asked to draw and discuss their respective interpretations of company approaches to achieving product longevity based on the different product lifetime stages. For example, the participants from one company thought that the approach they used to identify potential products with high longevity reflected all the factors that needed to be considered regarding longevity, and they marked this on the toolkit's poster. Others could then comment on or agree or disagree with the assertion, and the participants could form a common alignment step by step throughout the product's lifetime.

The second workshop aimed to set goals for improvement and discuss and arrive at a common understanding of visions or relatable approaches to improve. This was done based on the map drawn on the LaST toolkit from Workshop 1. Seeing the map drawn on the toolkit helped the participants identify areas that were most approachable for incrementally changing toward producing, selling, and profiting from products with high longevity. Many of the companies expressed that they were interested in improving their products in the early design phase as considering the implications of their decisions and the impacts of these on product longevity in the early design phase was commonly seen as having a large impact. Another example is that how to communicate the company and individual values and more directly engage customers with product longevity was also highly sought after.

Each company was asked to identify what realistic goals regarding the expressed focus areas they thought they could aim for in 5-, 10-, and 15-year periods. The participants from one company expressed that they wanted their company to become a "top producer of quality goods" within 10 years, while another expressed that they only wanted to explore the potential of producing products with higher longevity within the next 5 years.

The last workshop focused more on the methods that companies could utilize to achieve their desired transformation toward product longevity. Based on the findings from Workshops 1 and 2, the Workshop 3 participants were given a set of existing academic tools that could assist them in the process. The tools selected for the participants to use were based on an evaluation by the facilitator grounded in recommendations from the LaST toolkit. One company was interested in how to improve the desirability of a product in the early design phase, making the product more attractive to keep for a longer time. The Emotional Durability Design Nine tool (Haines-Gadd et al. 2018) was thus introduced for use by companies.

The post-workshop feedback from the companies was overwhelmingly positive, and the participants expressed great interest in participating in more workshops. In a post-interview with the participants from one company, they expressed that several initiatives to improve their products and businesses to support longevity had already been set in motion, and some products with high longevity had already been introduced to the market.

4.4.2. IMPLICATIONS OF FINDINGS

The data obtained from the workshops were analyzed based on the video and audio recordings of the sessions. The participants' conversations throughout the workshops provided indications of the participants' attitudes toward and knowledge about the subject, and a change in discourse indicating a change in attitude toward the subject to a more opportunistic one was observed.

The conversation in the first workshop was generally highly concentrated on the problems and obstacles to achieving product longevity that could be found in certain physical products in the company's portfolio. Below is an example.

> Increasing longevity for us is largely about the materials we choose. We have already chosen good materials, such as steel and brass, that ensure the highest longevity. (Company B)

However, as the workshops progressed and the companies actively worked with product longevity in their own contexts, the discourse in the conversations changed (Table 17).

COMPANY	WORKSHOP #	PRESENT PROBLEMS / FUTURE PROBLEMS	PRODUCT DETAILS / PRODUCT DNA	OBSTACLES / OPPORTUNI-TIES
A	1	Present problems	Product details	Obstacles
B	1	Present problems	Product details	Obstacles
C	1	Present problems	Product details	Obstacles
D	1	Present problems	Product details	Obstacles
A	2	Future problems	Product DNA	Opportunities
B	2	Present problems	Product DNA	Opportunities
C	2	Present problems	Product details	Opportunities
D	2	Future problems	Product DNA	Opportunities
A	3	Future problems	Product DNA	Opportunities
B	3	Future problems	Product DNA	Opportunities
C	3	Future problems	Product details	Opportunities
D	3	Future problems	Product DNA	Opportunities

Table 17. Overview of the discourse in the conversation in each workshop using the LaST toolkit (Jensen et al. 2023a)

As shown in Table 17, the foci in the conversations of the workshop participants from all the companies changed from a current problem (particularly product details and the challenges involved in increasing products' longevity) to future implementation problems, how the company DNA matches product longevity, and what opportunities lie within increasing product longevity. The discourse at the beginning of the workshops, in which the companies asked for knowledge about the subject (as they were insecure about it) and "how" to create transformation, also later changed to a more opportunistic perspective centered on the company vision and "why" the workshop participants from the companies previously and currently acted as they did. This change in discourse indicates that the participants' mentality also underwent a

change throughout the workshops as knowledge about the subject was provided therein, and that the participants' attitudes toward product longevity also changed due to the influence of the LaST toolkit.

As explained in section 3.3.4, heightening the knowledge about product longevity and creating a more positive attitude toward it are both important in creating room for future behavioral change. Kollmuss & Agyeman (2002) highlight this as the three decisive factors to organizational change involve knowledge, attitude and behavior. Increasing knowledge on a subject can in some cases eventually create a change in attitude and later behavior. Often however, attitude needs to be changed through interventions, such as the workshops, which in term, combined with the increased knowledge on product longevity, creates a behavioral change.

CHAPTER 5. CONCLUSION AND DISCUSSION

The main goals of the present research project were to expand the knowledge on the practical approaches to increasing product longevity and to support SMEs in their efforts to produce products with higher longevity. The project thus aimed to answer the following research question:

How are small and medium-sized companies supported in extending the lifetimes of their products to enable them to contribute to the attainment of the 12th United Nations Sustainable Development Goal of ensuring sustainable consumption and production patterns?

Through the studies reported in four papers, the aforementioned question was explored in depth through an investigation of (1) what is already known about product longevity and the barriers to achieving it; (2) the practical approaches that companies use to produce products with high longevity; (3) how academic knowledge and practical experience can be combined to form a tool to assist other companies in their transition toward higher product longevity; and (4) the impact of such a tool in a real-life practical setting.

This concluding chapter summarizes the findings regarding both the overarching research question and the research sub-questions in the studies reported in the four papers included in this dissertation. Thereafter, the position of the research within the current academic field and this dissertation's contributions are presented. Finally, the validity of the research and the avenues of further research are discussed.

5.1. ANSWERING THE RESEARCH QUESTION

This section summarizes the findings regarding the four research sub-questions presented in this dissertation:

- ***RQ1:*** *What are the barriers to developing and creating viable businesses based on long-lasting products and ensuring the long-term use of such products?*
- ***RQ2:*** *What are the tactical approaches and decisions within best-practice companies that enable a transition toward producing long-lasting products?*
- ***RQ3:*** *How can a new tool bridge existing mapping and action tools for product longevity to be more practically usable by industry practitioners?*
- ***RQ4:*** *To what extent does the LaST toolkit enable companies to change their attitude and behaviour towards product longevity and recognize incremental change opportunities that can improve product longevity?*

As Chapter 4 (Paper Outlines) already presents the findings regarding the aforementioned research sub-questions, a briefer walkthrough of the findings is presented in this chapter.

5.1.1. RQ1: WHAT ARE THE BARRIERS TO DEVELOPING AND CREATING VIABLE BUSINESSES BASED ON LONG-LASTING PRODUCTS AND ENSURING THE LONG-TERM USE OF SUCH PRODUCTS?

This research project endeavored to identify the potential barriers to companies', developers', and consumers' engagement with product longevity, whether in producing products with higher longevity, increasing their products' longevity, or maintaining a healthy business while selling products.

As an initial entrance into the subject of product longevity, a thorough investigation of the existing literature on it was conducted. A total of 4,204 articles were first screened based on different search criteria. They were then narrowed to 205 peer-reviewed articles. The literature review revealed 14 unique barriers to achieving product longevity. These barriers indicate that how companies conduct business, their approaches to developing products, and consumer attitudes and behaviors all affect the longevity of products, and that the actions of each stakeholder influence the other stakeholders.

The output of the study reported in Paper I was the identification and categorization of 14 barriers: five business barriers, five development barriers, and four user barriers (Table 18).

Barrier 1: High cost of changing the business model	Barrier 6: Inability to follow fast-moving trends	Barrier 10: Short lifecycles promoted by retailers that affect user behavior
Barrier 2: Customer rejection of change in the business model	Barrier 7: Technological innovation that makes long-lasting products obsolete	Barrier 11: Lack of consumer attachment to products
Barrier 3: High price points of long-lasting products	Barrier 8: Change in societal behavior that makes long-lasting products obsolete	Barrier 12: Customers' marginal awareness of the product quality
Barrier 4: Vulnerability regarding short, fixed leasing periods	Barrier 9: Lack of focus on longevity in innovation	Barrier 13: Evaluation of longevity in a purchase situation
Barrier 5: Time-consuming alteration of customer perceptions of products and brands		Barrier 14: Misperception of modularity in advanced products

Table 18. Overview of the barriers to achieving product longevity, as identified by Jensen et al. (2021b)

The aforementioned new categorization of the barriers to achieving product longevity created an overview of such barriers that future studies could reference, and displayed

a shift from the initial fragmented overview focused on individual barriers to a broader view of the mutual influence of the stakeholders. It likewise enabled a discussion of possible ways of overcoming the barriers while considering the influence of such strategies on other barriers, which was likewise tested in a workshop at the Design and Research Society Conference.

5.1.2. RQ2: WHAT ARE THE TACTICAL APPROACHES AND DECISIONS WITHIN BEST-PRACTICE COMPANIES THAT ENABLE A TRANSITION TOWARD PRODUCING LONG-LASTING PRODUCTS?

Another aim of the present research project was to determine the methods used by best-practice companies to develop and sell products with high longevity, despite the identified barriers. Determining the tactical approaches that companies use to overcome the barriers to achieving product longevity could provide an overview of practical approaches that the industry utilizes to succeed in marketing long-lasting products.

Best-practice companies were screened for their intentions and abilities to produce products with high longevity, and 18 were selected for participation in in-depth interviews. Twenty interviews with 29 participants were conducted throughout the research project.

The result was an overview of 14 tactical approaches to achieving product longevity, as follows:

Performance-driven approaches

1. Setting extraordinary performance criteria as a business and product developer
2. Following performance lead users and how they use products
3. Learning from and implementing performance criteria from older products
4. Accepting longer development processes

Behavior change–driven approaches

5. Creating transparent production and being open about how the company's products are produced
6. Being locally present and delivering after-sale services as a business to maintain customer engagement
7. Evolving existing products in the portfolio instead of broadening the portfolio
8. Aiming for long-lasting aesthetics and consumers' aesthetic familiarity with the brand
9. Limiting seasonal trends to product details
10. Involving the users/customers in the assembly process to promote the product details and attachment to the product

Vision-driven approaches

11. In the design process, aiming to solve long-lasting problems that outlive the products
12. Designing products that invite collective attachment and community-building
13. Having confidence in one's product portfolio and not easily discontinuing products
14. Perceiving longevity as a quality parameter rather than a sustainability parameter

The research results further showed that the approaches to achieving product longevity could be clustered into three groups: performance-driven approaches, behavior change–driven approaches, and vision-driven approaches.

Performance-driven approaches focus on how a company's efforts to create best-performing products enable it to create durable and long-lasting products. The pursuit of ultimate performance can often be seen in physical products through the selection of durable technical solutions, aesthetic considerations, interaction experiences, and general product performance aspects.

Behavior change–driven approaches focus on how a company's behavior can influence the customers and finally alter their behaviors toward keeping, maintaining, and appreciating the company's products more. The focus on service as a behavior can enable a company to change consumer behavior by releasing new ownership

models, holding product presentations, ensuring product care and maintenance, and being open about how the company's products are produced.

Finally, vision-driven approaches focus on how internal visions within a company can guide the agenda of creating long-lasting products throughout the company. Visions often originate from passionate visionaries in the company and can be seen by others as abstract and undefined. However, if applied throughout the company, a vision can create a clear direction and goal centered on producing longer-lasting products in all sectors of the company.

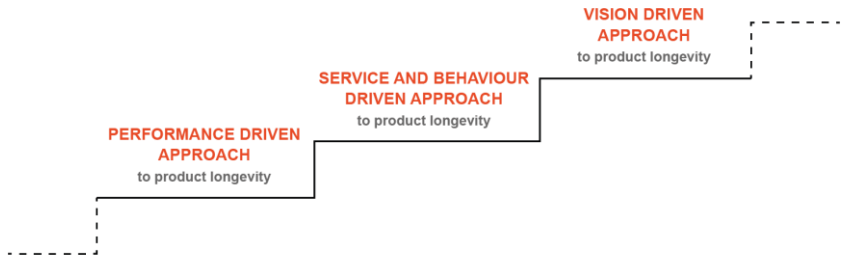

Figure 25. Types of approaches to achieving product longevity, as identified by Jensen et al. (2021a).

The aforementioned categorization of approaches to achieving product longevity enables further research on and development of new approaches to company transformation toward product longevity. This is further supported by the indications that there exists a hierarchy among the categories: focusing on performance-driven approaches is a necessary first step to further engage with behavior change–driven approaches, and behavior change–driven approaches are necessary to further engage with vision-driven approaches (Figure 25). To exemplify this, companies' extension of the acceptable time for developing products is not a huge intervention (this is a performance-driven approach); however, collectively defining and solving long-lasting problems can be challenging if there is no previous experience with longevity (this is a vision-driven approach). Therefore, it can be favorable for companies with no previous experience in product longevity to start with some of the more incremental, less intrusive approaches at the product level and then later build such approaches into their business through behavior change–driven approaches.

5.1.3. RQ3: HOW CAN A NEW TOOL BRIDGE EXISTING MAPPING AND ACTION TOOLS FOR PRODUCT LONGEVITY TO BE MORE PRACTICALLY USABLE BY INDUSTRY PRACTITIONERS?

The aim of the third research sub-question is to develop a new tool that links different types of existing academic knowledge in product longevity to practical knowledge from the industry. To do so, a systematic literature review on tools and toolkits for improving product longevity was conducted, which resulted in 37 peer-reviewed articles. The review showed that there exist two types of tools for product longevity: mapping and action tools.

The purpose of mapping tools is to identify companies' current attitudes toward and positions on product longevity and their possibilities for improving their products' longevity. In other words, these tools enable companies to identify their current standpoints and define new goals for improvement.

The purpose of action tools is to enable practitioners to pursue the transformation they need to attain their goal of producing products with higher longevity. Action tools are therefore guidelines for achieving transformation toward the pursuit of product longevity.

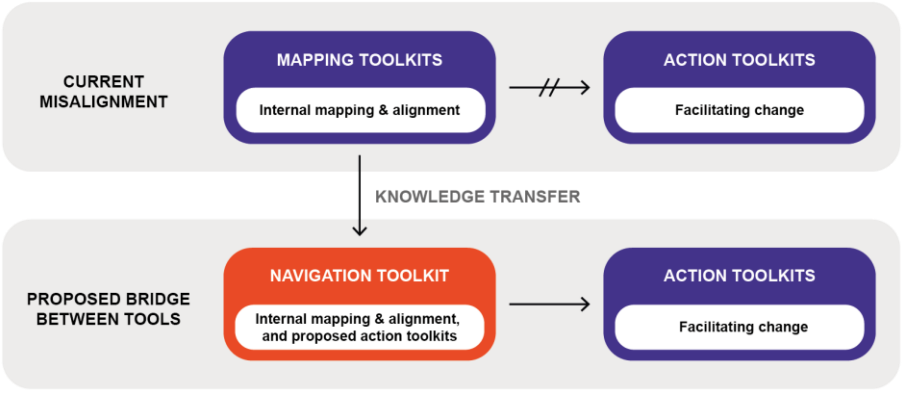

Figure 26. Visual representation of the shift to using a navigational tool to bridge the gap between the existing tool types (Jensen et al. 2023b).

However, a gap was seen between the two types of tools, which made practical access to them difficult for companies (Figure 26). Thus, a new toolkit, the LaST toolkit, which bridges the two tool types and facilitates an incremental approach to product longevity, was established. The aim of the toolkit is to enable SMEs to approach product longevity regardless of their previous experience with the subject, and to

provide suggestions for goals, actions, and approaches that can be adopted to achieve the desired transformation.

The toolkit was based on the identified literature on tools and toolkits for longevity. First, a circle represents a product's lifetime (Figure 27). This lifetime is divided into three main stages: design and development, business, and users, as inspired by Jensen et al. (2021b).

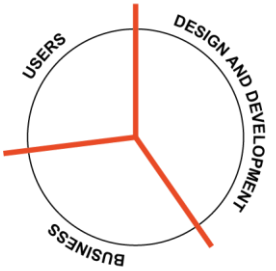

Figure 27. Representation of the three overall stakeholders influencing product longevity (Jensen et al. 2023b).

Second, the existing literature was analyzed. Each article was screened to determine which product lifetime stage it focused on and engaged with; this revealed 15 product lifetime substages relating to action toolkits (Figure 28). Each substage is related to several tools, and many of these tools involve and influence several substages. For example, the tools developed and proposed by Heyes et al. (2018), Mendoza et al. (2017), Antikainen et al. (2017), Manninen et al. (2018), and Whalen (2017) were all related to business development, and Cards for Circularity (Dokter et al. 2020) relates to idea generation, design brief creation, and design conceptualization. A full overview of the relationships between the existing toolkits and the identified product lifetime stages can be found in Appendix D.

Figure 28. Representation of the 14 product lifetime stages in which product longevity can be influenced (Jensen et al. 2023b).

Third, for the companies to evaluate their position and potentials, inspired by Jensen et al. (2021a), three levels were added to the model. Each level represents different ways of mental and physical engagement with product longevity. Companies can focus on performance-, behavior change–, or vision-driven approaches to achieving product longevity or on more than one type of approach at a time. These approaches can be used by companies to evaluate their positions in each product lifetime stage and as a tool for discussing their current focus on performance, behavior change, or vision for product longevity (Figure 29).

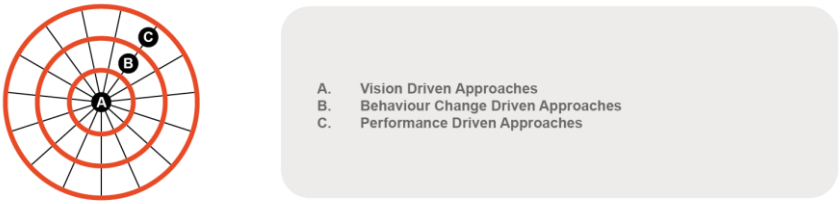

Figure 29. Sectioning the LaST toolkit into different categories to approach product longevity in each product lifetime stage (Jensen et al. 2023b).

The collective result of the foregoing is the LaST toolkit, which enables companies to map their current positions and ambitions and later guides them toward tools and toolkits that can enable them to achieve their ambitions (Figure 30). The toolkit does these by guiding them in evaluating the entire product lifetime, considering how to engage with product longevity from idea generation to development, how to make the business support it, and how to make customers select, purchase, care for, and maintain the products afterwards.

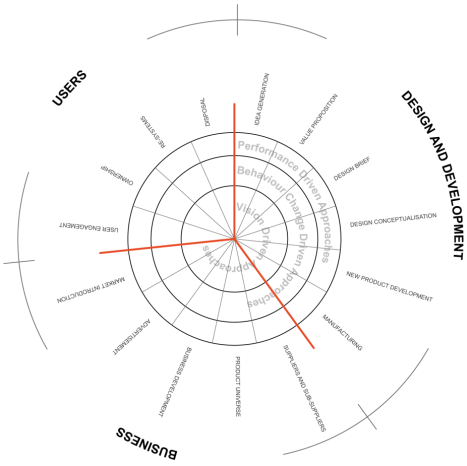

Figure 30. Illustration of the complete LaST toolkit model (Jensen et al. 2023b).

5.1.4. RQ4: TO WHAT EXTENT DOES THE LAST TOOLKIT ENABLE COMPANIES TO CHANGE THEIR ATTITUDE AND BEHAVIOUR TOWARDS PRODUCT LONGEVITY AND RECOGNIZE INCREMENTAL CHANGE OPPORTUNITIES THAT CAN IMPROVE PRODUCT LONGEVITY?

In the last article of this dissertation, the practical applicability of the newly developed LaST toolkit was tested in a workshop-based context with four SMEs through three workshops for each SME. The workshops were conducted as discussions facilitated by the approach described in the LaST toolkit.

The first workshop focused on mapping the companies' current attitudes and behaviors regarding product longevity to determine the level of their readiness for it and the extent of their motivation to achieve it, and to align the participants internally in the company with regard to their level of engagement with it.

The second workshop was a discussion of the companies' goals and ambitions in relation to product longevity in 5, 10, and 15 years. This, based on Workshop 1, enabled the participants to create a common goal for the future development of products with longevity.

The last workshop utilized the existing literature based on the ambitions expressed by the participating companies in the previous workshops. Based on their desired focus on product longevity, the companies were guided toward existing action tools for product longevity that could facilitate the necessary steps to achieve the desired transformation.

To qualify the toolkit, throughout the workshop, the participants' discourse in conversations was observed. Many of the participants changed their discourse toward the subject throughout the three workshops. They initially focused on "how" to achieve higher longevity and on knowledge acquisition. However, they later changed their discourse to "why" they behave in certain ways within their companies, mirroring a more attitude-focused perspective. This change in discourse indicates a change in mentality as the workshops progressed, which potentially manifests in new behaviors with the aim of creating products with higher longevity (Jensen et al. 2023a).

5.1.5. SUMMARY

To summarize, the research project reported in this dissertation synthesized the existing academic knowledge and practical approaches to achieving product longevity and utilized the combined knowledge to develop a new toolkit that, in a workshop-based context, can help practitioners who are currently in the transformation process toward producing products with higher longevity (Figure 31).

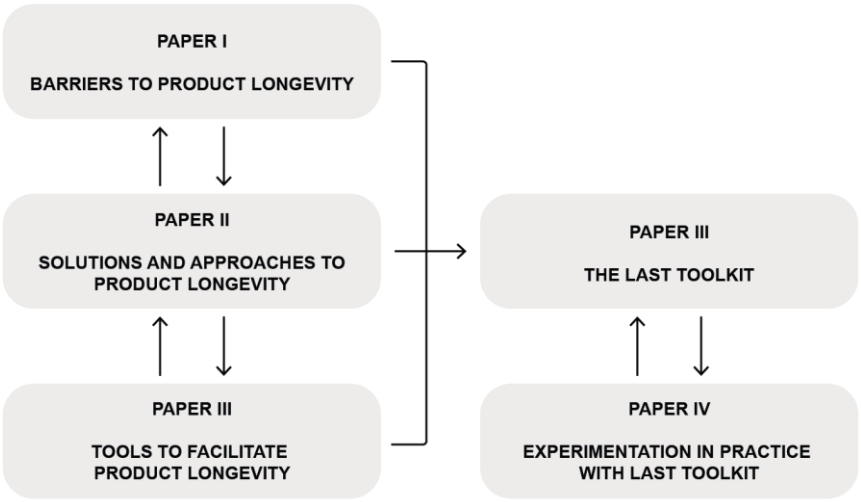

Figure 31. Overview of the connections between the research papers included in this dissertation.

Based on a methodological approach structured in accordance with DRM (Blessing & Amaresh 2014), the research project started with a study (reported in Paper I) that aimed to clarify the research aim and position within the existing academic knowledge by identifying the gaps in the current literature. Interviews were then conducted with best-practice companies in a second study (reported in Paper II) to determine the methods currently used by such companies to overcome the challenges associated with producing products with high longevity. Thereafter, in a third study (reported in Paper III), a toolkit based on a new perspective, the LaST toolkit, which could assist practitioners in improving their behaviors and understanding the research topic, was developed. Finally, in a last study (reported in Paper IV), the impact of the LaST toolkit on SMEs was tested.

5.2. REUNITING THE THEORETICAL FOUNDATION WITH THE FINDINGS

This section discusses the relevance and position of this dissertation within the currently popular research field of sustainability, specifically environmental sustainability, and in the context of longevity and product lifetimes. The four topics of discussion are further elaborated below.

5.2.1. CONTRIBUTION TO SUSTAINABILITY

Longevity plays a huge role in the sustainability agenda. As highlighted by Konietzko et al. (2020), it can be considered one of only five important ways of achieving sustainability: minimizing (consuming less), slowing (longevity), closing (recycling), narrowing (reusing), and informing (education). However, as mentioned in the Introduction chapter, product longevity is often neglected in discussions on environmental sustainability, and overlooked in favor of recyclability, biomaterials, or other sustainable initiatives. The reasons for this are only speculative, but initiatives such as introducing biomaterials and recycled materials in a company's product portfolio often entail very little organizational change (Hole & Hole 2020) and just substitute the existing plastic materials, without altering the production process. Second, the use of biomaterials and recycled materials has a visual impact on products, which can increase products' purchase rates (Lilley et al. 2016). Lastly, products produced in this way are more approachable and acceptable than products with high longevity, which customers often have difficulty identifying. Nonetheless, producing products with high longevity can provide opportunities for companies to position themselves as producers of quality products if the pursuit of product longevity is made approachable for companies and if high longevity is made visible in products.

5.2.2. CONTRIBUTION TO THE PRODUCT LIFETIME AND LONGEVITY LITERATURE

One of the aims of the research project reported in this dissertation was to expand the knowledge within the field of product longevity. First, previous studies have mostly focused on rapid solutions with large impacts on the company's business. Second, such studies focused on a single stakeholder and reflected only one perspective on product longevity, such as how to improve designers' abilities to design products with high longevity (Grosse-Hering et al. 2013), how to change a business model to support higher longevity (Lewandowski 2016), or how to inform consumers about higher product longevity (Roberts & Hughes 2014). Third, while previous studies have provided great insight into how individuals from companies can promote the companies' production of products with high longevity by changing their attitudes and behaviors regarding this subject, no previous study has adopted an overall perspective on organizational transformation toward achieving product longevity. The

present research project focused largely on how to incrementally change entire companies across several actors therein and how to embed the values and benefits of producing products with high longevity in business.

5.2.3. CONTRIBUTION TO MANAGEMENT POSITIONING

This dissertation also contributes to the academic understanding of how companies' current positions and opportunities in relation to product longevity can be improved. Most of the previous studies on this subject focused on theoretical approaches to achieving product longevity or on single approaches that could help improve companies' positions in this regard. An example of these approaches is using the consumer intervention mapping tool (Sinclair et al. 2018), which assists in mapping customers' current positions. This reflects the reality in industry, where innovation is often seen as being developed in organizational silos rather than in cross-departments. Before this research project, no research had been conducted that considered all three actors: companies, designers, and consumers.

The practical approaches identified in Paper II are based on real-life situations for companies, providing insight into the mentality of management when working actively with product longevity.

5.2.4. CONTRIBUTION TO ORGANIZATIONAL TRANSITIONING

As previously mentioned, many tools for increasing product longevity have already been developed; however, none of them aims to identify opportunities and facilitate change across entire organizations. To date, the tools aim to either map a company's current position, such as the circularity measurement toolkit (Garza-Reyes et al. 2019), the SME measurement tool (Pigosso et al. 2018), and the consumer intervention mapping tool (Sinclair et al. 2018), or facilitate change in a specific area, such as Cards for Circularity (Doktor et al. 2020) and the Emotional Durability Design Nine tool (Haines-Gadd et al. 2018). The present research project synthesized the existing tools into a single toolkit (LaST toolkit), which assists practitioners in identifying their current positions and opportunities in relation to product longevity based on mapping tools, and then suggests action tools that may be used to facilitate the desired change. It was observed that a change in the conversation discourse happened while the workshop participants were using the tool, which is an indicator of potential organizational changes. This dissertation is a micropicture of how this happens.

5.3. VALIDITY OF THE RESEARCH

The studies reported in the four papers included in this dissertation had different research designs. The considerations regarding the validity of the research conducted by each of the studies are explained below.

5.3.1. LIMITATIONS FOR SYSTEMATIC SEARCH AND DATABASE SELECTION

In the literature review conducted in the study reported in Paper I, different search criteria were established to delimit the search for relevant literature. In two comprehensive databases, three different search terms were used to identify as many relevant articles as possible. However, it is likely that some relevant articles were not included in the review as they were not present in the databases. Furthermore, some of the articles published before 2001 that were excluded from the systematic search might have provided appropriate findings to the review. Some of the data from the articles published before 2001 were likely included due to the snowball search; however, a systematic search likely reveals additional literature.

Across all the search methods used in the studies reported in Papers I and III, only full articles were included. It is likely that additional barriers to achieving product longevity (Paper I) and tools or toolkits for the same purpose (Paper III) would have been included if this restriction were not set.

As snowball search is an explorative technique, the time spent on it is critical. As this search method was used in Papers I and III, it is likely that additional articles could have been revealed had more time been devoted to the search.

5.3.2. BEST-PRACTICE CASE SELECTION

The selection of the best-practice cases and participants for the study reported in Paper II had several limitations, as discussed below.

Participants being only European

As the research project was conducted in Denmark and the interviews were targeted to be conducted face-to-face, only European best-practice companies were included in the project. Including companies situated in other parts of the world could have unfolded new perspectives and approaches to achieving product longevity as business traditions and culture might affect the perspectives and approaches.

Number of participants

The participants in the best-practice study were limited to those from the 18 participating companies. The data obtained from the 20 interviews with individuals from the companies revealed valuable information regarding approaches to achieving product longevity, but a larger study with additional participants would likely reveal a wide range of new practical approaches that have not yet been identified.

Selection of participating individuals

The selection of individuals from each best-practice company to participate in the study was based on the company's ability to select "key decision-makers." As there were only one to three participants per company, most of the participants were top management, owners, and CEOs. In several cases, this created a top-down management perspective on the approaches to achieving product longevity. Further study and interviews with more participants are likely to reveal undiscovered approaches from a bottom-up or middle-out perspective, meaning that innovation, specifically toward product longevity, can also likely be driven by the employees rather than management.

5.3.3. TOOL SELECTION

The review of the literature on tools for product longevity (Paper III) was based on a combination of the results of the review by Bocken et al. (2019) and a systematic search of tools or toolkits on two scientific databases. While 37 articles describing tools and toolkits for increasing product longevity were identified, several other tools could also have contributed to this research project if the search were broadened. It is also likely that other tools and toolkits that also positively affect product longevity could have been found if the subject were product quality rather than product longevity. Longevity is commonly considered a quality parameter in many product categories; therefore, it is likely that there are also articles that describe tools for product longevity using different terms.

5.3.4. ROLE OF THE RESEARCHER

The role of the researcher in the research often introduces bias into the data. This is further explained in the following section.

Researcher bias in the interviews

The interviews conducted in the study reported in Paper II were semi-structured interviews. This meant that there was an interview guide that described the topics to be explored. However, the semi-structured interview format allows the conversation to become more explorative. As the interview is conducted as a fluid conversation, the interviewer influences the interviewee. While efforts were made to limit this, it creates bias in the data that should not be overlooked.

Researcher's influence on the workshop participants

The same logic as above applies to the workshop scenarios reported in Paper IV. The workshops with SMEs were conducted by the researcher and developer of the LaST toolkit. This meant that the participants were influenced by both the presentation of the toolkit and the process of using the toolkit as the researcher functioned as a secondary workshop participant, seeking meaning in the participants' statements. This created uncertainty in the data obtained from the workshops. However, as what was monitored was the development of the discourse in the conversations among the participants, this uncertainty may be considered minimal.

5.4. AVENUES OF FURTHER RESEARCH

The evaluation of this dissertation made it apparent that there are avenues of further research. The knowledge that can be obtained through further research can support the knowledge reflected in this dissertation, strengthening and building on the established knowledge foundation. In addition, as the subjects of sustainable transformation and product longevity grow in popularity in academia, there is much to further investigate. The research project reported in this dissertation, including the LaST toolkit, can therefore be considered preliminary.

Some avenues of further research are discussed in the following section.

5.4.1. INFLUENCE OF OTHER ACTORS

As previously discussed, other actors influence product longevity. Because product longevity cannot be perceived only as physical durability, it is not only the product itself that determines its lifetime. This dissertation focuses on how companies or management, product designers and developers, and consumers or users influence product longevity. However, other stakeholders, such as the government, also influence the product lifetime. Through laws, regulations, taxes, and fees, lawmakers can either encourage companies to produce products with higher longevity and encourage consumers to purchase and use them or discourage them from doing so. As stated by the Green Deal (European Commission 2019), this can be done at the local, national (e.g., N° 4054 contre l'obsolescence programmée 2021), and international levels and is often pushed via monetary encouragement. The effect, behavior, and encouragement of this fourth stakeholder (government) as an enabler of more rapid transformation and a possible limiter of the risks involved in the transformation process must be further investigated.

5.4.2. PRODUCT LONGEVITY TRANSFORMATION IN LARGER COMAPNIES

The gaps throughout this dissertation imply that a different approach can be taken. The focus of the relevant research has been on how to improve SMEs' ability to approach product longevity more easily, but bigger companies' ability to transform and pursue product longevity is also worth investigating. It is likely that there are many similarities in the path to higher product longevity between the two types of companies as the approaches gathered in Paper II were based on a blend of companies of all sizes. These approaches revealed similar barriers and comparable approaches to solutions. A similar tendency was seen in the toolkits identified through the literature review in the study reported in Paper III, many of which did not distinguish between company sizes. Experimentation with the LaST toolkit in companies of varying sizes may provide new results and insights that can make the transformation toward product longevity more accessible.

5.4.3. IMPLICATIONS AND IMPACTS OF LAWS SUPPORTING PRODUCT LONGEVITY

The research project reported in this dissertation focused on three major stakeholders as factors influencing product longevity: companies/management, product developers, and users/consumers. However, as argued by Ciplet and Harrison (2020), and as mentioned earlier, the government also has a major influence on product longevity. Local, national, and international laws largely influence both company and consumer behaviors and can either push or slow innovation toward sustainability (Debref 2017). This is likely also the case for product longevity; thus, additional research on the implications of laws supporting product longevity and their impacts on the transformation toward producing products with higher longevity must be conducted.

5.4.4. STUDY OF THE LONG-TERM IMPACT OF USING THE LAST TOOLKIT

As this research project, "Designed to Last," was limited by the timeframe of a Ph.D. program, additional research on the impact of the prescriptive study must be investigated post-project. The initial results of the experimentation on the LaST toolkit with companies (Paper IV) were promising; however, the lasting impact of the workshops has yet to be proven. As argued in this dissertation, products with high longevity are not immediately recognized by consumers, and the brands producing them are not immediately recognized as such. The transition process toward producing products with high longevity therefore requires the company's commitment to continuously improving, informing, and building on the longevity of its products. However, the impact of the LaST toolkit on this endeavor has yet to be proven in practice, thus creating another avenue of further research.

5.4.5. GENERAL PERSPECTIVES FROM THE AUTHOR

This dissertation therefore contributes to solutions that support small and medium-sized companies in extending the longevity of their products through a clarification of the barriers and the approaches, and a new toolkit that collects knowledge in the field and presents it to the industry. This research project was a deep dive into a subject that is highly overlooked in the sustainability debate. Companies, governments, academics, and consumers alike need to take responsibility for our consumption and not wait for a deus ex machina. Future research needs to focus on how to make it accessible, affordable, and feasible to design, develop, and produce products with high longevity. The present research project and the development of the LaST toolkit merely scraped the surface of the possibilities offered by producing high-quality products. However, as argued in this dissertation, the solution cannot be found in silo thinking. For future progress in this project, consumers, governments, and nongovernmental organizations need to be involved in the development and definition

of solutions that can support a global transformation rooted in local cultures and traditions, craftmanship, and the love of making products that are environmentally better than the previous ones. This was the enduring hope of this research project.

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Appendix A. Paper I

Barriers to product longevity: A review of business, product development and user perspectives

Peter Byrial Jensen, Linda Nhu Laursen, Louise Møller Haase (2021)

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Barriers to product longevity: A review of business, product development and user perspectives

Peter Byrial Jensen, Linda Nhu Laursen, Louise Møller Haase (2021)

Abstract

Product longevity is an important part of the circular economy discussion, contributing to global sustainable development. However, practicing and adopting product longevity remain challenging. Currently, the literature primarily focuses on various proposals and strategies that could lead to an increase in the longevity of products. However, adopting product longevity in practice demands an overview of barriers that must be accounted for before appropriate strategies and proposals can be selected and implemented. Until now, such an overview of the barriers for longevity is largely undefined.

This paper contributes by identifying 14 distinct barriers that are likely to obstruct companies from introducing long-lasting products, to challenge their product development or to make it difficult for consumers to keep or maintain their products for a long time. In this paper, a comprehensive review provides a list of barriers that have been identified through the existing literature across three perspectives: 1) companies and manufacturers, 2) designers, engineers, and developers and 3) customers/consumers and users. A systematic search revealed 4204 academic papers that relate to the topic. After reviewing the titles, abstracts and keywords of these papers, a total of 143 papers combined with additional 62 articles identified through snowballing and post- identification were identified as eligible to constitute the foundation of this review. From these, a list of 14 product longevity barriers was created. The result is a unique identification and overview of barriers to product longevity as well as a categorisation of these barriers with respect to stakeholders.

Keywords: Long-lasting products; Product lifetime; Planned obsolesce; Product durability; Product lifetime extension; Prolonged product life

Introduction

Prolonging product lifetime and durability are simultaneously acknowledged to be unique selling points for producers of consumer goods (Bhaskaran and Gilbert, 2015) and important tools for minimising negative environmental consequences (Sinclair et al., 2018). However, they are quite challenging concepts for both practitioners and academics to adopt. For managers, designers and engineers, product longevity is often considered to be a complex matter and company-wide adoption is difficult because intervening influential factors span several perspec- tives. Challenges often relate to business, design and consumer behav- iour—for instance, uncertainty regarding new standards (Dalhammar, 2015), lack of design frameworks (Kopecka et al., 2011) and volatile consumer behaviour (Tang and Won, 2018).

The challenge of adopting product longevity initiatives can be reflected in the average lifetime of many consumer products. For example, although the environmentally optimal lifetime of a mobile phone is almost seven years (Frey et al., 2006; Bakker et al., 2014a), the actual average lifetime of a mobile phone is around three years (Suckling and Lee, 2015). This contributes to the 'throwaway society' (Cooper, 2005), thus directly counteracting sustainable production and consumption. Various sources point towards a general decrease in the longevity of consumer products, which is as high as 20% in some categories measured over a five-year period from 2000 to 2005 (Wang et al., 2013; Bakker et al., 2014a; Prakash et al., 2016). Planned obsolescence and the throwaway society actively contribute to this shift, as companies profit from a culture in which product lifetimes are shortened. However, this is not viable in terms of both environment and natural resources; hence, it is important to investigate the barriers to product longevity (Cooper, 2010; Cox et al., 2013).

Stakeholders in product longevity

Four stakeholder groups influence the longevity of products. The first stakeholder group consists of a company's top management members who are responsible for business strategy, economy and marketing — ultimately determining the framework for the longevity of the products a company sells. Circular business models (CBMs) can be used to create value from the production of longer-lasting products. These business models often utilise takeback initiatives, recycling, upcycling or extending product lifetimes, thereby creating the likelihood of increasing product longevity (Lewandowski, 2016; Bocken et al., 2016).

The second stakeholder group consists of product developers. The term developers refers to the designers and engineers who influence the physical product and the choices made in its development process, which in turn influence the potential full life of this product. These choices can include materials, technical solutions (Bradley and Guerrero, 2008), durability (Koenigsberg et al., 2011) and aesthetics, such as patina (Hagedorn et al., 2018).

The third stakeholder group consists of the buyers and users of products. The users are responsible for the use and maintenance of products after purchase and can push the market towards higher longevity through their purchase choices (Evans and Cooper, 2010). Consumer attachment to products is vital for the longevity of products (Mugge et al., 2006) because it leads customers to take better care of the products. Likewise, consumer attitude in a purchase situation influences the general longevity of products (Cooper, 2004).

The last stakeholder group consists of government members and policymakers who create rules, regulations and certifications. For instance, when France banned product obsolescence (R´epublique Francaise, 2015), it took a national step towards regulating the longevity of products. Additionally, the 'Right to Repair', 'Nordic Ecolabel' and 'Extended Warranty' initiatives—which are discussed by Bakker in The Long View (2017)—have arguably been successful in governing the initiatives that extend the longevity of certain product groups. Most recently, the 'European Green Deal' (European Commission, 2019) is expected to include European initiatives that would ensure longer-lasting products.

Product longevity terminology

Terminology needs to be explained in order to facilitate understanding of the perspective on product longevity presented in this paper. In research, product longevity encompasses four closely related and overlapping key terms—product lifecycle, product durability, product obsolescence and product lifetime. Consideration of the product life- cycle terminology highlights the nuances between these terms.

Product lifecycle refers to the life stages of a product and can include the extraction of raw materials, design, production, marketing, distribution, purchase, use, disposal and—in some models (e.g. circular economy)—collection and reuse (den Hollander et al., 2017). Product obsolescence is often discussed in the context of business-related stages. The term is often used interchangeably with the term planned obsolescence, which refers to the intentional act of reducing the lifetime of products. Obsolescence embraces many aspects, including technical, functional, economic and aesthetic obsolescence (Ertz et al., 2017); however, the goal of obsolescence is often to create profit for the company. The term product durability focuses on product characteristics, such as sturdiness, quality of materials and technical solutions, and often encompasses take-back systems to extend product life (Cooper, 1994)— not only in terms of first ownership. Consequently, it embodies a more technical perspective on product longevity. The term product lifetime often encompasses the use scenario and the user as an active participant in product longevity.

This paper defines long-lasting products as **products that are durable and considered to be useful and desirable by users for a long period of time, while simultaneously providing a viable business.**

When discussing the longevity of products, this paper considers product durability, product obsolescence and product lifetime. In particular, the focus in on consumer product research, as the increase in the global population and the growing global middle class have led to increased household consumption (European Environment Agency, 2014), which has had a major effect on total global consumption. The term long-lasting products covers personal products that can be found in typical homes, such as electronics, furniture and household appliances. However, it does not cover fast-moving consumer goods, such as pack- aging, consumables and food. Furthermore, this study does not include large-scale objects, such as architecture or housing, and it excludes the clothing and fashion industry. Additionally, recycling, upcycling and reutilisation of products are not included despite the fact that these can also be considered to represent life-prolonging initiatives.

Positioning

The existing literature on product longevity primarily focuses on specific solutions or specific barrier models in order to improve product longevity—for instance, choosing a business plan that is well-suited for producing durable products (Cooper, 2005) and improving product design to increase durability or remain relevant in the market (Hagedorn et al., 2018; Lilley et al., 2019) or to motivate consumers to keep and maintain their products (Ertz et al., 2017b). The result is an in-depth understanding of the specific problems related to product longevity and insights into potential specific solutions. However, as Bakker et al. (2014b) and den Hollander et al. (2017) have argued, product longevity can be altered at various stages of a product's lifetime (e.g. development, use, repair or refurbishment) and by different stakeholders (e.g. companies, designers, engineers, customers or users). Likewise, Evans and Cooper (2010) have highlighted further sub-stages of product lifetime within each stakeholder group (e.g. desire to buy, moment of acquisition or storage). In line with Rivera and Lallmahomed (2016), we argue that it is important to generate a comprehensive overview of barriers and problems vis-`a-vis product longevity, instead of providing an isolated identification of the ways in which one or two barriers could be overcome. This project is based on the following assumption. In order for companies to induce engineers, designers and developers to create and customers to keep long-lasting products, it is important to look across domains and understand how individual barriers influence one another from a systemic perspective before solutions for overcoming these barriers are developed and their effectiveness is proven.

The first step towards creating a new research agenda is to identify the underlying barriers to creating long-lasting products, which the current literature has either directly or indirectly identified (via solutions proposed). This would enable future

research to verify whether all potential barriers have been identified as well as to propose solutions that would take into account all different barriers and perspectives (or, at least, the majority of them). In practice, an overview of these barriers will create transparency across domains and insights into the barriers the stakeholders influence. This includes stakeholders who are motivated to adopt more sustainable methods and are most likely struggling to overcome a set of specific barriers. It also includes those who are not motivated and are most likely involved in creating or enabling one or more of these barriers.

The main research question explored in this paper is: **What are the barriers to developing and creating viable businesses based on long-lasting products and to ensuring their long-term use?**

Methodology

The literature review presented in this paper was carried out in a three-stage process to reflect the breadth and depth of the field. Snow- ball search was used to identify relevant search terms and then a comprehensive systematic literature review was conducted. Subsequently, post-identification of additional relevant literature was made.

Snowball search

A preliminary snowball search was conducted because it was presumed that the topic of interest spans several literature streams. The aim was to identify various terms that relate to elements of product longevity. While such a broad snowball search only scratches the surface of the literature, it nevertheless revealed that this subject spans several academic disciplines and helped the researchers identify the key literature to be used for a more systematic literature review.

The snowball search began with a Google Scholar search of the term 'product lifetime', which resulted in a large number of articles; however, many of these were related to the medical and health fields and not to consumer products. After these were eliminated, only a limited number of relevant articles remained. The search was subsequently continued on the basis of the references mentioned in these relevant selected articles. The search was considered to be complete when newly identified articles referred to articles already included in the original sample.

Altogether, 45 relevant peer-reviewed articles were identified and formed the basis for an introduction to the subject. The literature was found using both web and book searches and through recommended readings and quotations, thus forming a foundation of popular literature on the subject.

The snowball search revealed that the topic spans various fields that deal with product design and with users/consumers, producing companies and governments as influential stakeholders in relation to product lifetime. As each discipline describes long-lasting products and relevant knowledge using different terms, it was important to conduct several thorough searches that included adjacent literature from engineering, design, product psychology, business and marketing spheres. These terms, although not mutually exclusive and sometimes over- lapping in the literature, represented the terminology that is frequently used when addressing the longevity problem from a certain perspective. In particular, three terms were found to be central in papers that discuss a particular barrier or that identify models or frameworks for over- coming one or more barriers:

- The first term, *product obsolescence*, is used interchangeably with the term planned obsolescence in the literature and is commonly used in studies that examined business models, economy and marketing. Brooks Stevens has

defined the term as 'instilling in the buyer the desire to own something a little newer, a little better, and a little sooner than is necessary' (Adamson and Gordon, 2003). It is a concept used to describe a deliberate reduction in durability in order to increase sales (Bernard, 2019; Wieser, 2016). It falls within the business strategy of shortening a product's lifespan (Rivera and Lallmahomed, 2016)—that is, it stands in contrast to several business strategies found in circular economy that focus on long-lasting products, as described by Ertz et al. (2019).

- The second term, *product durability*, is related to product design, production and engineering results. Scholars have defined product durability as the ability to withstand wear, tear and decay, and its meaning includes the notion of resilience and the ability to recover and adapt when damaged (Haug, 2018). Product durability is a result of decisions made during product development. Material choices, product architectures, mechanics and digital parts greatly influence the durability of a product. Aesthetics, weight and tactility are also key aspects that affect how long a product is kept before disposal (Lilley et al., 2016; Lies, 2020; Grosse-Hering et al., 2013).
- The third term, product lifetime, is predominantly used to describe the full lifetime of a product and is influenced by the attitudes and be- haviours of users. Burns (2010) has defined product lifetime as the time before the product is no longer considered to be useful. Hence, the term primarily covers research that takes a user perspective and focuses on user attitude and behaviour. This stream of research recognises customers as having a significant influence on the total product lifetime and on the chance of second-life initiatives (multi-life practice). The user is able influence the market through their product choices and to be responsible for the maintenance and repair of products after purchase (Ackermann et al., 2018). Likewise, the multi-life practice enables a further extension of product lifetime if consumers buy and sell products second-hand (Ertz et al., 2017b; Nieuwenhuis, 2008).

Having concluded the snowball search, the key insights obtained were then distilled into the following search terms: product obsolescence, product durability and product lifetime. These served as the foundation for the systematic literature review presented in this paper.

Systematic search

This systematic literature review aimed to ensure study depth by conducting a methodical search of selected databases. To acknowledge the variety of fields identified in the snowball search, the databases selected for the systematic search spanned multiple fields and complemented one other, while their main focus differed.

The snowball search resulted in a large number of medical journals ('MEDI', 'BIOC', 'PHAR', 'HEAL', 'IMMU', 'NURS', 'VETE', 'NEUR' and 'DENT'). Consequently, related fields were excluded from the Scopus search. Likewise, many articles directly related to the fields of mathematics, chemistry and agriculture (and often related to fast-moving consumer goods, such as food) were largely deemed to be irrelevant; hence, the fields 'MATH', 'CHEM', 'AGRI' and 'CENG' were excluded.

Only full articles were included to ensure their quality and relevance, while literature prior to 2001 was excluded. Excluding data prior to 2001 might have removed a substantial portion of material in the field. Nevertheless, it was expected that the concluding identification of noticeable literature would include relevant material prior to 2001. The search was conducted in April 2020.

Table 1 *An overview of search databases and the number of resulting articles.*

Keywords	**Database**	**Number of articles (2001–2020)**
Product lifetime	Scopus	611
	EBSCOhost	243
Product AND obsolescence OR obsolete*	Scopus	1,391
	EBSCOhost	1,691
Product durability	Scopus	247
	EBSCOhost	558
Subtotal (including duplicates)		4,741
Total unique articles		4,204

The literature review search resulted in a total of 4204 articles, as shown in Table 1. Subsequently, these results were further narrowed by conducting a review of the article titles, keywords and abstracts, which resulted in a total of 143 articles being highlighted for their relevance in the chosen fields. The selection of these 143 papers was based on whether they adhered to one of the following three parameters:

- Title: The title showed (even remote) indications of relevance to the subject of product longevity.
- Abstract: The abstract showed clear indications of relevance to the subject of product longevity from any perspective.
- Keywords: The article had one of the following keywords: product obsolescence, product durability, product lifetime, lifecycle or circular economy.

The collected data were coded using a grounded theory approach with open coding (Strauss and Corbin, 1998). Comparison was subsequently enabled by breaking down

these data into discrete parts and examining them for similarities and differences. Next, parts and barriers were grouped into categories. The three categories identified (see Table 2) were based on Rivera and Lallmahomed (2016) three-level model, which is used to identify key actors and/or stakeholders. These are business barriers (business models, economy and marketing, business strategy or value creation), product development barriers (focusing primarily on product design, production and optimisation as well as technological, functional and aesthetic attributions) and consumer barriers (dealing mainly with user attitude and behaviour, choice, maintenance and repair). Moreover, it was evident that different search terms would lead to articles with different types of focus. The search term 'product lifetime' generated results that were predominantly related to user attitude and behaviour; 'product obsolescence' results were mainly related to business models, economy and marketing; while 'product durability' results were primarily related to product design, production and engineering.

Table 1 *An overview of search databases and the number of resulting articles.*

Product Longevity			
Type of barriers	**Business barrier**	**Product development barriers**	**Usage/consumer**
Focus points	Business models, the economy and marketing, business strategy, value creation	Product design, production and optimisation, technological, functional and aesthetic attributes	User attitude and behaviour, choice, maintenance and repair
List of identified literature in the systematic search	Agrawal et al. (2011)	Amankwah-Amoah (2017)	Ackermann et al. (2018)
	Alqahtani and Gupta (2017)	Ardente and Fulvio (2014)	Amolo and Beharry-Ramraj (2016)
	Bakker et al. (2014)	Asmatulu et al. (2020)	Bento et al. (2018)
	Bhaskaran et al. (2015)	Awano et al. (2017)	Bridgens et al. (2015)
	Bocken et al. (2016)	Aziz et al (2016)	Chung et al. (2012)
	Boons et al. (2013)	Bakırlıoğlu and Doğan (2020)	Cooper (2004)
	Burns (2010)	Bakker et al. (2014)	Cooper (2005)
	Dalhammar (2015)	Bernard (2019)	Cooper (2010)
	den Hollander et al. (2017)	Blonigen et al. (2017)	Cox et al. (2013)
	Dixon (2010)	Bobba et al. (2016)	Echegaray (2016)
	Donati et al. (2020)	Boks (2018)	Ertz et al. (2017)

	Eichner et al (2003)	Boot et al (2008)	Evans and Cooper (2010)
	Ertz et al. (2019)	Bradley and Guerrero (2008)	Gnanapragasam et al. (2018)
	Fosfuri et al. (2014)	Brouillat (2015)	Hou et al. (2020)
	Gan et al. (2019)	Choi et al. (2018)	Kim et al (2006)
	Gelbmann and Hammerl (2014)	Cupchik (2017)	Liabert and Haber (2013)
	Goering and Pippenger (2009)	El-Nounu et al. (2018)	Lilley et al. (2016)
	Grösser et al. (2017)	Ertz & Patrick (2020)	Loon et al. (2020)
	Halstenberg et al. (2019)	Ertz et al. (2017)	Montalvo et al. (2016)
	Ingemarsdotter et al. (2014)	Feldman and Sandborn (2007)	Mugge et al. (2006)
	Kagawa et al (2015)	Gill and Lopes (2011)	Page (2014)
	Kok et al (2013)	Goel (2006)	Paiano et al (2013)
	Konietzko et al. (2020)	Grosse-Hering et al. (2013)	Poppelaars et al (2018)
	Korhonen et al. (2018)	Hagedorn et al. (2018)	Saengchote and Nakavachara (2018)
	Lahiri et al. (2020)	Harmer (2005)	Selvefors et al. (2019)
	Lewandowski (2016)	Haug (2018)	Simpson and Radford (2012)
	Miao (2010)	Haug (2019)	Sinclair et al. (2018)
	Mohr et al. (2001)	Herrmann et al. (2011)	Tang and Won (2018)
	Mont et al. (2006)	Jenab et al. (2014)	Wilhelm (2012)
	Mura et al. (2020)	Jennings et al. (2016)	Erumban and Timmer (2012)
	Nußholz (2018)	Kang et al. (2012)	Galland and Lemel (2008)
	Pangburn and Stayrulaki (2014)	Khan et al. (2018)	He et al. (2016)
	Rivera and Lallmahomed (2016)	Koenigsberg et al (2011)	Kreiss (2014)
	Rizos et al. (2016)	Kopecka et al. (2011)	Kuppelwieser et al. (2019)
	Schaeffer (2016)	Krishnan and Ramachandran (2011)	Oguchi et al. (2017)
	Singh et al. (2019)	Lawlor (2014)	van Loon et al (2020)

	Singhal et al (2020)	Li et al. (2011)	Cooper (2005)
	Skene (2018)	Lies (2020)	Haines-Gadd et al. (2018)
	Tam et al. (2019)	Lilley et al. (2019)	Haryanto et al. (2014)
	Thiébaud et al. (2018)	Lio et al. (2015)	Wells and Nieuwenhuis (2018)
	Thiébaud et al. (2018)	Maldini et al. (2019)	Harmer et al. (2019)
	Ueda et al. (2005)	Maus (2019)	Jaeger-Erben et al. 2020
	Vermunt et al (2019)	Mugge and Bakker (2018)	Sarigöllü et al. (2020)
	Whalen (2019)	Nakamoto (2019)	
	Wieser (2016)	Nieuwenhuis (2008)	
	Xiong et al. (2012)	Nigam et al. (2009)	
	Zhou and Gupta (2019)	Nishijima (2016)	
		Richter et al. (2019)	
		Sandborn (2017)	
		Spielmann et al. (2007)	
		Suckling and Lee (2015)	
		Sumter et al. (2018)	
		van Nes and Cramer (2005)	

None of the categories exclusively concentrated on their own perspective because they all influenced one other—for example, it would be impossible to discuss marketing without consumer involvement. However, in each category, the dominant terminology in the existing literature created a perspective that examined the other categories from its own point of view, creating an in-depth understanding of the specific problems for that category but not a balanced perspective on the problem in its entirety.

Post-identification of relevant material

In the process of coding the systematic search, additional relevant articles and reports were discovered. These 17 publications were also included in the analysis in order to ensure further coverage of the topic. Ultimately, this resulted in a total of 205 papers (45 resulting from the snowball search, 143 from the systematic search and 17 from post- identification).

Analysis and Findings

Based on a thorough analysis of the 143 articles, 14 barriers were identified that might be influential with respect to business, development and usage of long-lasting products. Some barriers reduce the economic incentive to produce long-lasting products, while others directly shorten the product lifetime. Therefore, the barriers defined here are intended as focal points for readers to be aware of and to consider when studying product longevity.

In parallel with studying the literature, barriers were identified through the coding of the literature. Hence, for each article analysed, it was determined what underlying barrier was treated. The literature was then clustered, as it became apparent that certain categories of the literature treated the same barriers. This resulted in a framework of 14 barriers arranged into three topics—business barriers, product development barriers and usage barriers—which are discussed in the following sections.

Business barriers

Business barriers are defined as barriers that decrease the motivation for companies to adopt more sustainable production of longer-lasting products. If companies are not able to easily scale these barriers or are unable to see the direct payoff, they are likely to preserve and increasingly commit to their current business model.

Barrier 1: High cost of changing the business model

For many companies, the introduction of long-lasting products entails a change to the company's business model, which can be costly. Previous research shows that implementing a green business model generally requires a substantial investment for the company in terms of both time and resources (Rizos et al., 2016). Bakker et al. (2014a,b) and Ertz et al. (2019) have recently highlighted different ways of transforming traditional asset sale models and leasing services into business models that can support long-lasting products. However, these new business models may also involve new types of costs for companies. For instance, a shift from a sale–transaction business model to a pro- duct–service business model (e.g. leasing services) involves higher upfront costs (Kok et al., 2013). Smaller and medium-sized companies that are more vulnerable or are in markets with rapid technological development are either not able or are reluctant to pay large initial in- vestments without the certainty of a return on investment (Dalhammar, 2015; Mura et al., 2020).

Barrier 2: customer rejection of the business model change

It may not be viable for some companies to change their business model entirely because of customer demands (Gan et al., 2019). Leasing- or renting-oriented business models are arguably more readily suited to increasing product longevity than traditional asset sales (Loon et al., 2020). However, some product categories are not well-suited for pro- duct–service systems (Zhou and Gupta, 2019). If a company is selling products that customers perceive to be very personal, the customers are less likely to be willing to rent or lease them (e.g. personal computers or tablets). Likewise, new products previously sold through asset sales but now offered through service are likely to be rejected because customers are unfamiliar with the product being sold via this model (Poppelaars et al., 2018). Consequently, it is often not a viable option for companies to radically change their business model to accommodate longevity. However, transformation through incremental changes made over time proves to be more viable (Konietzko et al., 2020).

Barrier 3: High price points of long-lasting products

Companies seeking to introduce long-lasting products face the barrier that long-lasting products limit their ability to compete price-wise against discount products. If a company operates in a niche or monopolistic market, this may not be an issue. However, if a company is in a market with several actors, then the consumer has a choice between multiple product alternatives and this often makes price a key competitive parameter. Certain long-lasting initiatives, such as extended leasing, raise the market price of the product (Loon et al., 2020; Alqahtani and Gupta, 2017), Meanwhile, some companies are tempted to design products that intentionally break prematurely (Mohr et al., 2001) for instance, by lowering the quality and allowing them to fail or break after a certain number of uses or by limiting the options for repair. This is called planned obsolescence (Bradley and Guerrero, 2008) and challenge the companies engaged with longevity initiatives.

Barrier 4: Vulnerability regarding short, fixed leasing periods

In the circular economy debate, leasing (and many other product–service systems) is normally considered to enable greater longevity of products (Bakker, 2017; Goering and Pippenger, 2009). However, leasing of some product categories that have a short, fixed leasing period can, over time, affect the profitability of producing long-lasting products. Producing long-lasting products while maintaining a healthy business is challenging if retailers of a product promote, for example, short, fixed leasing or renting periods. Looking at products with high longevity, such as refrigerators, washing machines and dryers, leasing options can actually prove to be less environmentally responsible. Likewise, in some product categories, such as laptops, it is more profitable for companies to lease—however, it is less environmentally responsible (Agrawal et al., 2011). Bhaskaran and Gilbert (2015) have argued that

products sold through a retailer generally result in a decrease in durability due to the retailers mark-up on price. Thus, leasing options do not necessarily improve the longevity of products, if sold through retailers. In the case of baby strollers and baby prams, the products need to be specifically designed for leasing in order to be successful (Sumter et al., 2018; Mont et al., 2006). Another example has been given by Wieser (2016), in his study of the mobile phone market, where retailers offer yearly replacements of mobile phones through subscription plans. The producing company has limited motivation to increase longevity because retailers predefine the relevant lifespan. Competing companies offering longer-lasting products now cater to a niche market in which longevity is the focus, while the mass market seeks short-cycle products.

Barrier 5: Time-consuming changes in customer perceptions of products and brands

Another barrier to the introduction of long-lasting products by a company is if its customers already perceive the company to be a producer of products that have a short lifetime. Changing customer perceptions of a brand is time-consuming (Simpson and Radford, 2012). Their perceptions of quality and expected lifetime are largely influenced by previous experiences, prices and brands (Slack et al., 2007; Sinclair et al., 2018). Consequently, a change in perception is only achievable in the long term. A company that was previously known for producing short-cycle products would, therefore, be challenged by the slow con- version rate of customer perception. A transition period emerges, where the company produces long-lasting products but is not able to benefit from this due to unchanged customer perceptions.

A company that was previously selling short-cycle products is thus less likely to increase product longevity because the consumers' pre- determined perception of the company is that their products are short-cycled. Additionally, if the customers' expectations regarding longevity are low, then the company is likely to meet customer expectations and reduce the cost of production through life-shortening initiatives, such as the use of cheaper materials. This is because the benefit of exceeding customers' expectations is marginal (Dixon et al., 2010).

This also holds true for the customer perspective if companies that are already producing long-lasting products begin to reduce the longevity of their products. Amolo and Beharry-Ramraj (2016) have argued that companies that have already established themselves in the market as producers of long-lasting products maintain the customer perception of brand quality even if they start producing non-durable products. Consumers who already have a perception of the company as a reliable brand are unlikely to change this perception, even though the longevity of the products is reduced (Butz et al., 1996).

Product development barriers

Development barriers are defined as barriers faced by product designers, engineers and product developers in the process of developing long-lasting products. Development is likely to be hindered if it is not informed and mindful of the choices that influence product longevity. Different types of obsolescence are mentioned in this section that are used to describe why products are disregarded. Cooper (2004) and Rivera and Lallmahomed (2016) present a comprehensive overview of terminology in relation to obsolescence that has been used to classify obsolescence types in this paper.

Barrier 6: Inability to follow fast-moving trends and fashions

Products that are designed to aesthetically match current trends and fashion are likely to be prematurely disregarded by consumers when trends and fashions change (Hagedorn et al., 2018; Cupchik, 2017). Products that go out of fashion lose value for customers even though the product is fully functional (aesthetic/cosmetic obsolescence) (Lilley et al., 2016). This leads to premature disposal of products, which means that if development relies on fast-moving trends with respect to aesthetics, fashion or behavioural trends (e.g. selfie sticks or hoverboards), then the company is unable to profit from developing long-lasting products. It is thus not viable for product developers to develop long-lasting products if the business model aims to follow fast-moving trends. Furthermore, if products are developed following a certain trend or style, then they are likely to go out of fashion before they are worn out (den Hollander et al., 2017).

Barrier 7: Technological innovation makes long-lasting products obsolete

Another identified development barrier is that technological innovation in the market can decrease the value of products. Companies producing long-lasting technological products face challenges by committing themselves to specific technological solutions. A product that intends to remain relevant in the market must also contain technology that remains relevant. Therefore, if the producing company commits to standard technology that is later surpassed by new or other technologies, the product itself becomes less relevant and attractive for the market (obsolete). This is described as systematic or technical obsolescence (Rivera and Lallmahomed, 2016; Cooper, 2004). For example, if a loudspeaker company commits itself to Bluetooth communication, the products will only remain relevant as long as customers are committed to using this technology. If the majority of consumers commit themselves to newer technology (such as Wi-Fi streaming, Airplay or Chromecast Audio), then the Bluetooth speaker becomes less attractive and loses value. This creates a risk for companies in committing themselves to technology (particularly new technologies), especially if the technology has not yet proven its relevance in the market. A

consequence of this may be that producers of long-lasting products become second movers in the market due to their cautiousness regarding new technologies.

Barrier 8: Change in societal behaviour makes long-lasting products obsolete

Yet another development barrier identified is that designers need to predict future societal change in order for product developers to design long-lasting products. Boot et al. (2008) have argued that designers need to predict the future in order to avoid what they define as 'social obsolescence'. Even if a product's design is environmentally conscious (and by that definition is a good design), the laws, regulations and attitudes can change, which means that the product can become irrelevant (obsolete). Societal changes can occur for multiple reasons, such as changes in governmental laws and regulations, the introduction of international standards (e.g. changes in ISO/EIC every few years to meet new product standard requirements), trends, changes in consumer behaviour or even through design (Boks, 2018). Cooper (1994) has argued that new social attitudes can be challenging if companies practice long-term planning frameworks. Long-lasting products are more susceptible to societal change simply due to their longer lifetimes. An example of changing social values could be seen in the global focus on pollution produced by conventional combustion engines. This has led to an increased interest in and sale of electric cars despite consumers' lack of previous experience with these types of cars, brands or personal needs. A societal change that would have been difficult to predict in the past is making durable combustion-driven cars less attractive. Designers and product developers thus need to be increasingly conscious of potential future societal changes when developing long-lasting products in comparison to short-lasting products.

Barrier 9: Lack of focus on longevity in innovation

Still another development barrier identified is that designers and product developers need to have a divided focus with respect to both innovation and product longevity when developing long-lasting products. If not, innovation is likely to lead to a decrease in longevity. Product longevity initiatives can lead to other sustainability issues, such as a higher CO2 emissions in production, which in turn make it challenging to focus the process (Bernard, 2019). Goel (2006) has argued that, in innovation, the choice of durable (designing for longevity) or non-durable (planned obsolescence) innovation is a deliberate one if the focus area is in the development phase. However, in many cases, this choice is not deliberate and is decided by external factors—such as consumers, competitors or other products—resulting in unplanned obsolescence. If the focus is not primarily on product longevity or 'innovation for long-lasting products', then it is likely that innovation within the company will lead to a shorter product lifespan. At the same time, innovation is vital for business to stay relevant in the market (Schaeffer, 2016), which creates a two-sided evaluation

criterion for the development department in companies that produce long-lasting products.

Usage barriers

Usage barriers are defined as the barriers that users/customers face when purchasing and owning products with the intention of keeping them as long as possible. Although many customers perceive long- lasting products to be desirable, a lack of an estimated lifetime and a general lack of knowledge limits their ability to make an informed choice in a purchase situation.

Barrier 10: Short lifecycles promoted by retailers affects user behaviour

Products offered through short service lifecycles lower the general perception of durability and product attachment for customers. Customer perception of acceptable product longevity is reduced over time if the product is sold through a service that promotes frequent replacement. Likewise, customer motivation to properly maintain the product is reduced because its longevity is fixed through the service. Goering (1997) has argued that the incentive for producing companies to improve product longevity is minimised if customers abuse and neglect the product during their leasing period. This creates a negative spiralling effect for acceptable longevity of a certain product.

Hence, as in the example of certain car leasing services (Skene, 2018), this poses a barrier for companies that are seeking to produce long-lasting products in such a market. The negotiated longevity of a product decreases due to customer behaviour, resulting in misuse and poor maintenance—thus decreasing the longevity on the producer side.

Barrier 11: Lack of attachment to products

Lack of customers' emotional attachment to products causes these products to be treated more poorly, to be more poorly maintained and to be discarded earlier. Ackermann et al. (2018) have argued that products that are annoying, aesthetically displeasing, lack fun, do not instil a sense of pride or are technologically outdated are more likely to be poorly taken care of and, therefore, to break down at an earlier stage. Customers who experience frustration because products do not live up to their expectations substitute these products with new alter- natives—unless particularly attached to a product. However, if consumers associate products with self-expression, group affiliation, great memories or pleasure (Mugge et al., 2006; Page, 2014; van Nes and Cramer, 2005), then they are more likely to keep and maintain them for an extended period of time. The emotional and social value of products is thus an important factor when looking at customers' replacement intentions (Hou et al., 2020; Nieuwenhuis, 2008).

Likewise, this is problematic for the development team because it is challenging to design in order to induce customer attachment. Page (2014) has argued that designers can influence certain parameters that affect product attachment, such as durability, reliability, quality, tactility and audio feedback. However, some factors, such as memories, nostalgia and product association seem to be uncontrollable but still influential in relation to final product life.

Barrier 12: Customers are partly unaware of material quality

Customers often struggle to evaluate longevity in a purchase situation and are often unaware of how the materials in the product age aesthetically. Lilley et al. (2016) have argued that changes in the material as a result of exposure to light, air, wear, heat, etc. are often cause of premature substitution. Aesthetics play an important role in customers' choice of products in a buying situation. Likewise, the aesthetics of a product greatly influence user perceptions of that product when owned. A product that loses aesthetic value over time will eventually be discarded earlier than a similar product that ages gracefully and remains aesthetically pleasing—for example, plastic patio furniture that de-saturates due to UV exposure. Looking at prior research, there is little indication that consumers are conscious of and commonly agree about the deterioration of materials when deciding between products (Bridgens et al., 2015). If customers are unaware or do not share the same perceptions of graceful patina, then they do not perceive aesthetically durable products as superior, thus making it less relevant for companies or designers to pursue this aspect.

Barrier 13: Evaluating longevity in a purchase situation

It is often a challenge for customers to actively select long-lasting products due to a lack of information. Often, there is insufficient information available about product durability during a purchase situation. Montalvo et al. (2016) have argued that this lack of information creates unreliability for consumers and requires that they deal with great un- certainty. Nieuwenhuis (2008) has discussed this in the context of the automotive industry. Many car manufacturers promote the production of durable cars but no statistics are available to consumers. The lack of certification of product durability leaves consumers with only a few unreliable indicators of longevity, such as brand rather than actual lifetime. Consumers are thus more likely to choose products based on their evaluation of available information, such as energy consumption, brand and aesthetics, and are often less attentive to the reliability of the product (Gnanapragasam et al., 2018). Successful implementation of durability labelling across product categories requires governmental certification—however, as Cox et al. (2013) have argued, product labelling is only partially possible in many product categories. Although some companies are positive about durability standards, such as label- ling for a minimum number of uses (Dalhammar, 2015), they argue that consumer influence on product longevity through a lack of maintenance often results in decreased longevity.

Barrier 14: Misperception of modularity in advanced products

Customers often do not perceive modular products to be as attractive as integrated alternatives. In most product categories, customers perceive modularity to be a quality that adds to longevity (e.g. modular vacuum cleaners are perceived to have higher quality). However, if the product is sufficiently complex, modular products (which are made to last longer than their integrated counterparts) are perceived to be less advanced and consumers are therefore likely to choose an integrated product in a purchase situation. With respect to simple mechanical products, such as vacuum cleaners, customers perceive modularity to be an advantage and acknowledge it as a benefit of these products. How- ever, with more advanced electronic products, such as laptops or tablets, customer perception of modularity is negative (Chung et al., 2012). Modularity is perceived as a lowering of the technological advancement of products, thus making them less attractive in comparison to their integrated competitors, even if the products are equally advanced (Krishnan and Ramachandran, 2011). Consequently, from a customer perspective, modular products do not express advancement as well as integrated ones. Consumers are simply often unaware of the facets of sustainability in this regard (Simpson and Radford, 2012).

Conclusion

The aim of this review was to create an overview of the barriers that exist vis-`a-vis product longevity. To this end, barriers described in the existing literature were identified through a comprehensive literature review.

The barriers identified suggested that the responsibility for longevity

exists in the form of a common understanding and responsibility that is shared between companies, product developers and customers—all of whom affect one another. It has been made clear that business decisions affect the consumers' perceptions of companies and the internal product decisions made by product developers. A categorisation of the barriers was established to generate better understanding and a more manage- able overview. Building on categorisations of previous research, the barriers were into three categories—business barriers, product development barriers and usage barriers. Thus, through its comprehensive literature review, this study prompts a shift from a fragmented solution focus to a broader perspective of stakeholders in the longevity debate.

The identification of five business-related barriers, four product development barriers and five usage barriers serves as an outline for future research through which it can actively consider barriers, implications and solutions for product longevity. It allows for steps to be taken towards identifying barriers that influence product lifetime and creating a platform for discussing potential solutions. Product development decisions greatly influence customer attachment, which is directly related to product lifetime. In addition, customers demand knowledge and focus and directly influence companies and product development through their purchasing behaviour. The acknowledgement of this—based on barrier identification—results in a demand for a more general academic understanding and investigation of barriers, solutions and actors that affect product longevity and the environmental debate. This paper and the 14 barriers it identifies may serve as a foundation for such future research paths.

Discussion and implications for research, practice and policymakers

Although product longevity is attracting increasing interest among academics, it still remains a subject that is difficult to understand in both the Western political and public spheres. However, by analysing the existing literature and identifying barriers, new areas of research and practice have become apparent. Consequently, this study hopes to initiate research that will stimulate companies, product developers, policymakers and consumers to become more conscious of product longevity.

Researchers

For researchers, a comprehensive overview of product longevity barriers creates a framework for future research. This framework enables researchers to compare how

both new and already identified approaches propose solutions for certain barriers—as well as to ascertain which barriers have not yet been addressed. By examining approaches through the lenses of the barriers, future interdisciplinary research can more easily identify what problems have been addressed and what problems require additional attention.

Although it was not the initial aim of this research, based on the articles reviewed in this study, it became obvious that research on solution principles has a tendency to cluster in certain areas. For example, a major research focus on business models enables product longevity, while research on the positioning of producers of long-lasting products in the market is sparse. While it is generally accepted that certain business models—such as leasing or renting—create a foundation for the production of long-lasting products as a result of their setup, it is a major barrier that many companies are unable or reluctant to switch to these models without proper support. This indicates that barriers, business transformations and solutions for increasing product longevity have to be perceived as being co-dependant on and affecting one another.

Relationships between barriers

Barriers are often intertwined and largely dependent on and influenced by one another. Hence, the next natural step in the research process would be to investigate the relationships between the individual barriers and how their challenges and solutions influence one another. Some of these relationships have already been identified in the current literature—by Wieser (2016), for instance, who has discussed the problems that retailers face when promoting frequent replacement through product–service systems (Barrier 4), while also being affected by the consumer perception of longevity for a product category (Barrier 10). These connections between barriers could form a foundation not only for the identification of several additional barriers but also for the practical solutions that companies could use to overcome these barriers.

Likewise, in this discussion, a company has to be aware that it can be challenging to change business models. As many of the business barriers are based on profit loss, it is arguable that a radical change of business model is often not a viable option because it is a costly process (Barrier 1). Previous literature has highlighted ways in which a company can transition towards a more sustainable business model (Rizos et al., 2016; Bakker et al., 2014; Ertz et al., 2019). However, this study has not been able to identify literature that provides a broader understanding of this transition as well as the mechanisms affecting customers and their re- action patterns. Likewise, the connection between business aspects and product development has yet to be evaluated because business trans- formation might also require changes in product portfolios. Further investigation into this would provide a deeper understanding of these barriers and possible practical solutions.

Practical solutions to barriers

This research further suggests that it would be useful to conduct an in-depth qualitative study of companies that have succeeded in over- coming the identified barriers while seeking to increase the durability of their products and maintaining a healthy business. Several studies have investigated this in the circular economy context (e.g. Mura et al. (2020) with Italian SMEs) but a dedicated study on longevity is lacking. A qualitative study would provide a deeper understanding of barriers as well as practical solutions for management members, product developers and users. A pragmatic guide that provides concrete suggestions to improve the durability of products in a company portfolio while also improving profit could prove to be useful for practitioners. Suggestions for topics of interest include branding based on longevity, transparency for customers in the design process, accessibility of data on longevity and extended warranties. Investigating the stakeholder roles in these processes, as well as different practical perspectives, would also be valuable.

The roadmap for companies to produce durable products

Furthermore, little research has focused on the differing abilities of companies to overcome barriers and how they go about doing so. As indicated by Mugge et al. (2006), improving customer attachment through different measures also improves the likelihood of greater product care and, ultimately, of product longevity. A similar study of companies' attachment to durable products and their differing abilities to adapt in their fields could further improve understanding of successful longevity implementation across all businesses.

Practitioners

For managers and decision-makers at product-producing companies who are interested in heightening the longevity of current or future products, this paper provides a crucial overview of the potential barriers they may encounter. These 14 product longevity barriers identified here (see Table 3) can serve as a mapping tool for companies to use in order to identify the barriers that influence the longevity of their specific port- folios or product lines. Thus, this paper can help identify what barriers the company is currently facing or is potentially going to face as well as what barriers they are not likely to encounter. When addressing longevity in the decision-making process, practitioners and decision- makers would be supported by this mapping, which can reveal key topics that need to be taken into consideration for future products. Moreover, with the mapping of the most important barriers in place, practitioners and decision-makers would be supported in identifying the solutions or principles that are most relevant to them and that can help them overcome the specific barriers they are facing.

As mentioned previously, the transformation of businesses and portfolios often involves economic risk, especially for smaller companies for which a lack of support can prove fatal. However, even for large companies currently engaged in extending the longevity of their product portfolios, there is also a risk—because only focusing on certain problems in the transformation process can create unforeseen consequences.

To support transformation, knowledge about the topic is essential. For many companies—particularly SME's—identifying relevant knowledge, research and approaches can prove difficult because there is no easy starting point. The overview of product longevity barriers (see Table 3) and the categorisation of the research within this area (see Table 2) can be used as an entrance point. Companies that are better informed about the challenges are more likely to understand and map their future challenges, thus increasing their chances of successfully transforming.

Table 3 *Summary of the barriers in three fields—Business barriers, product development barriers and usage barriers.*

Barriers for long-lasting products		
Business barriers	**Product development barriers**	**Usage barriers**
Barrier 1: High cost of changing business model	Barrier 6: Inability to follow fast-moving trends and fashions	Barrier 10: Short lifecycles promoted by retailers affect user behaviour
Barrier 2: Customer rejection of change in business model	Barrier 7: Technological innovation makes long-lasting products obsolete	Barrier 11: Lack of attachment to products
Barrier 3: High price points of long-lasting products	Barrier 8: Change in societal behaviour makes long-lasting products obsolete	Barrier 12: Customers are partly unaware of material quality
Barrier 4: Vulnerability regarding short, fixed leasing periods	Barrier 9: Lack of focus on longevity in innovation	Barrier 13: Evaluating longevity in a purchase situation
Barrier 5: Time-consuming alteration of customer perception of product and brand		Barrier 14: Misperception of modularity in advanced products

Policymakers

For many policymakers who seek to support longevity initiatives, it is crucial to first understand the mechanisms, actors and stakeholders and how they influence barriers.

The 14 barriers (see Table 3) presented in this paper, enable policymakers to understand the complexity and difficulties involved with longevity. In order to provide a political frame- work that enables and supports product longevity, policymakers need to understand product longevity barriers. Broader understanding on this topic would enable policymakers at local, national and international levels to actively target policies towards relevant actors within given problematic areas. Being informed about barriers also allows policy- makers to understand the challenges that companies are facing and to consequently provide them with proper political frameworks for facilitation. One suggestion that has been discussed in the European Union on this topic is that of an eco-labelling system in order to guarantee a minimum product lifetime (Libaert and Haber, 2013). Such a labelling system would improve consumer awareness of product longevity and would potentially affect the choices in purchase situations. However, as discussed in this paper, sub-optimisation and initiatives that are primarily aimed at durability only provide parts of the solution.

Suggestions for other initiatives—such as the right to independent repairers instead of only approved repair shops, more modular product architecture to support substitution of, for example, batteries, avail- ability of spare parts and a more coherent understanding of the term 'planned obsolescence' (Marcus, J. S. 2020)—all contribute to how policymakers could improve product longevity. Governmental and policymaking initiatives create a common lower limit for acceptable quality, which collectively pushes product producers to improve product longevity. One advantage of this is that the risk for the individual company is minimised because all producers are equally obligated to meet standards.

Limitations of the study

Product longevity is a broad field that spans many interests, stakeholders and problems. It should, therefore, be noted that the authors of this study acknowledge that all barriers that exist in the field of product longevity are most likely not identified in this study. This is partly due to several limitations of the study, which are as follows.

Limitations in respect to systematic search, snowball search and databases

The databases used for conducting the systematic search—namely, Scopus and EBSCOhost—were chosen due to their broad focus, coverage of multiple disciplines, and different focal points. However, there likely exist articles that could not be included in this study because they were not represented in these databases. These articles could reveal additional barriers and problems related to product longevity.

Likewise, the search criteria used for the systematic search may have excluded certain articles that could prove to be insightful. While this includes the exclusion of specific fields, the omission that is more likely is the exclusion of articles from before 2001. Although the snowball search included much of the top relevant material from before

this date, it is likely that there exist both broad and niche barriers described in material written prior to 2001. As the search only included full articles, it is also likely that additional barriers could have been found had this restriction not been in place.

The snowball search is an explorative technique, leading to results that are based on the sources of previous studies. Hence, the duration of the snowball search is essential for the quality of the search. It is therefore expected that an even more comprehensive search could reveal new unidentified sources that could potentially point towards new barriers.

This paper concentrated on literature concerning business, product development and usage. However, it was earlier found that a fourth stakeholder—namely, policymakers—also influences the overall life- time of consumer products. As shown in this paper, barriers often involve multiple stakeholders and are intertwined. Thus, it is also possible that there exist a number of barriers related to policymaking that have not been identified in this paper.

Limitations with respect to product categories

There might exist barriers that are not applicable to all product categories. Many of the reviewed articles point towards certain barriers and challenges within a specific context or product category; however, future exploration of the applicability to multiple categories is necessary in order to uncover this. Likewise, it is possible that there exist specific barriers to some product categories that have not been identified in the current literature and that apply only to a specific context. There is also a differentiation regarding to what degree the data unfold the barriers described. While some articles are thorough and elaborate on a specific barrier, others are more vague. This limits the nuances and transparency of the barriers in the literature.

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Appendix B. Paper II

A Practical Approach to Companies' Transformation toward Product Longevity: A Best-Case Study

Peter Byrial Jensen, Louise Møller Haase, Linda Nhu Laursen (2021)

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A Practical Approach to Companies' Transformation toward Product Longevity: A Best-Case Study

Peter Byrial Jensen, Louise Møller Haase, Linda Nhu Laursen (2021)

Abstract

Product longevity is a key to improving the sustainability of production and consumption patterns. However, at many companies, extending product longevity requires overcoming several complex barriers. Identifying how to begin this process can be difficult; moreover, the available solutions may seem too complex or radical and, therefore, may be ignored as viable options. The purpose of this paper is to study the approaches and decision patterns that enable best-practice companies to produce high-longevity products. We aim to map approaches to implementing product longevity through a multiple-case study of 18 best-practice companies that systematically work to ensure product longevity. Through interviews with developers, CFOs and CEOs at companies that strive to design and produce long-lasting products, we identify three key types of approaches to implementing product longevity: performance-driven, behavioural change-driven and vision-driven approaches. This study reveals several types of approaches to implementing product longevity successfully. This contribution advances our understanding of how companies can engage with and foster product longevity at different stages of the development process.

Keywords: product lifetime; planned obsolescence; product durability; product lifetime extension; prolonged product life

Introduction

As increased product consumption and surging e-waste, waste and energy consumption become increasingly global concerns [1], product longevity presents itself among a range of tools that can decrease the flow of materials. Extending the period that a product remains in active use lowers total consumption. However, the longevity of many consumer product categories is decreasing [2], and the average lifetimes of many product categories are decreasing. Previous findings have revealed that this decrease is likely due to a large number of barriers that hinder both businesses and consumers in maintaining or increasing product longevity [3]. Some companies have succeeded in branding themselves as able to produce long-lasting products and positioning themselves as producers of 'high-quality products' [4], mainly due to their continually overcoming such barriers. We define long-lasting products as 'products that are durable and considered to be useful and desirable by users for a long period of time, while simultaneously providing a viable business' [3].

Product lifetimes often fall far short of optimal ranges due to either planned obsolescence or a failure to understand or identify products' sustainability potential. Planned obsolescence [5] refers to the act of companies purposely shortening the lifetimes of their products. On the other hand, some products are able to remain relevant for the user longer than others. Moreover, companies can develop a better understanding of available options to increase, sustain and profit from initiatives that ultimately achieve higher product longevity. In practical terms, however, practitioners may perceive this transformation of perspective as filled with uncertainty regarding both the results and consequences of actions [6]; therefore, it remains inaccessible to many.

From an environmental perspective, a heightened focus on longevity is necessary to meet the UN global goals for sustainable development [7]. One way to approach these targets is to understand this transformation as a form of sustainable innovation, a perspective that relates to Chofreh and Goni's [8] comparison of sustainable innovation to organisational levels of decision making, as described by Montana et al. [9]. Product longevity, therefore, reflects companies' actions and corporate activities that support particular products.

While many scholars have explored how radical innovative initiatives, such as a total and sudden change in business model, can produce long-lasting products [10], other researchers argue that an incremental approach is necessary to allow consumers to adapt and accept the changes [11].

Many companies may face difficulties in identifying how to approach and succeed in developing this process because it involves many mutually influential factors that are often considered exogenous, such as the purchase behaviour of the customers [6]. Such difficulties affect the pace of the overall transformation to producing long-lasting products by hindering their implementation and development. Consequently,

many researchers have argued for an incremental approach to extending product longevity, especially for companies that are vulnerable when engaging in radical changes in production [12]. Conny Bakker [13] describes how businesses' transformation toward longevity and changing business models to support longevity must be facilitated by incremental changes over long periods; however, a more descriptive and practical approach for companies is still lacking. The specific initiatives needed for each incremental step in this sustainable transition likely differ between product categories and even companies. A common understanding of the available solutions and their principles is, therefore, necessary.

Accordingly, a more rigorous investigation of how incremental changes, transformations within corporate structures and development approaches can help companies increase product longevity while maintaining a healthy and profitable business is crucial [14].

Incremental change and innovation within a company are often seen to emerge from many levels [15]. In line with Rivera and Lallmahomed [16], we adopt a focus on incremental changes at the tactical and strategic levels of companies' decision-making processes, particularly the decisions of top managers, other managers and designers. The strategic level describes the top management and the decisions pertaining to marketability, commercialization and marketing, while the tactical level describes management and design decisions, especially in regard to the design and management of products.

As described by Rivera and Lallmahomed [16], lower- and mid-level managers share knowledge and interact with top managers. This knowledge exchange is described as the *strategic level*. Likewise, designers obtain knowledge from consumers and governments through regulations and standards and also exchange knowledge with management. This knowledge exchange is described as the *tactical level*. Such knowledge exchanges, on the tactical level, represent the ideal space in which to foster incremental changes promoting product longevity.

Except for one study [17] of SMEs that investigated the drivers of and barriers to a circular economy, to the best of our knowledge, no comprehensive best-practice study across product categories has yet focused on product longevity. We investigate approaches to product longevity through an examination of tactics used among 18 best-practice companies that are either considered industry leaders or are seen to function as exemplars for other companies within their respective industries. The current paper, therefore, aims to answer the following question: **What are the tactical approaches and decisions within best-practice companies that enable a transition toward producing long-lasting products?**

Theory

Firstly, in order to understand the approaches to product longevity, we must investigate the potential barriers that can hinder the production of long-lasting products. In line with Jensen et al. [3], we adopt a framework suggesting that there are three main stakeholders influencing the longevity of products. The first is the consumers, through purchase decisions and use. The second is product development, namely, designers and engineers. The third is businesses, through marketing and sales. Through their extensive review, they have addressed 14 barriers that can hinder product longevity (Figure 1):

Barriers for long-lasting products		
Business barriers	**Product development barriers**	**Usage barriers**
Barrier 1: High cost of changing business model	Barrier 6: Inability to follow fast-moving trends and fashions	Barrier 10: Short lifecycles promoted by retailers affects user behaviour
Barrier 2: Customer rejection of change in business model	Barrier 7: Technological innovation makes long-lasting products obsolete	Barrier 11: Lack of attachment to products
Barrier 3: High price points of long-lasting products	Barrier 8: Change in societal behaviour makes long-lasting products obsolete	Barrier 12: Customers are partly unaware of material quality
Barrier 4: Vulnerability regarding short, fixed leasing periods	Barrier 9: Lack of focus on longevity in innovation	Barrier 13: Evaluating longevity in a purchase situation
Barrier 5: Time-consuming alteration of customer perception of product and brand		Barrier 14: Misperception of modularity in advanced products

Figure 1. Overview of Jensen, Laursen and Haase's [3] barriers to product longevity.

The barriers form a foundation, based on which this article focuses on the decisions companies' make to improve and maintain the longevity of their products. To investigate companies' decisions about promoting product longevity, a common understanding of the incremental transformation process and its limitations must first be established. In line with Müller and Pfleger's [18] suggestion that sustainable transformations can be perceived as three-dimensional, we propose a similar view of product longevity as measurable across three parameters.

Müller and Pfleger's [18] original model (see Figure 2) suggested that the three dimensions of the sustainability maturity cube were corporate activities, sustainability and sustainability maturity levels. The sustainability maturity cube is used in this article as a positioning device. The selection of this model as a positioning tool is chosen as it presented the broadest perspective of company transformation. The model considers many aspects of the company, including inbound and outbound logistics, marketing and sales, transformative operations, service, procurement, infrastructure, human resources and technology development. This qualifies the model as a tool that

considers as many perspectives and consequences when engaging in sustainable transformation.

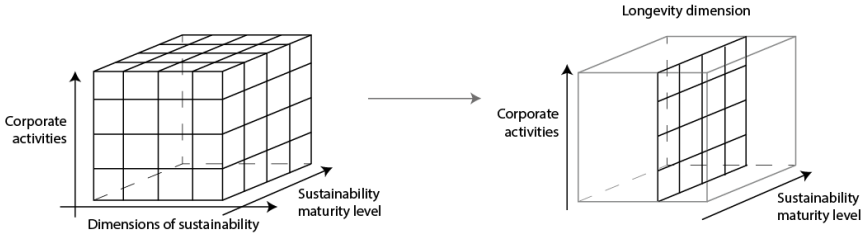

Figure 2. Müller and Pfleger's [18] 'Sustainability Maturity Cube' and model interpretation.

Regarding the sustainability maturity cube, Müller and Pfleger [18] propose the first parameter to be the dimensions of sustainability, namely, environmental, social and economic sustainability. These describe various aims of sustainability, and we argue that longevity can be perceived as a subcategory of environmental sustainability, thereby enabling a section view of the sustainability maturity cube. To investigate corporate activities and sustainability maturity levels, we now consider this section view.

The corporate activities describe what decisions and activities companies execute to improve the longevity of their products. Such activities aimed at extending product longevity have been widely described in the literature [16]. Researchers argue that businesses and business model innovation significantly influence decisions about producing high-longevity [2] products and that changes to business models themselves are top management activities. Business model innovations that support or even benefit from high-longevity products—such as Product service systems—usually encourage companies to produce high-longevity products because longer-lasting products minimise repair and replacement expenses for the companies that sell them. Product service systems that support longevity have been widely explored in the previous literature, where renting, leasing and takeback systems have been highlighted as business models that encourage increased longevity for products [19]. The definition we use for this aspect of business-model innovation is derived from Geissdoerfer et al. [20]: 'the conceptualisation and implementation of new business models that can comprise the development of entirely new business models, the diversification into additional business models, the acquisition of new business models, or the transformation from one business model to another.'

The second parameter of product longevity is sustainable maturity levels. Some longevity approaches are more easily implemented than others and, similarly, some are more approachable. Companies' abilities to engage and implement these approaches depends on their maturity regarding the subject. The literature has pinpointed many relevant stakeholders within such approaches to product longevity while also highlighting the complexity of this transformation [16]. These stakeholders include businesses, users and product developers. Business approaches include all options for management, marketing and sales professionals. Marketing influences customers' perceptions of products, product groups and companies. Thus, marketing can support, maintain and change customers' perception of brands or products, indirectly affecting the chances of achieving longer product longevity [21–25]. Meanwhile, product development activities include the available approaches for designers and engineers at a company. Product design and the development of aesthetically pleasing products can counter ever-changing fashion and trends. For instance, more durable materials can be chosen that age in more aesthetically pleasing manners [26], and sturdier construction can be implemented. Products can also, for example, promote longevity by being specifically designed as modular or easily repairable [27]. The ability to exchange product parts can enable consumers to maintain products and extend their longevity. However, many products are discarded before they break, so durability is not the sole influence on product longevity. If customers do not perceive products as valuable (monetarily, sentimentally or both), they are likely to discard these products prematurely [28]. Therefore, customers' relationships with products—entailing, for example, memories, pleasure and aesthetic appreciation—also influence product longevity [29]. Finally, users and consumers are stakeholders in approaches to longevity. Currently, society seldom encourages the proper maintenance and repair of products after they are purchased. Low product prices increase the likelihood of substitution rather than repair [12,30,31], and many modern families are unqualified to maintain even simple products [32–34], which is reflected in increased consumption [29,35]. However, consumers play a major role in determining product longevity.

A company's ability to engage and control its stakeholders, as well as influence the lifetimes of their products, is therefore an expression of their maturity in this area.

Materials and Methods

To research the decision-making processes and tactical approaches of managers in best-case companies, we apply an inductive method because the topic has received limited attention in the current literature.

Data Collection

Based on the methodology of inductive research employed by Goia et al. [36], the current study collected data through semi-structured interviews with the employees of best-practice companies. At each of the 18 participating companies, with the help of an interview guide, we conducted qualitative, semi-structured, open-ended interviews with 1 to 3 participants. The interview guide was supplemented with additional questions that were based on a thorough background check of each company, ensuring that the interview questions were as contextualised as possible. Some interviews were conducted with several participants, and other interviews were individual, reflecting interviewees' preferences. Before the interviews, interviewees were asked to name a single exemplary product in their company's portfolio. These responses made the interview conversations more precise and materially focused but still allowed for references to other products.

The interview guide centred on four topics: business (e.g., 'What do you experience as the greatest challenge or barrier when it comes to running a business based on long-lasting products?'), development (e.g., 'In what ways would you say that your products are "designed to last"?'), consumers (e.g., 'What do you experience as the greatest challenge or barrier with respect to the customer or user of a long-lasting product?') and future ambitions. Following Goia et al.'s [36] explorative approach, the interview guide was not systematic but, rather, a list of topics addressing different perspectives on product longevity. This strategy allowed for more relaxed conversations, with spontaneous questions that permitted participants to elaborate on their answers and stories.

Data were collected through interviews with key decision-makers from 18 physical-product-producing companies. Company selection was based on companies' efforts to increase product longevity and our assumption that the approaches they undertook could be applied across product categories. Some companies participate in markets in which high product longevity is expected, whereas other companies have historically proven to produce long-lasting products. Companies with profiles suggesting that they were engaged with the subject of product longevity were included.

To broaden the study as much as possible and ensure variety, we selected companies of various sizes and ages that produce products in various categories. Moreover, the companies we chose had different markets, portfolios and pricing structures. A few of the companies were relatively new but focused on delivering products with high longevity. Lastly, the participants chosen for this study were selected because they were key decision makers at the companies (see Table 1).

Our approach resulted in a collection of physical-product-producing B2B and B2C companies situated in Germany, the United Kingdom and Denmark because we set out to understand the general approaches across these segments. This differentiation allowed our data to reflect a more elaborate and realistic variety of approaches across companies.

The following companies, in random order, participated in this research: Miele, Vola, Danfoss, Bang & Olufsen, Vitsoe, Skagerak Denmark, Hydrema, Takt, Rosti, Porsche Automotive, Marcus Pedersen, Toni, Butchers & Bicycles, Demant, Fredericia Furniture, Monstrum, Morsø Jernstøberi and Nilfisk.

Table 1. *Participating best-practice companies and employees: The letters listed twice (e.g., for interviews 15 and 16, Company O) refer to two individual interviews with different participants from a single company, whereas interviews with multiple participants are listed as a single instance of a letter (e.g., Interview 2, Company B).*

Interview #	Company	# of Participants	Employment Position	Duration
1	A	1	Owner and CEO	1:44:13
2	B	2	CEO Lead industrial designer	1:22:35
3	C	2	CEO and founder Design director	1:03:45
4	D	1	CEO and co-founder	1:15:39
5	E	1	CEO	1:56:46
6	F	2	Owner and CEO Senior designer	1:56:55
7	G	3	CEO Sales and marketing director Head of design/MA	2:04:31
8	H	2	VP R&D Director of portfolio management	2:07:15
9	I	1	Global product manager	1:27:20
10	J	1	R&D manager	1:31:09
11	K	2	CEO Creative director	1:18:17
12	L	1	Head of hardware development	1:14:02
13	M	2	Brand manager Purchasing manager	2:00:51
14	N	1	Director, product quality management	1:45:46
15	O	1	Director	0:57:55
16	O	1	Manager advanced design	0:43:59
17	P	1	Vice president and head of innovation	1:37:20
18	Q	2	Owner Head of design and product management*	1:48:04
19	R	1	Vice president of design	1:03:19
20	R	1	Executive director	1:12:03

Data Analysis

Data were analysed concurrently with the interviews, allowing a grounded-theory approach to all 20 interviews. Using the analysis programme ATLAS.ti, the interviews were coded with a basic open coding technique [37] reflecting product longevity.

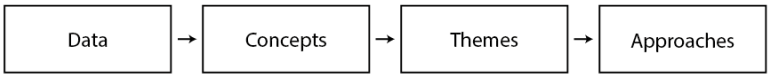

Figure 3. *Goia et al.'s [36] model of data structure.*

This analysis, therefore, combined breaking the data down into discrete parts, comparing the parts for similarities and differences and categorising the parts. Some key codes from this process were 'personal vanity towards result', 'business transparency', 'long development times', 'brand nurturing through design', 'selling professionalism' and 'personal pride reflected in products'. These codes were then structured using Gioia et al.'s [36] data structure model (see Figure 3) to distil the codes and thus analyse and identify a more coherent interpretation. Grouping the codes into themes allowed us to compare codes across interviews and identify similarities and differences. Further clustering revealed an emergent pattern: Several approaches to product longevity had been expressed throughout the interviews. To further distil the data, the same system was applied visually to our analysis (see, for example, Table 2).

Table 2. *Example of how the qualitative analysis of the data is conducted following Goia et al.'s [36] model of data structure to find groups of approaches.*

Data	Concepts	Themes	Approaches
'Our customers just want to be comfortable, so there's no reason for a wide range of customisation options. If we talk about low maintenance, then you also have to select components that are durable in the use situation' (Company D, 0:21:07).	High performance expectations and demand	Setting extraordinary performance criteria	Performance-driven approaches
'We are very careful not to interfere with these groups, as they provide us with the raw truth about our products. We use this a lot to tweak the product to become even better' (Company F, 1:17:00).	Observing lead-users	Following performance-Lead users	

Then, to reveal further patterns among the identified approaches, we shifted our coding techniques. With an offset from a review of the literature on barriers to product longevity [3], which has rigorously explored a wide variety of areas in the product longevity literature, the second part of our data coding was based on how practitioners handled and recognised the 14 barriers to product longevity described in the literature (see Figure 3).

Our data analysis focused on whether participating companies had faced or recognised the barriers described in the literature, as well as how they had managed these challenges. The solutions to the barriers and related principles that the companies presented paralleled our initial data analysis.

Analysis

As exemplified in the theory section, the coding the interviews with representatives of best-practice companies revealed three groups of approaches to product longevity in terms of their tactical decisions. Across widely divergent product categories, the approaches to product longevity shared multiple similarities, as the interviews revealed. Our findings could therefore be categorised into three groups of approaches to product longevity, as defined by participating companies' thought patterns: *performance-driven*, *behavioural-change-driven* and *vision-driven*.

Performance-Driven Approaches

Based on the interviews, the most salient approaches to product longevity concerned product performance. Striving for the best performance typically results in the use of better materials, more durable construction and increased sturdiness, reparability and modularity (all of which potentially prolong products' physical longevity). For customers, these qualities are the easiest improvements to longevity to recognise because many (but not all) are visually or tangibly obvious in purchasing situations. Differentiation from other brands through performance (e.g., with 'high-quality' designs or materials, such as solid wood instead of laminate or steel plate instead of plastic shells) can yield better customer impressions of product durability during purchasing situations. Similarly, customers often appreciate choosing a sturdy technical product build over time because such products exceed initial expectations.

Setting Extraordinary Performance Criteria

These companies set extraordinary performance criteria for their products and portfolios (e.g., being the most durable, fastest, clearest or strongest in the market). Products that deliver extraordinary performance and simultaneously differentiate themselves aesthetically from other products give customers satisfactory experiences and emotional fulfilment regarding their purchases. These effects stimulate attachment to and satisfaction with a product and, thereby, increase the likelihood that a consumer will keep the product longer:

> 'Our customers just want to be comfortable, so there's no reason for a wide range of customisation options. If we talk about low maintenance, then you also have to select components that are durable in the use situation' (Company D, 0:21:07).

> ‘I set up two criteria when we develop. The first is that it’s not allowed to look like anything else in the market […]. Secondly, it must perform extremely well. Naturally, there are also some underlying criteria to price points, etc.’ (Company F, 0:34:30).

Following Performance-Lead Users

For these companies, uniqueness and extraordinary performance differentiation have created unique situations. Independently, user communities centred around the use of the product have formed. These communities discuss, enhance and customise their products and share knowledge and experiences, often in online forums. These communities, therefore, form independent user bases that companies observe and cater to, thus ensuring extraordinary performance and longevity in the future. This relationship is described by the companies as synergetic because these customers benefit from product improvements while the companies strengthen the products’ dissemination and gain large quantities of data and testing results with which to improve products:

> ‘We are very careful not to interfere with these groups, as they provide us with the raw truth about our products. We use this a lot to tweak the product to become even better’ (Company F, 1:17:00).

> ‘We see changes in our community at the moment. Some patterns in regards to our community and market indicate that they want to buy fewer products, be conscious of how they spend their money but also to expect better and more durable ones. We see that as an opportunity’ (Company I, 0:20:00).

Implementing Performance Values from Previous Products

Participating companies closely compared their new products to older successful products. By considering the performance of previous products in their own portfolios, these companies were able to accumulate knowledge and experiences from previous designs to implement in the new products. These companies expressed that this ‘knowledge bank’ set them apart from competitors and that these insights ranged broadly from aesthetic details to overall process control. This approach applied to several companies, which were extremely aware of comparisons between older and newer products:

> ‘We need to design our future products to deliver on design, material and functionality’ (Company M, 0:38:00).

> ‘When we continue evaluating our product, we develop a set of requirements that we are bound to fulfil. This setup is our key to using the knowledge that we have to keep developing strong products. […] The

> requirements are the same for all our products and have been developed and updated over time' (Company N, 0:27:19).

Accepting Long Development Processes

These companies used extraordinarily long development times to support the development of their best-performing products. Using this extended development time, these companies were able to deliver products that outperformed their competitors' alternatives. To do so, the companies often had to accept not being first movers in their markets; however, they launched products with extraordinary performance. This extended development time enabled products that were 'future-proof' and, therefore, had higher longevity. Similarly, the products were less prone to trends and fashions and, therefore, premature substitution—due both to their later market launches and more tailored experiences but also as a consequence of higher sales prices:

> 'The simplest product possible […] thought through, but not exaggerated in any way' (Company H, 0:54:00).

> 'You can create products that can sell now, or you can create products that are future-proof for next sales. Even if the customer has new demands, the product still delivers' (Company B, 1:18:49).

Behavioural-Change-Driven Approaches

The findings from the interviews show that behavioural-change-driven approaches focus on how companies can change either their behaviour or their current or potential customers so as to increase their products' longevity in the market and, in some cases, encourage more sustainable production and consumption patterns. One example of a behavioural change is the selection of a business model that supports greater product longevity. This behaviour engages with consumers to support product longevity and potentially improve customers' perceptions of the company as a responsible seller. The behavioural change approach can also comprise company initiatives likely to increase customers' attachment to products, increasing their likelihood of better caring for these products. Both companies and customers actively change via such support initiatives, potentially prolonging purchased products' longevities and expectations for similar products.

Transparent Production

Being open and displaying how products are produced increased customers' trust and strengthened participating companies' brands. One approach used to provide more authentic service was increasing customers' accessibility and familiarity with brands. Brand trust and recognisability increased if customers were familiar with the company, increasing brand awareness. One participating company used this approach

by moving their production directly into their physical showrooms, mimicking the experience of an open-kitchen restaurant. Selling became an experience, rather than the mere selling of products, engaging customers and highlighting the company's values and products:

> 'We want to be completely naked. You can see your product being assembled, etc. It's almost a family feeling, that if you're one of our customers, then you're allowed to be part of the process' (Company K, (0:13:00).

> 'You can compare it to a restaurant with an open kitchen. You can see it all, the right raw ingredients and the cooking. When you are served your dinner, you have been on the full journey' (Company K, 0:14:00).

Local Presence and After-Sale Services

These companies were committed, through service agreements, to delivering high-longevity products. In some situations, customers expected and demanded continuous service after purchases, requiring a local presence on the part of the service provider. This local presence and service agreement is likely costly for companies; however, to minimise expenses, companies are encouraged to produce high-longevity products. More durable, longer-lifetime products require less service, thereby simultaneously lowering repair and substitution expenses and improving customers' perceived product experience. While this approach commits companies to strict service agreements, it also creates strong market advantages in their geographical locations:

> 'We have decided that service is a business opportunity for us. We have to be present in the market where we sell' (Company J, 0:21:00).

Evolving Existing Products

These companies consciously kept their portfolios limited and instead iterated existing products and designs, even after market launches. Limiting the number of products in portfolios enabled companies to limit spare part stocks, thereby increasing their products' reparability. Their limited number of products—all preserved in their portfolios—were, however, in constant development. This approach is only possible with a limited portfolio because a broad portfolio with seasonal product changes would counteract this goal. The company, therefore, accumulated specific knowledge of its exact products, maintaining a market advantage and an evolved product that became the best on the market:

> 'In nature, there are no new species. Species evolve, and it's a constant sequence of small changes. So, this whole notion that humans have come up with, that every year we have to go to a trade exhibition to see all this new stuff, that's absolute rubbish! We, as a society, have come to value

> new, rather than better. Yet, as an industrial designer yourself, you know that the most difficult challenge is to make something better. […] That's what nature does, and we, as an economic society, are a wholly owned subsidiary of nature' (Company P, 0:25:42).

> 'We haven't launched a new series in 15 years. It seems like almost the same product today as 15 years ago, but naturally with upgrades' (Company L, 0:19:48).

Long-Lasting Aesthetics

These participating companies were very cautious about the design language they saw as representing their identities. This language had to be unique, reflect their identity and apply to all their products. When designing new products, companies can mimic the aesthetics of older, successful, long-lasting products. Visually familiar products are associated with one another, as are their values and impressions, so customers also expect new products to be high quality and long lasting. One company, for example, expressed a desire to measure all new product suggestions against prior designs in order to mimic previous aesthetics:

> 'Before we even think about drawing anything, we need to find out what the DNA is. This was the first time in a long time the company wanted to introduce a new series of products, […] so it was very important that we continued to follow this DNA and that this, too, became a classic product. This was an ultimate requirement' (Company G, 0:07:23).

> 'The difference between being modern and being fashionable […]. Even when we make products that are supposed to be as modern as possible, we still try to keep away from fashionable design items and design languages. This is sometimes quite hard to distinguish, what is what' (Company O, 0:03:58).

Limiting Seasonal Trends

The participating companies that were in markets highly influenced by fashion only considered fashion in their products' interchangeable parts. Products designed for fast-moving fashion are prone to substitution before they wear out, conflicting with longevity. One company aimed to design products based not on fashion but on sustained market relevance. However, select product elements that were easily substituted were allowed to reflect fashion-driven design. The elements affected by changing trends were obviously substitutable, only influencing single parts' longevity rather than that of the entire product. The ability to cater to fashion-focused consumers positions companies in a unique market with a larger potential buyer group while maintaining product longevity:

> ‘We know that we’ve made a fashion element here, but we can also see a demand for this. So, if we’re pursuing these fashion elements, it must be on these selected parts’ (Company A, 1:02:27).

> ‘We try to make many of the visible parts of the products modular. If people move, some want to change the aesthetic of our product to match their new home. By changing the “shell”, they’re able to do so without exchanging the entire product’ (Company I, 0:45:30).

User Involvement in Assembly

Participating companies actively used customers’ first engagement with their products to facilitate great experiences. These experiences improved customer satisfaction and product-user relations, countering premature product substitution. Engaging customers in the assembly process can generate feelings of personal accomplishment, increase customer satisfaction and present a product’s hidden details. Customers with good assembly experiences will remember these experiences when looking at a product. These pleasant memories will likely increase attachment and, in turn, the length of time a customer retains a product:

> ‘Many brands make a great effort at storytelling. You can almost smell the workshop when you buy some products. Maybe you can deliver that experience to the customer in a more realistic way so that it doesn’t come through the ears and eyes but the hands and body. You get that from assembling your product. […] I might even become happier with the chair’ (Company C, 0:09:39).

Vision-Driven Approaches

Patterns from the interviews show that vision-driven approaches are ideas that companies implement throughout all departments. All company decisions are affected by this vision as a paradigm reminding employees of a common goal. Participating companies’ visions differed and were phrased variously, often emerging from a single visionary at a company. The vision-driven approaches seldom referred directly to products in the company’s usual category. Instead, they seemed undefined and universally applicable. However, some products that companies recognise as fulfilling their vision remain prized possessions among consumers due to high attachment, even after these products break down. A combination of a more specified business, design and customer management enables companies to establish and fulfil their visions.

Solving Long-Lasting Problems

One company expressed its vision as the pursuit of ‘long-lasting problems’. If a product solves a long-lasting problem, then it will likely remain relevant in the market longer. Producing products that remain relevant enables producers to invest more time

in development because the continuous sale of a product permits higher initial investments. The long-lasting problems presented by the company were more abstract than the initial product category, allowing for more creative solutions. The company defined long-lasting problems as universally agreeable and basic to humans (e.g., couples' difficulty agreeing on interior design). Although long-lasting problems may seem vague and undefinable from an outside perspective, they constitute a foundation upon which companies can build requirements and sub-problematics, thus directing design. Long-lasting problems, therefore, guide the design and decision-making processes toward solutions to surrounding problems that may not be immediately apparent by adding new elements, aesthetics or features that add to a product's uniqueness and longevity:

> 'You have to make absolutely sure that you're solving the right problem. […] and the problem that you are trying to solve needs to have a certain relevance and longevity. That's also how we differentiate from the archetype of how things are supposed to look' (Company I, 0:42:22).

Longevity through Collective Attachment

One company enabled the production of high-longevity products by designing for collective—rather than only personal—attachment. Stimulating collective attachment means that products are often better maintained, repaired and used because users not only appreciate their functionality but also their underlying personal values, such as pride or affiliation. This approach combines focusing on the products' artistic and aesthetic values with an understanding of customers' identities. It requires the production of custom-made solutions unique to an individual community. Products that represented their locations encouraged strong affection from users:

> 'Right now, we exist in a niche market, where we're quite different from our competitors, [with] specially designed products with no standard assortment, and this is the only thing you see when you visit our website' (company F, 0:09:00).

> 'No standard production means that we're more directed to the customers and that we become increasingly good at producing specially designed things that can match the other companies in price, with high-quality materials. Strike a balance between longevity, design and everything so that it just works' (Company F, 0:09:58).

> 'If we can create something that gives identity to an area, then it's especially meaningful' (Company F, 0:55:44).

> 'We always worked with what we called 'domestic design', designing things that appeal to the entire household and everyone living in it' (Company I, 0:48:00).

Confidence in a Product Portfolio

These companies expressed exceptionally high confidence in their product portfolios. The producers of high-longevity products have had previous experiences of confidence in their products that had sold poorly early in their launch but later attracted attention. By continuing this confidence in new products, many that at first seemed lacking became classic designs and sources of pride. The rapid discontinuation of a certain product likely leads to the product being forgotten by customers, implying a lack of confidence in the product. Therefore, if a product remains available for decades, it can gain more recognisability and show proof of concept. This effect increases the chance of creating a 'classic', signalling future relevance:

> 'If we had discontinued our production of the [product], it would not have become iconic, because it needs to be nurtured. You have to be brave enough to stick to one idea' (Company O, 0:20:18).

> 'It is, at its core, about running a business. Products that last are also about a well-managed business and that you keep showing the products and believe in them […]. If you believe in the product, you have to give it time to find its place in the market' (Company Q, 0:26:09).

> 'Everybody wants to do something iconic. There's one big issue. An icon isn't created. An icon is grown over decades. When we talk about making something iconic, it's not only about shape. It definitely helps when you have a distinctive shape, and I think, as well, there's pragmatics involved. Is it well designed?' (Company O, 0:17:16).

Longevity as a Quality Parameter

The participating companies perceived longevity as a quality parameter. Increasing longevity was understood as part of a vision to create quality products. The vision of quality was expressed differently for each product and product group, and longevity was always a parameter to consider alongside other parameters, such as convenience:

> 'Our customers are very experienced. They've already owned a lot of stuff. They know about the energy you need to substitute products. When you're busy, there's no energy left for this decision. […] Therefore, it's much better to have something better, durable, working and that doesn't add complexity to my life. This is an important success factor' (Company R, 0:15:12).

Concluding Discussion

Through interviews and an extensive multiple-case study of 18 best-practice companies producing a wide variety of products, we catalogued several business and development approaches that elucidate the concept of *longevity*. These approaches shared similarities and were divided into three major categories: *performance-driven*, *behavioural-change-driven* and *vision-driven approaches* (see Figure 4).

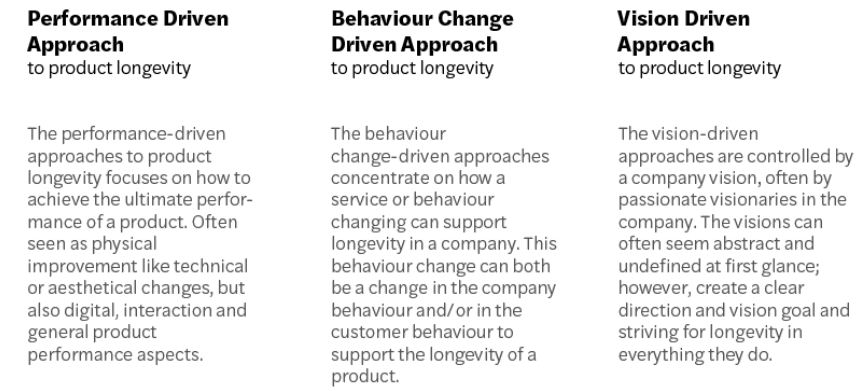

Figure 4. *The three types of approaches to product longevity expressed by participants.*

While the existing literature has mainly focused on product performance (e.g., [26,38]), this study investigates performance-driven approaches. Likewise, while the previous literature has investigated the implications for customer behaviour and purchase patterns (e.g., [29,39]), this study has investigated behaviour-changing approaches in companies. Lastly, we see that, in the existing literature, there has been a focus on the value proposition for product longevity (e.g., [40,41]) for companies; however, this paper investigates the vision-driven approaches that enable this. Through a rigorous analysis of our dataset, we provide the foundation for a more materially orientated approach to product longevity. The research conducted in this article, therefore, contributes to both design and business science with a framework of a perspective towards longevity. The perspective of practical approaches creates a basis for further exploration into both the business motivation for engaging with product longevity, as well as the design motivation for focusing on the subject.

Finally, this study's findings indicate that, despite engagement with different product categories, similar approaches are applied across product categories, forming the baseline for companies' views on product longevity. This knowledge can be used to develop more practical strategies to improve product longevity and encourage further research across product categories.

While this study was not prepared to examine the differences between B2B and B2C companies, this could be an interesting subject to explore. However, our study shows indications that there is a coherence between B2B and B2C companies in their approaches, even though B2B companies often provide longer warranties and other guaranties.

Reflection on Hierarchy of Approaches

Among the three groups of identified approaches to product longevity, namely, performance-driven, behavioural-change-driven and vision-driven approaches, we observed a hierarchy related to maturity (see Figure 5). To successfully produce long-lasting products, companies must first employ performance-driven approaches in their tactical thinking. The physical experiences of a product and the product–user interaction constitute the baseline for a product's longevity. Companies that employ vision-, service- or behaviour-driven approaches without experience with performance-driven approaches are likely to experience difficulties because physical longevity must live up to customers' expectations. Performance-driven approaches are also the most tangible because they primarily concern the material selection, patina, durability and performance. Companies committed to delivering high-longevity products can then develop and implement behavioural-change-driven approaches in their tactical decisions to support their products. Supporting an already durable product with service extends its potential longevity even further (e.g., authorised service and maintenance in the car industry prolongs cars' lifespans and signals that companies still vouch for their products even after they are purchased).

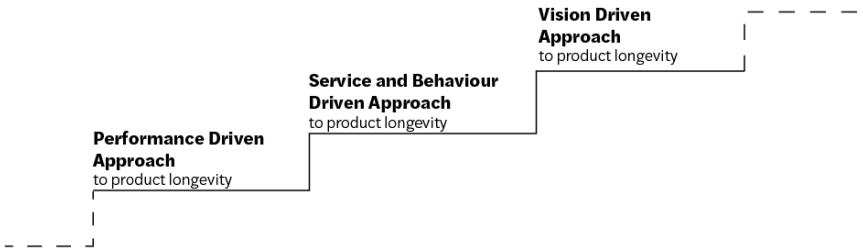

Figure 5. *Proposition of a sequence of approaches to longevity.*

The companies that employed more abstract approaches to longevity also seemed to have previously employed more physical approaches. However, over time, as more tangible and physical approaches were incorporated into their businesses, they could concentrate on more abstract approaches. At this point, the physical approaches became routine. The transition to producing long-lasting products, however, still seems gradual. Nonetheless, we observed a slow evolution in this process towards the

total implementation of approaches and a need for companies to improve already implemented approaches.

Limitations of the Study

The companies selected for this study are mainly producers of physical products; therefore, they do not include producers who solely produce digital services, digital products or software.

Furthermore, this study is limited to certain physical product categories and has therefore excluded producers who mainly produce clothing and textiles, packaging and rapidly consumed consumer goods, such as food.

Another limitation of this study is that the main business model of many of the best-case companies examined in this research centres around a conventional supply chain logic. This is designed to create coherence among the participants and eliminate unknown factors (e.g., hidden profit streams) that could influence the motivation to produce products with high longevity.

The study is limited to interviews with leaders or design leads (key decision makers). It is possible that insights from employees, on an operational level, would result in other perspectives and perceptions.

While this study was not focused on product obsolescence or product service systems, we believe the results may be relevant in these domains and, therefore, consider this an interesting avenue for further research.

A further limitation of studying best-case companies is that top management is already motivated to implement transformation and investing in this. Investigating companies in which top management has not engaged with the subject could prove interesting with regard to the transformative steps toward higher longevity.

Regarding practical implications, this study provides an overview of three approaches to product longevity that applies to companies at different levels of maturity. This means that none of the approaches can be regarded as superior to any other. Rather, this study suggests that different companies must engage with different approaches depending on their current maturity and situation. It also suggests that longevity parallels a continuous maturation process.

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Haase; investigation, Peter Byrial Jensen, Louise Møller Haase; resources, Peter Byrial Jensen, Louise Møller Haase; data curation, Peter Byrial Jensen, Louise Møller Haase; writing—original draft preparation, Peter Byrial Jensen, Louise Møller Haase; writing—review and editing, Peter Byrial Jensen, Linda Nhu Laursen and Louise Møller Haase; visualization, Peter Byrial Jensen; supervision, Louise Møller Haase and Linda Nhu Laursen; project administration, Louse Møller Haase; funding acquisition, Louise Møller Haase. All authors have read and agreed to the published version of the manuscript.

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Appendix C. Paper III

The LaST Tool – The Longevity and Sustainable Transition Tool

Peter Byrial Jensen, Louise Møller Haase, Tim Cooper, Joseph Steward, Phillipa Marsh, and Linda Nhu Laursen (2023)

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The LaST Tool – The Longevity and Sustainable Transition Tool

Peter Byrial Jensen, Louise Møller Haase, Tim Cooper, Joseph Steward, Phillipa Marsh, and Linda Nhu Laursen (2023)

Abstract

Due to customers' increased focus on environmental sustainability, companies have been looking to position themselves as producers of consumer goods with greater longevity. Useful tools exist within academia to assist companies in this transformation process. However, the knowledge is scattered, and the focus of tools is often on either the mapping of companies' status quo or actionable solutions that increase the longevity of their products. Creating a common understanding and coherency to make the knowledge usable in practice has proven to be difficult, as an immediate match of the most appropriate action tools to the mappings does not exist. Therefore, there is a need for a practical transition tool that, in the process of mapping, assists companies in understanding their positions and potential and proposes suitable action tools to assist in the required change process for producing consumer goods with greater longevity. This could mitigate the challenges for practitioners and bridge the different types of tools, hence enabling companies to develop products with increased longevity more easily.

Keywords: Sustainability, Tool, Product Longevity, Circular Economy

Introduction

Due to the rising global demand from consumers for sustainability, companies compete to position themselves in unique ways and deliver environmentally sustainable initiatives. Recycling, limiting plastic usage, lowering energy consumption and reducing production emissions have been among the main foci until now. However, the perception of product longevity as an important and effective element in the circular economy debate (Cooper, 2020) and as a quality parameter (Cooper, 2012) has raised demand for business and design methods to increase the longevity of their products. This paper adopts the definition presented by Bocken et al. (2016) that increased product longevity relates to slowing the consumption loop, with focus on the lifetime of a complete product including repair, multiple ownerships and remanufacturing but excluding recycling and upcycling, where the product is broken into sub-parts and used in new contexts.

For companies engaging with change towards producing consumer goods with greater longevity there exist several approaches, ranging from ways to increase the physical durability of products to adapting product service systems into business models (Jensen, 2021a; Kopecka et al., 2010; Verganti et al., 2011). How a company chooses to execute these can be difficult to decide in practice, however, as it depends on that company's attitude, willingness, investment and structure regarding the subject; consequently, the approaches suggested in the literature may be difficult for practitioners to utilise. This perception has also produced considerable fragmentation and theoretical confusion in academia. No common understanding exists regarding how to assist the navigation of an industry practitioner who aims to increase the longevity of their products (Bocken et al., 2019).

In this article, we adopt the perception that two types of tools exist for longevity: mapping and action. Mapping tools can provide a momentary view of a company's current situation, position and ambitions on a structural level towards product longevity. Action tools, on the other hand, are mostly focused on progress—how to enable change in a company and the necessary steps towards this. Hence, many tools already exist that can assist practitioners in most stages of product life and provide support in change towards developing viable products with greater longevity. Even so, it can be difficult for practitioners and researchers to define which insights to combine; it is challenging to translate the discoveries from the use of a mapping tool into more actionable tools and, in the end, into practically executable approaches (see Fig. 1).

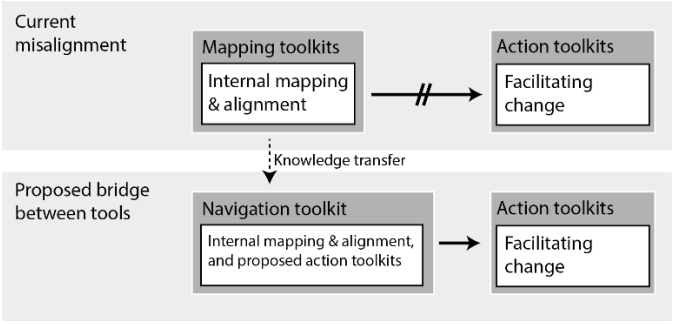

Fig. 32. *Misconnection between mapping tools and action tools, and the proposed new navigational tool that facilitates bridging the current literature.*

To mitigate these challenges and move the field towards a more unified process, an integrative understanding is needed. We propose a new navigation tool, synthesising the existing mapping tool, which could provide a bridge between mapping and understanding possibilities and creating the required change. Hence, we propose the following research question:

How can a new tool bridge existing mapping tools and action tools for product longevity to be more practically usable by industry practitioners?

Research Approach

To address this research question, an in-depth identification of existing tools for product longevity is necessary.

Phase 1: Identifying Existing Literature on Product Longevity Tools

The literature for this paper was identified in a three-stage process. First, a screening of the literature in Bocken et al.'s (2019) review of circular business innovation tools provided a solid basis of 13 tools and broad coverage of the existing tools. Second, through a forthcoming review of tools for product longevity by Özçelik et al. (2022), five additional relevant articles were added. Two tools produced by research teams led by one of the co-authors were also added (Cooper et al., 2016, 2021). Furthermore, a broad database search across Scopus, SciTech Premium Collection, DOAJ, ABI/INFORM Collection and Springer Online Journals Complete was conducted using the search term '"product longevity" AND "tool"', including peer-reviewed and open-access journal articles, book chapters and books. The search resulted in 124 articles that were screened, firstly by abstract then full text filtering, and narrowed down to 17 relevant papers on tools for longevity. In total, 37 articles were selected. App. 1 presents all the identified literature through the two-stage process and an overview of the format of the tools presented.

Phase 2: Clustering Types of Tools

As previously described, when looking at the identified literature on tools in App. 1, two major differences in the aims of the tools are apparent. On the one hand, several tools enable companies to understand their position broadly and assist in mapping out their aims, direction, goals and progression through a structured process. These are defined in this article as 'mapping tools'. On the other hand, several tools guide participants through actionable suggestions for transformation; these are referred to as 'action tools' in this article. The distinction seen in the clustering is further emphasised by the mention in the existing articles by the authors that tools are used to understand either the current situation (mapping tools) or how to change it (action tools).

Mapping Tools. Mapping tools provide participants with increased insight into their company's position and maturity, focusing on the general process at the managerial level and having a broad focus across different departments within a company. This can be helpful for practitioners aiming to produce consumer goods with greater longevity; however, evaluating the impact of a mapping tool is limited to the ability of participants to execute sub-activities that are often not thoroughly described. The identified mapping tool literature is displayed in App. 2. Because these tools vary in their approaches, focus and paradigm, they aim to help different stakeholders, so selecting the correct tool, that suit users' situations, is crucial.

This understanding of the basis of the methodology is crucial for achieving transformation towards developing products with greater longevity. Likewise, the overview of the stakeholders combined with the mapping provides information for the evaluation and selection of areas approachable for transformation in a given company and the extent of the transformation.

Action Tools. There also exists a range of action tools aimed at subprocesses within the transformation process. These tools provide the necessary knowledge to overcome the more specific challenges and barriers faced by designers or managers. However, participants need to be aware of their position, limitations and opportunities to successfully select the appropriate action tool. The identified action tool literature is displayed in App. 3. Through these tools, practical approaches to transformation should emerge that incrementally drive companies towards producing consumer goods with increased longevity.

Results of the Metatheoretical Analysis

The two types of tools have contrasting strengths and weaknesses. Using mapping tools and action tools in the most relevant practical situation can assist practitioners in making more knowledgeable decisions in the incremental change process. In an ideal situation, perceiving the process of using these tools can be seen as an iterative process that starts with a practitioner acknowledging the need for change, leading to the selection and execution of a mapping tool, followed by the use of action tools, which leads to practical change.

In some situations, to enable the use of action tools (App. 3) for the application of concrete actionable initiatives, practitioners need to be aware of their situation and opportunities. Existing mapping tools (App. 1) may provide an effective foundation for companies to increase awareness of opportunities, challenges and barriers, hence enabling them to make more conscious decisions regarding the selection of approaches and action tools. However, the current mapping tools lack a direct connection to the action tools and therefore do not bridge practical understanding and action.

Development of a Navigation Tool that Integrates Existing Knowledge and Bridges the Actionable Literature

We propose, with inspiration from the circular representation of product life in Sinclair et al. (2018), an overview of a product's life as a circle. The circle is divided into three spatial levels indicating the main ownership and stakeholders responsible for the longevity of the product, namely the designers and developers, businesses and the user, inspired by the stakeholders identified by Jensen et al. (2021b) in their exploration of barriers to product longevity (see Fig. 2.).

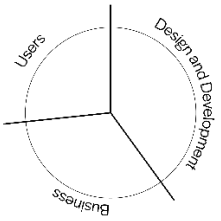

Fig. 2. *Representation of product life, divided into three spatial fields in the LaST tool.*

Based on the focus of the action tool, as seen in App. 3, the most influential life stages are included in the LaST navigational tool (Fig. 3). To bridge the LaST tool with the action tools (App. 3), the selection of the most relevant life stages is based on the life stages that the individual action tools mention and address, thereby aiming each subdivision of the spatial field towards appropriate action tools.

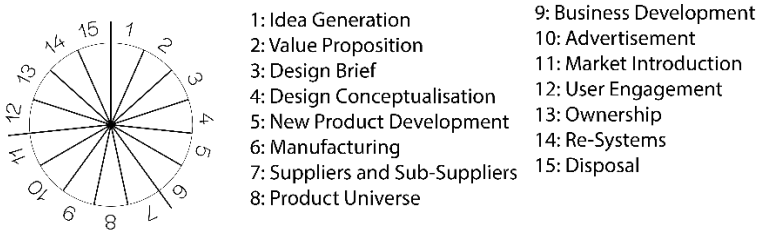

Fig. 3. *Sub-divisions of the spatial fields into smaller subdivisions of product life.*

To facilitate evaluation criteria for users of the LaST tool, evaluation parameters are likewise considered in the toolkit (Fig. 4.). These are based on the focus of proposed solutions, namely performance, behaviour or vision (inspired by Jensen et al., 2021b). Performance-driven approaches mainly focus on the physical characteristics of products and their performance, while behaviour change–driven approaches focus on how businesses can influence customers and create more value through service, business model and behaviour. The vision-driven approaches include determining if the company's approach to product longevity is a core value for it and collectively communicating the value of product longevity through product, business and customer engagement. The closer to the centre of the circle in each subdivision, the more holistic is the approach; the further away from the circle, the more product-orientated are the solutions presented. To incrementally move further towards the centre of the circle, action tools found in App. 3 that are linked to the specific subdivision can be applied.

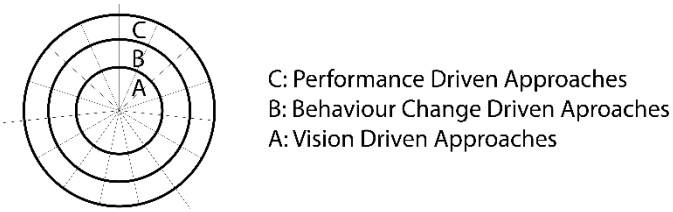

Fig. 4. *Evaluation parameters of the LaST tool.*

Conclusion and Limitations

Current literature reveals a disconnection between tools that assist practitioners in identifying their potential in terms of product longevity and those that assist in making the actual change. The main contribution of this paper is the creation of a navigation tool that binds together the knowledge from existing mapping tools and creates a direct link to the existing action tools, while facilitating the transition through incremental change in product life. The LaST tool could be used for companies that are inexperienced in considering product longevity and utilised repeatedly throughout a period, as incremental changes can facilitate continuous development within the field and improve the longevity of products. Participants are likely to benefit from repeating and adapting the methodology to new avenues of improvement, and it is important to explore newly discovered knowledge gaps or secondary business areas for improvement.

As highlighted by this paper, there are gaps within the connection between academia and practice in product longevity. An interesting avenue for future research might therefore be to investigate the connection between the action tools and the long-term impact on product longevity, company revenue and environmental implications. Likewise, an exploration of a company's willingness to adopt new and more explorative business models to improve product longevity could be valuable.

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Appendix D. Appendix for paper III

Appendix D1. Complete list of the identified literature through Bocken et al. (2019), özçelik et al. (2022), co-authors and a supplementary literature search.

Author	Title
Mendoza J.M.F., et al. (2017)	Integrating Backcasting and Eco-Design for the Circular economy: The BECE Framework
Sinclair M., et al. (2018)	Consumer intervention mapping: A tool for designing future product strategies within circular product service systems
Hainess-Gadd, H., et al., D. (2018)	Emotional durability design nine-A tool for product longevity
Evans S. and Bocken N. (2014)	A tool for manufacturers to find opportunity in the circular economy
Heyes G., et al. (2018)	Developing and implementing circular economy business models in service-oriented technology companies
Whalen K., et al. (2018)	'All they do is win': Lessons learned from the use of a serious game for circular economy education
Whalen, K. (2017)	Risk and race: Creation of a finance-focused circular economy serious game
Bocken, N., et al. (2018)	Experimenting with a circular business model: Lessons from eight cases
Antikainen M., et al. (2017)	Circular economy business model innovation process—Case study
Bocken N., Miller K., Evans, S (2016)	Assessing the environmental impact of new circular business models
Manninen K., et al. (2018)	Do circular economy business models capture intended environmental value propositions?
Nußholz J.L.K. (2018)	A circular business model mapping tool for creating value from prolonged product lifetime and closed material loops
Pigosso D.C.A., et al. (2018)	Measuring the Readiness of SMEs for Eco-Innovation and Industrial

	Symbiosis: Development of a Screening Tool
Jensen, P. B., et al. (2021)	Barriers to product longevity: A review of business, product development and user perspectives
Dokter, G., et al. (2020)	Cards for circularity: Towards circular design in practice
Jensen, P. B., et al. (2021)	A practical approach to companies' transformation toward product longevity: A best-case study
Rexfelt, O., Selvefors, A. (2021)	The use2use design tool—Tools for user-centred circular design
Garza-Reyes, J. A., et al. (2019)	A circularity measurement tool for manufacturing SMEs
Cooper, T., et al. (2021)	Clothing Durability Dozen: Strategies to improve design and testing for clothing longevity
Cooper, T., et al. (2016)	Dirt, Damage, Servicing and Repair: Understanding motivations for product disposal
Roberts, D., and Hughes, M. (2014)	Exploring consumers' motivations to engage in innovation through co-creation activities.
Hora, M., et al. (2016)	Designing Business Models for Sustainable Mass Customization: A Framework Proposal.
Yang, M., et al. (2018)	The Management of Operations Product-service systems business models for circular supply chains.
Wastling, T., et al. (2018).	Design for Circular Behaviour: Considering Users in a Circular Economy.
Cherry, C. E., & Pidgeon, N. F. (2018).	Why Is Ownership an Issue? Exploring Factors That Determine Public Acceptance of Product-Service Systems.
Wallner, T. S., et al. (2020).	An Exploration of the Value of Timeless Design Styles for the Consumer Acceptance of Refurbished Products.
Albæk, J. K., et al. (2020).	Circularity Evaluation of Alternative Concepts During Early Product Design and Development.

Terzioglu, N., & Wever, R. (2021).	Integrating Repair into Product Design Education: Insights on Repair, Design and Sustainability.
Moalem, R. M., and Mosgaard, M. A. (2021).	A Critical Review of the Role of Repair Café s in a Sustainable Circular Transition.
Bocken, N. M. P., et al. (2015).	Value mapping for sustainable business thinking
Rogers, J. G., et al. (2015).	Product longevity and shared ownership: Sustainable routes to satisfying the world' s growing demand for goods.
Chapman, J. (2009).	Design for (Emotional) Durability
Boavida, R., et al. (2020).	A Combined Use of TRIZ Methodology and Eco-Compass tool as a Sustainable Innovation Model.
Choi, Y. J., et al. (2018).	Carative Factors in the Design Development Process: Towards Understanding Owner–Object Detachment and Promoting Object Longevity.
Haug, A., (2018).	Defining 'Resilient Design' in the Context of Consumer Products Defining 'Resilient Design' in the Context of Consumer Products.
Gregori, E. J. S. P., and Wdowiak, I. K. M. A. (2021).	Entrepreneurial lean thinking for sustainable business modeling: a workshop design for incumbent firms.
Rivera-torres, P. (2019).	Is It Possible to Change from a Linear to a Circular Economy? An Overview of Opportunities and Barriers for European Small and Medium-Sized Enterprise Companies.

Appendix D2. List of mapping tools.

Author	Title	Type of situation where tool is applicable
Garza-Reyes, et al. (2019).	A circularity measurement tool for manufacturing SMEs	Measurement tool to identify SMEs' current maturity through an evaluation of circularity practices. Executed through a questionnaire.
Sinclair M., et al. (2018)	Consumer intervention mapping: A tool for designing future product strategies within circular product service systems	Identifying the possible intervention points for companies to improve circularity in relation to customers. Executed through collective discussion of participants.
Jensen, P.B., et al. (2021)	Barriers to product longevity: A review of business, product development and user perspectives	List of barriers that can hinder the development of products with high longevity. Serves as a foundation for the discussion of possible overlooked challenges.
Pigosso D.C.A., et al. (2018)	Measuring the readiness of SMEs for eco-innovation and industrial symbiosis: Development of a screening tool	A screening tool to measure the readiness for SMEs to adopt circularity initiatives through discussion based on a questionnaire.
Jensen, P. B., et al. (2021)	A practical approach to companies' transformation toward product longevity: A best-case study	Creates a foundation for understanding different maturity levels of companies, based on their perspective and focus in product, business and focus area.

Appendix D3. List of action tools based on the identified literature

Author	Title	Type of situation where tool is applicable
Dokter, G., et al. (2020)	Cards for circularity: Towards circular design in practice	Idea generation, design brief, and design conceptualisation process
Haines-Gadd, H., et al. (2018)	Emotional durability design nine-A tool for product longevity	Design brief, new product development, Ownership
Rexfelt, O., Selvefors, A. (2021)	The use2use design tool—Tools for user-centred circular design	Idea generation and re-systems and Product Universe
Evans, S., Bocken N. (2014)	A tool for manufacturers to find opportunity in the circular economy	Idea generation, manufacturing, and business development
Heyes G., et al. (2018)	Developing and implementing circular economy business models in service-oriented technology companies	Business development
Mendoza, J.M.F. et al. (2017)	Integrating backcasting and eco-design for the circular economy: The BECE framework	Business development
Cooper, T., et al. (2016)	Dirt, Damage, Servicing and Repair: Understanding motivations for product disposal	Idea generation, design conceptualisation.
Bocken, N., et al. (2018)	Experimenting with a circular business model: Lessons from eight cases	Value Proposition, Design Brief, and Design Conceptualisation
Antikainen M., et al. (2017)	Circular economy business model innovation process—Case study	Business Development and Market Introduction
Bocken N., et al. (2016)	Assessing the environmental impact of new circular business models	Manufacturing and Business Development
Manninen K., et al. (2018)	Do circular economy business models capture intended environmental value propositions?	Value Proposition, Design Brief, Business

		Development and Disposal
Nußholz, J.L.K. (2018)	A circular business model mapping tool for creating value from prolonged product lifetime and closed material loops	Business development, Re-systems, and Market Introduction
Whalen, K., et al. (2018)	'All they do is win': Lessons learned from the use of a serious game for circular economy education	New Product development, Manufacturing and Suppliers and Sub-suppliers
Whalen, K. (2017)	Risk and Race: Creation of a finance-focused circular economy serious game	Business Development, advertisement, market introduction
Cooper, T., et al. (2021)	Clothing Durability Dozen: Strategies to improve design and testing for clothing longevity	Idea generation, Design Brief and Business development.
Roberts, D., and Hughes, M. (2014)	Exploring consumers' motivations to engage in innovation through co-creation activities.	Business development, User Engagement and Ownership
Hora, M., et al. (2016)	Designing Business Models for Sustainable Mass Customization: A Framework Proposal.	Business Development, advertisement, and User Engagement
Yang, M., et al. (2018)	The Management of Operations Product-service systems business models for circular supply chains.	Suppliers and sub-suppliers, Business Model
Wastling, T., et al. (2018).	Design for Circular Behaviour: Considering Users in a Circular Economy.	User Engagement, Ownership, Re-systems
Cherry, C. E., & Pidgeon, N. F. (2018).	Why Is Ownership an Issue? Exploring Factors That Determine Public Acceptance of Product-Service Systems.	Business Development, User engagement, and Ownership
Wallner, T. S., et al. (2020).	An Exploration of the Value of Timeless Design Styles for the Consumer Acceptance of Refurbished Products.	New Product Development, Ownership, and Disposal
Albæk, J. K., et al. (2020).	Circularity Evaluation of Alternative Concepts During Early Product Design and Development.	Idea Generation, Design Brief, and Design Conceptualisation

Terzioglu, N., & Wever, R. (2021).	Integrating Repair into Product Design Education: Insights on Repair, Design and Sustainability.	Design Conceptualisation and New Product Development
Moalem, R. M., and Mosgaard, M. A. (2021).	A Critical Review of the Role of Repair Café s in a Sustainable Circular Transition.	Ownership, Re-systems, and Disposal
Bocken, N. M. P., et al. (2015).	Value mapping for sustainable business thinking	Business Development, Market Introduction
Rogers, J. G., et al. (2015).	Product longevity and shared ownership: Sustainable routes to satisfying the world' s growing demand for goods.	Business Development, Re-systems, and User Engagement
Chapman, J. (2009).	Design for (Emotional) Durability	Design Conceptualisation, New Product Development, and Ownership
Boavida, R., et al. (2020).	A Combined Use of TRIZ Methodology and Eco-Compass tool as a Sustainable Innovation Model.	Idea Generation, Design Brief, and Design Conceptualisation
Choi, Y. J., et al. (2018).	Carative Factors in the Design Development Process: Towards Understanding Owner–Object Detachment and Promoting Object Longevity.	New Product Development, Ownership, and Disposal
Haug, A., and Haug, A. (2018).	Defining 'Resilient Design' in the Context of Consumer Products Defining 'Resilient Design' in the Context of Consumer Products.	Design Conceptualisation, New Product Development
Gregori, E. J. S. P., and Wdowiak, I. K. M. A. (2021).	Entrepreneurial lean thinking for sustainable business modelling: a workshop design for incumbent firms.	Business Development, User Engagement, and Ownership
Rivera-torres, P. (2019).	Is It Possible to Change from a Linear to a Circular Economy? An Overview of Opportunities and Barriers for European Small and Medium-Sized Enterprise Companies.	Business Development, Ownership

Appendix E. Paper IV

The LaST toolkit – a practical experimentation using a product longevity toolkit in SME development teams

Peter Byrial Jensen, Louise Møller Haase, and Linda Nhu Laursen (2023)

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